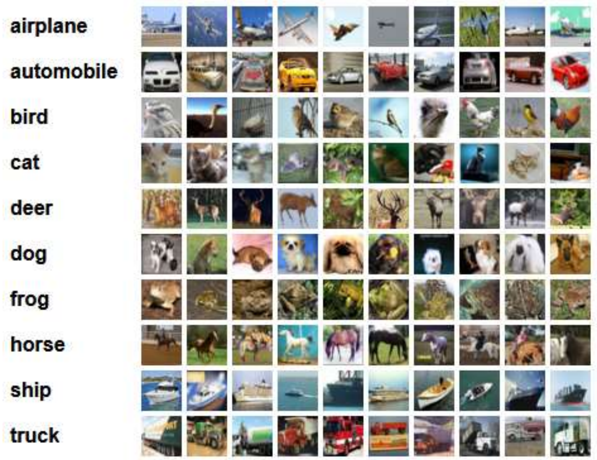
Mehrdad Baradaran - Cifar-10 Classification CNN

99222020 - assignment 2

In this series of exercises, we try to train 50,000 photos from 10 classes. To implement the neural network, we use convolution and pooling layers to have fewer parameters so that we can train easily. In addition, we check the effects of the number of blocks and hidden layers and use dropout and early stopping methods to obtain higher accuracy and display these changes in the graph. Let's go to start!.



Import libraries

In [1]:

```
import tensorflow as tf
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
%matplotlib inline
```

Load CIFAR_10 Data

```
In [2]:  (train_x, train_y), (test_x, test_y) = tf.keras.datasets.cifar10.load_data()
```

Check for Shapes and Types

```
In [3]:  train_x.shape, train_x.dtype, type(train_x)

Out[3]:  ((50000, 32, 32, 3), dtype('uint8'), numpy.ndarray)
```

```
In [4]:  train_y.shape, train_y.dtype, type(train_y)

Out[4]:  ((50000, 1), dtype('uint8'), numpy.ndarray)
```

```
In [5]:  test_x.shape, test_x.dtype, type(test_x)

Out[5]:  ((10000, 32, 32, 3), dtype('uint8'), numpy.ndarray)
```

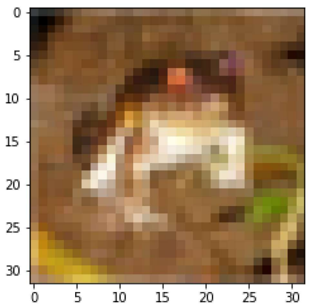
```
In [6]:  test_y.shape, test_y.dtype, type(test_y)

Out[6]:  ((10000, 1), dtype('uint8'), numpy.ndarray)
```

plot some pics of CIFAR_10 Dataset

```
In [7]:  plt.imshow(train_x[0])

Out[7]:  <matplotlib.image.AxesImage at 0x1e4ca130280>
```



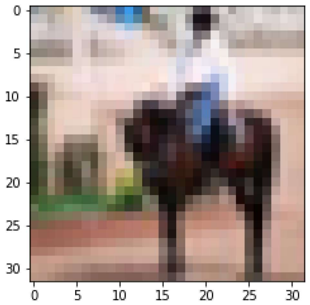
```
In [8]:  train_y[0]

Out[8]:  array([6], dtype=uint8)
```

In this dataset, the sixth grade belongs to frogs!

```
In [9]:  plt.imshow(train_x[11])

Out[9]:  <matplotlib.image.AxesImage at 0x1e4cc6692e0>
```



```
In [10]:  train_y[11]

Out[10]:  array([7], dtype=uint8)
```

import to_categorical method for converting labels to one-hot

In converting the labels to one-hot, instead of displaying the number of each class, we create an array with the length of the number of classes, and in that we display the probability of the existence of each class, which is used in such a way that all the elements of the array are zero and the index to which the photo belongs that class is one. Or is it that all the numerical elements are between 0 or 1, that the probability of each class in that photo is shown . the sum of all the numbers must be equal to 1.

```
In [11]:  from tensorflow.keras.utils import to_categorical
```

```
In [12]:  train_cat_y = to_categorical(train_y, num_classes=10)
          train_cat_y.shape, train_cat_y.dtype

Out[12]:  ((50000, 10), dtype('float32'))
```

```
In [13]:  test_cat_y = to_categorical(test_y, num_classes=10)
          test_cat_y.shape, test_cat_y.dtype

Out[13]:  ((10000, 10), dtype('float32'))
```

