In [ ]:
```
!pip install spectral
```

```
Collecting spectral
  Downloading spectral-0.23.1-py3-none-any.whl (212 kB)
     ━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 212.9/212.9 kB 4.1 MB/s eta 0:0
0:00
Requirement already satisfied: numpy in /usr/local/lib/python3.10/dist-packages
(from spectral) (1.23.5)
Installing collected packages: spectral
Successfully installed spectral-0.23.1
```

In [ ]:
```
import keras
import tensorflow as tf
from keras.layers import Conv2D, Conv3D, Flatten, Dense, Reshape, BatchNormali
from keras.layers import Dropout, Input
from keras.models import Model
from tensorflow.keras.optimizers import Adam
from keras.callbacks import ModelCheckpoint
from tensorflow.keras.utils import to_categorical


from sklearn.decomposition import PCA
from sklearn.model_selection import train_test_split
from sklearn.metrics import confusion_matrix, accuracy_score, classification_r

from operator import truediv

from plotly.offline import init_notebook_mode

import numpy as np
import matplotlib.pyplot as plt
import scipy.io as sio
import os
import spectral

init_notebook_mode(connected=True)
%matplotlib inline
```

In [ ]:
```
if not (os.path.isfile('Indian_pines_corrected.mat')):
  !wget http://www.ehu.eus/ccwintco/uploads/6/67/Indian_pines_corrected.mat
if not (os.path.isfile('Indian_pines_gt.mat')):
  !wget http://www.ehu.eus/ccwintco/uploads/c/c4/Indian_pines_gt.mat
```

```
--2023-12-09 17:24:40--  http://www.ehu.eus/ccwintco/uploads/6/67/Indian_pine
s_corrected.mat
Resolving www.ehu.eus (www.ehu.eus)... 158.227.0.65, 2001:720:1410::65
Connecting to www.ehu.eus (www.ehu.eus)|158.227.0.65|:80... connected.
HTTP request sent, awaiting response... 301 Moved Permanently
Location: https://www.ehu.eus/ccwintco/uploads/6/67/Indian_pines_corrected.mat
[following]
--2023-12-09 17:24:40--  https://www.ehu.eus/ccwintco/uploads/6/67/Indian_pine
s_corrected.mat
Connecting to www.ehu.eus (www.ehu.eus)|158.227.0.65|:443... connected.
HTTP request sent, awaiting response... 200 OK
Length: 5953527 (5.7M)
Saving to: ‘Indian_pines_corrected.mat’

Indian_pines_correc 100%[===================>]   5.68M  1.62MB/s    in 3.5s

2023-12-09 17:24:44 (1.62 MB/s) - ‘Indian_pines_corrected.mat’ saved [5953527/5
953527]

URL transformed to HTTPS due to an HSTS policy
--2023-12-09 17:24:44--  https://www.ehu.eus/ccwintco/uploads/c/c4/Indian_pine
s_gt.mat
Resolving www.ehu.eus (www.ehu.eus)... 158.227.0.65, 2001:720:1410::65
Connecting to www.ehu.eus (www.ehu.eus)|158.227.0.65|:443... connected.
HTTP request sent, awaiting response... 200 OK
Length: 1125 (1.1K)
Saving to: ‘Indian_pines_gt.mat’

Indian_pines_gt.mat 100%[===================>]   1.10K  --.-KB/s    in 0s

2023-12-09 17:24:45 (66.7 MB/s) - ‘Indian_pines_gt.mat’ saved [1125/1125]
```

# Data Loading

In [ ]:
```python
## GLOBAL VARIABLES
dataset = 'IP'
test_ratio = 0.7
windowSize = 25
```

In [ ]:
```python
def loadData(name):
    data_path = os.path.join(os.getcwd(),'')
    if name == 'IP':
        data = sio.loadmat(os.path.join(data_path, 'Indian_pines_corrected.mat
        labels = sio.loadmat(os.path.join(data_path, 'Indian_pines_gt.mat'))['
    elif name == 'SA':
        data = sio.loadmat(os.path.join(data_path, 'Salinas_corrected.mat'))['
        labels = sio.loadmat(os.path.join(data_path, 'Salinas_gt.mat'))['salin
    elif name == 'PU':
        data = sio.loadmat(os.path.join(data_path, 'PaviaU.mat'))['paviaU']
        labels = sio.loadmat(os.path.join(data_path, 'PaviaU_gt.mat'))['paviaU
```

```
    return data, labels
```

In [ ]:
```
def splitTrainTestSet(X, y, testRatio, randomState=345):
    X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=testRa
                                                        stratify=y)
    return X_train, X_test, y_train, y_test
```

In [ ]:
```
def applyPCA(X, numComponents=75):
    newX = np.reshape(X, (-1, X.shape[2]))
    pca = PCA(n_components=numComponents, whiten=True)
    newX = pca.fit_transform(newX)
    newX = np.reshape(newX, (X.shape[0],X.shape[1], numComponents))
    return newX, pca
```

In [ ]:
```
def padWithZeros(X, margin=2):
    newX = np.zeros((X.shape[0] + 2 * margin, X.shape[1] + 2* margin, X.shape[
    x_offset = margin
    y_offset = margin
    newX[x_offset:X.shape[0] + x_offset, y_offset:X.shape[1] + y_offset, :] =
    return newX
```

In [ ]:
```
def createImageCubes(X, y, windowSize=5, removeZeroLabels = True):
    margin = int((windowSize - 1) / 2)
    zeroPaddedX = padWithZeros(X, margin=margin)
    # split patches
    patchesData = np.zeros((X.shape[0] * X.shape[1], windowSize, windowSize, X
    patchesLabels = np.zeros((X.shape[0] * X.shape[1]))
    patchIndex = 0
    for r in range(margin, zeroPaddedX.shape[0] - margin):
        for c in range(margin, zeroPaddedX.shape[1] - margin):
            patch = zeroPaddedX[r - margin:r + margin + 1, c - margin:c + marg
            patchesData[patchIndex, :, :, :] = patch
            patchesLabels[patchIndex] = y[r-margin, c-margin]
            patchIndex = patchIndex + 1
    if removeZeroLabels:
        patchesData = patchesData[patchesLabels>0,:,:,:]
        patchesLabels = patchesLabels[patchesLabels>0]
        patchesLabels -= 1
    return patchesData, patchesLabels
```

In [ ]:
```
X, y = loadData(dataset)

X.shape, y.shape
```

Out[ ]:
```
((145, 145, 200), (145, 145))
```

In [ ]:
```
K = X.shape[2]
```

In [ ]:
```
K = 30 if dataset == 'IP' else 15
X,pca = applyPCA(X,numComponents=K)
```

```
X.shape
```

Out[ ]:
```
(145, 145, 30)
```

In [ ]:
```
X, y = createImageCubes(X, y, windowSize=windowSize)

X.shape, y.shape
```

Out[ ]:
```
((10249, 25, 25, 30), (10249,))
```

In [ ]:
```
Xtrain, Xtest, ytrain, ytest = splitTrainTestSet(X, y, test_ratio)

Xtrain.shape, Xtest.shape, ytrain.shape, ytest.shape
```

Out[ ]:
```
((3074, 25, 25, 30), (7175, 25, 25, 30), (3074,), (7175,))
```

# Model and Training

In [ ]:
```
Xtrain = Xtrain.reshape(-1, windowSize, windowSize, K, 1)
Xtrain.shape
```

Out[ ]:
```
(3074, 25, 25, 30, 1)
```

In [ ]:
```
ytrain = to_categorical(ytrain)
ytrain.shape
```

Out[ ]:
```
(3074, 16)
```

In [ ]:
```
S = windowSize
L = K
output_units = 9 if (dataset == 'PU' or dataset == 'PC') else 16
```

In [ ]:
```
## input layer
input_layer = Input((S, S, L, 1))

## convolutional layers
conv_layer1 = Conv3D(filters=8, kernel_size=(3, 3, 7), activation='relu')(inpu
conv_layer2 = Conv3D(filters=16, kernel_size=(3, 3, 5), activation='relu')(cor
conv_layer3 = Conv3D(filters=32, kernel_size=(3, 3, 3), activation='relu')(cor
#print(conv_layer3._keras_shape)
conv3d_shape = conv_layer3.shape
conv_layer3 = Reshape((conv3d_shape[1], conv3d_shape[2], conv3d_shape[3]*conv3
conv_layer4 = Conv2D(filters=64, kernel_size=(3,3), activation='relu')(conv_la

flatten_layer = Flatten()(conv_layer4)

## fully connected layers
dense_layer1 = Dense(units=256, activation='relu')(flatten_layer)
dense_layer1 = Dropout(0.4)(dense_layer1)
```

```
dense_layer2 = Dense(units=128, activation='relu')(dense_layer1)
dense_layer2 = Dropout(0.4)(dense_layer2)
output_layer = Dense(units=output_units, activation='softmax')(dense_layer2)
```

