Problem 6.12

```python
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

```python
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: qiushaotings-MacBook-Pro-2.local
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/RI
Machine: arm64
Processor: i386
```

Helper function

```python
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

```python
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
```

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

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

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

```python
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

```python
# 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

```python
# 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 0x29f411e20>,
 'block2_pool': <keras.engine.functional.Functional at 0x2af72ecd0>,
 'block3_pool': <keras.engine.functional.Functional at 0x2b06b63d0>,
 'block4_pool': <keras.engine.functional.Functional at 0x2b06be5b0>,
 'block5_pool': <keras.engine.functional.Functional at 0x2b06bedf0>}
```

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

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

```python
# 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.]])}
```

```python
# Feature extraction with VGG16
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
    #save file
    paths =  dict(zip(["train", "test"],\
        [os.path.join(dpath, "feature_{}.pkl".format(n))\
         for n in ["train", "test"]]))
    ## 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()
```

SVM

```python
# 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

```
ltest["label"].to_numpy()
```

```
array([2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2,
       2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2,
       2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2,
       2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 0, 0, 0, 0, 2, 0, 0, 0, 0, 0, 0, 2,
       0, 2, 2, 0, 2, 0, 2, 0, 2, 2, 2, 2, 2, 2, 0, 2, 2, 0, 2, 2, 2, 0,
       0, 0, 2, 2, 0, 2, 2, 0, 2, 0, 2, 2, 0, 0, 0, 0, 2, 0, 0, 2, 2, 2,
       2, 2, 0, 0, 2, 2, 0, 2, 2, 2, 2, 0, 2, 2, 0, 0, 2, 2, 2, 2, 0, 2,
       0, 2, 0, 2, 2, 2, 2, 2, 2, 0, 0, 0, 0, 0, 0, 2, 2, 2, 2, 2, 2, 0,
       0, 2, 2, 2, 2, 0, 0, 2, 2, 2, 2, 0, 2, 2, 2, 2, 2, 0, 2, 2, 2, 2,
       2, 2, 0, 2, 2, 2, 2, 2, 2, 2, 2, 2, 0, 2, 2, 2, 2, 2, 2, 0, 0,
       2, 0, 2, 2, 0, 2, 0, 2, 2, 3, 0, 2, 2, 0, 3, 2, 2, 0, 0, 2, 0, 2,
       0, 2, 2, 2, 2, 0, 2, 3, 0, 2, 0, 2, 0, 3, 2, 0, 2, 0, 2, 2, 2, 3,
       2, 2, 0, 0, 2, 2, 0, 2, 2, 2, 3, 2, 0, 2, 0, 2, 2, 2, 2, 2, 2, 0,
       0, 2, 0, 2, 0, 0, 2, 0, 3, 0, 2, 2, 2, 2, 3, 3, 0, 2, 0, 0, 2, 0,
       0, 2, 2, 2, 0, 2, 1, 2, 0, 2, 2, 0, 0, 0, 3, 1, 3, 1, 0, 2, 2, 1,
       0, 2, 2, 2, 2, 0, 2, 2, 2, 2, 3, 2, 2, 0, 1, 1, 2, 1, 3, 3, 1, 2,
       2, 0, 3, 0, 2, 0, 2, 2, 2, 3, 0, 2, 2, 2, 0, 0, 3, 1, 1, 1, 0, 1,
```

```
          3, 0, 1, 2, 2, 3, 2, 2, 0, 2, 2, 0, 2, 0, 2, 2, 2, 1, 1, 2, 1, 2,
          2, 2, 1, 1, 0, 0, 2, 1, 2, 3, 2, 2, 2, 0, 2, 2, 2, 2, 1, 1, 0, 2,
          2, 0, 2, 2, 0, 0, 2, 1, 2, 3, 2, 1, 1])
```

