install

```
!pip install --upgrade tensorflow==2.12.0 tensorflow-addons==0.21.0
import tensorflow as tf
print(tf.__version__)
```

Show hidden output

```
!pip install -q kaggle
from google.colab import files

files.upload()
```

Choose Files kaggle.json

- **kaggle.json**(application/json) - 69 bytes, last modified: 5/2/2025 - 100% done

```
Saving kaggle.json to kaggle.json
```
{'kaggle.json': b'{"username":"ayaehabsalama","key":"455042fd2c61af709713bfc2d12e899f"}'}

```
!mkdir -p ~/.kaggle
!cp kaggle.json ~/.kaggle/
!chmod 600 ~/.kaggle/kaggle.json
```

```
!kaggle datasets download -d shreelakshmigp/cedardataset
!unzip cedardataset.zip -d data
```

Show hidden output

```
!pip install tensorflow
!pip install scikit-learn
!pip install matplotlib
!pip install Pillow
!pip install keras
!pip install opencv-python
```

Show hidden output

```
import os
import random
import numpy as np
import pandas as pd

import cv2
import matplotlib.pyplot as plt
from sklearn.model_selection import train_test_split
from sklearn.metrics import roc_curve, auc

import tensorflow as tf
from tensorflow.keras.models import Model
from tensorflow.keras.layers import Input, Conv2D, MaxPooling2D, Flatten, Dense, Lambda, Dropout, BatchNormaliz
from tensorflow.keras.regularizers import l2
from tensorflow.keras.optimizers import Adam
from tensorflow.keras.callbacks import ModelCheckpoint, ReduceLROnPlateau, LearningRateScheduler
from tensorflow.keras import layers, models, applications, backend as K
```

```
from tensorflow.keras.preprocessing.image import load_img, img_to_array
from sklearn.metrics import roc_curve, auc
from PIL import Image
from datetime import datetime
import tensorflow_addons as tfa

SEED = 42
os.environ['PYTHONHASHSEED'] = str(SEED)
random.seed(SEED)
np.random.seed(SEED)
tf.random.set_seed(SEED)
```

Show hidden output

```
print(os.listdir('data'))
```

```
['signatures']
```

```
print(os.listdir('data/signatures'))
```

```
['full_forg', 'full_org', 'Readme.txt']
```

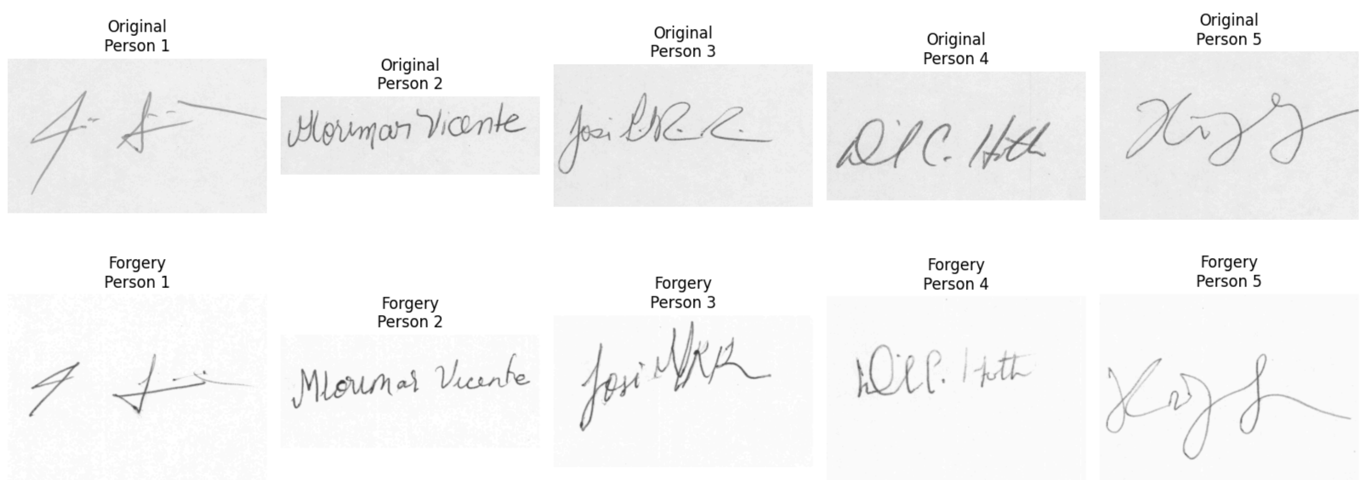
Load Data

```
org_path = 'data/signatures/full_org'
forg_path = 'data/signatures/full_forg'

original_files = sorted([f for f in os.listdir(org_path) if f.endswith('.png')])
forged_files = sorted([f for f in os.listdir(forg_path) if f.endswith('.png')])

def parse_filename(filename):
    try:
        if filename.startswith('original_'):
            parts = filename.split('_')
            person_id = int(parts[1])
            sample_num = int(parts[2].split('.')[0])
            return person_id, sample_num, 'original'
        elif filename.startswith('forgeries_'):
            parts = filename.split('_')
            person_id = int(parts[1])
            sample_num = int(parts[2].split('.')[0])
            return person_id, sample_num, 'forgery'
    except:
        return None, None, None

signature_db = {}
for file in original_files:
    person_id, _, _ = parse_filename(file)
    if person_id is not None:
        if person_id not in signature_db:
            signature_db[person_id] = {'original': [], 'forgery': []}
        signature_db[person_id]['original'].append(file)

for file in forged_files:
    person_id, _, _ = parse_filename(file)
    if person_id is not None:
        if person_id not in signature_db:
            signature_db[person_id] = {'original': [], 'forgery': []}
        signature_db[person_id]['forgery'].append(file)
```

```
signature_db = {k: v for k, v in signature_db.items() if len(v['original']) >= 2 and len(v['forgery']) >= 1}

print(f"Number of original signatures: {sum(len(v['original']) for v in signature_db.values())}")
print(f"Number of forged signatures: {sum(len(v['forgery']) for v in signature_db.values())}")
print(f"Total unique persons: {len(signature_db)}")
print(f"Samples per person - Original: {len(signature_db[list(signature_db.keys())[0]]['original'])}, Forged: {
```

```
Number of original signatures: 1320
Number of forged signatures: 1320
Total unique persons: 55
Samples per person - Original: 24, Forged: 24
```

```
plt.figure(figsize=(15, 6))
display_count = 0
for person_id in sorted(signature_db.keys())[:5]:

    plt.subplot(2, 5, display_count+1)
    img = load_img(os.path.join(org_path, signature_db[person_id]['original'][0]))
    plt.imshow(img)
    plt.title(f"Original\nPerson {person_id}")
    plt.axis('off')

    plt.subplot(2, 5, display_count+6)
    img = load_img(os.path.join(forg_path, signature_db[person_id]['forgery'][0]))
    plt.imshow(img)
    plt.title(f"Forgery\nPerson {person_id}")
    plt.axis('off')

    display_count += 1
    if display_count >= 5:
        break
plt.tight_layout()
plt.show()
```