In [ ]:
```
# define the model with input layer and output layer
model = Model(inputs=input_layer, outputs=output_layer)
```

In [ ]:
```
model.summary()
```

```
Model: "model"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 input_1 (InputLayer)        [(None, 25, 25, 30, 1)]   0

 conv3d (Conv3D)             (None, 23, 23, 24, 8)     512

 conv3d_1 (Conv3D)           (None, 21, 21, 20, 16)    5776

 conv3d_2 (Conv3D)           (None, 19, 19, 18, 32)    13856

 reshape (Reshape)           (None, 19, 19, 576)       0

 conv2d (Conv2D)             (None, 17, 17, 64)        331840

 flatten (Flatten)           (None, 18496)             0

 dense (Dense)               (None, 256)               4735232

 dropout (Dropout)           (None, 256)               0

 dense_1 (Dense)             (None, 128)               32896

 dropout_1 (Dropout)         (None, 128)               0

 dense_2 (Dense)             (None, 16)                2064

=================================================================
Total params: 5122176 (19.54 MB)
Trainable params: 5122176 (19.54 MB)
Non-trainable params: 0 (0.00 Byte)
_________________________________________________________________
```

In [ ]:
```
from tensorflow.keras.optimizers.legacy import Adam

# Define the learning rate and decay
learning_rate = 0.001
decay = 1e-06

# Create an Adam optimizer with the specified learning rate and decay
adam = Adam(learning_rate=learning_rate, decay=decay)

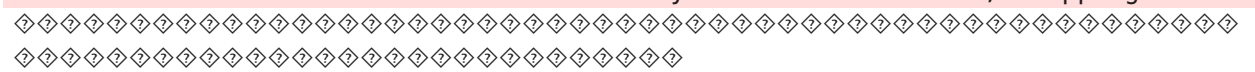
# Compile the model
```

```
model.compile(loss='categorical_crossentropy', optimizer=adam, metrics=['accur
```

In [ ]:
```
# checkpoint
filepath = "best-model.hdf5"
checkpoint = ModelCheckpoint(filepath, monitor='acc', verbose=1, save_best_onl
callbacks_list = [checkpoint]
```

In [ ]:
```
history = model.fit(x=Xtrain, y=ytrain, batch_size=256, epochs=100, callbacks=
```

```
Epoch 1/100
13/13 [==============================] - ETA: 0s - loss: 2.6102 - accuracy: 0.1
591
WARNING:tensorflow:Can save best model only with acc available, skipping.
<illegible>
13/13 [==============================] - 22s 206ms/step - loss: 2.6102 - accura
cy: 0.1591
Epoch 2/100
12/13 [==========================>...] - ETA: 0s - loss: 2.2426 - accuracy: 0.2
428
WARNING:tensorflow:Can save best model only with acc available, skipping.
<illegible>
13/13 [==============================] - 3s 194ms/step - loss: 2.2421 - accurac
y: 0.2433
Epoch 3/100
12/13 [==========================>...] - ETA: 0s - loss: 1.4817 - accuracy: 0.5
003
WARNING:tensorflow:Can save best model only with acc available, skipping.
<illegible>
13/13 [==============================] - 3s 199ms/step - loss: 1.4809 - accurac
y: 0.5007
Epoch 4/100
12/13 [==========================>...] - ETA: 0s - loss: 0.9445 - accuracy: 0.6
807
WARNING:tensorflow:Can save best model only with acc available, skipping.
<illegible>
13/13 [==============================] - 3s 198ms/step - loss: 0.9439 - accurac
y: 0.6809
Epoch 5/100
12/13 [==========================>...] - ETA: 0s - loss: 0.5668 - accuracy: 0.8
164
WARNING:tensorflow:Can save best model only with acc available, skipping.
<illegible>
13/13 [==============================] - 3s 199ms/step - loss: 0.5664 - accurac
y: 0.8165
Epoch 6/100
12/13 [==========================>...] - ETA: 0s - loss: 0.2964 - accuracy: 0.9
098
```

WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 200ms/step - loss: 0.2973 - accuracy: 0.9096
Epoch 7/100
12/13 [==========================>...] - ETA: 0s - loss: 0.2380 - accuracy: 0.9362
WARNING:tensorflow:Can save best model only with acc available, skipping.

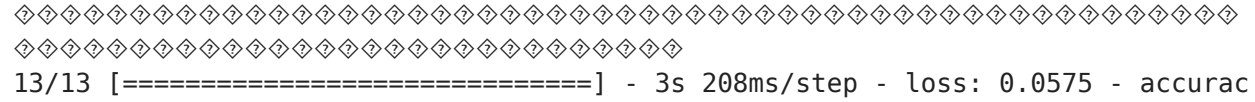
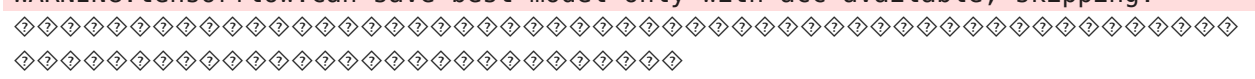
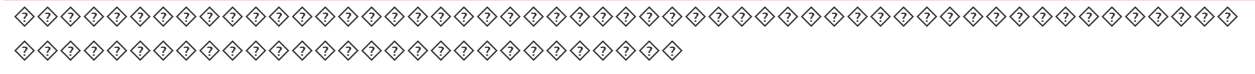
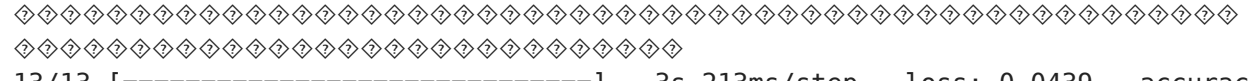
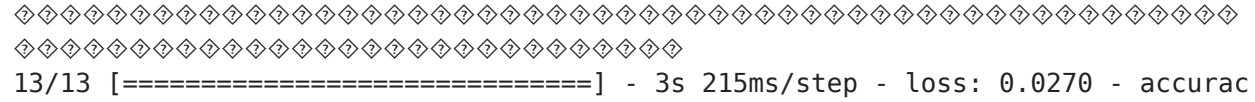
13/13 [==============================] - 3s 201ms/step - loss: 0.2379 - accuracy: 0.9362
Epoch 8/100
12/13 [==========================>...] - ETA: 0s - loss: 0.1418 - accuracy: 0.9551
WARNING:tensorflow:Can save best model only with acc available, skipping.

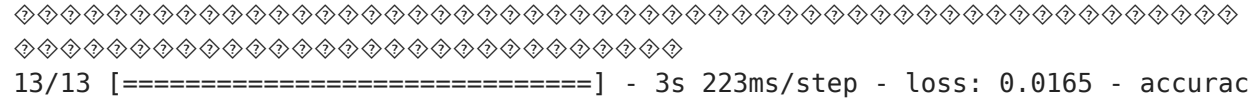
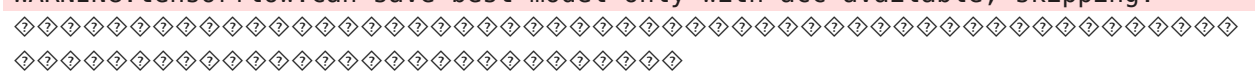
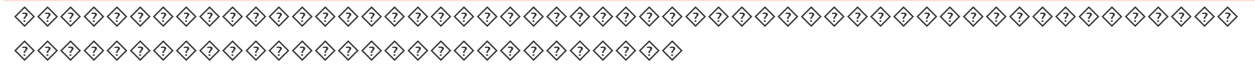
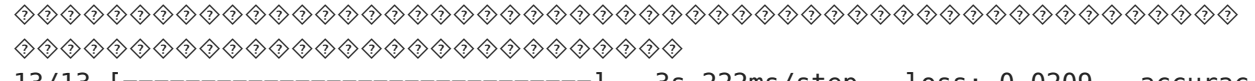
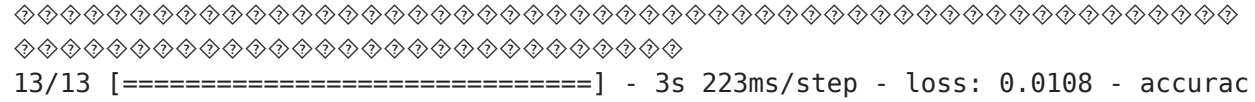
13/13 [==============================] - 3s 204ms/step - loss: 0.1417 - accuracy: 0.9551
Epoch 9/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0757 - accuracy: 0.9753
WARNING:tensorflow:Can save best model only with acc available, skipping.