```
clf.predict(featt["block1_pool"])
```

```
array([2, 3, 2, 1, 2, 1, 2, 3, 2, 2, 1, 2, 2, 2, 2, 2, 2, 1, 2, 2, 2, 2,
       2, 3, 0, 2, 2, 2, 2, 0, 2, 2, 2, 3, 2, 2, 1, 2, 1, 2, 3, 2, 3, 2,
       2, 2, 3, 2, 3, 2, 2, 3, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 3, 2, 2, 0,
       3, 2, 2, 0, 1, 1, 1, 2, 3, 2, 0, 0, 3, 0, 2, 2, 0, 0, 0, 0, 2, 2,
       3, 2, 1, 3, 2, 2, 0, 0, 2, 1, 2, 2, 2, 3, 0, 2, 2, 0, 3, 2, 2, 2,
       3, 3, 2, 2, 0, 2, 2, 3, 2, 2, 2, 2, 2, 0, 0, 3, 0, 3, 0, 2, 2, 0,
       2, 1, 2, 0, 2, 2, 3, 2, 1, 2, 2, 0, 2, 2, 0, 2, 2, 2, 2, 2, 2, 2,
       0, 2, 0, 0, 2, 2, 2, 2, 2, 0, 0, 0, 0, 0, 2, 0, 2, 1, 2, 2, 2, 2,
       0, 2, 2, 1, 2, 2, 0, 2, 2, 2, 0, 0, 3, 2, 2, 2, 2, 0, 2, 2, 2, 2,
       2, 2, 2, 2, 2, 2, 2, 2, 2, 0, 2, 2, 1, 3, 2, 2, 2, 2, 2, 1, 2, 0,
       2, 2, 3, 2, 0, 0, 2, 2, 2, 2, 0, 2, 2, 2, 2, 2, 2, 0, 2, 2, 0, 2,
       0, 0, 3, 2, 2, 0, 2, 3, 2, 2, 0, 2, 0, 3, 2, 2, 2, 2, 1, 3, 3, 0,
       1, 2, 2, 0, 0, 2, 0, 2, 3, 2, 2, 2, 0, 2, 0, 2, 2, 1, 2, 2, 2, 0,
       0, 2, 2, 2, 3, 2, 2, 0, 2, 0, 2, 2, 3, 0, 3, 1, 0, 2, 3, 2, 2, 2,
       2, 2, 3, 2, 0, 3, 2, 2, 0, 2, 2, 2, 2, 0, 3, 2, 1, 1, 3, 2, 2, 1,
       0, 1, 2, 2, 2, 0, 2, 2, 1, 0, 0, 1, 0, 0, 1, 1, 1, 0, 1, 3, 2, 2,
       2, 2, 1, 2, 2, 3, 2, 2, 2, 0, 2, 3, 0, 2, 0, 0, 3, 1, 1, 1, 0, 1,
       2, 2, 1, 0, 2, 2, 2, 0, 2, 2, 2, 2, 2, 0, 2, 2, 0, 1, 3, 2, 1, 2,
       2, 2, 2, 1, 2, 3, 2, 0, 2, 2, 2, 2, 0, 0, 1, 3, 0, 2, 1, 2, 3, 1,
       2, 2, 2, 2, 0, 0, 1, 1, 0, 3, 2, 1, 1])
```

One-to-One SVM

```
class One2OneSVM:
    def __init__(self, n_class=4):
        self.n_class = n_class
        self.clfs = [[svm.SVC(kernel="rbf", C=1., gamma="auto")\
                      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()
```

```python
            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
                self.clfs[i][j].fit(X,Y)
                self.cv[i][j] = 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

(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.

```python
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

```python
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 Score
0	block1_pool	0	1	0.823529	0.500
1	block1_pool	0	2	0.290155	0.550
2	block1_pool	0	3	0.157895	0.625
3	block1_pool	1	2	0.906040	0.500
4	block1_pool	1	3	0.466667	0.625
5	block1_pool	2	3	0.071186	0.625
0	block2_pool	0	1	0.823529	0.650
1	block2_pool	0	2	0.709845	0.650
2	block2_pool	0	3	0.157895	0.625
3	block2_pool	1	2	0.919463	0.500
4	block2_pool	1	3	0.466667	0.625
5	block2_pool	2	3	0.071186	0.625
0	block3_pool	0	1	0.823529	0.600
1	block3_pool	0	2	0.290155	0.600
2	block3_pool	0	3	0.157895	0.625
3	block3_pool	1	2	0.080537	0.550
4	block3_pool	1	3	0.466667	0.625
5	block3_pool	2	3	0.071186	0.625
0	block4_pool	0	1	0.823529	0.500
1	block4_pool	0	2	0.290155	0.550
2	block4_pool	0	3	0.157895	0.625
3	block4_pool	1	2	0.080537	0.500
4	block4_pool	1	3	0.466667	0.625
5	block4_pool	2	3	0.071186	0.625
0	block5_pool	0	1	0.073529	1.000
1	block5_pool	0	2	0.033679	1.000
2	block5_pool	0	3	0.060150	1.000
3	block5_pool	1	2	0.000000	1.000
4	block5_pool	1	3	0.088889	1.000
5	block5_pool	2	3	0.061017	0.875

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(1 - error(y_predm, ltest["label"].to_numpy()))

# Display result
res_multi1v1 = pd.DataFrame({"Info": out_layer_ns, "Score": dfm_errors})
res_multi1v1
```

	Info	Score
0	block1_pool	0.064965
1	block2_pool	0.055684
2	block3_pool	0.635731
3	block4_pool	0.635731
4	block5_pool	0.928074

(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
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88	spheroidite	spheroidite	spheroidite
89	spheroidite	spheroidite	spheroidite
90	spheroidite	spheroidite	spheroidite+widmanstatten
91	spheroidite	spheroidite	spheroidite
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93	spheroidite	spheroidite	spheroidite
94	spheroidite	spheroidite	spheroidite
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111	spheroidite	spheroidite	spheroidite
112	spheroidite	spheroidite	spheroidite+widmanstatten
113	spheroidite	spheroidite	spheroidite
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116	spheroidite	spheroidite	spheroidite
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164	spheroidite	spheroidite	spheroidite
165	spheroidite	spheroidite	spheroidite
166	spheroidite	spheroidite	network
167	spheroidite	spheroidite	spheroidite
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178	spheroidite	spheroidite	spheroidite+widmanstatten
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190	spheroidite	spheroidite	spheroidite+widmanstatten
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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
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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
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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
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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