ECGR_4105_HW6_Problem_3

November 28, 2024

```python
[3]: import numpy as np
     import matplotlib.pyplot as plt
     import time
     import tensorflow as tf

     from tensorflow.keras import models, layers
     from tensorflow.keras.datasets import cifar10
```

```python
[4]: # Load CIFAR-10 dataset
     (x_train, y_train), (x_test, y_test) = cifar10.load_data()

     x_train = x_train.astype('float32') / 255.0
     x_test = x_test.astype('float32') / 255.0

     y_train = tf.keras.utils.to_categorical(y_train, 10)
     y_test = tf.keras.utils.to_categorical(y_test, 10)
```

```
Downloading data from https://www.cs.toronto.edu/~kriz/cifar-10-python.tar.gz
170498071/170498071        2s
0us/step
```

```python
[5]: # Define the model
     model = models.Sequential([
         layers.Flatten(input_shape=(32, 32, 3)), # CIFAR-10 images
         layers.Dense(256, activation='relu'),     # Hidden layer
         layers.Dense(10, activation='softmax')    # Output layer for 10 classes
     ])

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

```
/usr/local/lib/python3.10/dist-
packages/keras/src/layers/reshaping/flatten.py:37: UserWarning: Do not pass an
`input_shape`/`input_dim` argument to a layer. When using Sequential models,
prefer using an `Input(shape)` object as the first layer in the model instead.
  super().__init__(**kwargs)
```

```
# Train the model
start_time = time.time()  # Start timing
history = model.fit(x_train, y_train, epochs=100, batch_size=64,
                    validation_data=(x_test, y_test), verbose=2)
end_time = time.time()    # End timing

# Calculate training time
training_time = end_time - start_time
print(f"Training Time: {training_time:.2f} seconds")
```

```
Epoch 1/100
782/782 - 13s - 17ms/step - accuracy: 0.3191 - loss: 1.9152 - val_accuracy:
0.3623 - val_loss: 1.7760
Epoch 2/100
782/782 - 11s - 14ms/step - accuracy: 0.3840 - loss: 1.7274 - val_accuracy:
0.3976 - val_loss: 1.6815
Epoch 3/100
782/782 - 11s - 14ms/step - accuracy: 0.4075 - loss: 1.6646 - val_accuracy:
0.4234 - val_loss: 1.6328
Epoch 4/100
782/782 - 11s - 14ms/step - accuracy: 0.4190 - loss: 1.6331 - val_accuracy:
0.4226 - val_loss: 1.6174
Epoch 5/100
782/782 - 21s - 26ms/step - accuracy: 0.4296 - loss: 1.6039 - val_accuracy:
0.4199 - val_loss: 1.6145
Epoch 6/100
782/782 - 21s - 26ms/step - accuracy: 0.4385 - loss: 1.5812 - val_accuracy:
0.4420 - val_loss: 1.5853
Epoch 7/100
782/782 - 11s - 14ms/step - accuracy: 0.4450 - loss: 1.5646 - val_accuracy:
0.4429 - val_loss: 1.5638
Epoch 8/100
782/782 - 21s - 26ms/step - accuracy: 0.4504 - loss: 1.5468 - val_accuracy:
0.4276 - val_loss: 1.5890
Epoch 9/100
782/782 - 20s - 26ms/step - accuracy: 0.4574 - loss: 1.5293 - val_accuracy:
0.4509 - val_loss: 1.5496
Epoch 10/100
782/782 - 20s - 25ms/step - accuracy: 0.4603 - loss: 1.5197 - val_accuracy:
0.4444 - val_loss: 1.5685
Epoch 11/100
782/782 - 11s - 14ms/step - accuracy: 0.4634 - loss: 1.5042 - val_accuracy:
0.4335 - val_loss: 1.5690
Epoch 12/100
782/782 - 11s - 14ms/step - accuracy: 0.4677 - loss: 1.4970 - val_accuracy:
0.4445 - val_loss: 1.5576
Epoch 13/100
```

```
782/782 - 10s - 13ms/step - accuracy: 0.4739 - loss: 1.4839 - val_accuracy:
0.4576 - val_loss: 1.5285
Epoch 14/100
782/782 - 10s - 13ms/step - accuracy: 0.4776 - loss: 1.4733 - val_accuracy:
0.4459 - val_loss: 1.5419
Epoch 15/100
782/782 - 11s - 14ms/step - accuracy: 0.4778 - loss: 1.4696 - val_accuracy:
0.4394 - val_loss: 1.5675
Epoch 16/100
782/782 - 11s - 14ms/step - accuracy: 0.4790 - loss: 1.4615 - val_accuracy:
0.4395 - val_loss: 1.5644
Epoch 17/100
782/782 - 10s - 13ms/step - accuracy: 0.4841 - loss: 1.4553 - val_accuracy:
0.4556 - val_loss: 1.5220
Epoch 18/100
782/782 - 21s - 27ms/step - accuracy: 0.4865 - loss: 1.4460 - val_accuracy:
0.4670 - val_loss: 1.5134
Epoch 19/100
782/782 - 11s - 14ms/step - accuracy: 0.4862 - loss: 1.4397 - val_accuracy:
0.4638 - val_loss: 1.5188
Epoch 20/100
782/782 - 20s - 25ms/step - accuracy: 0.4893 - loss: 1.4312 - val_accuracy:
0.4617 - val_loss: 1.5160
Epoch 21/100
782/782 - 10s - 13ms/step - accuracy: 0.4939 - loss: 1.4308 - val_accuracy:
0.4525 - val_loss: 1.5330
Epoch 22/100
782/782 - 22s - 28ms/step - accuracy: 0.4922 - loss: 1.4236 - val_accuracy:
0.4601 - val_loss: 1.5144
Epoch 23/100
782/782 - 11s - 13ms/step - accuracy: 0.4940 - loss: 1.4193 - val_accuracy:
0.4682 - val_loss: 1.5208
Epoch 24/100
782/782 - 20s - 26ms/step - accuracy: 0.4964 - loss: 1.4161 - val_accuracy:
0.4538 - val_loss: 1.5587
Epoch 25/100
782/782 - 11s - 14ms/step - accuracy: 0.4977 - loss: 1.4094 - val_accuracy:
0.4642 - val_loss: 1.5415
Epoch 26/100
782/782 - 11s - 14ms/step - accuracy: 0.4993 - loss: 1.4061 - val_accuracy:
0.4609 - val_loss: 1.5344
Epoch 27/100
782/782 - 10s - 12ms/step - accuracy: 0.4987 - loss: 1.4045 - val_accuracy:
0.4594 - val_loss: 1.5315
Epoch 28/100
782/782 - 10s - 13ms/step - accuracy: 0.5039 - loss: 1.3958 - val_accuracy:
0.4648 - val_loss: 1.5071
Epoch 29/100
```