Data Augmentation

```
IMG_SIZE = (224, 224)
INPUT_SHAPE = (224, 224, 3)
BATCH_SIZE = 32
EMBEDDING_DIM = 256
```

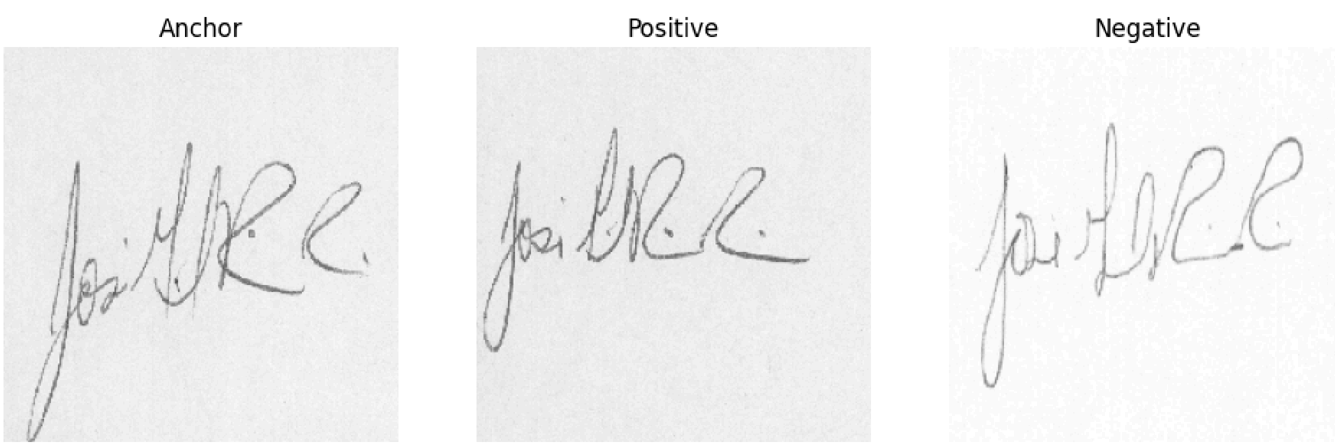
```
def preprocess_image(filepath):
    img = load_img(filepath, target_size=IMG_SIZE, color_mode='rgb')
    img = img_to_array(img)
    img = img / 255.0
    return img.astype('float32')

data_augmentation = tf.keras.Sequential([
    layers.RandomRotation(0.02),
    layers.RandomZoom(0.1),
    layers.RandomContrast(0.1),
    layers.RandomBrightness(0.1),
])
```