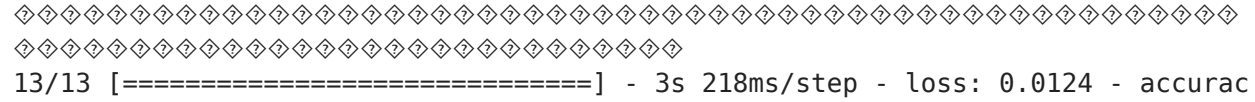
13/13 [==============================] - 3s 206ms/step - loss: 0.0757 - accuracy: 0.9753
Epoch 10/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0580 - accuracy: 0.9847
WARNING:tensorflow:Can save best model only with acc available, skipping.

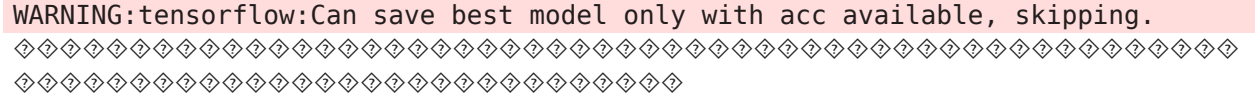
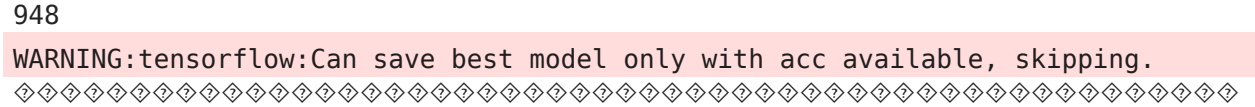
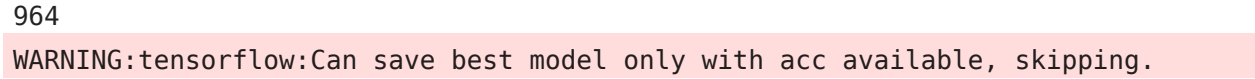
13/13 [==============================] - 3s 204ms/step - loss: 0.0579 - accuracy: 0.9847
Epoch 11/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0532 - accuracy: 0.9863
WARNING:tensorflow:Can save best model only with acc available, skipping.

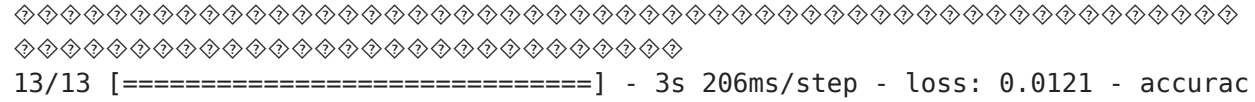
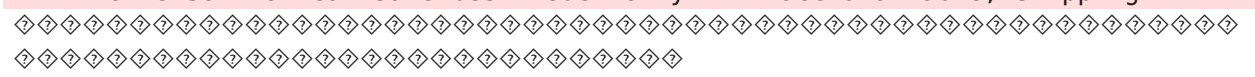
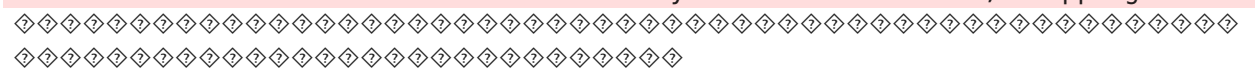
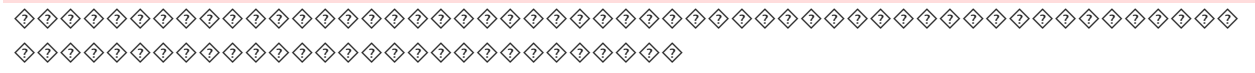
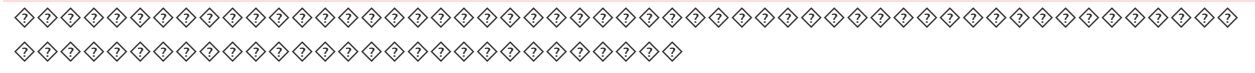
13/13 [==============================] - 3s 205ms/step - loss: 0.0531 - accuracy: 0.9863
Epoch 12/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0451 - accuracy: 0.9867
WARNING:tensorflow:Can save best model only with acc available, skipping.

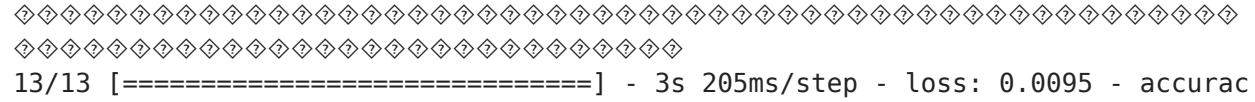
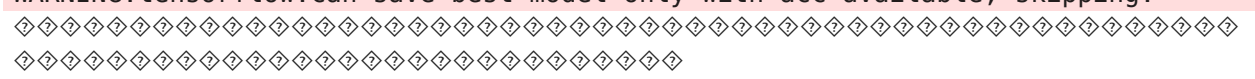
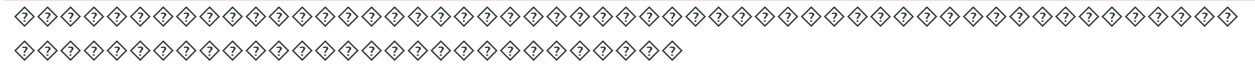
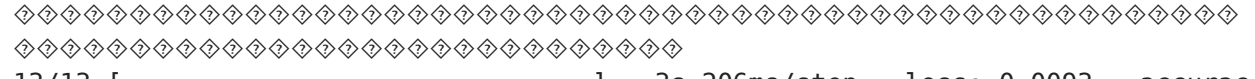
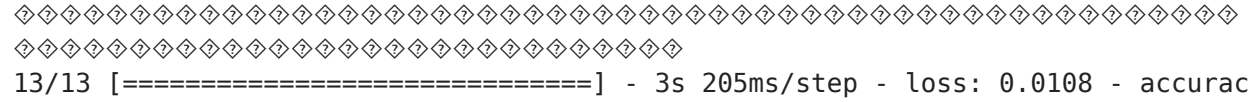

13/13 [==============================] - 3s 206ms/step - loss: 0.0451 - accurac
y: 0.9867
Epoch 13/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0575 - accuracy: 0.9
876
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 208ms/step - loss: 0.0575 - accurac
y: 0.9876
Epoch 14/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0484 - accuracy: 0.9
873
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 209ms/step - loss: 0.0484 - accurac
y: 0.9873
Epoch 15/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0393 - accuracy: 0.9
870
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 209ms/step - loss: 0.0393 - accurac
y: 0.9870
Epoch 16/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0440 - accuracy: 0.9
873
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 213ms/step - loss: 0.0439 - accurac
y: 0.9873
Epoch 17/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0270 - accuracy: 0.9
915
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 215ms/step - loss: 0.0270 - accurac
y: 0.9915
Epoch 18/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0310 - accuracy: 0.9
915
WARNING:tensorflow:Can save best model only with acc available, skipping.

