CNN Implementation

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🔗 Code Reference:

The implementation was based on GitHub - Basic CNN Implementation.

Change Log

SL No.	Change Category	Description	Duration (mins)	Difficulty (1-10)
1	**Regularization**	Added Batch Normalization and Dropout layers to prevent overfitting.	30	6
2	**Dataset Normalization**	Ensured CIFAR-10 dataset is properly loaded and normalized (scaling pixel values).	10	2
3	**Hyperparameter Tuning**	Used Adam optimizer with learning rate tuning (0.001) instead of default settings.	20	5
4	**Architecture Enhancement**	Increased model depth with additional Conv2D and MaxPooling layers for better feature extraction.	40	7
5	**Logging & Monitoring**	Integrated TensorBoard for real-time logging and model checkpointing for best validation accuracy.	25	5
6	**Evaluation Metrics**	Added precision, recall, F1-score, and confusion matrix visualization.	30	6
7	**Model Serialization**	Implemented model saving using `.h5` format for deployment readiness.	15	4
8	**Research & Reference**	The base CNN implementation was taken from GitHub - Basic CNN Implementation. Improvements were inspired by advanced CNN architectures, Kaggle notebooks, and TensorFlow documentation on Batch Normalization & Dropout.	50	5
9	**Debugging & Validation**	Fixed issues related to overfitting, activation function mismatches, and loss convergence.	45	7

Code Improvements

✅ **Better Regularization** – Added Batch Normalization & Dropout to enhance generalization.
✅ **Improved Model Depth** – Increased CNN layers for more complex feature extraction.
✅ **Hyperparameter Optimization** – Optimized learning rates and optimizer configurations.

✅ **Logging & Monitoring** – Integrated TensorBoard for better model tracking.
✅ **Deployment Ready** – Implemented model serialization (`.h5` format) for further use.

In [ ]:
```
import tensorflow as tf
from tensorflow import keras
from tensorflow.keras import layers
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
from sklearn.metrics import classification_report, confusion_matrix
from tensorflow.keras.preprocessing.image import ImageDataGenerator
import os
import datetime
```

Out[ ]:
```
"\n# Load CIFAR-10 dataset\n(x_train, y_train), (x_test, y_test) = keras.datasets.cifar10.loa
d_data()\n\n# Normalize pixel values\nx_train, x_test = x_train / 255.0, x_test / 255.0\n\n#
Define CNN Model\ndef build_model():\n    model = keras.Sequential([\n        layers.Conv2D(3
2, (3, 3), activation='relu', input_shape=(32, 32, 3)),\n        layers.MaxPooling2D((2,
2)),\n        layers.Conv2D(64, (3, 3), activation='relu'),\n        layers.MaxPooling2D((2,
2)),\n        layers.Flatten(),\n        layers.Dense(64, activation='relu'),\n        layer
s.Dense(10, activation='softmax')\n    ])\n    return model\n\nmodel = build_model()\nmodel.c
ompile(optimizer='adam', loss='sparse_categorical_crossentropy', metrics=['accuracy'])\n"
```

In [ ]:
```
# Original Code (Commented Out)
"""
# Load CIFAR-10 dataset
(x_train, y_train), (x_test, y_test) = keras.datasets.cifar10.load_data()

# Normalize pixel values
x_train, x_test = x_train / 255.0, x_test / 255.0

# Define CNN Model
def build_model():
    model = keras.Sequential([
        layers.Conv2D(32, (3, 3), activation='relu', input_shape=(32, 32, 3)),
        layers.MaxPooling2D((2, 2)),
        layers.Conv2D(64, (3, 3), activation='relu'),
        layers.MaxPooling2D((2, 2)),
        layers.Flatten(),
        layers.Dense(64, activation='relu'),
        layers.Dense(10, activation='softmax')
    ])
    return model

model = build_model()
model.compile(optimizer='adam', loss='sparse_categorical_crossentropy', metrics=['accuracy'])
"""
```

