Problem Statement 6: Object detection using Transfer Learning of CNN architectures.

1. Load in a pre-trained CNN model trained on a large dataset
2. Freeze parameters (weights) in model's lower convolutional layers
3. Add custom classifier with several layers of trainable parameters to model
4. Train classifier layers on training data available for task
5. Fine-tune hyper parameters and unfreeze more layers as needed

```python
# Import necessary libraries
import numpy as np
import tensorflow as tf
from tensorflow.keras.applications import MobileNetV2
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense, GlobalAveragePooling2D
import matplotlib.pyplot as plt
```

```python
# Generate example data (Replace this with your actual dataset)
num_samples = 1000  # Number of samples
num_classes = 10    # Number of classes
X_train = np.random.rand(num_samples, 224, 224, 3).astype(np.float32)
y_train = np.random.randint(0, num_classes, num_samples)

print("X_train shape:", X_train.shape)
print("y_train shape:", y_train.shape)
```

```
X_train shape: (1000, 224, 224, 3)
y_train shape: (1000,)
```

```python
# Load pre-trained MobileNetV2 model + higher-level layers
base_model = MobileNetV2(weights='imagenet', include_top=False, input_shape=(224, 224, 3)

# Display the model architecture
base_model.summary()
```

Model: "mobilenetv2_1.00_224"

Layer (type)	Output Shape	Param #	Connected to
input_layer (InputLayer)	(None, 224, 224, 3)	0	-
Conv1 (Conv2D)	(None, 112, 112, 32)	864	input_layer[0
bn_Conv1 (BatchNormalization)	(None, 112, 112, 32)	128	Conv1[0][0]
Conv1_relu (ReLU)	(None, 112, 112, 32)	0	bn_Conv1[0][0
expanded_conv_depthwise (DepthwiseConv2D)	(None, 112, 112, 32)	288	Conv1_relu[0]
expanded_conv_depthwise_… (BatchNormalization)	(None, 112, 112, 32)	128	expanded_conv
expanded_conv_depthwise_… (ReLU)	(None, 112, 112, 32)	0	expanded_conv
expanded_conv_project (Conv2D)	(None, 112, 112, 16)	512	expanded_conv
expanded_conv_project_BN (BatchNormalization)	(None, 112, 112, 16)	64	expanded_conv
block_1_expand (Conv2D)	(None, 112, 112, 96)	1,536	expanded_conv
block_1_expand_BN (BatchNormalization)	(None, 112, 112, 96)	384	block_1_expar
block_1_expand_relu (ReLU)	(None, 112, 112, 96)	0	block_1_expar
block_1_pad (ZeroPadding2D)	(None, 113, 113, 96)	0	block_1_expar
block_1_depthwise (DepthwiseConv2D)	(None, 56, 56, 96)	864	block_1_pad[0
block_1_depthwise_BN (BatchNormalization)	(None, 56, 56, 96)	384	block_1_depth
block_1_depthwise_relu (ReLU)	(None, 56, 56, 96)	0	block_1_depth
block_1_project (Conv2D)	(None, 56, 56, 24)	2,304	block_1_depth
block_1_project_BN (BatchNormalization)	(None, 56, 56, 24)	96	block_1_proje
block_2_expand (Conv2D)	(None, 56, 56, 144)	3,456	block_1_proje
block_2_expand_BN (BatchNormalization)	(None, 56, 56, 144)	576	block_2_expar
block_2_expand_relu	(None, 56, 56, 144)	0	block_2_expar