```
782/782 - 11s - 14ms/step - accuracy: 0.5053 - loss: 1.3926 - val_accuracy:
0.4715 - val_loss: 1.5001
Epoch 30/100
782/782 - 20s - 26ms/step - accuracy: 0.5037 - loss: 1.3931 - val_accuracy:
0.4651 - val_loss: 1.5176
Epoch 31/100
782/782 - 9s - 12ms/step - accuracy: 0.5081 - loss: 1.3818 - val_accuracy:
0.4652 - val_loss: 1.5083
Epoch 32/100
782/782 - 11s - 14ms/step - accuracy: 0.5064 - loss: 1.3848 - val_accuracy:
0.4714 - val_loss: 1.4990
Epoch 33/100
782/782 - 21s - 26ms/step - accuracy: 0.5092 - loss: 1.3818 - val_accuracy:
0.4750 - val_loss: 1.4875
Epoch 34/100
782/782 - 10s - 13ms/step - accuracy: 0.5104 - loss: 1.3784 - val_accuracy:
0.4519 - val_loss: 1.5753
Epoch 35/100
782/782 - 10s - 13ms/step - accuracy: 0.5118 - loss: 1.3745 - val_accuracy:
0.4735 - val_loss: 1.4796
Epoch 36/100
782/782 - 11s - 14ms/step - accuracy: 0.5114 - loss: 1.3692 - val_accuracy:
0.4643 - val_loss: 1.5133
Epoch 37/100
782/782 - 20s - 26ms/step - accuracy: 0.5132 - loss: 1.3630 - val_accuracy:
0.4688 - val_loss: 1.5053
Epoch 38/100
782/782 - 9s - 12ms/step - accuracy: 0.5139 - loss: 1.3638 - val_accuracy:
0.4768 - val_loss: 1.4787
Epoch 39/100
782/782 - 11s - 14ms/step - accuracy: 0.5154 - loss: 1.3577 - val_accuracy:
0.4730 - val_loss: 1.5060
Epoch 40/100
782/782 - 11s - 14ms/step - accuracy: 0.5194 - loss: 1.3573 - val_accuracy:
0.4713 - val_loss: 1.5014
Epoch 41/100
782/782 - 11s - 13ms/step - accuracy: 0.5184 - loss: 1.3528 - val_accuracy:
0.4776 - val_loss: 1.4877
Epoch 42/100
782/782 - 19s - 25ms/step - accuracy: 0.5198 - loss: 1.3513 - val_accuracy:
0.4743 - val_loss: 1.5094
Epoch 43/100
782/782 - 11s - 14ms/step - accuracy: 0.5209 - loss: 1.3490 - val_accuracy:
0.4715 - val_loss: 1.5012
Epoch 44/100
782/782 - 21s - 27ms/step - accuracy: 0.5203 - loss: 1.3424 - val_accuracy:
0.4768 - val_loss: 1.5094
Epoch 45/100
```

```
782/782 - 9s - 12ms/step - accuracy: 0.5271 - loss: 1.3373 - val_accuracy:
0.4695 - val_loss: 1.5283
Epoch 46/100
782/782 - 11s - 14ms/step - accuracy: 0.5210 - loss: 1.3442 - val_accuracy:
0.4846 - val_loss: 1.4780
Epoch 47/100
782/782 - 11s - 14ms/step - accuracy: 0.5224 - loss: 1.3405 - val_accuracy:
0.4808 - val_loss: 1.4872
Epoch 48/100
782/782 - 11s - 14ms/step - accuracy: 0.5267 - loss: 1.3311 - val_accuracy:
0.4684 - val_loss: 1.5157
Epoch 49/100
782/782 - 11s - 14ms/step - accuracy: 0.5236 - loss: 1.3350 - val_accuracy:
0.4799 - val_loss: 1.5231
Epoch 50/100
782/782 - 11s - 14ms/step - accuracy: 0.5265 - loss: 1.3316 - val_accuracy:
0.4663 - val_loss: 1.5031
Epoch 51/100
782/782 - 20s - 26ms/step - accuracy: 0.5266 - loss: 1.3272 - val_accuracy:
0.4730 - val_loss: 1.5111
Epoch 52/100
782/782 - 20s - 25ms/step - accuracy: 0.5294 - loss: 1.3250 - val_accuracy:
0.4782 - val_loss: 1.4875
Epoch 53/100
782/782 - 21s - 27ms/step - accuracy: 0.5297 - loss: 1.3219 - val_accuracy:
0.4746 - val_loss: 1.5184
Epoch 54/100
782/782 - 11s - 14ms/step - accuracy: 0.5311 - loss: 1.3206 - val_accuracy:
0.4711 - val_loss: 1.5156
Epoch 55/100
782/782 - 11s - 14ms/step - accuracy: 0.5327 - loss: 1.3169 - val_accuracy:
0.4745 - val_loss: 1.4948
Epoch 56/100
782/782 - 20s - 26ms/step - accuracy: 0.5320 - loss: 1.3174 - val_accuracy:
0.4647 - val_loss: 1.5334
Epoch 57/100
782/782 - 11s - 14ms/step - accuracy: 0.5332 - loss: 1.3110 - val_accuracy:
0.4786 - val_loss: 1.5120
Epoch 58/100
782/782 - 11s - 14ms/step - accuracy: 0.5303 - loss: 1.3172 - val_accuracy:
0.4865 - val_loss: 1.4985
Epoch 59/100
782/782 - 10s - 13ms/step - accuracy: 0.5338 - loss: 1.3138 - val_accuracy:
0.4759 - val_loss: 1.5186
Epoch 60/100
782/782 - 11s - 14ms/step - accuracy: 0.5324 - loss: 1.3121 - val_accuracy:
0.4812 - val_loss: 1.4923
Epoch 61/100
```