Check new labels

```
In [14]:  train_cat_y[0]

Out[14]:  array([0., 0., 0., 0., 0., 0., 1., 0., 0., 0.], dtype=float32)
```

```
In [15]:  train_cat_y[11]

Out[15]:  array([0., 0., 0., 0., 0., 0., 0., 1., 0., 0.], dtype=float32)
```

Normalize Data

Inputs between 0 and 1 . type shoud be float32

```
In [16]:  train_x = train_x.astype(np.float32) / 255.0
          test_x = test_x.astype(np.float32) / 255.0
```

```
In [17]:  train_x.shape, train_x.max(), train_x.min(), train_x.dtype

Out[17]:  ((50000, 32, 32, 3), 1.0, 0.0, dtype('float32'))
```

```
In [18]:  test_x.shape, test_x.max(), test_x.min(), test_x.dtype

Out[18]:  ((10000, 32, 32, 3), 1.0, 0.0, dtype('float32'))
```

Reshape Data

input : (None, height, weight, channel) , output : (None, class_numbers)
output should be one-hot
we want to data to be network compatible

Since all train and test data and labels have correct dimensions and can be trained, we do not need to reshape.

Recheck Data

```
In [19]: train_x.shape, train_x.dtype
Out[19]: ((50000, 32, 32, 3), dtype('float32'))
```

```
In [20]: train_cat_y.shape, train_cat_y.dtype
Out[20]: ((50000, 10), dtype('float32'))
```

```
In [21]: test_x.shape, test_x.dtype
Out[21]: ((10000, 32, 32, 3), dtype('float32'))
```

```
In [22]: test_cat_y.shape, test_cat_y.dtype
Out[22]: ((10000, 10), dtype('float32'))
```

All is well!

Create CNN Model

import libraries

```
In [23]: from tensorflow.keras.models import Model
         from tensorflow.keras.layers import Input, Dense, Dropout, MaxPool2D, Conv2D, Flatten, GlobalAveragePooling2D, ReLU, Activation
```

In [25]:

```
input = Input(shape=(32, 32, 3))

#block1
x = Conv2D(filters=32, kernel_size=(5, 5), strides=1, padding='same')(input)
x = ReLU()(x)
x = MaxPool2D(pool_size=(2, 2), strides=2, padding='same')(x)

#block2
x = Conv2D(filters=64, kernel_size=(3, 3), strides=1, padding='same')(x)
x = ReLU()(x)
x = MaxPool2D(pool_size=(2, 2), strides=2, padding='same')(x)

#block3
x = Conv2D(filters=128, kernel_size=(3, 3), strides=1, padding='same')(x)
x = ReLU()(x)
x = MaxPool2D(pool_size=(2, 2), strides=2, padding='same')(x)

#flatten
x = Flatten()(x)

# fully connected
x = Dense(units=128)(x)
x = ReLU()(x)

x = Dense(units=10)(x)
output = Activation(activation='softmax')(x)

cnn_model = Model(input, output)
cnn_model.summary()
```

```
Model: "model"
_________________________________________________________________
 Layer (type)                Output Shape              Param #   
=================================================================
 input_2 (InputLayer)        [(None, 32, 32, 3)]       0         
                                                                 
 conv2d_3 (Conv2D)           (None, 32, 32, 32)        2432      
                                                                 
 re_lu_4 (ReLU)              (None, 32, 32, 32)        0         
                                                                 
 max_pooling2d_3 (MaxPooling  (None, 16, 16, 32)       0         
 2D)                                                             
                                                                 
 conv2d_4 (Conv2D)           (None, 16, 16, 64)        18496     
                                                                 
 re_lu_5 (ReLU)              (None, 16, 16, 64)        0         
                                                                 
 max_pooling2d_4 (MaxPooling  (None, 8, 8, 64)         0         
 2D)                                                             
```

Compile my Model

In [26]:

```
cnn_model.compile(optimizer='adam', loss='categorical_crossentropy', metrics=['accuracy'])
```