(ReLU)			
block_2_depthwise (DepthwiseConv2D)	(None, 56, 56, 144)	1,296	block_2_expar
block_2_depthwise_BN (BatchNormalization)	(None, 56, 56, 144)	576	block_2_depth
block_2_depthwise_relu (ReLU)	(None, 56, 56, 144)	0	block_2_depth
block_2_project (Conv2D)	(None, 56, 56, 24)	3,456	block_2_depth
block_2_project_BN (BatchNormalization)	(None, 56, 56, 24)	96	block_2_proje
block_2_add (Add)	(None, 56, 56, 24)	0	block_1_proje block_2_proje
block_3_expand (Conv2D)	(None, 56, 56, 144)	3,456	block_2_add[(
block_3_expand_BN (BatchNormalization)	(None, 56, 56, 144)	576	block_3_expar
block_3_expand_relu (ReLU)	(None, 56, 56, 144)	0	block_3_expar
block_3_pad (ZeroPadding2D)	(None, 57, 57, 144)	0	block_3_expar
block_3_depthwise (DepthwiseConv2D)	(None, 28, 28, 144)	1,296	block_3_pad[(
block_3_depthwise_BN (BatchNormalization)	(None, 28, 28, 144)	576	block_3_depth
block_3_depthwise_relu (ReLU)	(None, 28, 28, 144)	0	block_3_depth
block_3_project (Conv2D)	(None, 28, 28, 32)	4,608	block_3_depth
block_3_project_BN (BatchNormalization)	(None, 28, 28, 32)	128	block_3_proje
block_4_expand (Conv2D)	(None, 28, 28, 192)	6,144	block_3_proje
block_4_expand_BN (BatchNormalization)	(None, 28, 28, 192)	768	block_4_expar
block_4_expand_relu (ReLU)	(None, 28, 28, 192)	0	block_4_expar
block_4_depthwise (DepthwiseConv2D)	(None, 28, 28, 192)	1,728	block_4_expar
block_4_depthwise_BN (BatchNormalization)	(None, 28, 28, 192)	768	block_4_depth
block_4_depthwise_relu (ReLU)	(None, 28, 28, 192)	0	block_4_depth
block_4_project (Conv2D)	(None, 28, 28, 32)	6,144	block_4_depth

block_4_project_BN (BatchNormalization)	(None, 28, 28, 32)	128	block_4_proje
block_4_add (Add)	(None, 28, 28, 32)	0	block_3_proje block_4_proje
block_5_expand (Conv2D)	(None, 28, 28, 192)	6,144	block_4_add[(
block_5_expand_BN (BatchNormalization)	(None, 28, 28, 192)	768	block_5_expar
block_5_expand_relu (ReLU)	(None, 28, 28, 192)	0	block_5_expar
block_5_depthwise (DepthwiseConv2D)	(None, 28, 28, 192)	1,728	block_5_expar
block_5_depthwise_BN (BatchNormalization)	(None, 28, 28, 192)	768	block_5_depth
block_5_depthwise_relu (ReLU)	(None, 28, 28, 192)	0	block_5_depth
block_5_project (Conv2D)	(None, 28, 28, 32)	6,144	block_5_depth
block_5_project_BN (BatchNormalization)	(None, 28, 28, 32)	128	block_5_proje
block_5_add (Add)	(None, 28, 28, 32)	0	block_4_add[(block_5_proje
block_6_expand (Conv2D)	(None, 28, 28, 192)	6,144	block_5_add[(
block_6_expand_BN (BatchNormalization)	(None, 28, 28, 192)	768	block_6_expar
block_6_expand_relu (ReLU)	(None, 28, 28, 192)	0	block_6_expar
block_6_pad (ZeroPadding2D)	(None, 29, 29, 192)	0	block_6_expar
block_6_depthwise (DepthwiseConv2D)	(None, 14, 14, 192)	1,728	block_6_pad[(
block_6_depthwise_BN (BatchNormalization)	(None, 14, 14, 192)	768	block_6_depth
block_6_depthwise_relu (ReLU)	(None, 14, 14, 192)	0	block_6_depth
block_6_project (Conv2D)	(None, 14, 14, 64)	12,288	block_6_depth
block_6_project_BN (BatchNormalization)	(None, 14, 14, 64)	256	block_6_proje
block_7_expand (Conv2D)	(None, 14, 14, 384)	24,576	block_6_proje
block_7_expand_BN (BatchNormalization)	(None, 14, 14, 384)	1,536	block_7_expar

