Fine-Tuning Keras Models

LaTeX, Puteaux, 2020, 2021

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1 Understanding model optimization

1.1 [note-1] Why optimization is hard

- Simultaneously optimizing 1000s of parameters with complex relationships.
- Updates may not improve the model meaningfully.
- Updates could be too small (if the learning rate is low) or too large (if the learning rate is high).

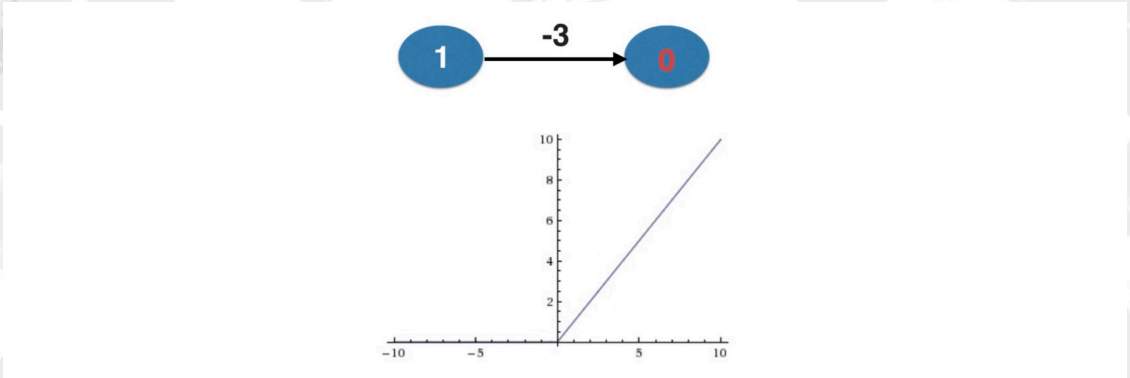
1.2 [code-1] Stochastic gradient descent

[1]:
```
import pandas as pd
from tensorflow.keras.layers import Dense
from tensorflow.keras.models import Sequential
from tensorflow.keras.utils import to_categorical
from tensorflow.keras.optimizers import SGD


def data_preparation(data):
    df = data.reindex(columns=[
        'SHOT_CLOCK', 'DRIBBLES', 'TOUCH_TIME', 'SHOT_DIST', 'CLOSE_DEF_DIST',
        'SHOT_RESULT'
    ])
    df['SHOT_CLOCK'] = df['SHOT_CLOCK'].fillna(0)
    df['SHOT_RESULT'].replace('missed', 0, inplace=True)
    df['SHOT_RESULT'].replace('made', 1, inplace=True)
    df.columns = df.columns.str.lower()
    return df


data = pd.read_csv('../Datasets/1. Basketball shot log.csv')
df = data_preparation(data)

predictors = df.drop(['shot_result'], axis=1).to_numpy()
n_cols = predictors.shape[1]
target = to_categorical(df.shot_result)
input_shape = (n_cols, )


def get_new_model(input_shape=input_shape):
    model = Sequential()
    model.add(Dense(100, activation='relu', input_shape=input_shape))
    model.add(Dense(100, activation='relu'))
```

```
    model.add(Dense(2, activation='softmax'))
    return (model)


lr_to_test = [.000001, 0.01, 1]

# loop over learning rates
for lr in lr_to_test:
    model = get_new_model()
    my_optimizer = SGD(lr=lr)
    model.compile(optimizer=my_optimizer, loss='categorical_crossentropy')
    model.fit(predictors, target)
```

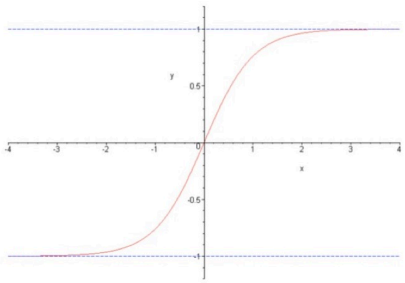
```
4003/4003 [==============================] - 4s 958us/step - loss: 1.2821
4003/4003 [==============================] - 4s 937us/step - loss: 0.6770
4003/4003 [==============================] - 4s 954us/step - loss: nan
```

1.3 [note-2] The dying neuron problem



1.4 [note-3] Vanishing gradients

- It occurs when many layers have very small slopes (*e.g., due to being on at part of tanh curve*).
- In deep networks, updates to backpropagation were close to 0.



tanh function

1.5 [quiz-1] Diagnosing optimization problems

- Which of the following could prevent a model from showing an improved loss in its first few epochs?