Train Data using Early Stopping

In [27]:

```
from tensorflow.keras.callbacks import EarlyStopping
```

In [28]:

```
early_stop = EarlyStopping(monitor='val_accuracy', mode='max', patience=5, restore_best_weights=True)
```

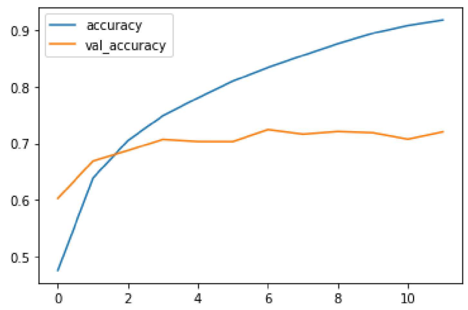
```
In [31]: cnn_model.fit(x=train_x, y=train_cat_y, epochs=30, batch_size=32,
                       validation_data=(test_x, test_cat_y), callbacks=[early_stop])
```

```
Epoch 1/30
1563/1563 [==============================] - 100s 63ms/step - loss: 1.4461 - accuracy: 0.4758 - val_loss: 1.1300 - val_accuracy: 0.6029
Epoch 2/30
1563/1563 [==============================] - 104s 66ms/step - loss: 1.0247 - accuracy: 0.6387 - val_loss: 0.9538 - val_accuracy: 0.6689
Epoch 3/30
1563/1563 [==============================] - 102s 65ms/step - loss: 0.8383 - accuracy: 0.7050 - val_loss: 0.9057 - val_accuracy: 0.6874
Epoch 4/30
1563/1563 [==============================] - 110s 70ms/step - loss: 0.7182 - accuracy: 0.7489 - val_loss: 0.8383 - val_accuracy: 0.7071
Epoch 5/30
1563/1563 [==============================] - 103s 66ms/step - loss: 0.6254 - accuracy: 0.7804 - val_loss: 0.8783 - val_accuracy: 0.7034
Epoch 6/30
1563/1563 [==============================] - 104s 67ms/step - loss: 0.5417 - accuracy: 0.8099 - val_loss: 0.9002 - val_accuracy: 0.7033
Epoch 7/30
1563/1563 [==============================] - 103s 66ms/step - loss: 0.4689 - accuracy: 0.8340 - val_loss: 0.8714 - val_accuracy: 0.7243
Epoch 8/30
1563/1563 [==============================] - 105s 67ms/step - loss: 0.4061 - accuracy: 0.8553 - val_loss: 0.9787 - val_accuracy: 0.7163
Epoch 9/30
1563/1563 [==============================] - 105s 67ms/step - loss: 0.3492 - accuracy: 0.8760 - val_loss: 1.0004 - val_accuracy: 0.7210
Epoch 10/30
```

Plot History of Model

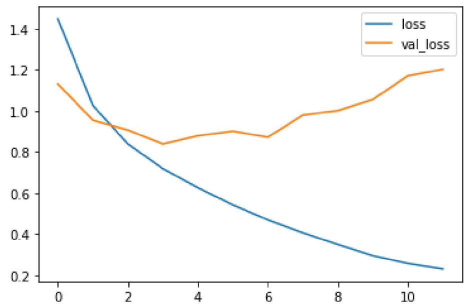
```
In [36]: model_history = pd.DataFrame(cnn_model.history.history)
         model_history[['accuracy', 'val_accuracy']].plot()
```

```
Out[36]: <AxesSubplot:>
```



```
In [37]: model_history[['loss', 'val_loss']].plot()
```

```
Out[37]: <AxesSubplot:>
```



Evaluate Model

In [38]:

```
cnn_model.evaluate(test_x, test_cat_y)
```

```
313/313 [==============================] - 5s 16ms/step - loss: 0.8714 - accuracy: 0.7243
```

Out[38]:

```
[0.871376633644104, 0.7243000268936157]
```

Sparse Model

In [40]:

```
predictions = cnn_model.predict(test_x)
predictions_sparse = np.argmax(predictions, axis=1)
predictions[0], predictions_sparse[0]
```

```
313/313 [==============================] - 5s 16ms/step
```