Generate Triplets

```
def get_hard_triplets(embeddings, labels, num_hard=10):
    """
    Generate hard triplets based on the current embeddings

    Args:
        embeddings: numpy array of shape (batch_size, embedding_dim)
        labels: numpy array of shape (batch_size,)
        num_hard: number of hard triplets to return

    Returns:
        indices of anchors, positives, negatives for hard triplets
    """

    pairwise_dist = np.sqrt(np.sum(np.square(
        np.expand_dims(embeddings, 1) - np.expand_dims(embeddings, 0)
    ), axis=2))

    anchors = []
    positives = []
    negatives = []

    for i in range(len(labels)):

        pos_indices = np.where(labels == labels[i])[0]
        pos_indices = pos_indices[pos_indices != i]


        neg_indices = np.where(labels != labels[i])[0]

        if len(pos_indices) == 0 or len(neg_indices) == 0:
            continue


        hardest_pos = pos_indices[np.argmax(pairwise_dist[i, pos_indices])]


        hardest_neg = neg_indices[np.argmin(pairwise_dist[i, neg_indices])]

        anchors.append(i)
        positives.append(hardest_pos)
        negatives.append(hardest_neg)


    if len(anchors) > num_hard:
        selected = np.random.choice(len(anchors), num_hard, replace=False)
```

```
        return (
            np.array(anchors)[selected],
            np.array(positives)[selected],
            np.array(negatives)[selected]
        )
    return np.array(anchors), np.array(positives), np.array(negatives)


def generate_triplets(signature_db, org_path, forg_path, batch_size=32, seed=42, hard_mining=False, model=None)
    person_ids = list(signature_db.keys())
    while True:
        selected_ids = random.choices(person_ids, k=batch_size)
        anchors, positives, negatives = [], [], []

        for person_id in selected_ids:
            orig_samples = signature_db[person_id]['original']
            forg_samples = signature_db[person_id]['forgery']


            anchor, positive = random.sample(orig_samples, 2)


            if len(forg_samples) > 0:
                rand_val = random.random()
                if rand_val < 0.7:
                    negative = random.choice(forg_samples)
                    neg_path = forg_path
                elif rand_val < 0.85:
                    other_person = random.choice([p for p in person_ids if p != person_id])
                    negative = random.choice(signature_db[other_person]['original'])
                    neg_path = org_path
                else:
                    other_person = random.choice([p for p in person_ids if p != person_id])
                    if len(signature_db[other_person]['forgery']) > 0:
                        negative = random.choice(signature_db[other_person]['forgery'])
                        neg_path = forg_path
                    else:
                        negative = random.choice(signature_db[other_person]['original'])
                        neg_path = org_path
            else:
                other_person = random.choice([p for p in person_ids if p != person_id])
                negative = random.choice(signature_db[other_person]['original'])
                neg_path = org_path


            anchor_img = preprocess_image(os.path.join(org_path, anchor))
            positive_img = preprocess_image(os.path.join(org_path, positive))
            negative_img = preprocess_image(os.path.join(neg_path, negative))

            anchors.append(anchor_img)
            positives.append(positive_img)
            negatives.append(negative_img)


        if hard_mining and model:

            embeddings = model.predict([np.array(anchors), np.array(positives), np.array(negatives)], verbose=0


            anchors_emb = embeddings[0]
            positives_emb = embeddings[1]
            negatives_emb = embeddings[2]
```

```
            all_embeddings = np.concatenate([anchors_emb, positives_emb, negatives_emb])
            labels = np.array([0]*len(anchors_emb) + [0]*len(positives_emb) + [1]*len(negatives_emb))


            anchor_idx, pos_idx, neg_idx = get_hard_triplets(all_embeddings, labels, num_hard=batch_size)


            anchors = np.array(anchors)[anchor_idx % len(anchors)]
            positives = np.array(positives)[pos_idx % len(positives)]
            negatives = np.array(negatives)[neg_idx % len(negatives)]

        yield [np.array(anchors), np.array(positives), np.array(negatives)], np.zeros((batch_size,))


triplet_gen = generate_triplets(signature_db, org_path, forg_path, batch_size=1)
(anchor, positive, negative), _ = next(triplet_gen)

plt.figure(figsize=(12, 4))
plt.subplot(1, 3, 1)
plt.imshow(anchor[0])
plt.title("Anchor")
plt.axis('off')

plt.subplot(1, 3, 2)
plt.imshow(positive[0])
plt.title("Positive")
plt.axis('off')

plt.subplot(1, 3, 3)
plt.imshow(negative[0])
plt.title("Negative")
plt.axis('off')
plt.show()
```