```
782/782 - 12s - 15ms/step - accuracy: 0.5341 - loss: 1.3047 - val_accuracy:
0.4839 - val_loss: 1.4845
Epoch 62/100
782/782 - 19s - 25ms/step - accuracy: 0.5344 - loss: 1.3073 - val_accuracy:
0.4723 - val_loss: 1.5227
Epoch 63/100
782/782 - 10s - 13ms/step - accuracy: 0.5370 - loss: 1.3014 - val_accuracy:
0.4652 - val_loss: 1.5442
Epoch 64/100
782/782 - 11s - 14ms/step - accuracy: 0.5356 - loss: 1.3015 - val_accuracy:
0.4831 - val_loss: 1.5108
Epoch 65/100
782/782 - 21s - 26ms/step - accuracy: 0.5364 - loss: 1.3000 - val_accuracy:
0.4599 - val_loss: 1.5345
Epoch 66/100
782/782 - 10s - 13ms/step - accuracy: 0.5378 - loss: 1.2981 - val_accuracy:
0.4727 - val_loss: 1.5191
Epoch 67/100
782/782 - 21s - 27ms/step - accuracy: 0.5397 - loss: 1.2938 - val_accuracy:
0.4727 - val_loss: 1.5050
Epoch 68/100
782/782 - 20s - 26ms/step - accuracy: 0.5392 - loss: 1.2943 - val_accuracy:
0.4840 - val_loss: 1.4924
Epoch 69/100
782/782 - 10s - 12ms/step - accuracy: 0.5406 - loss: 1.2939 - val_accuracy:
0.4731 - val_loss: 1.5230
Epoch 70/100
782/782 - 11s - 14ms/step - accuracy: 0.5395 - loss: 1.2955 - val_accuracy:
0.4816 - val_loss: 1.5216
Epoch 71/100
782/782 - 11s - 14ms/step - accuracy: 0.5415 - loss: 1.2905 - val_accuracy:
0.4629 - val_loss: 1.5628
Epoch 72/100
782/782 - 20s - 26ms/step - accuracy: 0.5422 - loss: 1.2872 - val_accuracy:
0.4687 - val_loss: 1.5503
Epoch 73/100
782/782 - 10s - 12ms/step - accuracy: 0.5413 - loss: 1.2858 - val_accuracy:
0.4699 - val_loss: 1.5360
Epoch 74/100
782/782 - 11s - 14ms/step - accuracy: 0.5407 - loss: 1.2869 - val_accuracy:
0.4772 - val_loss: 1.5370
Epoch 75/100
782/782 - 11s - 14ms/step - accuracy: 0.5440 - loss: 1.2837 - val_accuracy:
0.4805 - val_loss: 1.5180
Epoch 76/100
782/782 - 11s - 14ms/step - accuracy: 0.5429 - loss: 1.2800 - val_accuracy:
0.4713 - val_loss: 1.5383
Epoch 77/100
```

```
782/782 - 21s - 27ms/step - accuracy: 0.5449 - loss: 1.2798 - val_accuracy:
0.4719 - val_loss: 1.5671
Epoch 78/100
782/782 - 11s - 14ms/step - accuracy: 0.5434 - loss: 1.2832 - val_accuracy:
0.4784 - val_loss: 1.5320
Epoch 79/100
782/782 - 20s - 25ms/step - accuracy: 0.5459 - loss: 1.2784 - val_accuracy:
0.4697 - val_loss: 1.5669
Epoch 80/100
782/782 - 10s - 13ms/step - accuracy: 0.5455 - loss: 1.2769 - val_accuracy:
0.4805 - val_loss: 1.5171
Epoch 81/100
782/782 - 21s - 27ms/step - accuracy: 0.5487 - loss: 1.2738 - val_accuracy:
0.4751 - val_loss: 1.5243
Epoch 82/100
782/782 - 11s - 14ms/step - accuracy: 0.5454 - loss: 1.2740 - val_accuracy:
0.4594 - val_loss: 1.5568
Epoch 83/100
782/782 - 21s - 26ms/step - accuracy: 0.5459 - loss: 1.2756 - val_accuracy:
0.4808 - val_loss: 1.5039
Epoch 84/100
782/782 - 11s - 14ms/step - accuracy: 0.5489 - loss: 1.2666 - val_accuracy:
0.4673 - val_loss: 1.5638
Epoch 85/100
782/782 - 11s - 14ms/step - accuracy: 0.5491 - loss: 1.2679 - val_accuracy:
0.4713 - val_loss: 1.5589
Epoch 86/100
782/782 - 12s - 15ms/step - accuracy: 0.5448 - loss: 1.2777 - val_accuracy:
0.4786 - val_loss: 1.5213
Epoch 87/100
782/782 - 19s - 25ms/step - accuracy: 0.5504 - loss: 1.2674 - val_accuracy:
0.4777 - val_loss: 1.5316
Epoch 88/100
782/782 - 11s - 14ms/step - accuracy: 0.5504 - loss: 1.2672 - val_accuracy:
0.4705 - val_loss: 1.5496
Epoch 89/100
782/782 - 10s - 13ms/step - accuracy: 0.5487 - loss: 1.2635 - val_accuracy:
0.4663 - val_loss: 1.5410
Epoch 90/100
782/782 - 10s - 13ms/step - accuracy: 0.5497 - loss: 1.2635 - val_accuracy:
0.4728 - val_loss: 1.5546
Epoch 91/100
782/782 - 11s - 14ms/step - accuracy: 0.5502 - loss: 1.2611 - val_accuracy:
0.4805 - val_loss: 1.5196
Epoch 92/100
782/782 - 11s - 14ms/step - accuracy: 0.5501 - loss: 1.2597 - val_accuracy:
0.4830 - val_loss: 1.5176
Epoch 93/100
```