block_7_expand_relu (ReLU)	(None, 14, 14, 384)	0	block_7_expar
block_7_depthwise (DepthwiseConv2D)	(None, 14, 14, 384)	3,456	block_7_expar
block_7_depthwise_BN (BatchNormalization)	(None, 14, 14, 384)	1,536	block_7_depth
block_7_depthwise_relu (ReLU)	(None, 14, 14, 384)	0	block_7_depth
block_7_project (Conv2D)	(None, 14, 14, 64)	24,576	block_7_depth
block_7_project_BN (BatchNormalization)	(None, 14, 14, 64)	256	block_7_proje
block_7_add (Add)	(None, 14, 14, 64)	0	block_6_proje block_7_proje
block_8_expand (Conv2D)	(None, 14, 14, 384)	24,576	block_7_add[0
block_8_expand_BN (BatchNormalization)	(None, 14, 14, 384)	1,536	block_8_expar
block_8_expand_relu (ReLU)	(None, 14, 14, 384)	0	block_8_expar
block_8_depthwise (DepthwiseConv2D)	(None, 14, 14, 384)	3,456	block_8_expar
block_8_depthwise_BN (BatchNormalization)	(None, 14, 14, 384)	1,536	block_8_depth
block_8_depthwise_relu (ReLU)	(None, 14, 14, 384)	0	block_8_depth
block_8_project (Conv2D)	(None, 14, 14, 64)	24,576	block_8_depth
block_8_project_BN (BatchNormalization)	(None, 14, 14, 64)	256	block_8_proje
block_8_add (Add)	(None, 14, 14, 64)	0	block_7_add[0 block_8_proje
block_9_expand (Conv2D)	(None, 14, 14, 384)	24,576	block_8_add[0
block_9_expand_BN (BatchNormalization)	(None, 14, 14, 384)	1,536	block_9_expar
block_9_expand_relu (ReLU)	(None, 14, 14, 384)	0	block_9_expar
block_9_depthwise (DepthwiseConv2D)	(None, 14, 14, 384)	3,456	block_9_expar
block_9_depthwise_BN (BatchNormalization)	(None, 14, 14, 384)	1,536	block_9_depth
block_9_depthwise_relu (ReLU)	(None, 14, 14, 384)	0	block_9_depth

block_9_project (Conv2D)	(None, 14, 14, 64)	24,576	block_9_depth
block_9_project_BN (BatchNormalization)	(None, 14, 14, 64)	256	block_9_proje
block_9_add (Add)	(None, 14, 14, 64)	0	block_8_add[(block_9_proje
block_10_expand (Conv2D)	(None, 14, 14, 384)	24,576	block_9_add[(
block_10_expand_BN (BatchNormalization)	(None, 14, 14, 384)	1,536	block_10_expa
block_10_expand_relu (ReLU)	(None, 14, 14, 384)	0	block_10_expa
block_10_depthwise (DepthwiseConv2D)	(None, 14, 14, 384)	3,456	block_10_expa
block_10_depthwise_BN (BatchNormalization)	(None, 14, 14, 384)	1,536	block_10_dept
block_10_depthwise_relu (ReLU)	(None, 14, 14, 384)	0	block_10_dept
block_10_project (Conv2D)	(None, 14, 14, 96)	36,864	block_10_dept
block_10_project_BN (BatchNormalization)	(None, 14, 14, 96)	384	block_10_proj
block_11_expand (Conv2D)	(None, 14, 14, 576)	55,296	block_10_proj
block_11_expand_BN (BatchNormalization)	(None, 14, 14, 576)	2,304	block_11_expa
block_11_expand_relu (ReLU)	(None, 14, 14, 576)	0	block_11_expa
block_11_depthwise (DepthwiseConv2D)	(None, 14, 14, 576)	5,184	block_11_expa
block_11_depthwise_BN (BatchNormalization)	(None, 14, 14, 576)	2,304	block_11_dept
block_11_depthwise_relu (ReLU)	(None, 14, 14, 576)	0	block_11_dept
block_11_project (Conv2D)	(None, 14, 14, 96)	55,296	block_11_dept
block_11_project_BN (BatchNormalization)	(None, 14, 14, 96)	384	block_11_proj
block_11_add (Add)	(None, 14, 14, 96)	0	block_10_proj block_11_proj
block_12_expand (Conv2D)	(None, 14, 14, 576)	55,296	block_11_add[
block_12_expand_BN (BatchNormalization)	(None, 14, 14, 576)	2,304	block_12_expa
block_12_expand_relu	(None, 14, 14, 576)	0	block_12_expa