  ☐ Learning rate too low.

  ☐ Learning rate too high.

  ☐ Poor choice of the activation function.

  ☒ All of the above.

1.6 [task-1] Changing optimization parameters

▶ Package pre-loading

[2]:
```
import pandas as pd
from tensorflow.keras.layers import Dense
from tensorflow.keras.models import Sequential
from tensorflow.keras.utils import to_categorical
```

▶ Data pre-loading

[3]:
```
df = pd.read_csv('../Datasets/2. Titanic.csv')

df.replace(False, 0, inplace=True)
df.replace(True, 1, inplace=True)

predictors = df.drop(['survived'], axis=1).to_numpy()
n_cols = predictors.shape[1]
target = to_categorical(df.survived)
input_shape = (n_cols, )
```

▶ Code pre-loading

[4]:
```
def get_new_model(input_shape=input_shape):
    model = Sequential()
    model.add(Dense(100, activation='relu', input_shape=input_shape))
    model.add(Dense(100, activation='relu'))
    model.add(Dense(2, activation='softmax'))
    return (model)
```

▶ Task practice

[5]:
```
# Import the SGD optimizer
from tensorflow.keras.optimizers import SGD

# Create list of learning rates: lr_to_test
lr_to_test = [.000001, 0.01, 1]
```

```
# Loop over learning rates
for lr in lr_to_test:
    print('\n\nTesting model with learning rate: %f\n' % lr)

    # Build new model to test, unaffected by previous models
    model = get_new_model()

    # Create SGD optimizer with specified learning rate: my_optimizer
    my_optimizer = SGD(lr=lr)

    # Compile the model
    model.compile(optimizer=my_optimizer, loss='categorical_crossentropy')

    # Fit the model
    model.fit(predictors, target)
```

```
Testing model with learning rate: 0.000001

28/28 [==============================] - 0s 1ms/step - loss: 4.6519

Testing model with learning rate: 0.010000

28/28 [==============================] - 0s 1ms/step - loss: 2.9535

Testing model with learning rate: 1.000000

28/28 [==============================] - 0s 979us/step - loss: 30021.6365
```

2 Model validation

2.1 [note-1] Validation in deep learning

- Commonly use validation split rather than cross-validation.
- Deep learning is widely used on large datasets.
- A single validation score is based on a large amount of data and is reliable.
- Repeated training from cross-validation would take a long time.

2.2 [code-1] Model validation

[6]:
```
import pandas as pd
from tensorflow.keras.layers import Dense
from tensorflow.keras.models import Sequential
from tensorflow.keras.utils import to_categorical


def data_preparation(data):
    df = data.reindex(columns=[
        'SHOT_CLOCK', 'DRIBBLES', 'TOUCH_TIME', 'SHOT_DIST', 'CLOSE_DEF_DIST',
        'SHOT_RESULT'
    ])
    df['SHOT_CLOCK'] = df['SHOT_CLOCK'].fillna(0)
    df['SHOT_RESULT'].replace('missed', 0, inplace=True)
    df['SHOT_RESULT'].replace('made', 1, inplace=True)
    df.columns = df.columns.str.lower()
    return df


data = pd.read_csv('../Datasets/1. Basketball shot log.csv')
df = data_preparation(data)
predictors = df.drop(['shot_result'], axis=1).to_numpy()
n_cols = predictors.shape[1]
input_shape = (n_cols, )
target = to_categorical(df.shot_result)


def get_new_model(input_shape=input_shape):
    model = Sequential()
    model.add(Dense(100, activation='relu', input_shape=input_shape))
    model.add(Dense(100, activation='relu'))
    model.add(Dense(2, activation='softmax'))
    return (model)


model = get_new_model()

model.compile(optimizer='adam',
              loss='categorical_crossentropy',
              metrics=['accuracy'])
model.fit(predictors, target, validation_split=0.3)
```

```
2802/2802 [==============================] - 6s 2ms/step - loss: 0.6798 -
accuracy: 0.5944 - val_loss: 0.6540 - val_accuracy: 0.6153
```