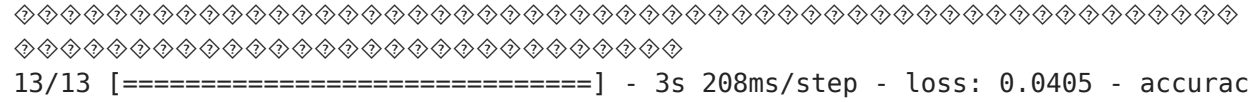
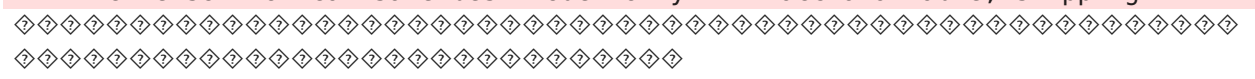
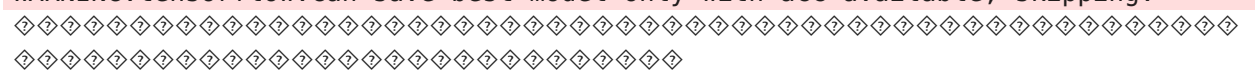
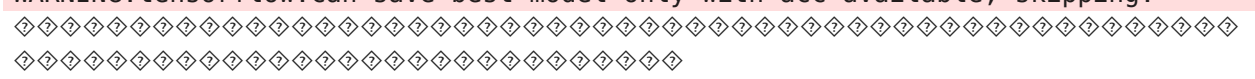
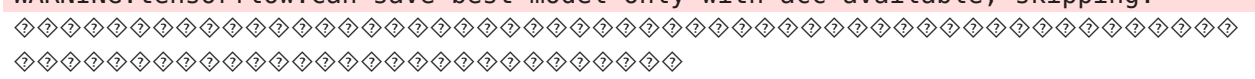

13/13 [==============================] - 3s 218ms/step - loss: 0.0310 - accurac
y: 0.9915
Epoch 19/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0165 - accuracy: 0.9
951
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 223ms/step - loss: 0.0165 - accurac
y: 0.9951
Epoch 20/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0179 - accuracy: 0.9
954
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 221ms/step - loss: 0.0179 - accurac
y: 0.9954
Epoch 21/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0157 - accuracy: 0.9
954
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 223ms/step - loss: 0.0157 - accurac
y: 0.9954
Epoch 22/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0209 - accuracy: 0.9
938
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 222ms/step - loss: 0.0209 - accurac
y: 0.9938
Epoch 23/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0108 - accuracy: 0.9
977
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 223ms/step - loss: 0.0108 - accurac
y: 0.9977
Epoch 24/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0258 - accuracy: 0.9
932
WARNING:tensorflow:Can save best model only with acc available, skipping.

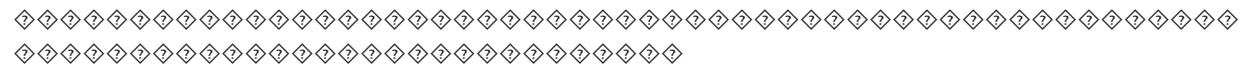
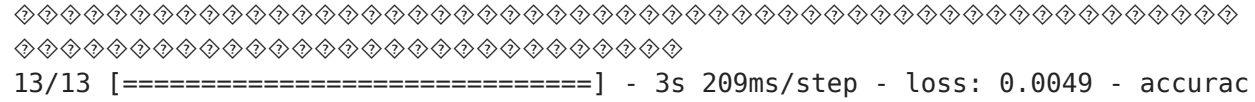
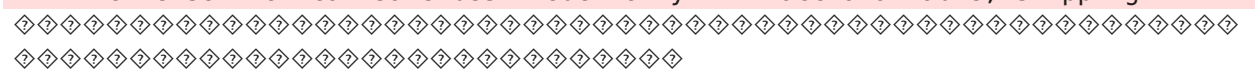
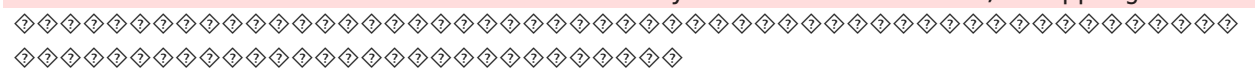
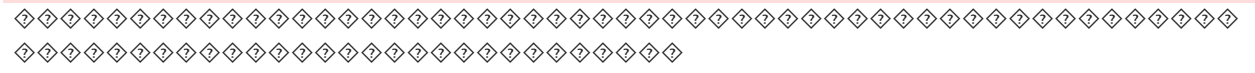
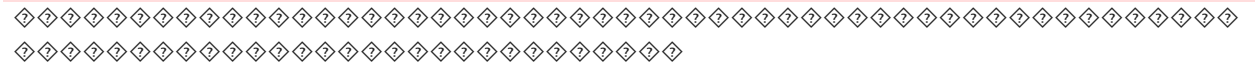

13/13 [==============================] - 3s 221ms/step - loss: 0.0258 - accuracy: 0.9932
Epoch 25/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0124 - accuracy: 0.9964
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 218ms/step - loss: 0.0124 - accuracy: 0.9964
Epoch 26/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0153 - accuracy: 0.9948
WARNING:tensorflow:Can save best model only with acc available, skipping.

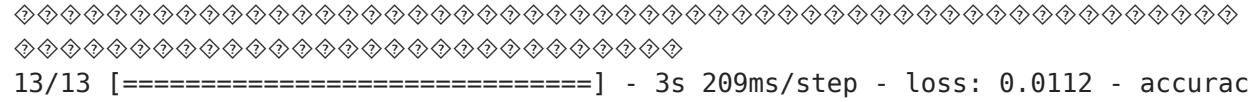
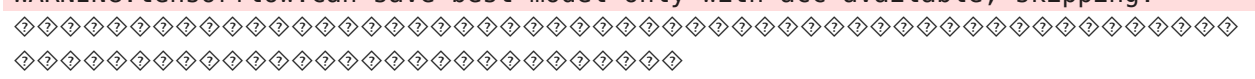
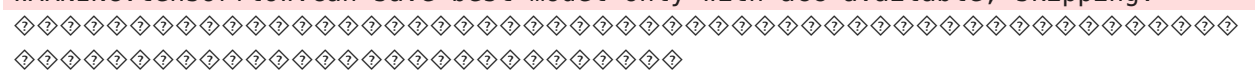
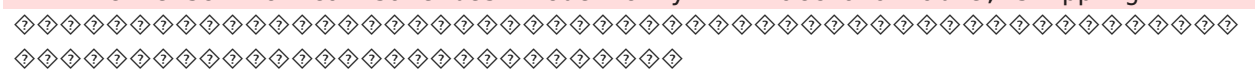
13/13 [==============================] - 3s 215ms/step - loss: 0.0153 - accuracy: 0.9948
Epoch 27/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0118 - accuracy: 0.9964
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 213ms/step - loss: 0.0118 - accuracy: 0.9964
Epoch 28/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0174 - accuracy: 0.9948
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 214ms/step - loss: 0.0174 - accuracy: 0.9948
Epoch 29/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0156 - accuracy: 0.9964
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 211ms/step - loss: 0.0156 - accuracy: 0.9964
Epoch 30/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0117 - accuracy: 0.9961
WARNING:tensorflow:Can save best model only with acc available, skipping.


13/13 [==============================] - 3s 209ms/step - loss: 0.0117 - accuracy: 0.9961
Epoch 31/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0120 - accuracy: 0.9967
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 206ms/step - loss: 0.0121 - accuracy: 0.9967
Epoch 32/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0114 - accuracy: 0.9964
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 207ms/step - loss: 0.0114 - accuracy: 0.9964
Epoch 33/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0133 - accuracy: 0.9954
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 225ms/step - loss: 0.0133 - accuracy: 0.9954
Epoch 34/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0162 - accuracy: 0.9958
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 216ms/step - loss: 0.0162 - accuracy: 0.9958
Epoch 35/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0144 - accuracy: 0.9964
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 206ms/step - loss: 0.0143 - accuracy: 0.9964
Epoch 36/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0139 - accuracy: 0.9951
WARNING:tensorflow:Can save best model only with acc available, skipping.