Split Data

```
person_ids = list(signature_db.keys())
train_ids, test_ids = train_test_split(person_ids, test_size=0.3, random_state=42)
val_ids, test_ids = train_test_split(test_ids, test_size=0.5, random_state=42)

print(f"Training persons: {len(train_ids)}")
print(f"Validation persons: {len(val_ids)}")
```

```
print(f"Test persons: {len(test_ids)}")
```

```
Training persons: 38
Validation persons: 8
Test persons: 9
```

```
train_db = {pid: signature_db[pid] for pid in train_ids}
val_db = {pid: signature_db[pid] for pid in val_ids}
test_db = {pid: signature_db[pid] for pid in test_ids}


def calculate_steps(db, batch_size):
    return max(1, len(db) * 2 // batch_size)

train_steps = calculate_steps(train_db, BATCH_SIZE)
val_steps = calculate_steps(val_db, BATCH_SIZE)
test_steps = calculate_steps(test_db, BATCH_SIZE)

print(f"\nTraining steps per epoch: {train_steps}")
print(f"Validation steps: {val_steps}")
print(f"Test steps: {test_steps}")
```

```

Training steps per epoch: 2
Validation steps: 1
Test steps: 1
```

Model

```
def create_embedding_model(input_shape):
    base_model = applications.DenseNet201(
        include_top=False,
        weights='imagenet',
        input_shape=input_shape,
        pooling='max'
    )


    for layer in base_model.layers[:-30]:
        layer.trainable = False



    inputs = layers.Input(input_shape)
    x = data_augmentation(inputs)
    x = base_model(x)


    x = layers.Dense(1024, activation='relu', kernel_regularizer=l2(0.001))(x)
    x = layers.BatchNormalization()(x)
    x = layers.Dropout(0.2)(x)

    x = layers.Dense(EMBEDDING_DIM, activation='linear', kernel_regularizer=l2(0.01))(x)
    x = layers.BatchNormalization()(x)
```

```
    output = layers.Lambda(lambda x: tf.math.l2_normalize(x, axis=1))(x)

    return models.Model(inputs, output)

def create_siamese_model(input_shape, embedding_model):

    anchor_input = layers.Input(input_shape, name='anchor_input')
    positive_input = layers.Input(input_shape, name='positive_input')
    negative_input = layers.Input(input_shape, name='negative_input')


    embedding_network = embedding_model
    anchor_embedding = embedding_network(anchor_input)
    positive_embedding = embedding_network(positive_input)
    negative_embedding = embedding_network(negative_input)


    pos_distance = tf.reduce_sum(tf.square(anchor_embedding - positive_embedding), axis=-1)
    neg_distance = tf.reduce_sum(tf.square(anchor_embedding - negative_embedding), axis=-1)


    accuracy = tf.reduce_mean(tf.cast(pos_distance < neg_distance, tf.float32))


    siamese_network = models.Model(
        inputs=[anchor_input, positive_input, negative_input],
        outputs=[anchor_embedding, positive_embedding, negative_embedding]
    )


    siamese_network.add_metric(accuracy, name='accuracy')

    return siamese_network


embedding_model = create_embedding_model(INPUT_SHAPE)
siamese_model = create_siamese_model(INPUT_SHAPE, embedding_model)


triplet_loss = tfa.losses.TripletHardLoss(margin=0.4)
optimizer = tf.keras.optimizers.Adam(learning_rate=0.0001)
siamese_model.compile(optimizer=optimizer, loss=triplet_loss)

siamese_model.summary()
```

```
Downloading data from https://storage.googleapis.com/tensorflow/keras-applications/densenet/densenet201_wei
74836368/74836368 [==============================] - 1s 0us/step
Model: "model_1"
__________________________________________________________________________________________________
 Layer (type)                   Output Shape         Param #     Connected to
==================================================================================================
 anchor_input (InputLayer)      [(None, 224, 224, 3  0           []
                                )]

 positive_input (InputLayer)    [(None, 224, 224, 3  0           []
                                )]

 negative_input (InputLayer)    [(None, 224, 224, 3  0           []
                                )]

 model (Functional)             (None, 256)          20556608    ['anchor_input[0][0]',
```

```
                                                                  'positive_input[0][0]',
                                                                  'negative_input[0][0]']

 tf.math.subtract (TFOpLambda)  (None, 256)          0           ['model[0][0]',
                                                                  'model[1][0]']

 tf.math.subtract_1 (TFOpLambda  (None, 256)         0           ['model[0][0]',
 )                                                                'model[2][0]']

 tf.math.square (TFOpLambda)    (None, 256)          0           ['tf.math.subtract[0][0]']

 tf.math.square_1 (TFOpLambda)  (None, 256)          0           ['tf.math.subtract_1[0][0]']

 tf.math.reduce_sum (TFOpLambda  (None,)             0           ['tf.math.square[0][0]']
 )

 tf.math.reduce_sum_1 (TFOpLamb  (None,)             0           ['tf.math.square_1[0][0]']
 da)

 tf.math.less (TFOpLambda)      (None,)              0           ['tf.math.reduce_sum[0][0]',
                                                                  'tf.math.reduce_sum_1[0][0]']

 tf.cast (TFOpLambda)           (None,)              0           ['tf.math.less[0][0]']

 tf.math.reduce_mean (TFOpLambd  ()                  0           ['tf.cast[0][0]']
 a)

 add_metric (AddMetric)         ()                   0           ['tf.math.reduce_mean[0][0]']

==================================================================================================
Total params: 20,556,608
Trainable params: 3,337,600
Non-trainable params: 17,219,008
__________________________________________________________________________________________________
```