Out[40]:

```
(array([1.3141484e-04, 1.4132947e-03, 4.6473715e-04, 6.9945353e-01,
        4.6539153e-05, 2.6557797e-01, 6.7096837e-03, 7.1045570e-06,
        2.6175009e-02, 2.0679985e-05], dtype=float32),
 3)
```

Classification report and Confusion_Matrix

In [41]:

```
from sklearn.metrics import confusion_matrix, classification_report
```

In [42]:

```
print(classification_report(test_y, predictions_sparse))
```

```
              precision    recall  f1-score   support

           0       0.83      0.72      0.77      1000
           1       0.83      0.85      0.84      1000
           2       0.61      0.62      0.62      1000
           3       0.53      0.57      0.55      1000
           4       0.72      0.63      0.67      1000
           5       0.56      0.72      0.63      1000
           6       0.82      0.75      0.78      1000
           7       0.79      0.75      0.77      1000
           8       0.83      0.84      0.84      1000
           9       0.81      0.78      0.80      1000

    accuracy                           0.72     10000
   macro avg       0.73      0.72      0.73     10000
weighted avg       0.73      0.72      0.73     10000
```

In [43]:

```
confusion_matrix(test_y, predictions_sparse)
```

Out[43]:

```
array([[720,  17,  70,  22,  14,  14,  13,  12,  71,  47],
       [ 10, 855,  12,  10,   2,   7,   7,   1,  28,  68],
       [ 42,   7, 625,  77,  77,  78,  43,  32,  12,   7],
       [ 11,  14,  51, 569,  40, 215,  39,  36,  13,  12],
       [ 14,   1,  80,  93, 631,  78,  32,  58,   7,   6],
       [  6,   5,  43, 144,  27, 719,  16,  32,   2,   6],
       [  6,   7,  51,  91,  28,  50, 750,   6,   7,   4],
       [ 11,   3,  42,  35,  52,  91,   3, 751,   2,  10],
       [ 32,  31,  28,  16,   5,  15,   3,   7, 842,  21],
       [ 19,  94,  18,  24,   4,  19,   5,  11,  25, 781]], dtype=int64)
```

Show some Predictions

In [44]:

```
cnn_model.predict(np.reshape(test_x[0], (1, 32, 32, 3))).argmax()
```

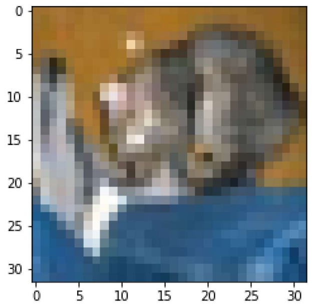
```
1/1 [==============================] - 0s 25ms/step
```

Out[44]:

```
3
```

```
In [45]:    plt.imshow(test_x[0])

   Out[45]: <matplotlib.image.AxesImage at 0x1e4ca00acd0>
```



```
In [46]:    test_y[0]

   Out[46]: array([3], dtype=uint8)
```

CNN Model with more Hidden layer and GlobalAveragePooling

```
In [48]:    from tensorflow.keras.models import Model
            from tensorflow.keras.layers import Input, Dense, Dropout, MaxPool2D
            from tensorflow.keras.layers import Conv2D, Flatten, GlobalAveragePooling2D, ReLU, Activation
```