(ReLU)			
block_12_depthwise (DepthwiseConv2D)	(None, 14, 14, 576)	5,184	block_12_expa
block_12_depthwise_BN (BatchNormalization)	(None, 14, 14, 576)	2,304	block_12_dept
block_12_depthwise_relu (ReLU)	(None, 14, 14, 576)	0	block_12_dept
block_12_project (Conv2D)	(None, 14, 14, 96)	55,296	block_12_dept
block_12_project_BN (BatchNormalization)	(None, 14, 14, 96)	384	block_12_proj
block_12_add (Add)	(None, 14, 14, 96)	0	block_11_add[block_12_proj
block_13_expand (Conv2D)	(None, 14, 14, 576)	55,296	block_12_add[
block_13_expand_BN (BatchNormalization)	(None, 14, 14, 576)	2,304	block_13_expa
block_13_expand_relu (ReLU)	(None, 14, 14, 576)	0	block_13_expa
block_13_pad (ZeroPadding2D)	(None, 15, 15, 576)	0	block_13_expa
block_13_depthwise (DepthwiseConv2D)	(None, 7, 7, 576)	5,184	block_13_pad[
block_13_depthwise_BN (BatchNormalization)	(None, 7, 7, 576)	2,304	block_13_dept
block_13_depthwise_relu (ReLU)	(None, 7, 7, 576)	0	block_13_dept
block_13_project (Conv2D)	(None, 7, 7, 160)	92,160	block_13_dept
block_13_project_BN (BatchNormalization)	(None, 7, 7, 160)	640	block_13_proj
block_14_expand (Conv2D)	(None, 7, 7, 960)	153,600	block_13_proj
block_14_expand_BN (BatchNormalization)	(None, 7, 7, 960)	3,840	block_14_expa
block_14_expand_relu (ReLU)	(None, 7, 7, 960)	0	block_14_expa
block_14_depthwise (DepthwiseConv2D)	(None, 7, 7, 960)	8,640	block_14_expa
block_14_depthwise_BN (BatchNormalization)	(None, 7, 7, 960)	3,840	block_14_dept
block_14_depthwise_relu (ReLU)	(None, 7, 7, 960)	0	block_14_dept

Layer (type)	Output Shape	Param #	Connected to
block_14_project (Conv2D)	(None, 7, 7, 160)	153,600	block_14_dept...
block_14_project_BN (BatchNormalization)	(None, 7, 7, 160)	640	block_14_proj...
block_14_add (Add)	(None, 7, 7, 160)	0	block_13_proj... block_14_proj...
block_15_expand (Conv2D)	(None, 7, 7, 960)	153,600	block_14_add[...
block_15_expand_BN (BatchNormalization)	(None, 7, 7, 960)	3,840	block_15_expa...
block_15_expand_relu (ReLU)	(None, 7, 7, 960)	0	block_15_expa...
block_15_depthwise (DepthwiseConv2D)	(None, 7, 7, 960)	8,640	block_15_expa...
block_15_depthwise_BN (BatchNormalization)	(None, 7, 7, 960)	3,840	block_15_dept...
block_15_depthwise_relu (ReLU)	(None, 7, 7, 960)	0	block_15_dept...
block_15_project (Conv2D)	(None, 7, 7, 160)	153,600	block_15_dept...
block_15_project_BN (BatchNormalization)	(None, 7, 7, 160)	640	block_15_proj...
block_15_add (Add)	(None, 7, 7, 160)	0	block_14_add[... block_15_proj...
block_16_expand (Conv2D)	(None, 7, 7, 960)	153,600	block_15_add[...
block_16_expand_BN (BatchNormalization)	(None, 7, 7, 960)	3,840	block_16_expa...
block_16_expand_relu	(None, 7, 7, 960)	0	block_16_expa...

```
# Freeze the lower convolutional layers
for layer in base_model.layers:
    layer.trainable = False

# Check which layers are frozen
frozen_layers = [layer.name for layer in base_model.layers if not layer.trainable]
print("Frozen layers:", frozen_layers)
```