```
782/782 - 19s - 25ms/step - accuracy: 0.5520 - loss: 1.2560 - val_accuracy:
0.4746 - val_loss: 1.5352
Epoch 94/100
782/782 - 11s - 14ms/step - accuracy: 0.5531 - loss: 1.2529 - val_accuracy:
0.4775 - val_loss: 1.5331
Epoch 95/100
782/782 - 21s - 26ms/step - accuracy: 0.5525 - loss: 1.2573 - val_accuracy:
0.4734 - val_loss: 1.5500
Epoch 96/100
782/782 - 20s - 26ms/step - accuracy: 0.5543 - loss: 1.2565 - val_accuracy:
0.4812 - val_loss: 1.5158
Epoch 97/100
782/782 - 12s - 16ms/step - accuracy: 0.5518 - loss: 1.2566 - val_accuracy:
0.4624 - val_loss: 1.5790
Epoch 98/100
782/782 - 11s - 14ms/step - accuracy: 0.5515 - loss: 1.2557 - val_accuracy:
0.4741 - val_loss: 1.5538
Epoch 99/100
782/782 - 20s - 26ms/step - accuracy: 0.5545 - loss: 1.2490 - val_accuracy:
0.4767 - val_loss: 1.5424
Epoch 100/100
782/782 - 11s - 14ms/step - accuracy: 0.5555 - loss: 1.2477 - val_accuracy:
0.4731 - val_loss: 1.5718
Training Time: 1389.30 seconds
```

[7]:
```python
test_loss, test_accuracy = model.evaluate(x_test, y_test, verbose=0)
print(f"Test Loss: {test_loss:.4f}")
print(f"Test Accuracy: {test_accuracy:.4f}")
```

```
Test Loss: 1.5718
Test Accuracy: 0.4731
```

[9]:
```python
# Plot training & validation loss
plt.plot(history.history['loss'], label='Training Loss')
plt.plot(history.history['val_loss'], label='Validation Loss')
plt.title('Loss')
plt.xlabel('Epoch')
plt.ylabel('Loss')
plt.legend()
plt.show()