Generator

```
def get_fixed_generator(db, org_path, forg_path, batch_size, seed=42, hard_mining=False, model=None):
    random.seed(seed)
    np.random.seed(seed)
    tf.random.set_seed(seed)
    return generate_triplets(db, org_path, forg_path, batch_size,hard_mining=hard_mining, model=model)

train_generator = generate_triplets(train_db, org_path, forg_path, BATCH_SIZE,seed=42,hard_mining=True, model=s
val_generator = get_fixed_generator(val_db, org_path, forg_path, BATCH_SIZE,seed=42,hard_mining=False)
test_generator = get_fixed_generator(test_db, org_path, forg_path, BATCH_SIZE,seed=42)


checkpoint = ModelCheckpoint(
    'best_model.h5',
    monitor='val_accuracy',
    save_best_only=True,
    mode='max',
    verbose=1
)

reduce_lr = ReduceLROnPlateau(
    monitor='val_loss',
    factor=0.5,
    patience=10,
    min_lr=1e-8,
    verbose=1,
    mode='min'
```

```
)



history = siamese_model.fit(
    train_generator,
    steps_per_epoch=train_steps,
    validation_data=val_generator,
    validation_steps=val_steps,
    epochs=100,
    callbacks=[checkpoint, reduce_lr],
    verbose=1
)
```

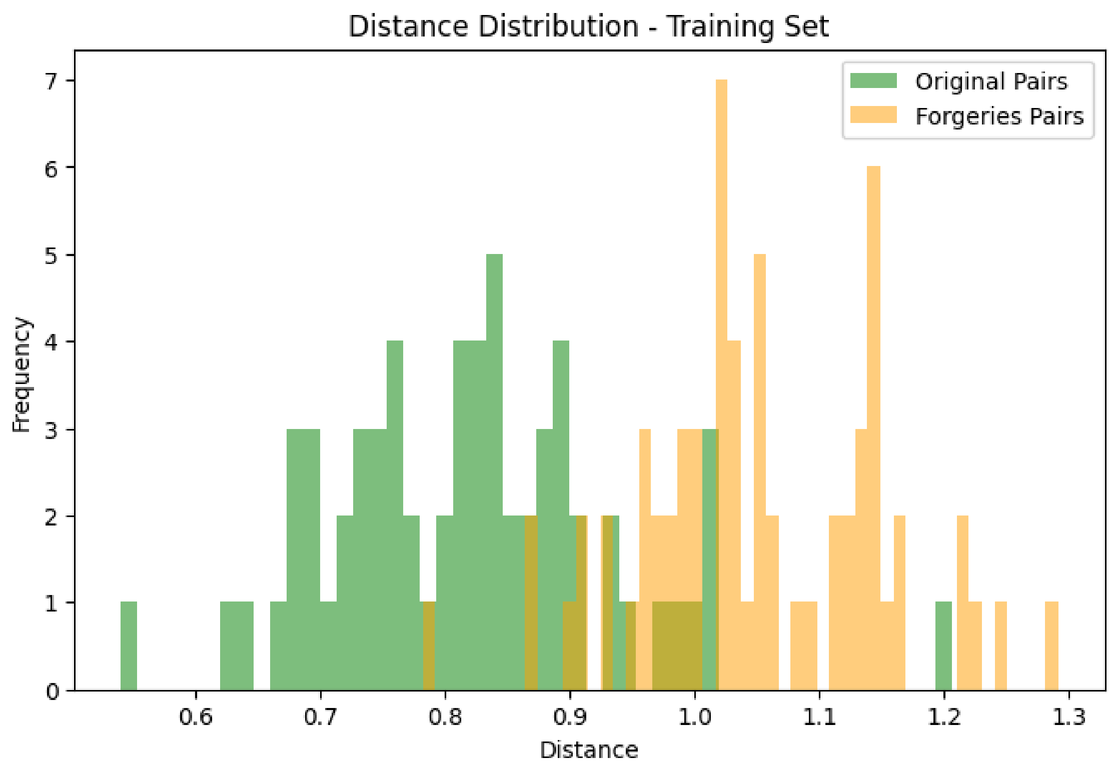
```
2/2 [==============================] - 100s 61s/step - loss: 3.1920 - model_loss: 0.4000 - model_1_loss: (
Epoch 100/100
2/2 [==============================] - ETA: 0s - loss: 3.1712 - model_loss: 0.4000 - model_1_loss: 0.4000
Epoch 100: val_accuracy did not improve from 1.00000
2/2 [==============================] - 102s 72s/step - loss: 3.1712 - model_loss: 0.4000 - model_1_loss: (
```