In [51]:

```
input = Input(shape=(32, 32, 3))

#block1
x = Conv2D(filters=32, kernel_size=(7, 7), strides=1, padding='same')(input)
x = ReLU()(x)
x = MaxPool2D(pool_size=(2, 2), strides=2, padding='same')(x)

#block2
x = Conv2D(filters=64, kernel_size=(5, 5), strides=1, padding='same')(x)
x = ReLU()(x)
x = MaxPool2D(pool_size=(2, 2), strides=2, padding='same')(x)

#block3
x = Conv2D(filters=128, kernel_size=(3, 3), strides=1, padding='same')(x)
x = ReLU()(x)
x = MaxPool2D(pool_size=(2, 2), strides=2, padding='same')(x)

#block4
x = Conv2D(filters=256, kernel_size=(3, 3), strides=1, padding='same')(x)
x = ReLU()(x)
x = MaxPool2D(pool_size=(2, 2), strides=2, padding='same')(x)

#globalaveragepooling
x = GlobalAveragePooling2D()(x)

# fully connected
x = Dense(units=128)(x)
x = ReLU()(x)
x = Dense(units=32)(x)
x = ReLU()(x)
x = Dense(units=10)(x)
output = Activation(activation='softmax')(x)

cnn_model2 = Model(input, output)
cnn_model2.summary()
```

```
Model: "model_3"
_________________________________________________________________
 Layer (type)                Output Shape              Param #   
=================================================================
 input_5 (InputLayer)        [(None, 32, 32, 3)]       0         
                                                                 
 conv2d_15 (Conv2D)          (None, 32, 32, 32)        4736      
                                                                 
 re_lu_21 (ReLU)             (None, 32, 32, 32)        0         
                                                                 
 max_pooling2d_15 (MaxPoolin  (None, 16, 16, 32)       0         
 g2D)                                                            
                                                                 
 conv2d_16 (Conv2D)          (None, 16, 16, 64)        51264     
                                                                 
 re_lu_22 (ReLU)             (None, 16, 16, 64)        0         
                                                                 
 max_pooling2d_16 (MaxPoolin  (None, 8, 8, 64)         0         
 g2D)                                                            
                                                                 
 conv2d_17 (Conv2D)          (None, 8, 8, 128)         73856     
                                                                 
 re_lu_23 (ReLU)             (None, 8, 8, 128)         0         
                                                                 
 max_pooling2d_17 (MaxPoolin  (None, 4, 4, 128)        0         
 g2D)                                                            
                                                                 
 conv2d_18 (Conv2D)          (None, 4, 4, 256)         295168    
                                                                 
 re_lu_24 (ReLU)             (None, 4, 4, 256)         0         
                                                                 
 max_pooling2d_18 (MaxPoolin  (None, 2, 2, 256)        0         
 g2D)                                                            
                                                                 
 global_average_pooling2d_2   (None, 256)              0         
 (GlobalAveragePooling2D)                                        
 dense_9 (Dense)             (None, 128)               32896

 re_lu_25 (ReLU)             (None, 128)               0

 dense_10 (Dense)            (None, 32)                4128

 re_lu_26 (ReLU)             (None, 32)                0

 dense_11 (Dense)            (None, 10)                330

 activation_3 (Activation)   (None, 10)                0

=================================================================
Total params: 462,378
Trainable params: 462,378
Non-trainable params: 0
_________________________________________________________________
```

In [62]:
```python
cnn_model2.compile(optimizer='adam', loss='categorical_crossentropy', metrics=['accuracy'])
```

In [63]:
```python
from tensorflow.keras.callbacks import EarlyStopping
```

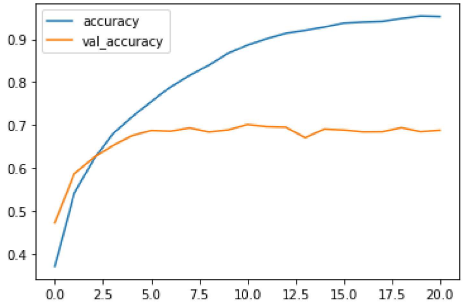
In [64]:
```python
early_stop2 = EarlyStopping(monitor='val_accuracy', mode='max', patience=10, restore_best_weights=True)
```