[6]:
```
<tensorflow.python.keras.callbacks.History at 0x7f05103dd990>
```

2.3 [code-2] Early stopping

[7]:
```
from tensorflow.keras.callbacks import EarlyStopping

early_stopping_monitor = EarlyStopping(patience=2)

model.fit(predictors,
          target,
          validation_split=0.3,
          epochs=20,
          callbacks=[early_stopping_monitor])
```

```
Epoch 1/20
2802/2802 [==============================] - 5s 2ms/step - loss: 0.6547 -
accuracy: 0.6162 - val_loss: 0.6512 - val_accuracy: 0.6178
Epoch 2/20
2802/2802 [==============================] - 5s 2ms/step - loss: 0.6523 -
accuracy: 0.6189 - val_loss: 0.6516 - val_accuracy: 0.6133
Epoch 3/20
2802/2802 [==============================] - 5s 2ms/step - loss: 0.6510 -
accuracy: 0.6200 - val_loss: 0.6512 - val_accuracy: 0.6148
Epoch 4/20
2802/2802 [==============================] - 5s 2ms/step - loss: 0.6506 -
accuracy: 0.6191 - val_loss: 0.6499 - val_accuracy: 0.6192
Epoch 5/20
2802/2802 [==============================] - 5s 2ms/step - loss: 0.6501 -
accuracy: 0.6199 - val_loss: 0.6499 - val_accuracy: 0.6184
Epoch 6/20
2802/2802 [==============================] - 5s 2ms/step - loss: 0.6497 -
accuracy: 0.6202 - val_loss: 0.6498 - val_accuracy: 0.6176
Epoch 7/20
2802/2802 [==============================] - 5s 2ms/step - loss: 0.6495 -
accuracy: 0.6202 - val_loss: 0.6496 - val_accuracy: 0.6173
Epoch 8/20
2802/2802 [==============================] - 5s 2ms/step - loss: 0.6492 -
accuracy: 0.6203 - val_loss: 0.6505 - val_accuracy: 0.6193
Epoch 9/20
2802/2802 [==============================] - 5s 2ms/step - loss: 0.6493 -
accuracy: 0.6207 - val_loss: 0.6489 - val_accuracy: 0.6190
Epoch 10/20
2802/2802 [==============================] - 5s 2ms/step - loss: 0.6491 -
accuracy: 0.6217 - val_loss: 0.6495 - val_accuracy: 0.6175
Epoch 11/20
2802/2802 [==============================] - 5s 2ms/step - loss: 0.6489 -
accuracy: 0.6210 - val_loss: 0.6497 - val_accuracy: 0.6170
```

[7]:
```
<tensorflow.python.keras.callbacks.History at 0x7f0510803b90>
```

2.4 [note-2] Experimentation

- Experiment with different architectures.
- More layers.
- Fewer layers.
- Layers with more nodes.
- Layers with fewer nodes.
- Creating a great model requires experimentation.

2.5 [task-1] Evaluating model accuracy on a validation dataset

▶ Package pre-loading

[8]:
```
import pandas as pd
from tensorflow.keras.layers import Dense
from tensorflow.keras.models import Sequential
from tensorflow.keras.utils import to_categorical
```

▶ Data pre-loading

[9]:
```
df = pd.read_csv('../Datasets/2. Titanic.csv')

df.replace(False, 0, inplace=True)
df.replace(True, 1, inplace=True)

predictors = df.drop(['survived'], axis=1).to_numpy()
n_cols = predictors.shape[1]
input_shape = (n_cols, )
target = to_categorical(df.survived)
```