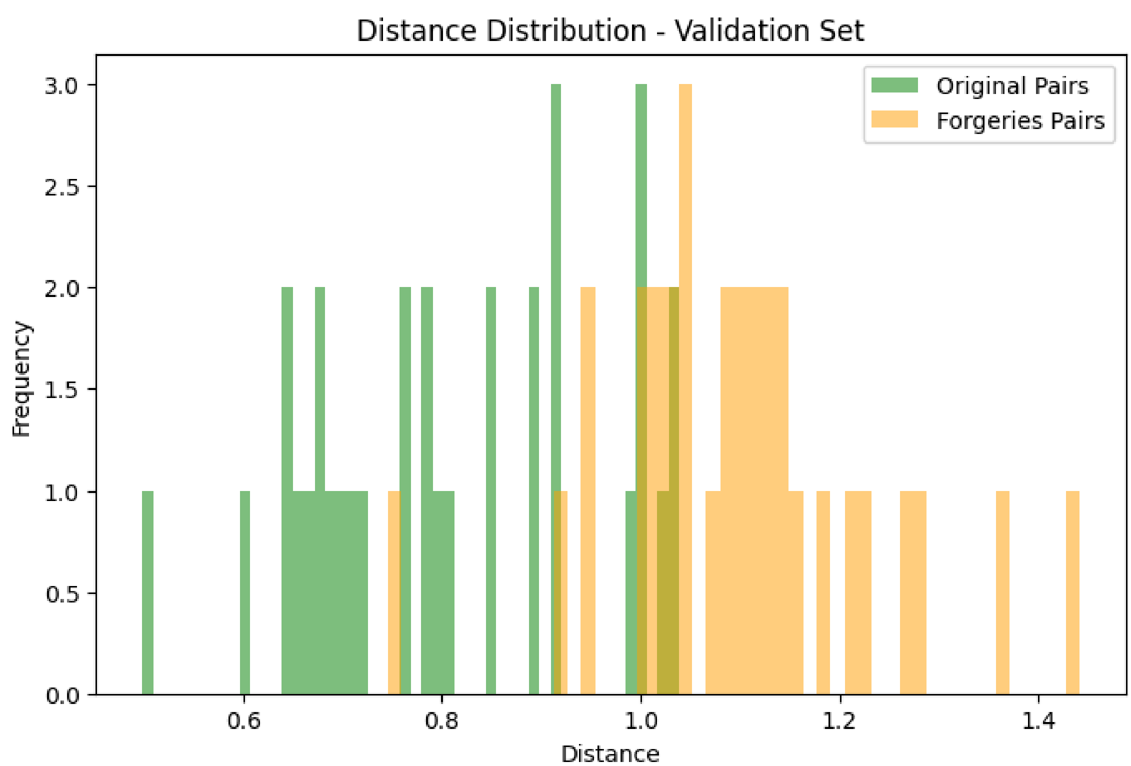
Evaluation

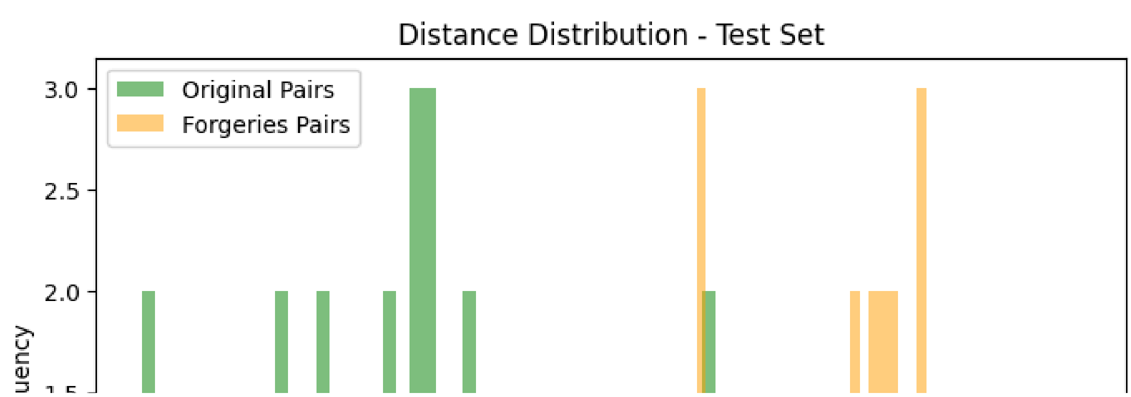
```
siamese_model.load_weights('best_model.h5')

def evaluate_model(db, org_path, forg_path, steps, batch_size, name, seed=42):
    generator = get_fixed_generator(db, org_path, forg_path, batch_size, seed)
    distances_pos = []
    distances_neg = []

    for _ in range(steps):
        (anchor, positive, negative), _ = next(generator)
        anchor_emb, pos_emb, neg_emb = siamese_model.predict([anchor, positive, negative], verbose=0)

        dist_pos = np.linalg.norm(anchor_emb - pos_emb, axis=1)
        dist_neg = np.linalg.norm(anchor_emb - neg_emb, axis=1)

        distances_pos.extend(dist_pos)
        distances_neg.extend(dist_neg)

    accuracy = np.mean(np.array(distances_pos) < np.array(distances_neg))
    print(f"{name} Accuracy: {accuracy:.4f}")

    return distances_pos, distances_neg

print("\nFinal Model Evaluation:")
train_dist_pos, train_dist_neg = evaluate_model(train_db, org_path, forg_path, train_steps, BATCH_SIZE, "Training