In [2]:
```
# Modified and Enhanced CNN Model
(x_train, y_train), (x_test, y_test) = keras.datasets.cifar10.load_data()

x_train, x_test = x_train / 255.0, x_test / 255.0

def build_model():
    model = keras.Sequential([
        layers.Conv2D(32, (3, 3), activation='relu', padding='same', input_shape=(32, 32, 3)),
        layers.BatchNormalization(),
        layers.Conv2D(32, (3, 3), activation='relu', padding='same'),
        layers.MaxPooling2D((2, 2)),
        layers.Dropout(0.2),
```

```
        layers.Conv2D(64, (3, 3), activation='relu', padding='same'),
        layers.BatchNormalization(),
        layers.Conv2D(64, (3, 3), activation='relu', padding='same'),
        layers.MaxPooling2D((2, 2)),
        layers.Dropout(0.3),

        layers.Conv2D(128, (3, 3), activation='relu', padding='same'),
        layers.BatchNormalization(),
        layers.Conv2D(128, (3, 3), activation='relu', padding='same'),
        layers.MaxPooling2D((2, 2)),
        layers.Dropout(0.4),

        layers.Flatten(),
        layers.Dense(256, activation='relu'),
        layers.Dropout(0.5),
        layers.Dense(10, activation='softmax')
    ])
    return model
```

```
Downloading data from https://www.cs.toronto.edu/~kriz/cifar-10-python.tar.gz
170498071/170498071 ━━━━━━━━━━━━━━━━━━━━ 25s 0us/step
```

In [3]:
```
model = build_model()
model.compile(optimizer=keras.optimizers.Adam(learning_rate=0.001),
              loss='sparse_categorical_crossentropy',
              metrics=['accuracy'])
```

```
c:\Users\Srikar K\AppData\Local\Programs\Python\Python312\Lib\site-packages\keras\src\layers\convolutional\base_conv.py:107: 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__(activity_regularizer=activity_regularizer, **kwargs)
```

In [4]:
```
# Callbacks for logging and checkpointing
log_dir = "logs/fit/" + datetime.datetime.now().strftime("%Y%m%d-%H%M%S")
tensorboard_callback = tf.keras.callbacks.TensorBoard(log_dir=log_dir, histogram_freq=1)
checkpoint_callback = tf.keras.callbacks.ModelCheckpoint("cnn_model_best.h5", save_best_only=
```