▶ Task practice

[10]:
```
# Save the number of columns in predictors: n_cols
n_cols = predictors.shape[1]
input_shape = (n_cols, )

# Specify the model
model = Sequential()
model.add(Dense(100, activation='relu', input_shape=input_shape))
model.add(Dense(100, activation='relu'))
model.add(Dense(2, activation='softmax'))

# Compile the model
model.compile(optimizer='adam',
              loss='categorical_crossentropy',
              metrics=['accuracy'])
```

```
# Fit the model
hist = model.fit(predictors, target, validation_split=0.3)
```

```
20/20 [==============================] - 1s 11ms/step - loss: 0.9088 - accuracy:
0.5695 - val_loss: 0.6584 - val_accuracy: 0.6418
```

2.6 [task-2] Early stopping: optimizing the optimization

▶ Task practice

[11]:
```
# Import EarlyStopping
from tensorflow.keras.callbacks import EarlyStopping

# Save the number of columns in predictors: n_cols
n_cols = predictors.shape[1]
input_shape = (n_cols, )

# Specify the model
model = Sequential()
model.add(Dense(100, activation='relu', input_shape=input_shape))
model.add(Dense(100, activation='relu'))
model.add(Dense(2, activation='softmax'))

# Compile the model
model.compile(optimizer='adam',
              loss='categorical_crossentropy',
              metrics=['accuracy'])

# Define early_stopping_monitor
early_stopping_monitor = EarlyStopping(patience=2)

# Fit the model
model.fit(predictors,
          target,
          validation_split=0.3,
          epochs=30,
          callbacks=[early_stopping_monitor])
```

```
Epoch 1/30
20/20 [==============================] - 1s 11ms/step - loss: 1.0658 - accuracy:
0.5395 - val_loss: 0.8986 - val_accuracy: 0.6791
Epoch 2/30
20/20 [==============================] - 0s 4ms/step - loss: 0.6949 - accuracy:
0.6583 - val_loss: 0.5223 - val_accuracy: 0.7463
Epoch 3/30
20/20 [==============================] - 0s 4ms/step - loss: 0.6271 - accuracy:
0.6737 - val_loss: 0.5056 - val_accuracy: 0.7687
```

```
Epoch 4/30
20/20 [==============================] - 0s 4ms/step - loss: 0.6135 - accuracy:
0.6534 - val_loss: 0.5378 - val_accuracy: 0.7537
Epoch 5/30
20/20 [==============================] - 0s 4ms/step - loss: 0.6698 - accuracy:
0.6720 - val_loss: 0.5483 - val_accuracy: 0.7463
```