Frozen layers: ['input_layer', 'Conv1', 'bn_Conv1', 'Conv1_relu', 'expanded_conv_dept

◄ ▮   ►

```
# Create a new model with the base and custom classifier
model = Sequential()
model.add(base_model)
model.add(GlobalAveragePooling2D())
model.add(Dense(256, activation='relu'))
model.add(Dense(num_classes, activation='softmax'))  # Adjust the number of classes as ne

# Compile the model
model.compile(optimizer='adam', loss='sparse_categorical_crossentropy', metrics=['accurac

# Display the complete model architecture
model.summary()
```

```
---------------------------------------------------------------------------
ValueError                                Traceback (most recent call last)
<ipython-input-13-360c73788e4b> in <cell line: 12>()
     10
     11 # Display the complete model architecture
---> 12 model.summary()

                              ▲ 1 frames
                              ▼
/usr/local/lib/python3.10/dist-packages/optree/ops.py in tree_map(func, tree,
is_leaf, none_is_leaf, namespace, *rests)
    745         leaves, treespec = _C.flatten(tree, is_leaf, none_is_leaf, namespace)
    746         flat_args = [leaves] + [treespec.flatten_up_to(r) for r in rests]
--> 747         return treespec.unflatten(map(func, *flat_args))
    748
    749

ValueError: Undefined shapes are not supported.
```