# Plot training & validation accuracy
plt.plot(history.history['accuracy'], label='Training Accuracy')
plt.plot(history.history['val_accuracy'], label='Validation Accuracy')
plt.title('Accuracy')
plt.xlabel('Epoch')
plt.ylabel('Accuracy')
```
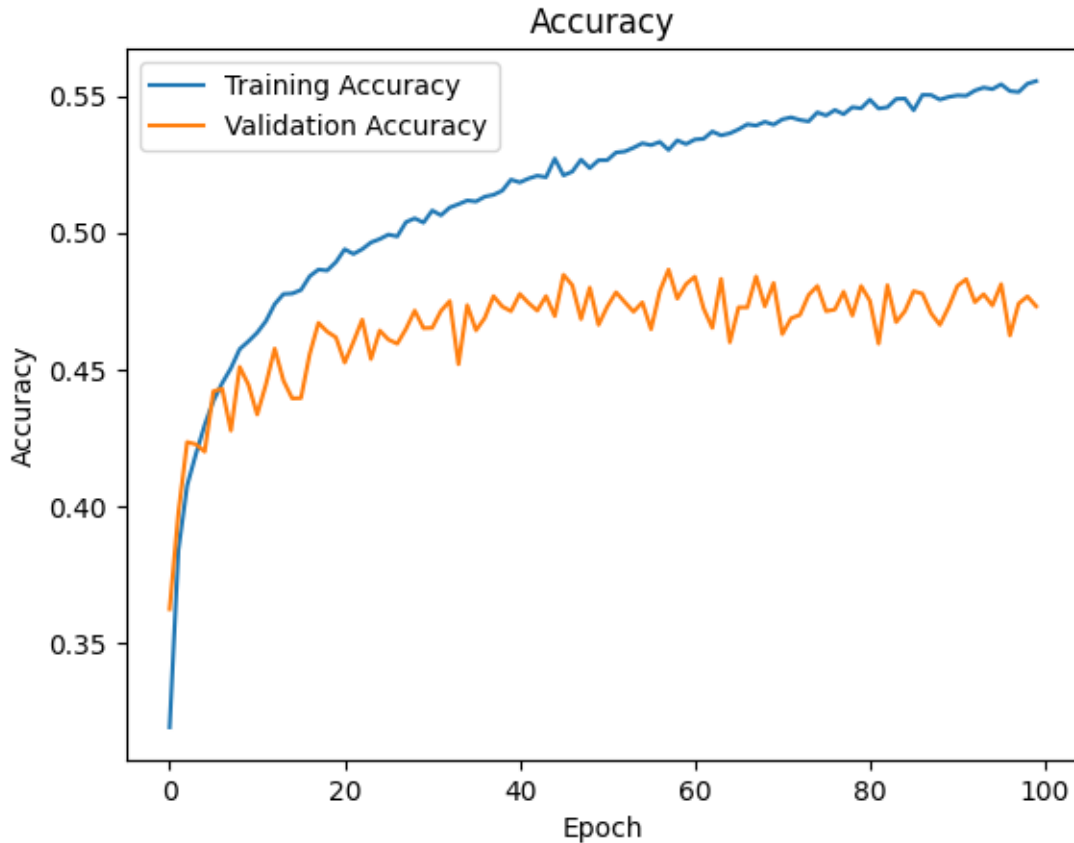
```
plt.legend()
plt.show()
```

Loss

Accuracy
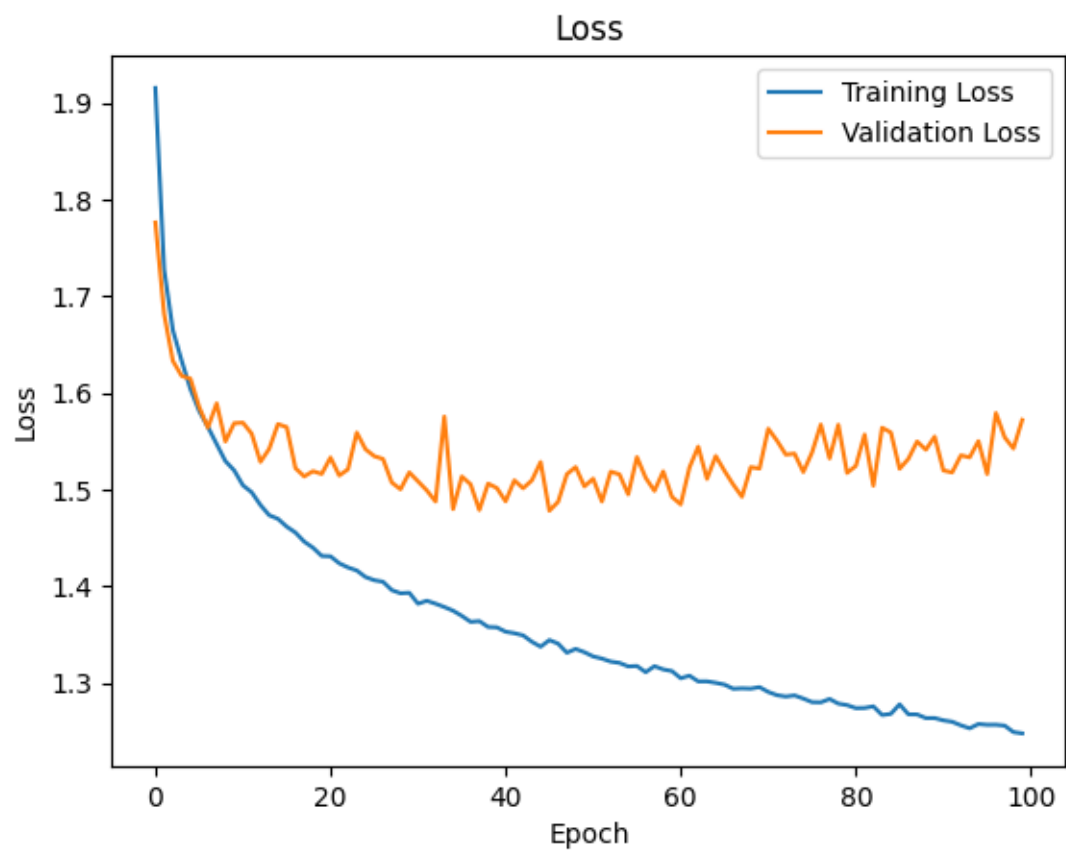
```
[10]:  # Define the extended model with two additional hidden layers
       extended_model = models.Sequential([
           layers.Flatten(input_shape=(32, 32, 3)),   # Flatten CIFAR-10 images
           layers.Dense(256, activation='relu'),      # First hidden layer
           layers.Dense(128, activation='relu'),      # Second hidden layer
           layers.Dense(64, activation='relu'),       # Third hidden layer
           layers.Dense(10, activation='softmax')     # Output layer for 10 classes
       ])

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

```
[11]:  # Train the extended model
       start_time = time.time()   # Start timing
       extended_history = extended_model.fit(x_train, y_train, epochs=100,␣
        ↪batch_size=64,
                                             validation_data=(x_test, y_test),␣
        ↪verbose=2)
```