In [65]:
```python
cnn_model2.fit(x=train_x, y=train_cat_y, epochs=30, batch_size=32, validation_data=(test_x, test_cat_y), callbacks=[early_stop2])
```

```
Epoch 1/30
1563/1563 [==============================] - 212s 135ms/step - loss: 1.6838 - accuracy: 0.3710 - val_loss: 1.4338 - val_accuracy: 0.4726
Epoch 2/30
1563/1563 [==============================] - 220s 141ms/step - loss: 1.2687 - accuracy: 0.5411 - val_loss: 1.1507 - val_accuracy: 0.5866
Epoch 3/30
1563/1563 [==============================] - 224s 143ms/step - loss: 1.0663 - accuracy: 0.6192 - val_loss: 1.0549 - val_accuracy: 0.6240
Epoch 4/30
1563/1563 [==============================] - 221s 141ms/step - loss: 0.9139 - accuracy: 0.6793 - val_loss: 0.9896 - val_accuracy: 0.6522
Epoch 5/30
1563/1563 [==============================] - 220s 141ms/step - loss: 0.8010 - accuracy: 0.7190 - val_loss: 0.9426 - val_accuracy: 0.6752
Epoch 6/30
1563/1563 [==============================] - 215s 138ms/step - loss: 0.7001 - accuracy: 0.7547 - val_loss: 0.9185 - val_accuracy: 0.6875
Epoch 7/30
1563/1563 [==============================] - 215s 138ms/step - loss: 0.6039 - accuracy: 0.7887 - val_loss: 0.9488 - val_accuracy: 0.6858
Epoch 8/30
1563/1563 [==============================] - 217s 139ms/step - loss: 0.5275 - accuracy: 0.8157 - val_loss: 0.9523 - val_accuracy: 0.6937
Epoch 9/30
1563/1563 [==============================] - 220s 141ms/step - loss: 0.4535 - accuracy: 0.8399 - val_loss: 1.0808 - val_accuracy: 0.6839
Epoch 10/30
1563/1563 [==============================] - 219s 140ms/step - loss: 0.3822 - accuracy: 0.8672 - val_loss: 1.0478 - val_accuracy: 0.6880
```

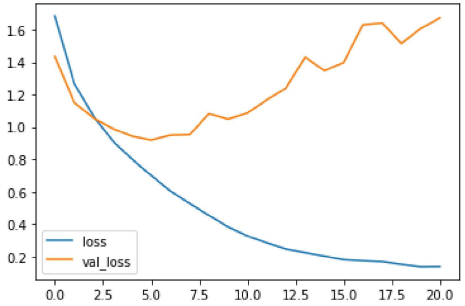
In [66]:
```python
model_history2 = pd.DataFrame(cnn_model2.history.history)
model_history2[['accuracy', 'val_accuracy']].plot()
```

Out[66]:
```
<AxesSubplot:>
```



```
In [67]:  model_history2[['loss', 'val_loss']].plot()
```

```
Out[67]: <AxesSubplot:>
```



```
In [68]:  cnn_model2.evaluate(test_x, test_cat_y)
```

```
313/313 [==============================] - 9s 28ms/step - loss: 1.0853 - accuracy: 0.7016
```

```
Out[68]: [1.0853139162063599, 0.7016000151634216]
```

```
In [69]:  predictions2 = cnn_model2.predict(test_x)
          predictions_sparse2 = np.argmax(predictions2, axis=1)
          predictions2[0], predictions_sparse2[0]
```

```
313/313 [==============================] - 9s 27ms/step
```

```
Out[69]: (array([0.05668004, 0.05526455, 0.00238728, 0.77401835, 0.00213873,
                 0.03204102, 0.01024812, 0.00196561, 0.01592639, 0.04932988],
                dtype=float32),
          3)
```

```
In [70]:  print(classification_report(test_y, predictions_sparse2))
```

```
              precision    recall  f1-score   support

           0       0.76      0.74      0.75      1000
           1       0.84      0.81      0.83      1000
           2       0.53      0.67      0.59      1000
           3       0.50      0.50      0.50      1000
           4       0.70      0.61      0.65      1000
           5       0.62      0.59      0.60      1000
           6       0.71      0.78      0.74      1000
           7       0.79      0.74      0.76      1000
           8       0.85      0.80      0.83      1000
           9       0.79      0.77      0.78      1000

    accuracy                           0.70     10000
   macro avg       0.71      0.70      0.70     10000
weighted avg       0.71      0.70      0.70     10000
```

In [71]:

```
confusion_matrix(test_y, predictions_sparse2)
```

Out[71]:

```
array([[743,   9,  96,  17,  14,   6,  14,   8,  49,  44],
       [ 11, 813,  15,  11,   2,   6,  10,   5,  34,  93],
       [ 47,   7, 671,  66,  66,  37,  77,  20,   4,   5],
       [ 22,  14, 114, 498,  39, 175,  87,  34,   8,   9],
       [ 19,   6, 133,  69, 607,  47,  60,  49,   5,   5],
       [  7,   7,  83, 166,  39, 593,  41,  53,   4,   7],
       [  5,   8,  58,  75,  27,  37, 779,   2,   6,   3],
       [ 16,   2,  52,  55,  62,  52,   8, 736,   3,  14],
       [ 77,  24,  25,  19,   8,   4,   9,   7, 804,  23],
       [ 32,  79,  30,  25,   5,   4,   8,  17,  28, 772]], dtype=int64)
```