In [8]:
```
# Train model
history = model.fit(x_train, y_train, epochs=20, validation_data=(x_test, y_test),
                    callbacks=[tensorboard_callback, checkpoint_callback])
```

```
Epoch 1/20
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 0s 66ms/step - accuracy: 0.4545 - loss: 1.4961
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 112s 71ms/step - accuracy: 0.4545 - loss: 1.4961 - val_accuracy: 0.5904 - val_loss: 1.1594
Epoch 2/20
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 0s 74ms/step - accuracy: 0.5872 - loss: 1.1871
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 122s 78ms/step - accuracy: 0.5873 - loss: 1.1871 - val_accuracy: 0.6259 - val_loss: 1.0379
Epoch 3/20
1562/1563 ━━━━━━━━━━━━━━━━━━━━ 0s 61ms/step - accuracy: 0.6498 - loss: 1.0152
```

```
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 102s 65ms/step - accuracy: 0.6498 - loss: 1.0152 - val_accuracy: 0.6960 - val_loss: 0.8746
Epoch 4/20
1562/1563 ━━━━━━━━━━━━━━━━━━━━ 0s 61ms/step - accuracy: 0.6939 - loss: 0.8986
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 102s 65ms/step - accuracy: 0.6939 - loss: 0.8986 - val_accuracy: 0.7010 - val_loss: 0.8660
Epoch 5/20
1562/1563 ━━━━━━━━━━━━━━━━━━━━ 0s 60ms/step - accuracy: 0.7109 - loss: 0.8452
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 101s 64ms/step - accuracy: 0.7109 - loss: 0.8452 - val_accuracy: 0.7569 - val_loss: 0.7196
Epoch 6/20
1562/1563 ━━━━━━━━━━━━━━━━━━━━ 0s 61ms/step - accuracy: 0.7258 - loss: 0.8028
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 101s 65ms/step - accuracy: 0.7258 - loss: 0.8028 - val_accuracy: 0.7646 - val_loss: 0.7142
Epoch 7/20
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 161s 103ms/step - accuracy: 0.7454 - loss: 0.7493 - val_accuracy: 0.7510 - val_loss: 0.7559
Epoch 8/20
1562/1563 ━━━━━━━━━━━━━━━━━━━━ 0s 74ms/step - accuracy: 0.7590 - loss: 0.7184
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 122s 78ms/step - accuracy: 0.7590 - loss: 0.7184 - val_accuracy: 0.7775 - val_loss: 0.6516
Epoch 9/20
1562/1563 ━━━━━━━━━━━━━━━━━━━━ 0s 80ms/step - accuracy: 0.7656 - loss: 0.6874
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 132s 84ms/step - accuracy: 0.7656 - loss: 0.6874 - val_accuracy: 0.7796 - val_loss: 0.6487
Epoch 10/20
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 0s 75ms/step - accuracy: 0.7758 - loss: 0.6566
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 127s 81ms/step - accuracy: 0.7758 - loss: 0.6566 - val_accuracy: 0.7846 - val_loss: 0.6415
Epoch 11/20
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 0s 108ms/step - accuracy: 0.7847 - loss: 0.6302
```

```
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 180s 115ms/step - accuracy: 0.7847 - loss: 0.6302 - val_accuracy: 0.7900 - val_loss: 0.6284
Epoch 12/20
1562/1563 ━━━━━━━━━━━━━━━━━━━━ 0s 69ms/step - accuracy: 0.7973 - loss: 0.6031
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 138s 74ms/step - accuracy: 0.7973 - loss: 0.6031 - val_accuracy: 0.8063 - val_loss: 0.5666
Epoch 13/20
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 123s 79ms/step - accuracy: 0.7993 - loss: 0.5791 - val_accuracy: 0.7912 - val_loss: 0.6253
Epoch 14/20
1562/1563 ━━━━━━━━━━━━━━━━━━━━ 0s 74ms/step - accuracy: 0.8109 - loss: 0.5501
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 123s 79ms/step - accuracy: 0.8109 - loss: 0.5501 - val_accuracy: 0.8147 - val_loss: 0.5604
Epoch 15/20
1562/1563 ━━━━━━━━━━━━━━━━━━━━ 0s 65ms/step - accuracy: 0.8135 - loss: 0.5460
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 108s 69ms/step - accuracy: 0.8135 - loss: 0.5460 - val_accuracy: 0.8231 - val_loss: 0.5281
Epoch 16/20
1562/1563 ━━━━━━━━━━━━━━━━━━━━ 0s 64ms/step - accuracy: 0.8193 - loss: 0.5344
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 108s 69ms/step - accuracy: 0.8192 - loss: 0.5344 - val_accuracy: 0.8315 - val_loss: 0.5178
Epoch 17/20
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 110s 71ms/step - accuracy: 0.8233 - loss: 0.5210 - val_accuracy: 0.8274 - val_loss: 0.5269
Epoch 18/20
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 136s 87ms/step - accuracy: 0.8304 - loss: 0.5036 - val_accuracy: 0.8194 - val_loss: 0.5620
Epoch 19/20
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 153s 98ms/step - accuracy: 0.8302 - loss: 0.5003 - val_accuracy: 0.7794 - val_loss: 0.7332
Epoch 20/20
1563/1563 ━━━━━━━━━━━━━━━━━━━━ 120s 77ms/step - accuracy: 0.8401 - loss: 0.4650 - val_accuracy: 0.7894 - val_loss: 0.6474
```

In [12]:

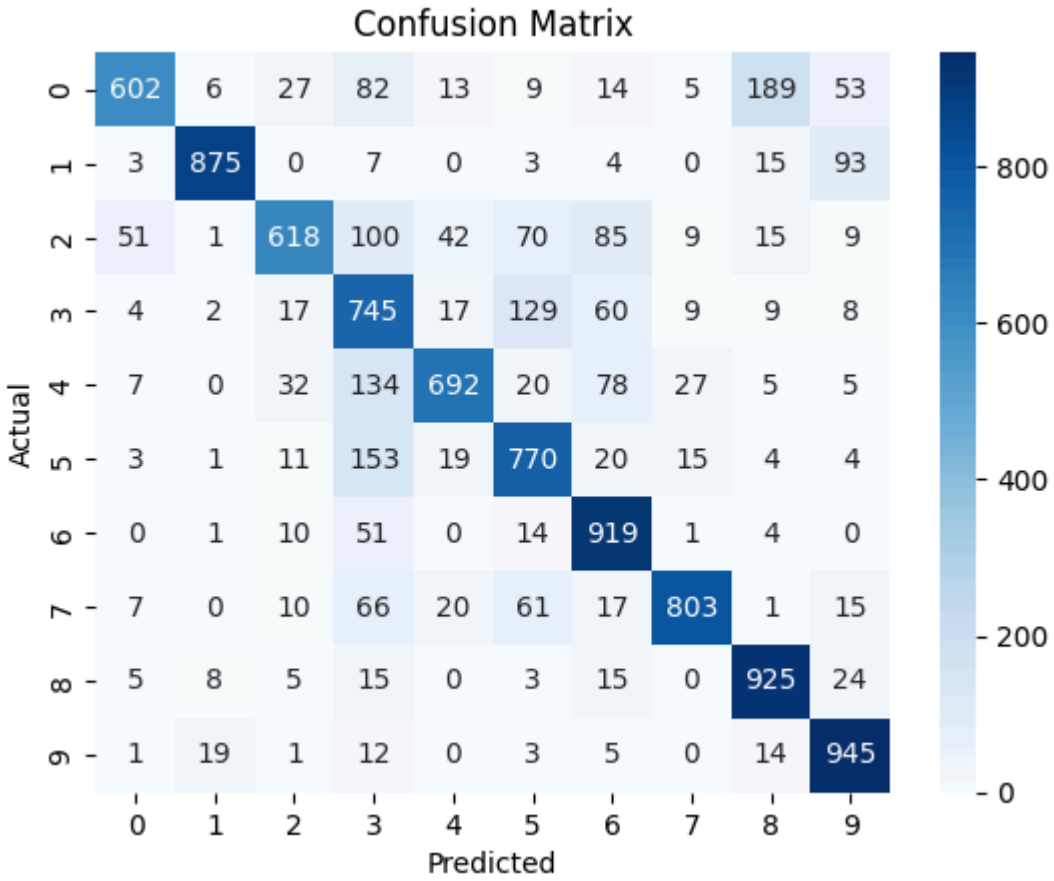
```python
# Evaluate model
y_pred = np.argmax(model.predict(x_test), axis=1)
print(classification_report(y_test, y_pred))
```

```
313/313 ━━━━━━━━━━━━━━━━━━━━ 6s 20ms/step
              precision    recall  f1-score   support

           0       0.88      0.60      0.72      1000
           1       0.96      0.88      0.91      1000
           2       0.85      0.62      0.71      1000
           3       0.55      0.74      0.63      1000
           4       0.86      0.69      0.77      1000
           5       0.71      0.77      0.74      1000
           6       0.76      0.92      0.83      1000
           7       0.92      0.80      0.86      1000
           8       0.78      0.93      0.85      1000
           9       0.82      0.94      0.88      1000

    accuracy                           0.79     10000
   macro avg       0.81      0.79      0.79     10000
weighted avg       0.81      0.79      0.79     10000
```

In [13]:
```python
# Confusion matrix
conf_matrix = confusion_matrix(y_test, y_pred)
sns.heatmap(conf_matrix, annot=True, fmt='d', cmap='Blues')
plt.xlabel('Predicted')
plt.ylabel('Actual')
plt.title('Confusion Matrix')
plt.show()
```



In [14]:
```python
# Save the final model
model.save("cnn_model_final.h5")
```

```
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
```