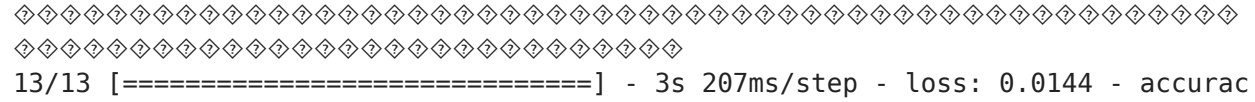
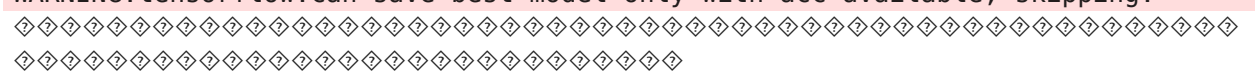
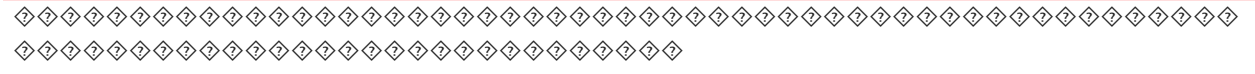
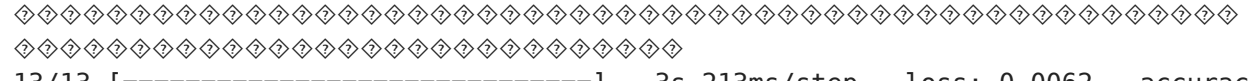
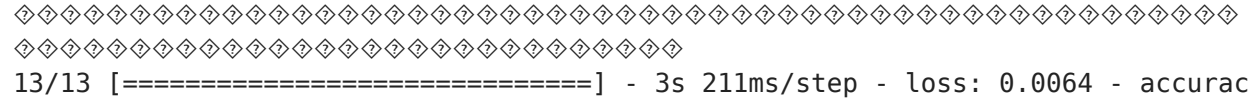

13/13 [==============================] - 3s 206ms/step - loss: 0.0139 - accurac
y: 0.9951
Epoch 37/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0095 - accuracy: 0.9
967
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 205ms/step - loss: 0.0095 - accurac
y: 0.9967
Epoch 38/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0046 - accuracy: 0.9
990
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 206ms/step - loss: 0.0046 - accurac
y: 0.9990
Epoch 39/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0086 - accuracy: 0.9
984
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 206ms/step - loss: 0.0086 - accurac
y: 0.9984
Epoch 40/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0093 - accuracy: 0.9
977
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 206ms/step - loss: 0.0093 - accurac
y: 0.9977
Epoch 41/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0108 - accuracy: 0.9
971
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 205ms/step - loss: 0.0108 - accurac
y: 0.9971
Epoch 42/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0246 - accuracy: 0.9
958
WARNING:tensorflow:Can save best model only with acc available, skipping.

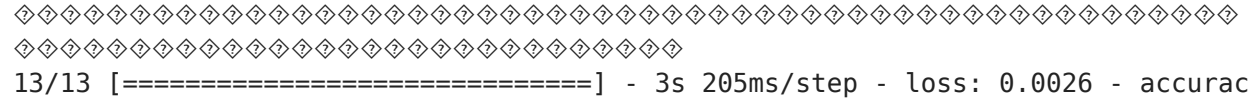
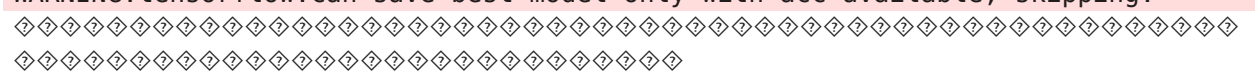
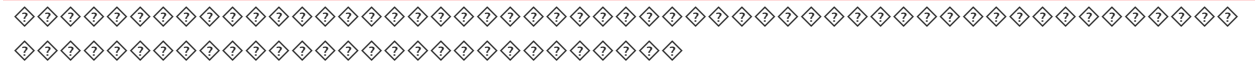
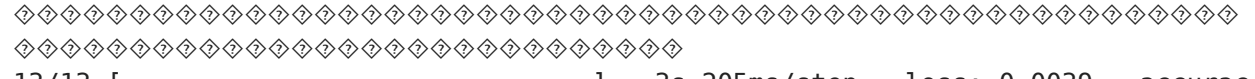
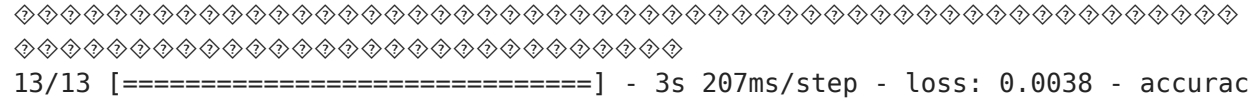

13/13 [==============================] - 3s 206ms/step - loss: 0.0246 - accurac
y: 0.9958
Epoch 43/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0406 - accuracy: 0.9
925
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 208ms/step - loss: 0.0405 - accurac
y: 0.9925
Epoch 44/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0133 - accuracy: 0.9
954
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 205ms/step - loss: 0.0133 - accurac
y: 0.9954
Epoch 45/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0067 - accuracy: 0.9
984
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 205ms/step - loss: 0.0067 - accurac
y: 0.9984
Epoch 46/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0051 - accuracy: 0.9
990
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 206ms/step - loss: 0.0050 - accurac
y: 0.9990
Epoch 47/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0045 - accuracy: 0.9
984
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 207ms/step - loss: 0.0045 - accurac
y: 0.9984
Epoch 48/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0043 - accuracy: 0.9
980
WARNING:tensorflow:Can save best model only with acc available, skipping.

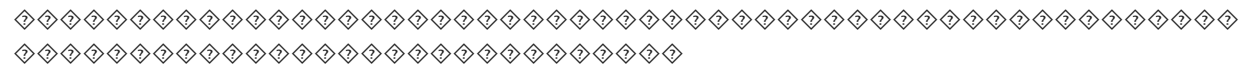
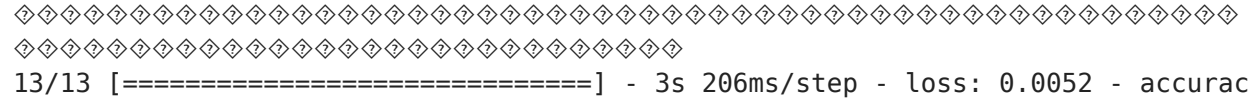
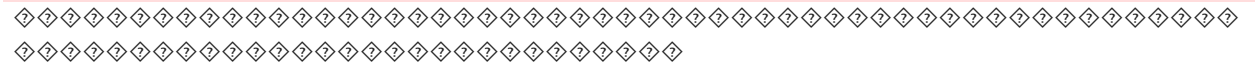
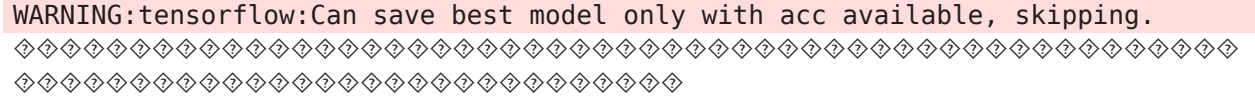
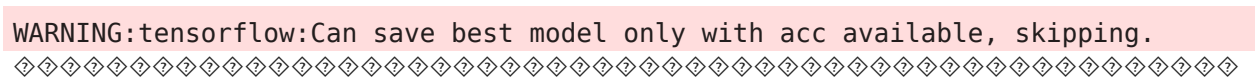
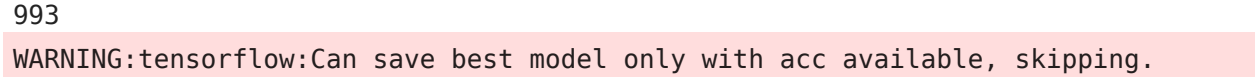

13/13 [==============================] - 3s 208ms/step - loss: 0.0043 - accurac
y: 0.9980
Epoch 49/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0049 - accuracy: 0.9
980
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 209ms/step - loss: 0.0049 - accurac
y: 0.9980
Epoch 50/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0040 - accuracy: 0.9
984
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 207ms/step - loss: 0.0040 - accurac
y: 0.9984
Epoch 51/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0052 - accuracy: 0.9
987
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 209ms/step - loss: 0.0052 - accurac
y: 0.9987
Epoch 52/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0144 - accuracy: 0.9
971
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 210ms/step - loss: 0.0144 - accurac
y: 0.9971
Epoch 53/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0088 - accuracy: 0.9
971
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 208ms/step - loss: 0.0088 - accurac
y: 0.9971
Epoch 54/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0059 - accuracy: 0.9
980
WARNING:tensorflow:Can save best model only with acc available, skipping.

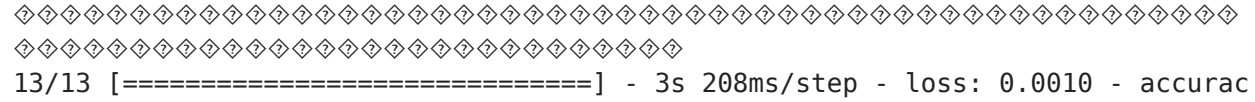
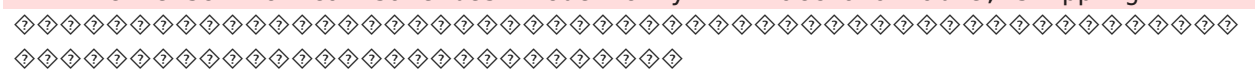

13/13 [==============================] - 3s 214ms/step - loss: 0.0059 - accurac
y: 0.9980
Epoch 55/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0112 - accuracy: 0.9
974
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 209ms/step - loss: 0.0112 - accurac
y: 0.9974
Epoch 56/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0133 - accuracy: 0.9
961
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 210ms/step - loss: 0.0133 - accurac
y: 0.9961
Epoch 57/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0060 - accuracy: 0.9
974
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 209ms/step - loss: 0.0060 - accurac
y: 0.9974
Epoch 58/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0059 - accuracy: 0.9
987
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 210ms/step - loss: 0.0059 - accurac
y: 0.9987
Epoch 59/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0056 - accuracy: 0.9
980
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 210ms/step - loss: 0.0056 - accurac
y: 0.9980
Epoch 60/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0040 - accuracy: 0.9
977
WARNING:tensorflow:Can save best model only with acc available, skipping.