[11]: <tensorflow.python.keras.callbacks.History at 0x7f05103073d0>

2.7 [task-3] Experimenting with wider networks

▶ **Package pre-loading**

[12]:
```
import matplotlib.pyplot as plt
```

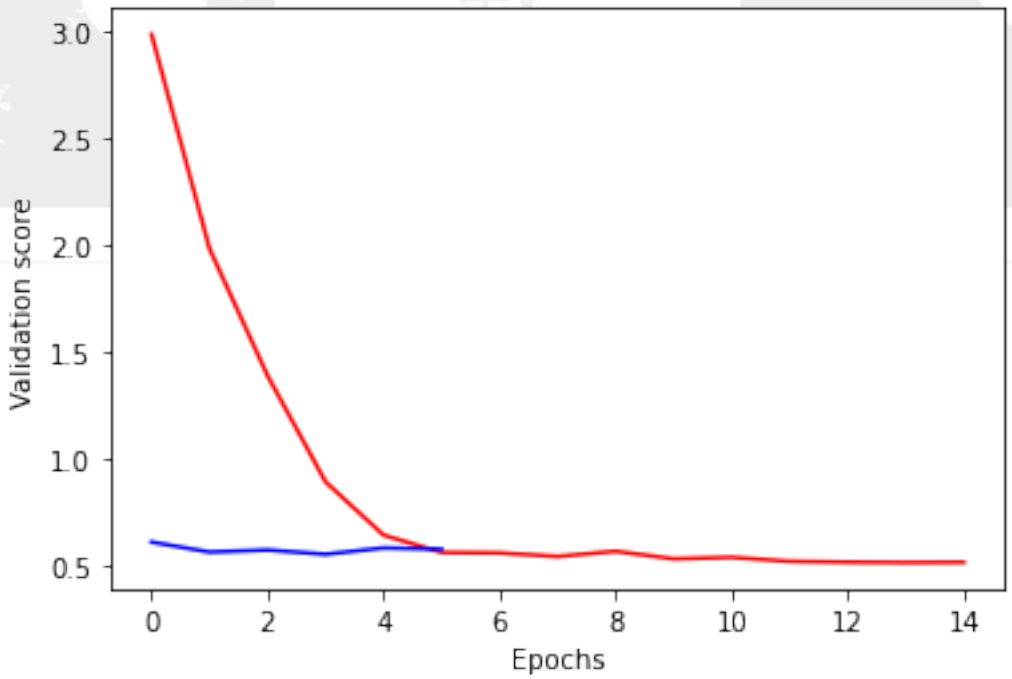
▶ **Code pre-loading**

[13]:
```
def get_new_model(input_shape=input_shape):
    model = Sequential()
    model.add(Dense(10, activation='relu', input_shape=input_shape))
    model.add(Dense(10, activation='relu'))
    model.add(Dense(2, activation='softmax'))
    model.compile(optimizer='adam',
                  loss='categorical_crossentropy',
                  metrics=['accuracy'])
    return model


model_1 = get_new_model()
```

▶ **Task practice**

[14]:
```
# Define early_stopping_monitor
early_stopping_monitor = EarlyStopping(patience=2)

# Create the new model: model_2
model_2 = Sequential()

# Add the first and second layers
model_2.add(Dense(100, activation='relu', input_shape=input_shape))
model_2.add(Dense(100, activation='relu'))

# Add the output layer
model_2.add(Dense(2, activation='softmax'))

# Compile model_2
model_2.compile(optimizer='adam',
                loss='categorical_crossentropy',
```

```
                metrics=['accuracy'])

# Fit model_1
model_1_training = model_1.fit(predictors,
                               target,
                               epochs=15,
                               validation_split=0.2,
                               callbacks=[early_stopping_monitor],
                               verbose=False)

# Fit model_2
model_2_training = model_2.fit(predictors,
                               target,
                               epochs=15,
                               validation_split=0.2,
                               callbacks=[early_stopping_monitor],
                               verbose=False)

# Create the plot
plt.plot(model_1_training.history['val_loss'], 'r',
         model_2_training.history['val_loss'], 'b')
plt.xlabel('Epochs')
plt.ylabel('Validation score')
plt.show()
```