10

```
end_time = time.time()      # End timing

# Calculate training time
extended_training_time = end_time - start_time
print(f"Extended Model Training Time: {extended_training_time:.2f} seconds")
```

```
Epoch 1/100
782/782 - 13s - 17ms/step - accuracy: 0.3226 - loss: 1.8757 - val_accuracy:
0.3918 - val_loss: 1.6942
Epoch 2/100
782/782 - 11s - 14ms/step - accuracy: 0.3976 - loss: 1.6803 - val_accuracy:
0.4210 - val_loss: 1.6251
Epoch 3/100
782/782 - 11s - 14ms/step - accuracy: 0.4229 - loss: 1.6091 - val_accuracy:
0.4440 - val_loss: 1.5504
Epoch 4/100
782/782 - 11s - 15ms/step - accuracy: 0.4472 - loss: 1.5475 - val_accuracy:
0.4402 - val_loss: 1.5459
Epoch 5/100
782/782 - 21s - 26ms/step - accuracy: 0.4599 - loss: 1.5106 - val_accuracy:
0.4631 - val_loss: 1.5160
Epoch 6/100
782/782 - 11s - 14ms/step - accuracy: 0.4718 - loss: 1.4747 - val_accuracy:
0.4603 - val_loss: 1.5022
Epoch 7/100
782/782 - 11s - 14ms/step - accuracy: 0.4815 - loss: 1.4470 - val_accuracy:
0.4877 - val_loss: 1.4570
Epoch 8/100
782/782 - 12s - 16ms/step - accuracy: 0.4926 - loss: 1.4238 - val_accuracy:
0.4755 - val_loss: 1.4754
Epoch 9/100
782/782 - 12s - 15ms/step - accuracy: 0.4992 - loss: 1.3976 - val_accuracy:
0.4672 - val_loss: 1.5005
Epoch 10/100
782/782 - 21s - 27ms/step - accuracy: 0.5033 - loss: 1.3887 - val_accuracy:
0.4894 - val_loss: 1.4497
Epoch 11/100
782/782 - 20s - 25ms/step - accuracy: 0.5136 - loss: 1.3625 - val_accuracy:
0.4873 - val_loss: 1.4415
Epoch 12/100
782/782 - 22s - 28ms/step - accuracy: 0.5167 - loss: 1.3486 - val_accuracy:
0.4798 - val_loss: 1.4605
Epoch 13/100
782/782 - 19s - 24ms/step - accuracy: 0.5248 - loss: 1.3309 - val_accuracy:
0.4955 - val_loss: 1.4180
Epoch 14/100
782/782 - 12s - 15ms/step - accuracy: 0.5326 - loss: 1.3112 - val_accuracy:
```

```
0.4935 - val_loss: 1.4230
Epoch 15/100
782/782 - 20s - 26ms/step - accuracy: 0.5337 - loss: 1.2966 - val_accuracy:
0.4956 - val_loss: 1.4355
Epoch 16/100
782/782 - 11s - 14ms/step - accuracy: 0.5399 - loss: 1.2865 - val_accuracy:
0.5020 - val_loss: 1.4049
Epoch 17/100
782/782 - 21s - 27ms/step - accuracy: 0.5440 - loss: 1.2705 - val_accuracy:
0.5058 - val_loss: 1.4067
Epoch 18/100
782/782 - 12s - 15ms/step - accuracy: 0.5494 - loss: 1.2567 - val_accuracy:
0.4866 - val_loss: 1.4599
Epoch 19/100
782/782 - 20s - 25ms/step - accuracy: 0.5548 - loss: 1.2452 - val_accuracy:
0.4925 - val_loss: 1.4490
Epoch 20/100
782/782 - 21s - 27ms/step - accuracy: 0.5584 - loss: 1.2384 - val_accuracy:
0.5004 - val_loss: 1.4288
Epoch 21/100
782/782 - 21s - 27ms/step - accuracy: 0.5594 - loss: 1.2236 - val_accuracy:
0.5084 - val_loss: 1.4129
Epoch 22/100
782/782 - 21s - 27ms/step - accuracy: 0.5653 - loss: 1.2117 - val_accuracy:
0.4965 - val_loss: 1.4423
Epoch 23/100
782/782 - 20s - 25ms/step - accuracy: 0.5668 - loss: 1.2095 - val_accuracy:
0.4898 - val_loss: 1.4647
Epoch 24/100
782/782 - 12s - 15ms/step - accuracy: 0.5754 - loss: 1.1873 - val_accuracy:
0.4905 - val_loss: 1.4679
Epoch 25/100
782/782 - 11s - 14ms/step - accuracy: 0.5754 - loss: 1.1774 - val_accuracy:
0.5086 - val_loss: 1.4152
Epoch 26/100
782/782 - 21s - 27ms/step - accuracy: 0.5779 - loss: 1.1725 - val_accuracy:
0.5099 - val_loss: 1.4216
Epoch 27/100
782/782 - 22s - 28ms/step - accuracy: 0.5821 - loss: 1.1635 - val_accuracy:
0.4987 - val_loss: 1.4352
Epoch 28/100
782/782 - 19s - 24ms/step - accuracy: 0.5857 - loss: 1.1523 - val_accuracy:
0.5128 - val_loss: 1.4263
Epoch 29/100
782/782 - 21s - 27ms/step - accuracy: 0.5894 - loss: 1.1419 - val_accuracy:
0.4999 - val_loss: 1.4492
Epoch 30/100
782/782 - 20s - 26ms/step - accuracy: 0.5918 - loss: 1.1320 - val_accuracy:
```

```
0.4939 - val_loss: 1.4934
Epoch 31/100
782/782 - 12s - 16ms/step - accuracy: 0.5934 - loss: 1.1254 - val_accuracy:
0.4999 - val_loss: 1.4898
Epoch 32/100
782/782 - 20s - 25ms/step - accuracy: 0.5997 - loss: 1.1144 - val_accuracy:
0.4794 - val_loss: 1.5574
Epoch 33/100
782/782 - 11s - 14ms/step - accuracy: 0.6021 - loss: 1.1087 - val_accuracy:
0.5033 - val_loss: 1.4656
Epoch 34/100
782/782 - 21s - 27ms/step - accuracy: 0.6019 - loss: 1.1081 - val_accuracy:
0.4978 - val_loss: 1.4845
Epoch 35/100
782/782 - 21s - 27ms/step - accuracy: 0.6053 - loss: 1.0933 - val_accuracy:
0.5052 - val_loss: 1.4468
Epoch 36/100
782/782 - 11s - 14ms/step - accuracy: 0.6089 - loss: 1.0871 - val_accuracy:
0.5039 - val_loss: 1.4930
Epoch 37/100
782/782 - 23s - 30ms/step - accuracy: 0.6085 - loss: 1.0840 - val_accuracy:
0.5086 - val_loss: 1.4769
Epoch 38/100
782/782 - 12s - 15ms/step - accuracy: 0.6151 - loss: 1.0684 - val_accuracy:
0.4998 - val_loss: 1.5304
Epoch 39/100
782/782 - 20s - 26ms/step - accuracy: 0.6139 - loss: 1.0700 - val_accuracy:
0.4959 - val_loss: 1.5159
Epoch 40/100
782/782 - 21s - 26ms/step - accuracy: 0.6173 - loss: 1.0622 - val_accuracy:
0.5000 - val_loss: 1.5288
Epoch 41/100
782/782 - 21s - 27ms/step - accuracy: 0.6228 - loss: 1.0480 - val_accuracy:
0.4995 - val_loss: 1.5118
Epoch 42/100
782/782 - 21s - 27ms/step - accuracy: 0.6247 - loss: 1.0446 - val_accuracy:
0.5009 - val_loss: 1.5228
Epoch 43/100
782/782 - 19s - 24ms/step - accuracy: 0.6226 - loss: 1.0437 - val_accuracy:
0.5106 - val_loss: 1.5017
Epoch 44/100
782/782 - 12s - 15ms/step - accuracy: 0.6258 - loss: 1.0388 - val_accuracy:
0.4981 - val_loss: 1.5238
Epoch 45/100
782/782 - 11s - 14ms/step - accuracy: 0.6237 - loss: 1.0341 - val_accuracy:
0.4958 - val_loss: 1.5563
Epoch 46/100
782/782 - 11s - 14ms/step - accuracy: 0.6320 - loss: 1.0217 - val_accuracy:
```

```
0.5069 - val_loss: 1.5450
Epoch 47/100
782/782 - 21s - 27ms/step - accuracy: 0.6349 - loss: 1.0168 - val_accuracy:
0.4936 - val_loss: 1.5826
Epoch 48/100
782/782 - 12s - 15ms/step - accuracy: 0.6342 - loss: 1.0145 - val_accuracy:
0.4989 - val_loss: 1.5766
Epoch 49/100
782/782 - 20s - 25ms/step - accuracy: 0.6356 - loss: 1.0077 - val_accuracy:
0.4971 - val_loss: 1.5671
Epoch 50/100
782/782 - 12s - 15ms/step - accuracy: 0.6362 - loss: 1.0027 - val_accuracy:
0.4993 - val_loss: 1.5485
Epoch 51/100
782/782 - 12s - 15ms/step - accuracy: 0.6383 - loss: 0.9962 - val_accuracy:
0.4963 - val_loss: 1.5785
Epoch 52/100
782/782 - 21s - 27ms/step - accuracy: 0.6412 - loss: 0.9890 - val_accuracy:
0.4986 - val_loss: 1.5605
Epoch 53/100
782/782 - 21s - 26ms/step - accuracy: 0.6394 - loss: 0.9861 - val_accuracy:
0.5028 - val_loss: 1.5760
Epoch 54/100
782/782 - 20s - 25ms/step - accuracy: 0.6460 - loss: 0.9802 - val_accuracy:
0.4926 - val_loss: 1.5934
Epoch 55/100
782/782 - 11s - 14ms/step - accuracy: 0.6473 - loss: 0.9780 - val_accuracy:
0.5024 - val_loss: 1.5926
Epoch 56/100
782/782 - 21s - 27ms/step - accuracy: 0.6481 - loss: 0.9757 - val_accuracy:
0.4810 - val_loss: 1.6145
Epoch 57/100
782/782 - 11s - 15ms/step - accuracy: 0.6517 - loss: 0.9630 - val_accuracy:
0.4912 - val_loss: 1.6374
Epoch 58/100
782/782 - 12s - 15ms/step - accuracy: 0.6538 - loss: 0.9585 - val_accuracy:
0.4946 - val_loss: 1.6028
Epoch 59/100
782/782 - 21s - 26ms/step - accuracy: 0.6558 - loss: 0.9529 - val_accuracy:
0.4940 - val_loss: 1.6539
Epoch 60/100
782/782 - 12s - 15ms/step - accuracy: 0.6562 - loss: 0.9543 - val_accuracy:
0.5050 - val_loss: 1.6177
Epoch 61/100
782/782 - 11s - 15ms/step - accuracy: 0.6614 - loss: 0.9442 - val_accuracy:
0.4950 - val_loss: 1.6082
Epoch 62/100
782/782 - 11s - 15ms/step - accuracy: 0.6598 - loss: 0.9403 - val_accuracy:
```

```
0.4967 - val_loss: 1.6442
Epoch 63/100
782/782 - 20s - 25ms/step - accuracy: 0.6588 - loss: 0.9412 - val_accuracy:
0.4957 - val_loss: 1.6602
Epoch 64/100
782/782 - 21s - 27ms/step - accuracy: 0.6626 - loss: 0.9317 - val_accuracy:
0.4865 - val_loss: 1.6540
Epoch 65/100
782/782 - 20s - 25ms/step - accuracy: 0.6632 - loss: 0.9313 - val_accuracy:
0.4911 - val_loss: 1.6699
Epoch 66/100
782/782 - 21s - 27ms/step - accuracy: 0.6634 - loss: 0.9311 - val_accuracy:
0.5008 - val_loss: 1.6377
Epoch 67/100
782/782 - 21s - 27ms/step - accuracy: 0.6681 - loss: 0.9205 - val_accuracy:
0.4949 - val_loss: 1.6850
Epoch 68/100
782/782 - 11s - 14ms/step - accuracy: 0.6671 - loss: 0.9154 - val_accuracy:
0.4976 - val_loss: 1.6989
Epoch 69/100
782/782 - 11s - 14ms/step - accuracy: 0.6699 - loss: 0.9141 - val_accuracy:
0.4860 - val_loss: 1.7276
Epoch 70/100
782/782 - 21s - 27ms/step - accuracy: 0.6725 - loss: 0.9055 - val_accuracy:
0.4953 - val_loss: 1.7028
Epoch 71/100
782/782 - 12s - 15ms/step - accuracy: 0.6721 - loss: 0.9063 - val_accuracy:
0.4844 - val_loss: 1.7290
Epoch 72/100
782/782 - 20s - 26ms/step - accuracy: 0.6742 - loss: 0.8980 - val_accuracy:
0.4928 - val_loss: 1.7524
Epoch 73/100
782/782 - 20s - 26ms/step - accuracy: 0.6745 - loss: 0.8954 - val_accuracy:
0.4935 - val_loss: 1.7156
Epoch 74/100
782/782 - 12s - 15ms/step - accuracy: 0.6767 - loss: 0.8925 - val_accuracy:
0.4831 - val_loss: 1.7432
Epoch 75/100
782/782 - 11s - 14ms/step - accuracy: 0.6788 - loss: 0.8859 - val_accuracy:
0.4765 - val_loss: 1.8178
Epoch 76/100
782/782 - 22s - 28ms/step - accuracy: 0.6809 - loss: 0.8844 - val_accuracy:
0.4924 - val_loss: 1.7653
Epoch 77/100
782/782 - 11s - 15ms/step - accuracy: 0.6791 - loss: 0.8834 - val_accuracy:
0.4893 - val_loss: 1.7359
Epoch 78/100
782/782 - 11s - 15ms/step - accuracy: 0.6810 - loss: 0.8786 - val_accuracy:
```