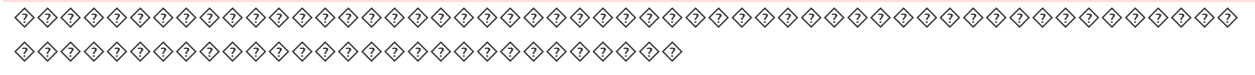

13/13 [==============================] - 3s 208ms/step - loss: 0.0040 - accurac
y: 0.9977
Epoch 61/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0144 - accuracy: 0.9
987
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 207ms/step - loss: 0.0144 - accurac
y: 0.9987
Epoch 62/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0167 - accuracy: 0.9
971
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 207ms/step - loss: 0.0167 - accurac
y: 0.9971
Epoch 63/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0045 - accuracy: 0.9
990
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 208ms/step - loss: 0.0045 - accurac
y: 0.9990
Epoch 64/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0062 - accuracy: 0.9
980
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 213ms/step - loss: 0.0062 - accurac
y: 0.9980
Epoch 65/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0064 - accuracy: 0.9
984
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 211ms/step - loss: 0.0064 - accurac
y: 0.9984
Epoch 66/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0098 - accuracy: 0.9
977
WARNING:tensorflow:Can save best model only with acc available, skipping.

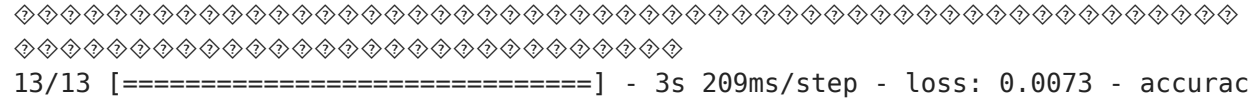
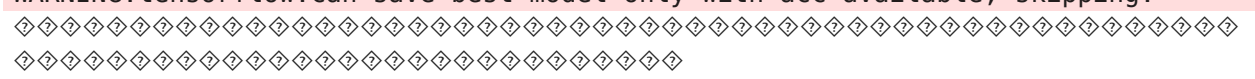
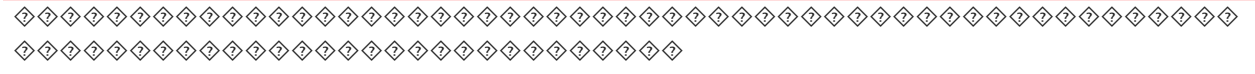
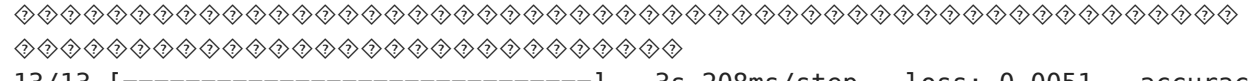
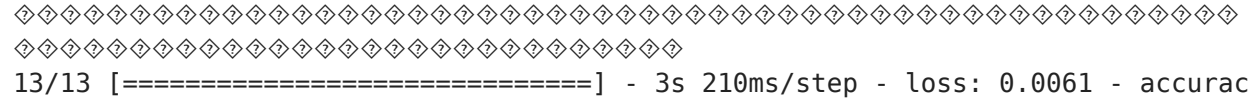

13/13 [==============================] - 3s 207ms/step - loss: 0.0098 - accuracy: 0.9977
Epoch 67/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0026 - accuracy: 0.9993
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 205ms/step - loss: 0.0026 - accuracy: 0.9993
Epoch 68/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0042 - accuracy: 0.9990
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 208ms/step - loss: 0.0042 - accuracy: 0.9990
Epoch 69/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0049 - accuracy: 0.9987
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 210ms/step - loss: 0.0049 - accuracy: 0.9987
Epoch 70/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0039 - accuracy: 0.9987
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 205ms/step - loss: 0.0039 - accuracy: 0.9987
Epoch 71/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0038 - accuracy: 0.9980
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 207ms/step - loss: 0.0038 - accuracy: 0.9980
Epoch 72/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0048 - accuracy: 0.9990
WARNING:tensorflow:Can save best model only with acc available, skipping.

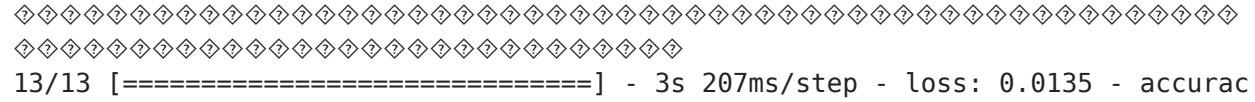
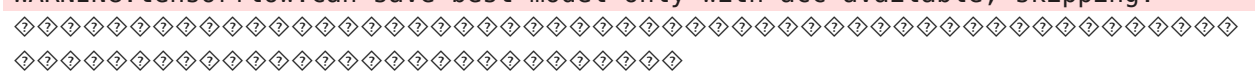
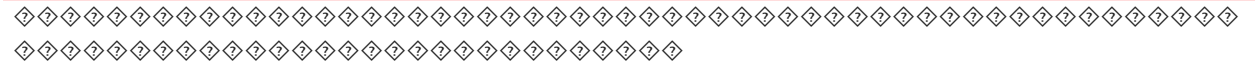
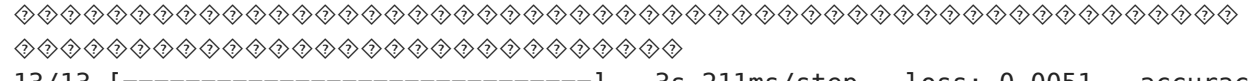
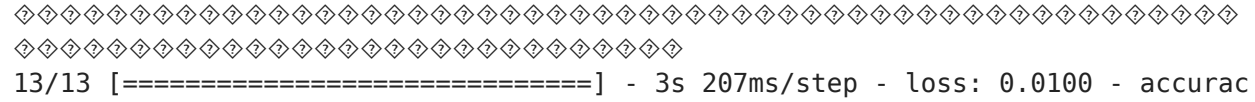

13/13 [==============================] - 3s 206ms/step - loss: 0.0048 - accurac
y: 0.9990
Epoch 73/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0052 - accuracy: 0.9
987
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 206ms/step - loss: 0.0052 - accurac
y: 0.9987
Epoch 74/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0119 - accuracy: 0.9
980
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 208ms/step - loss: 0.0118 - accurac
y: 0.9980
Epoch 75/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0056 - accuracy: 0.9
987
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 208ms/step - loss: 0.0056 - accurac
y: 0.9987
Epoch 76/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0043 - accuracy: 0.9
984
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 206ms/step - loss: 0.0043 - accurac
y: 0.9984
Epoch 77/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0026 - accuracy: 0.9
993
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 207ms/step - loss: 0.0026 - accurac
y: 0.9993
Epoch 78/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0011 - accuracy: 0.9
997
WARNING:tensorflow:Can save best model only with acc available, skipping.


13/13 [==============================] - 3s 206ms/step - loss: 0.0011 - accuracy: 0.9997
Epoch 79/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0010 - accuracy: 0.9997
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 208ms/step - loss: 0.0010 - accuracy: 0.9997
Epoch 80/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0139 - accuracy: 0.9984
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 207ms/step - loss: 0.0139 - accuracy: 0.9984
Epoch 81/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0108 - accuracy: 0.9971
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 207ms/step - loss: 0.0108 - accuracy: 0.9971
Epoch 82/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0030 - accuracy: 0.9993
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 205ms/step - loss: 0.0030 - accuracy: 0.9993
Epoch 83/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0034 - accuracy: 0.9990
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 205ms/step - loss: 0.0034 - accuracy: 0.9990
Epoch 84/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0043 - accuracy: 0.9980
WARNING:tensorflow:Can save best model only with acc available, skipping.