Next steps: [Explain error]

```
# Train the classifier layers
history = model.fit(X_train, y_train, epochs=10, batch_size=32, validation_split=0.2)

# Plot training history (optional)
plt.plot(history.history['accuracy'], label='Train Accuracy')
plt.plot(history.history['val_accuracy'], label='Validation Accuracy')
plt.title('Model Accuracy')
plt.xlabel('Epochs')
plt.ylabel('Accuracy')
```
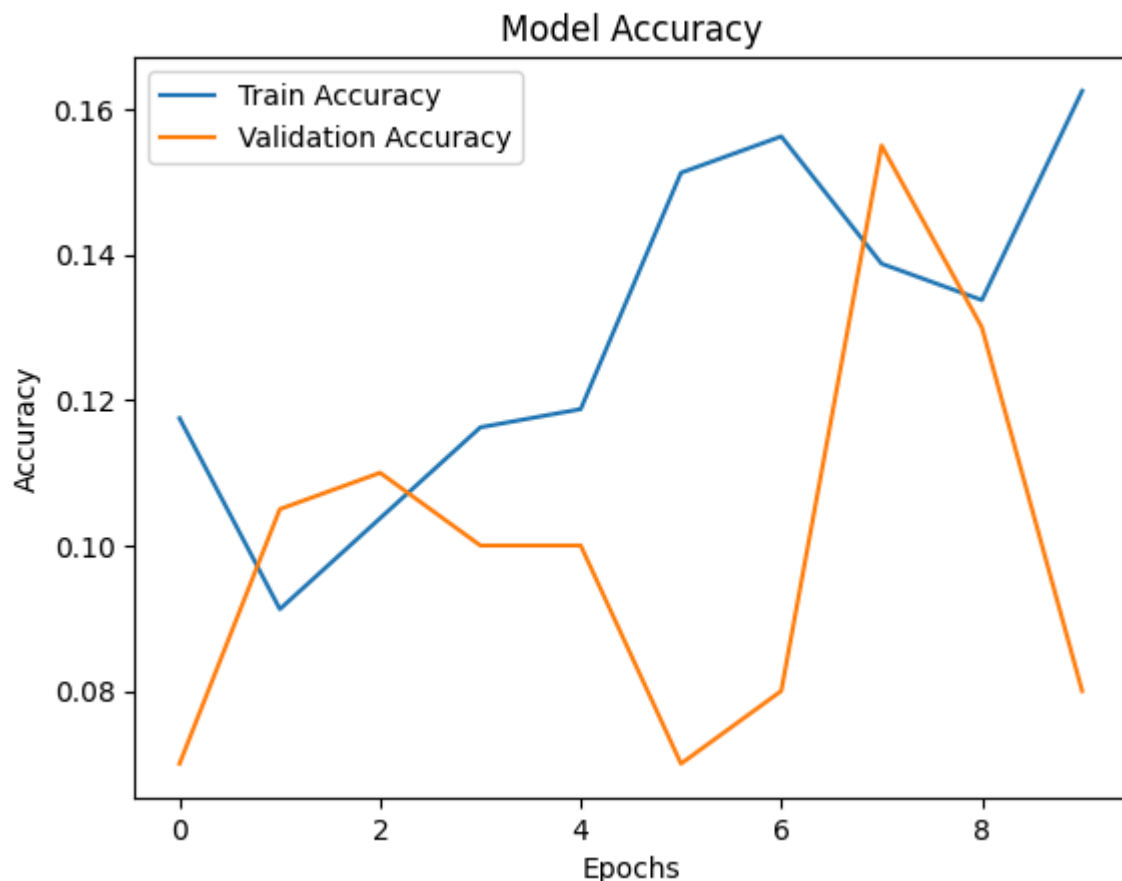
```
plt.legend()
plt.show()
```

```
Epoch 1/10
25/25 ———————————————— 62s 2s/step - accuracy: 0.1190 - loss: 2.7262 - val_accura
Epoch 2/10
25/25 ———————————————— 74s 2s/step - accuracy: 0.0804 - loss: 2.3947 - val_accura
Epoch 3/10
25/25 ———————————————— 42s 2s/step - accuracy: 0.1016 - loss: 2.3904 - val_accura
Epoch 4/10
25/25 ———————————————— 40s 2s/step - accuracy: 0.1204 - loss: 2.3462 - val_accura
Epoch 5/10
25/25 ———————————————— 41s 2s/step - accuracy: 0.1031 - loss: 2.3755 - val_accura
Epoch 6/10
25/25 ———————————————— 40s 2s/step - accuracy: 0.1574 - loss: 2.2969 - val_accura
Epoch 7/10
25/25 ———————————————— 41s 2s/step - accuracy: 0.1601 - loss: 2.3426 - val_accura
Epoch 8/10
25/25 ———————————————— 44s 2s/step - accuracy: 0.1246 - loss: 2.3102 - val_accura
Epoch 9/10
25/25 ———————————————— 39s 2s/step - accuracy: 0.1336 - loss: 2.2738 - val_accura
Epoch 10/10
25/25 ———————————————— 38s 2s/step - accuracy: 0.1545 - loss: 2.2519 - val_accura
```