val_dist_pos, val_dist_neg = evaluate_model(val_db, org_path, forg_path, val_steps, BATCH_SIZE, "Validation")
test_dist_pos, test_dist_neg = evaluate_model(test_db, org_path, forg_path, test_steps, BATCH_SIZE, "Test")
```

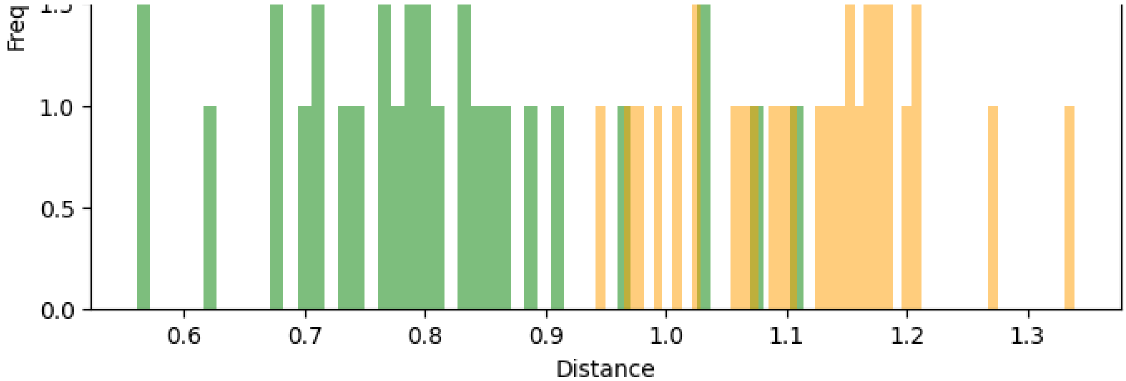
```
Final Model Evaluation:
Training Accuracy: 0.9688
Validation Accuracy: 1.0000
Test Accuracy: 1.0000
```

```
def plot_distances(pos_dist, neg_dist, title):
    plt.figure(figsize=(8, 5))
    plt.hist(pos_dist, bins=50, alpha=0.5, label='Original Pairs', color='green')
    plt.hist(neg_dist, bins=50, alpha=0.5, label='Forgeries Pairs', color='orange')
    plt.title(title)
    plt.xlabel('Distance')
    plt.ylabel('Frequency')
    plt.legend()
    plt.show()

plot_distances(train_dist_pos, train_dist_neg, "Distance Distribution - Training Set")
plot_distances(val_dist_pos, val_dist_neg, "Distance Distribution - Validation Set")
plot_distances(test_dist_pos, test_dist_neg, "Distance Distribution - Test Set")
```