13/13 [==============================] - 3s 212ms/step - loss: 0.0043 - accurac
y: 0.9980
Epoch 85/100
12/13 [============================>...] - ETA: 0s - loss: 0.0073 - accuracy: 0.9
984
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 209ms/step - loss: 0.0073 - accurac
y: 0.9984
Epoch 86/100
12/13 [============================>...] - ETA: 0s - loss: 0.0020 - accuracy: 0.9
990
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 207ms/step - loss: 0.0020 - accurac
y: 0.9990
Epoch 87/100
12/13 [============================>...] - ETA: 0s - loss: 0.0029 - accuracy: 0.9
987
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 207ms/step - loss: 0.0029 - accurac
y: 0.9987
Epoch 88/100
12/13 [============================>...] - ETA: 0s - loss: 0.0051 - accuracy: 0.9
987
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 208ms/step - loss: 0.0051 - accurac
y: 0.9987
Epoch 89/100
12/13 [============================>...] - ETA: 0s - loss: 0.0061 - accuracy: 0.9
990
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 210ms/step - loss: 0.0061 - accurac
y: 0.9990
Epoch 90/100
12/13 [============================>...] - ETA: 0s - loss: 0.0040 - accuracy: 0.9
990
WARNING:tensorflow:Can save best model only with acc available, skipping.


13/13 [==============================] - 3s 208ms/step - loss: 0.0040 - accurac
y: 0.9990
Epoch 91/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0135 - accuracy: 0.9
974
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 207ms/step - loss: 0.0135 - accurac
y: 0.9974
Epoch 92/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0083 - accuracy: 0.9
990
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 208ms/step - loss: 0.0083 - accurac
y: 0.9990
Epoch 93/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0065 - accuracy: 0.9
984
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 206ms/step - loss: 0.0065 - accurac
y: 0.9984
Epoch 94/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0051 - accuracy: 0.9
990
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 211ms/step - loss: 0.0051 - accurac
y: 0.9990
Epoch 95/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0101 - accuracy: 0.9
977
WARNING:tensorflow:Can save best model only with acc available, skipping.

13/13 [==============================] - 3s 207ms/step - loss: 0.0100 - accurac
y: 0.9977
Epoch 96/100
12/13 [==========================>...] - ETA: 0s - loss: 0.0037 - accuracy: 0.9
984
WARNING:tensorflow:Can save best model only with acc available, skipping.

```
◆◆◆
```

# Validation

In [ ]:
```
# load best weights
model.load_weights("best-model.hdf5")
model.compile(loss='categorical_crossentropy', optimizer=adam, metrics=['accur
```

In [ ]:
```
Xtest = Xtest.reshape(-1, windowSize, windowSize, K, 1)
Xtest.shape
```

Out[ ]:
```
(7175, 25, 25, 30, 1)
```

In [ ]:
```
ytest = to_categorical(ytest)
ytest.shape
```

Out[ ]:
```
(7175, 16)
```

In [ ]:
```
Y_pred_test = model.predict(Xtest)
y_pred_test = np.argmax(Y_pred_test, axis=1)

classification = classification_report(np.argmax(ytest, axis=1), y_pred_test)
print(classification)
```

```
225/225 [==============================] - 3s 11ms/step
              precision    recall  f1-score   support

           0       0.97      1.00      0.98        32
           1       0.99      0.99      0.99      1000
           2       1.00      0.97      0.98       581
           3       0.99      0.96      0.97       166
           4       0.99      0.99      0.99       338
           5       0.99      0.99      0.99       511
           6       1.00      0.90      0.95        20
           7       0.99      1.00      0.99       335
           8       1.00      0.64      0.78        14
           9       1.00      1.00      1.00       680
          10       0.98      0.99      0.98      1719
          11       0.97      0.93      0.95       415
          12       0.99      0.99      0.99       143
          13       0.97      1.00      0.99       886
          14       0.99      1.00      1.00       270
          15       1.00      0.92      0.96        65

    accuracy                           0.99      7175
   macro avg       0.99      0.96      0.97      7175
weighted avg       0.99      0.99      0.99      7175
```

In [ ]:
```
def AA_andEachClassAccuracy(confusion_matrix):
    counter = confusion_matrix.shape[0]
    list_diag = np.diag(confusion_matrix)
    list_raw_sum = np.sum(confusion_matrix, axis=1)
```

```
    each_acc = np.nan_to_num(truediv(list_diag, list_raw_sum))
    average_acc = np.mean(each_acc)
    return each_acc, average_acc
```

In [ ]:
```
def reports (X_test,y_test,name):
    #start = time.time()
    Y_pred = model.predict(X_test)
    y_pred = np.argmax(Y_pred, axis=1)
    #end = time.time()
    #print(end - start)
    if name == 'IP':
        target_names = ['Alfalfa', 'Corn-notill', 'Corn-mintill', 'Corn'
                        ,'Grass-pasture', 'Grass-trees', 'Grass-pasture-mowed'
                        'Hay-windrowed', 'Oats', 'Soybean-notill', 'Soybean-mi
                        'Soybean-clean', 'Wheat', 'Woods', 'Buildings-Grass-Tr
                        'Stone-Steel-Towers']
    elif name == 'SA':
        target_names = ['Brocoli_green_weeds_1','Brocoli_green_weeds_2','Fallo
                        'Stubble','Celery','Grapes_untrained','Soil_vinyard_de
                        'Lettuce_romaine_4wk','Lettuce_romaine_5wk','Lettuce_r
                        'Vinyard_untrained','Vinyard_vertical_trellis']
    elif name == 'PU':
        target_names = ['Asphalt','Meadows','Gravel','Trees', 'Painted metal s
                        'Self-Blocking Bricks','Shadows']

    classification = classification_report(np.argmax(y_test, axis=1), y_pred,
    oa = accuracy_score(np.argmax(y_test, axis=1), y_pred)
    confusion = confusion_matrix(np.argmax(y_test, axis=1), y_pred)
    each_acc, aa = AA_andEachClassAccuracy(confusion)
    kappa = cohen_kappa_score(np.argmax(y_test, axis=1), y_pred)
    score = model.evaluate(X_test, y_test, batch_size=32)
    Test_Loss =  score[0]*100
    Test_accuracy = score[1]*100

    return classification, confusion, Test_Loss, Test_accuracy, oa*100, each_a
```

In [ ]:
```
classification, confusion, Test_loss, Test_accuracy, oa, each_acc, aa, kappa =
classification = str(classification)
confusion = str(confusion)
file_name = "classification_report.txt"

with open(file_name, 'w') as x_file:
    x_file.write('{} Test loss (%)'.format(Test_loss))
    x_file.write('\n')
    x_file.write('{} Test accuracy (%)'.format(Test_accuracy))
    x_file.write('\n')
    x_file.write('\n')
    x_file.write('{} Kappa accuracy (%)'.format(kappa))
    x_file.write('\n')
    x_file.write('{} Overall accuracy (%)'.format(oa))
    x_file.write('\n')
    x_file.write('{} Average accuracy (%)'.format(aa))
    x_file.write('\n')
```

```
    x_file.write('\n')
    x_file.write('{}'.format(classification))
    x_file.write('\n')
    x_file.write('{}'.format(confusion))
```

```
225/225 [==============================] - 2s 10ms/step
225/225 [==============================] - 3s 12ms/step - loss: 0.0391 - accura
cy: 0.9862
```

In [ ]:
```
def Patch(data,height_index,width_index):
    height_slice = slice(height_index, height_index+PATCH_SIZE)
    width_slice = slice(width_index, width_index+PATCH_SIZE)
    patch = data[height_slice, width_slice, :]

    return patch
```

In [ ]:
```
# load the original image
X, y = loadData(dataset)
```

In [ ]:
```
height = y.shape[0]
width = y.shape[1]
PATCH_SIZE = windowSize
numComponents = K
```

In [ ]:
```
X,pca = applyPCA(X, numComponents=numComponents)
```

In [ ]:
```
X = padWithZeros(X, PATCH_SIZE//2)
```

In [ ]:
```
# calculate the predicted image
outputs = np.zeros((height,width))
for i in range(height):
    for j in range(width):
        target = int(y[i,j])
        if target == 0 :
            continue
        else :
            image_patch=Patch(X,i,j)
            X_test_image = image_patch.reshape(1,image_patch.shape[0],image_pa
            prediction = (model.predict(X_test_image))
            prediction = np.argmax(prediction, axis=1)
            outputs[i][j] = prediction+1
```