2.8 [task-4] Adding layers to a network

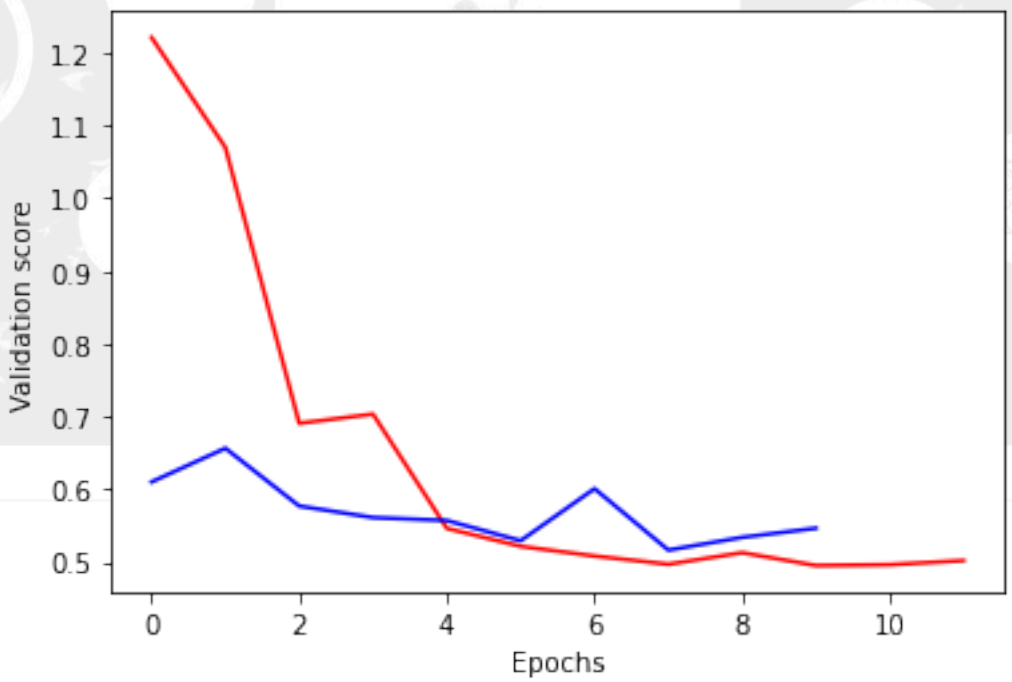
▶ Code pre-loading

[15]:
```
def get_new_model(input_shape=input_shape):
    model = Sequential()
    model.add(Dense(50, activation='relu', input_shape=input_shape))
    model.add(Dense(2, activation='softmax'))
    model.compile(optimizer='adam',
                  loss='categorical_crossentropy',
                  metrics=['accuracy'])
    return model


model_1 = get_new_model()
```

▶ Task practice

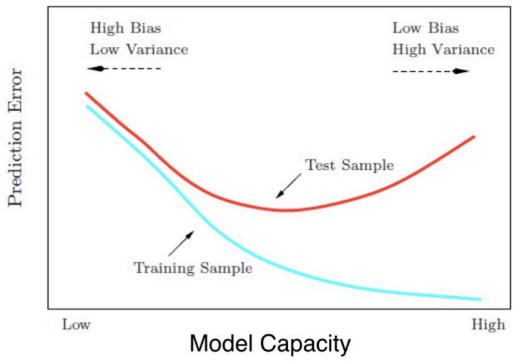
[16]:
```
# The input shape to use in the first hidden layer
input_shape = (n_cols, )

# Create the new model: model_2
model_2 = Sequential()

# Add the first, second, and third hidden layers
model_2.add(Dense(50, activation='relu', input_shape=input_shape))
model_2.add(Dense(50, activation='relu'))
model_2.add(Dense(50, activation='relu'))

# Add the output layer
model_2.add(Dense(2, activation='softmax'))

# Compile model_2
model_2.compile(optimizer='adam',
                loss='categorical_crossentropy',
                metrics=['accuracy'])

# Fit model 1
model_1_training = model_1.fit(predictors,
                               target,
                               epochs=20,
                               validation_split=0.4,
                               callbacks=[early_stopping_monitor],
                               verbose=False)

# Fit model 2
model_2_training = model_2.fit(predictors,
                               target,
```

```
                                epochs=20,
                                validation_split=0.4,
                                callbacks=[early_stopping_monitor],
                                verbose=False)

# Create the plot
plt.plot(model_1_training.history['val_loss'], 'r',
         model_2_training.history['val_loss'], 'b')
plt.xlabel('Epochs')
plt.ylabel('Validation score')
plt.show()
```



3 Thinking about model capacity

3.1 [note-1] Overfitting



3.2 [note-2] Workflow for optimizing model capacity

- Start with a small network.
- Gradually increase capacity.
- Keep increasing capacity until the validation score is no longer improving.

3.3 [note-3] Sequential experiments

Hidden Layers	Nodes Per Layer	Mean Squared Error	Next Step
1	100	5.4	Increase Capacity
1	250	4.8	Increase Capacity
2	250	4.4	Increase Capacity
3	250	4.5	Decrease Capacity
3	200	4.3	Done

3.4 [quiz-1] Experimenting with model structures

- An experiment has run where has compared two networks that were identical except that the 2nd network had an extra hidden layer. It could be seen that this 2nd network (the deeper network) had better performance. Given that, which of the following would be a good experiment to run next for even better performance?