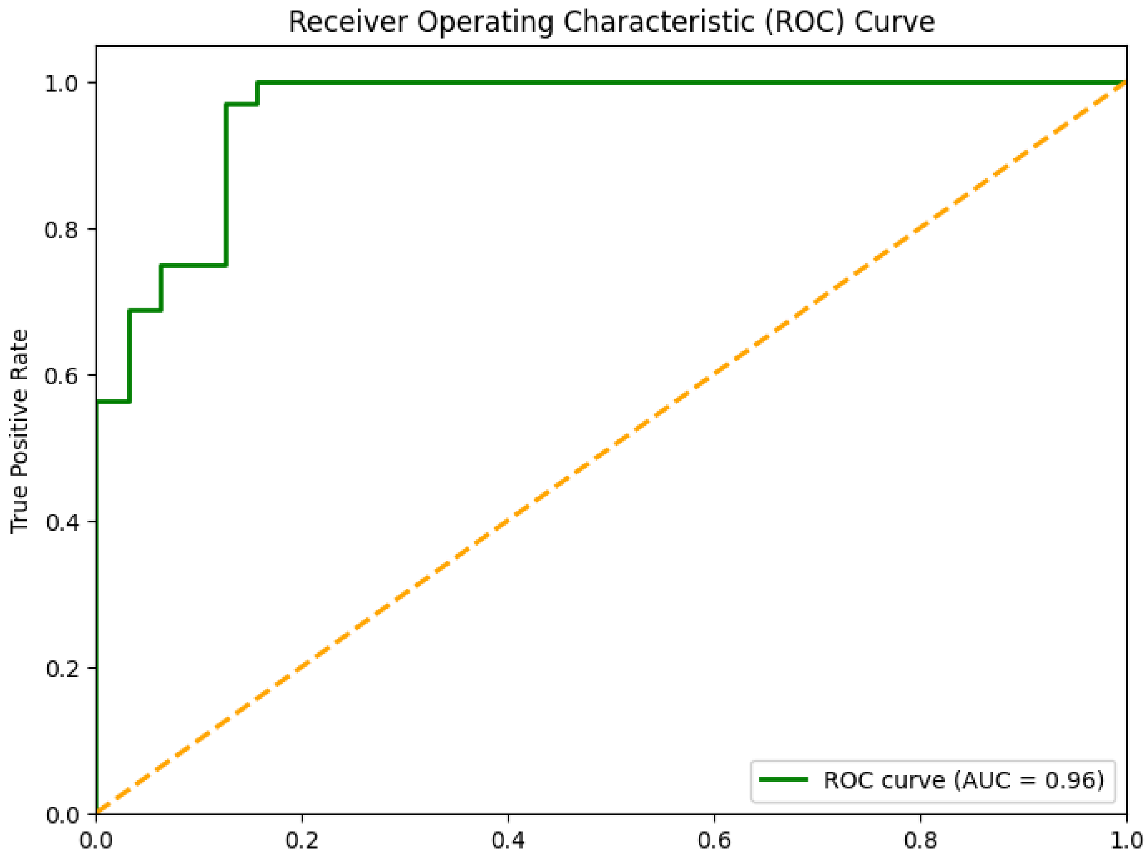

Distance Distribution - Training Set
Original Pairs
Forgeries Pairs
Frequency
Distance
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3


Distance Distribution - Validation Set
Original Pairs
Forgeries Pairs
Frequency
Distance
0.6
0.8
1.0
1.2
1.4


Distance Distribution - Test Set
Original Pairs
Forgeries Pairs




```
def calculate_roc(pos_dist, neg_dist):
    y_true = np.concatenate([np.ones(len(pos_dist)), np.zeros(len(neg_dist))])
    y_score = np.concatenate([pos_dist, neg_dist])

    fpr, tpr, thresholds = roc_curve(y_true, y_score, pos_label=0)
    roc_auc = auc(fpr, tpr)

    return fpr, tpr, roc_auc, thresholds

fpr, tpr, roc_auc, thresholds = calculate_roc(test_dist_pos, test_dist_neg)

plt.figure(figsize=(8, 6))
plt.plot(fpr, tpr, color='green', lw=2, label=f'ROC curve (AUC = {roc_auc:.2f})')
plt.plot([0, 1], [0, 1], color='orange', lw=2, linestyle='--')
plt.xlim([0.0, 1.0])
plt.ylim([0.0, 1.05])
plt.xlabel('False Positive Rate')
plt.ylabel('True Positive Rate')
plt.title('Receiver Operating Characteristic (ROC) Curve')
plt.legend(loc="lower right")
plt.show()

optimal_idx = np.argmax(tpr - fpr)
optimal_threshold = thresholds[optimal_idx]
print(f"Optimal threshold: {optimal_threshold:.4f}")
print(f"True Positive Rate at optimal threshold: {tpr[optimal_idx]:.4f}")
print(f"False Positive Rate at optimal threshold: {fpr[optimal_idx]:.4f}")
```


Receiver Operating Characteristic (ROC) Curve
True Positive Rate
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
ROC curve (AUC = 0.96)