CNN Model using Batch_normalization and Dropout

In [72]:

```
from tensorflow.keras.models import Model
from tensorflow.keras.layers import Input, Dense, Dropout, MaxPool2D
from tensorflow.keras.layers import Conv2D, Flatten, GlobalAveragePooling2D, ReLU, Activation, BatchNormalization
```

In [116]:

```
input = Input(shape=(32, 32, 3))

#block1
x = Conv2D(filters=32, kernel_size=(5, 5), strides=1, padding='same')(input)
x = BatchNormalization()(x)
x = ReLU()(x)
x = MaxPool2D(pool_size=(2, 2), strides=2, padding='same')(x)

#block2
x = Conv2D(filters=64, kernel_size=(3, 3), strides=1, padding='same')(x)
x = BatchNormalization()(x)
x = ReLU()(x)
x = MaxPool2D(pool_size=(2, 2), strides=2, padding='same')(x)

#block3
x = Conv2D(filters=128, kernel_size=(3, 3), strides=1, padding='same')(x)
x = BatchNormalization()(x)
x = ReLU()(x)
x = MaxPool2D(pool_size=(2, 2), strides=2, padding='same')(x)

#flatten
x = Flatten()(x)

# fully connected
x = Dense(units=128)(x)
x = ReLU()(x)
x = Dense(units=10)(x)
output = Activation(activation='softmax')(x)

cnn_model3 = Model(input, output)
cnn_model3.summary()
```

```
Model: "model_18"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 input_21 (InputLayer)       [(None, 32, 32, 3)]       0

 conv2d_73 (Conv2D)          (None, 32, 32, 32)        2432

 batch_normalization_51 (Bat  (None, 32, 32, 32)       128
 chNormalization)

 re_lu_96 (ReLU)             (None, 32, 32, 32)        0

 max_pooling2d_67 (MaxPoolin  (None, 16, 16, 32)       0
 g2D)

 conv2d_74 (Conv2D)          (None, 16, 16, 64)        18496

 batch_normalization_52 (Bat  (None, 16, 16, 64)       256
```

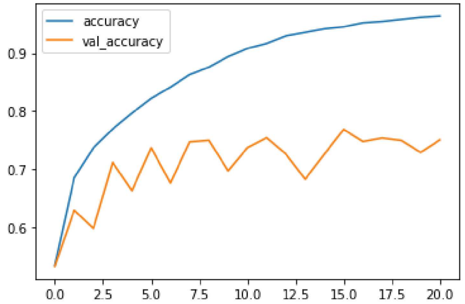
In [117]:
```
cnn_model3.compile(optimizer='adam', loss='categorical_crossentropy', metrics=['accuracy'])
```

In [118]:
```
cnn_model3.fit(x=train_x, y=train_cat_y, epochs=30, batch_size=32, validation_data=(test_x, test_cat_y), callbacks=[early_stop])
```

```
Epoch 1/30
1563/1563 [==============================] - 138s 88ms/step - loss: 1.3039 - accuracy: 0.5349 - val_loss: 1.4107 - val_accuracy: 0.5331
Epoch 2/30
1563/1563 [==============================] - 144s 92ms/step - loss: 0.8979 - accuracy: 0.6853 - val_loss: 1.0579 - val_accuracy: 0.6297
Epoch 3/30
1563/1563 [==============================] - 143s 92ms/step - loss: 0.7555 - accuracy: 0.7371 - val_loss: 1.3228 - val_accuracy: 0.5983
Epoch 4/30
1563/1563 [==============================] - 142s 91ms/step - loss: 0.6588 - accuracy: 0.7695 - val_loss: 0.8341 - val_accuracy: 0.7119
Epoch 5/30
1563/1563 [==============================] - 150s 96ms/step - loss: 0.5817 - accuracy: 0.7968 - val_loss: 0.9824 - val_accuracy: 0.6633
Epoch 6/30
1563/1563 [==============================] - 144s 92ms/step - loss: 0.5123 - accuracy: 0.8221 - val_loss: 0.7841 - val_accuracy: 0.7370
Epoch 7/30
1563/1563 [==============================] - 141s 90ms/step - loss: 0.4509 - accuracy: 0.8414 - val_loss: 1.0123 - val_accuracy: 0.6766
Epoch 8/30
1563/1563 [==============================] - 143s 91ms/step - loss: 0.3931 - accuracy: 0.8631 - val_loss: 0.7992 - val_accuracy: 0.7473
Epoch 9/30
1563/1563 [==============================] - 140s 90ms/step - loss: 0.3509 - accuracy: 0.8758 - val_loss: 0.8105 - val_accuracy: 0.7499
Epoch 10/30
```