  ☐ Try a new network with fewer layers than anything you have tried yet.

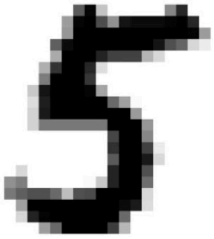
  ☒ Use more units in each hidden layer.

  ☐ Use fewer units in each hidden layer.

4 Stepping up to images

4.1 [note-1] Recognizing handwritten digits

- MNIST dataset.
- 28 x 28 grid flattened to 784 values for each image.
- Value in each part of the array denotes the darkness of that pixel.



4.2 [task-1] Building an own digit recognition model

▶ **Package pre-loading**

[17]:
```
import pandas as pd
from tensorflow.keras.layers import Dense
from tensorflow.keras.models import Sequential
from tensorflow.keras.utils import to_categorical
```

▶ **Data pre-loading**

[18]:
```
df = pd.read_csv('../Datasets/3. MNIST.csv', header=None)
X = df.iloc[:, 1:].to_numpy()
y = to_categorical(df.iloc[:, 0])
```

▶ **Task practice**

[19]:
```
# Create the model: model
model = Sequential()

# Add the first hidden layer
model.add(Dense(50, activation='relu', input_shape=(784, )))

# Add the second hidden layer
model.add(Dense(50, activation='relu'))

# Add the output layer
model.add(Dense(10, activation='softmax'))

# Compile the model
model.compile(optimizer='adam',
```

```
              loss='categorical_crossentropy',
              metrics=['accuracy'])

# Fit the model
model.fit(X, y, validation_split=0.3)
```

```
44/44 [==============================] - 1s 6ms/step - loss: 54.3641 - accuracy:
0.2529 - val_loss: 7.2395 - val_accuracy: 0.4925
```

[19]:
```
<tensorflow.python.keras.callbacks.History at 0x7f04e411e750>
```

5 Final thoughts

5.1 [note-1] Next steps

- Start with standard prediction problems on tables of numbers.
- Images (with convolutional neural networks) are common next steps.
- keras.io for excellent documentation.
- The graphical processing unit (GPU) provides dramatic speedups in model training times.
- Need a CUDA-compatible GPU.

6 Requirements

[20]:
```
from platform import python_version
import tensorflow as tf
import matplotlib

python_version = ('python=={}'.format(python_version()))
pandas_version = ('pandas=={}'.format(pd.__version__))
tensorflow_version = ('tensorflow=={}'.format(tf.__version__))
matplotlib_version = ('matplotlib=={}'.format(matplotlib.__version__))

writepath = '../../requirements.txt'
requirements = []
packages = [pandas_version, tensorflow_version, matplotlib_version]

try:
    with open(writepath, 'r+') as file:
        for line in file:
            requirements.append(line.strip('\n'))
except:
    with open(writepath, 'w+') as file:
        for line in file:
            requirements.append(line.strip('\n'))
```

```
with open(writepath, 'a') as file:
    for package in packages:
        if package not in requirements:
            file.write(package + '\n')

max_characters = len(python_version)
for package in packages:
    if max(max_characters, len(package)) > max_characters:
        max_characters = max(max_characters, len(package))

print('#' * (max_characters + 8))
print('#' * 2 + ' ' * (max_characters + 4) + '#' * 2)
print('#' * 2 + ' ' * 2 + python_version + ' ' *
      (max_characters - len(python_version) + 2) + '#' * 2)
for package in packages:
    print('#' * 2 + ' ' * 2 + package + ' ' *
          (max_characters - len(package) + 2) + '#' * 2)
print('#' * 2 + ' ' * (max_characters + 4) + '#' * 2)
print('#' * (max_characters + 8))
```

```
##########################
##                      ##
##  python==3.7.9       ##
##  pandas==1.2.1       ##
##  tensorflow==2.4.1   ##
##  matplotlib==3.3.4   ##
##                      ##
##########################
```