Model Accuracy

Train Accuracy
Validation Accuracy

(plot: Accuracy vs Epochs)

```
# Unfreeze some of the last convolutional layers for fine-tuning
for layer in base_model.layers[-20:]:  # Unfreeze last 20 layers; adjust as needed
    layer.trainable = True

# Recompile the model with a lower learning rate for fine-tuning
model.compile(optimizer=tf.keras.optimizers.Adam(learning_rate=1e-5),
              loss='sparse_categorical_crossentropy',
              metrics=['accuracy'])
```

```python
# Continue training with fine-tuning
fine_tune_history = model.fit(X_train, y_train, epochs=5, batch_size=32, validation_split
```

```
Epoch 1/5
25/25 ——————————— 58s 2s/step - accuracy: 0.1156 - loss: 2.5001 - val_accura
Epoch 2/5
25/25 ——————————— 79s 2s/step - accuracy: 0.1319 - loss: 2.3767 - val_accura
Epoch 3/5
25/25 ——————————— 81s 2s/step - accuracy: 0.1777 - loss: 2.2635 - val_accura
Epoch 4/5
25/25 ——————————— 84s 2s/step - accuracy: 0.1957 - loss: 2.2230 - val_accura
Epoch 5/5
25/25 ——————————— 45s 2s/step - accuracy: 0.2321 - loss: 2.2031 - val_accura
```

```python
# Plot training history (optional)
plt.plot(fine_tune_history.history['accuracy'], label='Train Accuracy')
plt.plot(fine_tune_history.history['val_accuracy'], label='Validation Accuracy')
plt.title('Model Accuracy')
plt.xlabel('Epochs')
plt.ylabel('Accuracy')
plt.legend()
plt.show()
```
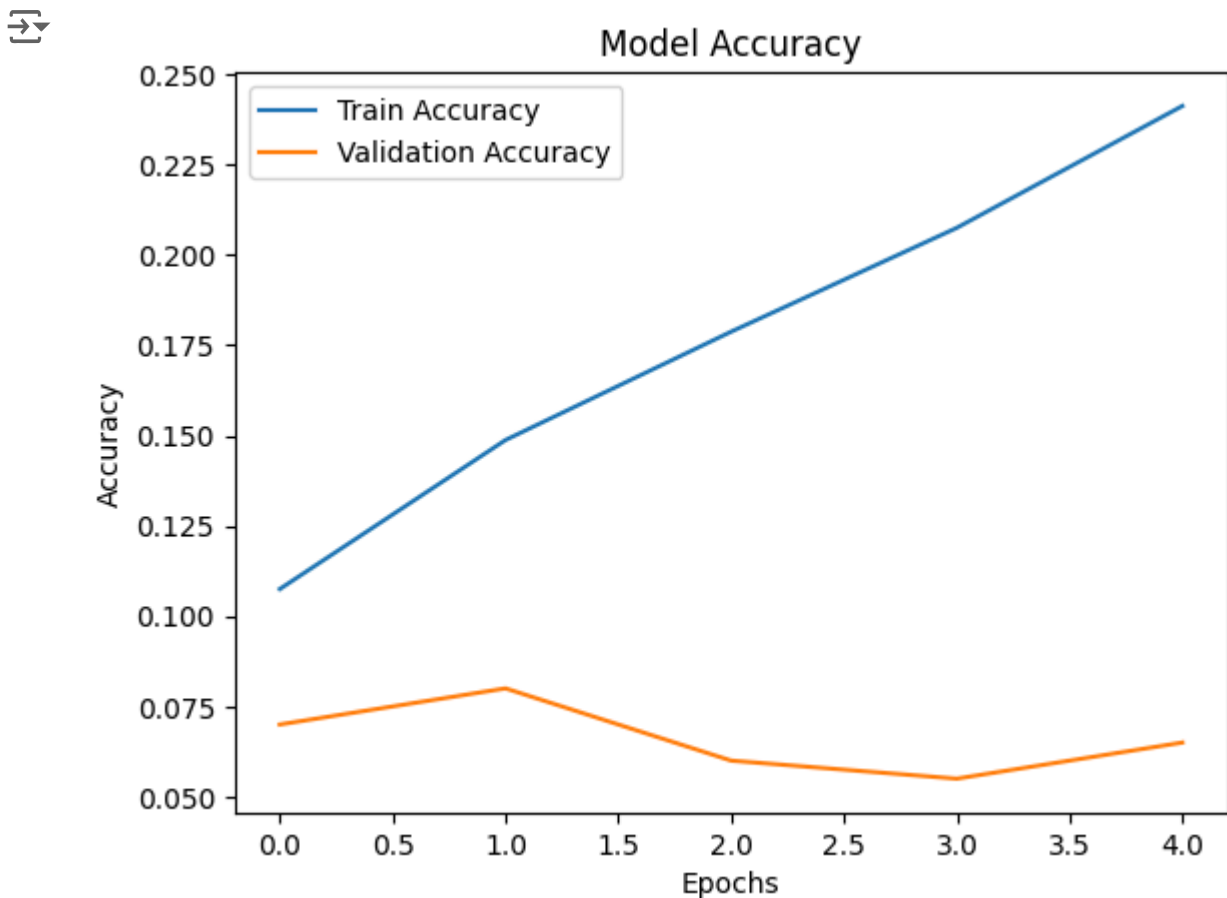

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