**Streaming output truncated to the last 5000 lines.**

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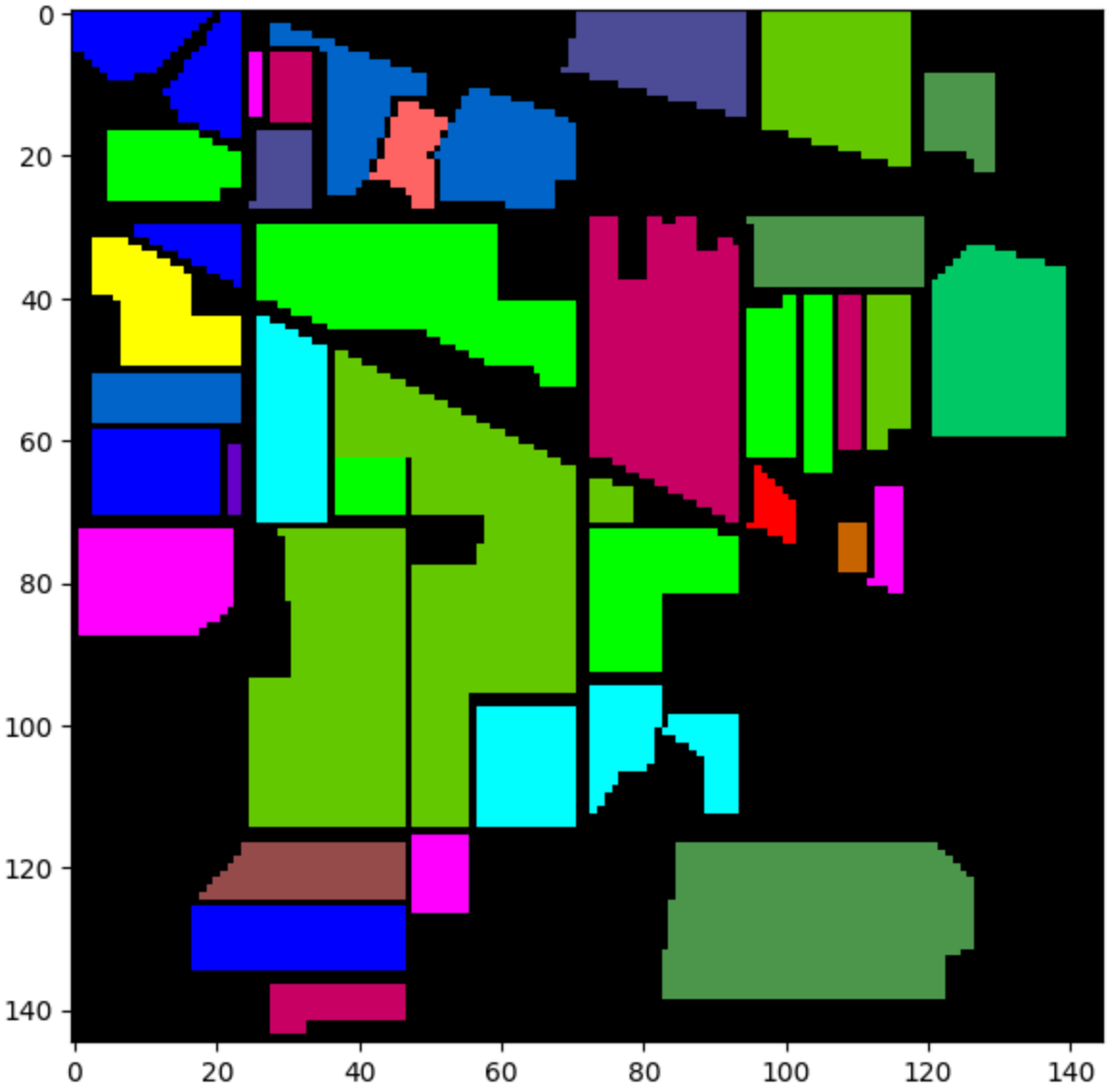
```

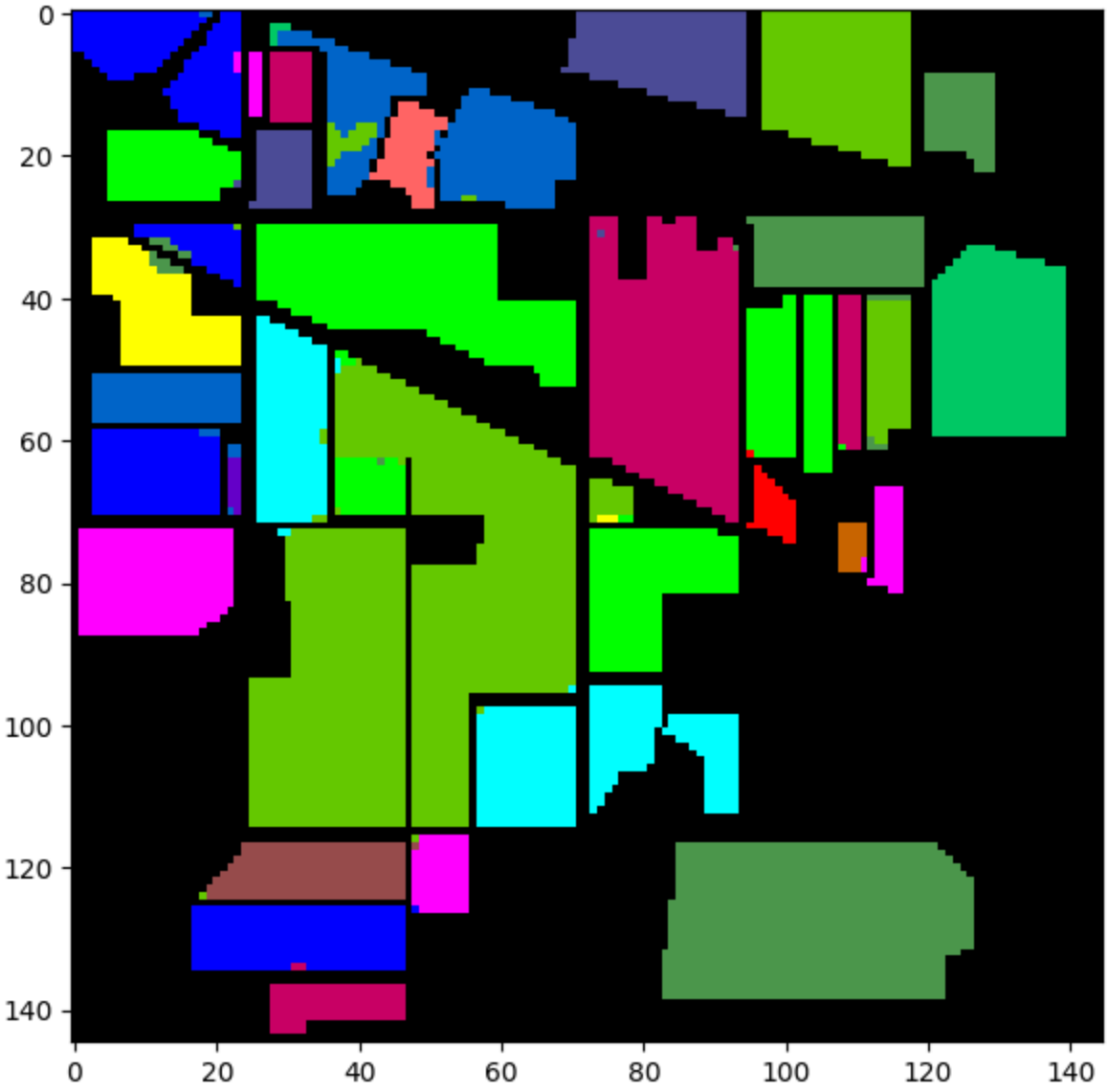
In [ ]:
```
ground_truth = spectral.imshow(classes = y,figsize =(7,7))
```

```
/usr/local/lib/python3.10/dist-packages/spectral/graphics/spypylab.py:796: User
Warning:

Failed to create RectangleSelector object. Interactive pixel class labeling wil
l be unavailable.
```




In [ ]:
```
predict_image = spectral.imshow(classes = outputs.astype(int),figsize =(7,7))
```




In [ ]:
```
spectral.save_rgb("predictions.jpg", outputs.astype(int), colors=spectral.spy_
```