0.4842 - val_loss: 1.8147
Epoch 79/100
782/782 - 12s - 15ms/step - accuracy: 0.6828 - loss: 0.8765 - val_accuracy:
0.4836 - val_loss: 1.8322
Epoch 80/100
782/782 - 20s - 26ms/step - accuracy: 0.6839 - loss: 0.8732 - val_accuracy:
0.4904 - val_loss: 1.7539
Epoch 81/100
782/782 - 11s - 15ms/step - accuracy: 0.6852 - loss: 0.8688 - val_accuracy:
0.4857 - val_loss: 1.7545
Epoch 82/100
782/782 - 11s - 15ms/step - accuracy: 0.6872 - loss: 0.8640 - val_accuracy:
0.4835 - val_loss: 1.7589
Epoch 83/100
782/782 - 19s - 25ms/step - accuracy: 0.6842 - loss: 0.8698 - val_accuracy:
0.4832 - val_loss: 1.8316
Epoch 84/100
782/782 - 22s - 28ms/step - accuracy: 0.6909 - loss: 0.8553 - val_accuracy:
0.4889 - val_loss: 1.7848
Epoch 85/100
782/782 - 12s - 15ms/step - accuracy: 0.6899 - loss: 0.8602 - val_accuracy:
0.4884 - val_loss: 1.7936
Epoch 86/100
782/782 - 19s - 24ms/step - accuracy: 0.6912 - loss: 0.8508 - val_accuracy:
0.4880 - val_loss: 1.8292
Epoch 87/100
782/782 - 21s - 27ms/step - accuracy: 0.6959 - loss: 0.8432 - val_accuracy:
0.4872 - val_loss: 1.8136
Epoch 88/100
782/782 - 11s - 15ms/step - accuracy: 0.6938 - loss: 0.8485 - val_accuracy:
0.4928 - val_loss: 1.7856
Epoch 89/100
782/782 - 20s - 25ms/step - accuracy: 0.6953 - loss: 0.8393 - val_accuracy:
0.4833 - val_loss: 1.8785
Epoch 90/100
782/782 - 22s - 28ms/step - accuracy: 0.6956 - loss: 0.8427 - val_accuracy:
0.4871 - val_loss: 1.8120
Epoch 91/100
782/782 - 12s - 16ms/step - accuracy: 0.6958 - loss: 0.8369 - val_accuracy:
0.4902 - val_loss: 1.8486
Epoch 92/100
782/782 - 12s - 15ms/step - accuracy: 0.6952 - loss: 0.8336 - val_accuracy:
0.4839 - val_loss: 1.8628
Epoch 93/100
782/782 - 12s - 15ms/step - accuracy: 0.6984 - loss: 0.8293 - val_accuracy:
0.4871 - val_loss: 1.8522
Epoch 94/100
782/782 - 23s - 29ms/step - accuracy: 0.6996 - loss: 0.8279 - val_accuracy:

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0.4919 - val_loss: 1.8605
Epoch 95/100
782/782 - 18s - 23ms/step - accuracy: 0.6976 - loss: 0.8311 - val_accuracy:
0.4873 - val_loss: 1.8649
Epoch 96/100
782/782 - 12s - 15ms/step - accuracy: 0.6989 - loss: 0.8235 - val_accuracy:
0.4891 - val_loss: 1.8954
Epoch 97/100
782/782 - 11s - 14ms/step - accuracy: 0.7022 - loss: 0.8201 - val_accuracy:
0.4747 - val_loss: 1.9599
Epoch 98/100
782/782 - 23s - 29ms/step - accuracy: 0.7042 - loss: 0.8140 - val_accuracy:
0.4823 - val_loss: 1.9594
Epoch 99/100
782/782 - 12s - 15ms/step - accuracy: 0.7079 - loss: 0.8090 - val_accuracy:
0.4886 - val_loss: 1.8757
Epoch 100/100
782/782 - 12s - 16ms/step - accuracy: 0.7067 - loss: 0.8091 - val_accuracy:
0.4839 - val_loss: 1.9097
Extended Model Training Time: 1637.40 seconds
```

[12]:
```python
# Evaluate the extended model
test_loss, test_accuracy = extended_model.evaluate(x_test, y_test, verbose=0)
print(f"Extended Model Test Loss: {test_loss:.4f}")
print(f"Extended Model Test Accuracy: {test_accuracy:.4f}")
```

```
Extended Model Test Loss: 1.9097
Extended Model Test Accuracy: 0.4839
```

[13]:
```python
# Plot training & validation loss
plt.plot(extended_history.history['loss'], label='Training Loss')
plt.plot(extended_history.history['val_loss'], label='Validation Loss')
plt.title('Extended Model Loss')
plt.xlabel('Epoch')
plt.ylabel('Loss')
plt.legend()
plt.show()

# Plot training & validation accuracy
plt.plot(extended_history.history['accuracy'], label='Training Accuracy')
plt.plot(extended_history.history['val_accuracy'], label='Validation Accuracy')
plt.title('Extended Model Accuracy')
plt.xlabel('Epoch')
plt.ylabel('Accuracy')
plt.legend()
plt.show()
```

Extended Model Loss