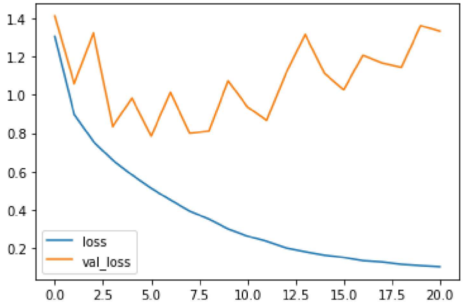
In [119]:
```
model_history3 = pd.DataFrame(cnn_model3.history.history)
model_history3[['accuracy', 'val_accuracy']].plot()
```

Out[119]:
```
<AxesSubplot:>
```



In [120]:
```
model_history3[['loss', 'val_loss']].plot()
```

Out[120]:
```
<AxesSubplot:>
```



In [121]:
```
cnn_model3.evaluate(test_x, test_cat_y)
```

```
313/313 [==============================] - 7s 21ms/step - loss: 1.0260 - accuracy: 0.7687
```

Out[121]:
```
[1.0259929895401, 0.7687000036239624]
```

In [122]:

```
predictions3 = cnn_model3.predict(test_x)
predictions_sparse3 = np.argmax(predictions3, axis=1)
predictions3[0], predictions_sparse3[0]
```

```
313/313 [==============================] - 6s 20ms/step
```

Out[122]:

```
(array([1.7266836e-02, 4.6387175e-04, 3.6339355e-07, 9.5014435e-01,
        2.1161333e-07, 1.6581584e-02, 7.9665035e-05, 5.8303767e-10,
        1.5462052e-02, 1.1197709e-06], dtype=float32),
 3)
```

In [123]:

```
print(classification_report(test_y, predictions_sparse3))
```

```
              precision    recall  f1-score   support

           0       0.75      0.82      0.79      1000
           1       0.90      0.85      0.87      1000
           2       0.78      0.59      0.67      1000
           3       0.63      0.55      0.59      1000
           4       0.66      0.83      0.74      1000
           5       0.67      0.71      0.69      1000
           6       0.78      0.87      0.82      1000
           7       0.83      0.77      0.80      1000
           8       0.87      0.87      0.87      1000
           9       0.85      0.83      0.84      1000

    accuracy                           0.77     10000
   macro avg       0.77      0.77      0.77     10000
weighted avg       0.77      0.77      0.77     10000
```

In [124]:

```
confusion_matrix(test_y, predictions_sparse3)
```

Out[124]:

```
array([[822,  14,  45,  11,  15,   6,  10,  11,  46,  20],
       [ 24, 849,   2,   8,   4,   2,   7,   1,  20,  83],
       [ 59,   4, 590,  53, 113,  57,  75,  38,  10,   1],
       [ 23,   3,  26, 548,  87, 173,  76,  36,  20,   8],
       [ 22,   3,  27,  34, 829,  24,  33,  21,   5,   2],
       [ 18,   4,  25, 117,  54, 709,  24,  39,   7,   3],
       [  3,   1,  18,  29,  45,  18, 873,   4,   6,   3],
       [ 16,   2,  15,  40,  96,  46,   8, 771,   2,   4],
       [ 61,  11,   8,  10,   4,   8,   5,   4, 870,  19],
       [ 45,  54,   3,  17,   8,   9,  12,   9,  17, 826]], dtype=int64)
```