ProjetoFinal

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0.0.1 Pós-graduação em Ciência de Dados e Machine Learning

Disciplina: Introdução a Redes Neurais

Projeto Final para disciplina Introdução a Redes Neurais

0.0.2 Integrantes:

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1 Classificação de Tumores de Mama em Imagens de Ultrassom

Objetivos
1. **Pré-processamento**: usar máscaras para recortar região de tumor.
2. **Modelagem**: ResNet50 pré-treinada + blocos customizados (PDFBlock + SEBlock).
3. **Treino**: otimizar usando loss binária, métricas AUC e acurácia.
4. **Avaliação**: matriz de confusão, AUC e relatório de resultados.

Métricas de Sucesso
- Acurácia X%
- AUC Y%
- Boa separação das classes (confusion matrix bem balanceada)

1.1 1. Introdução

O câncer de mama é uma das principais causas de morte por câncer em mulheres. O diagnóstico precoce é fundamental para o sucesso do tratamento. Dentre os exames de imagem utilizados, o ultrassom é amplamente aplicado, principalmente para distinguir tumores benignos de malignos. Este projeto tem como objetivo construir um modelo baseado em deep learning capaz de classificar tumores a partir de imagens de ultrassom.

1.2 2. Objetivos do Projeto

- Realizar o pré-processamento das imagens utilizando as máscaras de segmentação para destacar a região de interesse.
- Desenvolver um modelo de classificação utilizando uma rede EfficientNetB0 pré-treinada, complementada com blocos customizados (PDFBlock e SEBlock).
- Treinar e avaliar o modelo utilizando métricas como AUC e acurácia.
- Analisar o desempenho através de matriz de confusão e relatório de classificação.

1.3 3. Metodologia

Nesta seção descrevemos todo o pipeline, desde o ambiente e bibliotecas até a modelagem e treinamento.

[ ]:
```
import gc
import tensorflow as tf

# Limpar sessão TensorFlow
tf.keras.backend.clear_session()

# Coletar lixo do Python
gc.collect()
```

```
2025-04-29 19:32:46.030208: E
external/local_xla/xla/stream_executor/cuda/cuda_fft.cc:467] Unable to register
cuFFT factory: Attempting to register factory for plugin cuFFT when one has
already been registered
WARNING: All log messages before absl::InitializeLog() is called are written to
STDERR
E0000 00:00:1745965966.042841  247347 cuda_dnn.cc:8579] Unable to register cuDNN
factory: Attempting to register factory for plugin cuDNN when one has already
been registered
E0000 00:00:1745965966.046731  247347 cuda_blas.cc:1407] Unable to register
cuBLAS factory: Attempting to register factory for plugin cuBLAS when one has
already been registered
W0000 00:00:1745965966.057816  247347 computation_placer.cc:177] computation
placer already registered. Please check linkage and avoid linking the same
target more than once.
W0000 00:00:1745965966.057893  247347 computation_placer.cc:177] computation
placer already registered. Please check linkage and avoid linking the same
target more than once.
W0000 00:00:1745965966.057896  247347 computation_placer.cc:177] computation
placer already registered. Please check linkage and avoid linking the same
target more than once.
W0000 00:00:1745965966.057897  247347 computation_placer.cc:177] computation
placer already registered. Please check linkage and avoid linking the same
```

```
target more than once.
2025-04-29 19:32:46.063049: I tensorflow/core/platform/cpu_feature_guard.cc:210]
This TensorFlow binary is optimized to use available CPU instructions in
performance-critical operations.
To enable the following instructions: AVX2 FMA, in other operations, rebuild
TensorFlow with the appropriate compiler flags.
```

[ ]:
```
0
```

1.3.1 3.1 Ambiente e Bibliotecas

- Python 3.9
- TensorFlow / Keras
- scikit-learn, pandas, numpy, matplotlib
- Execução com suporte a GPU (RTX 2060 ou similar)

[ ]:
```
import os
import glob

# Removido: os.environ["CUDA_VISIBLE_DEVICES"] = ""

import numpy as np
import pandas as pd
import matplotlib.pyplot as plt

from sklearn.model_selection import train_test_split
from sklearn.utils import shuffle as skshuffle

import tensorflow as tf
from tensorflow import keras
from tensorflow.keras import layers, callbacks, Input, Model
from tensorflow.keras.applications import ResNet50, EfficientNetB0
from tensorflow.keras.preprocessing.image import ImageDataGenerator

from sklearn.metrics import confusion_matrix, classification_report
import seaborn as sns


print("Dispositivos visíveis:", tf.config.list_physical_devices('GPU'))
print("Versão do TensorFlow:", tf.__version__)
```

```
Dispositivos visíveis: [PhysicalDevice(name='/physical_device:GPU:0',
device_type='GPU')]
Versão do TensorFlow: 2.19.0
```

1.3.2 3.2 Exploração dos Dados

O dataset possui 811 imagens e 811 máscaras, divididos em: - Benignos: 358
- Malignos: 453

[ ]:
```
df = pd.read_csv('dataset.csv', sep=',')
df.head(10)
```

[ ]:

	Level	Name	Type	Description	File Count
0	0	.	directory	Root directory	2
1	1	images	directory	Contains all ultrasound images	811
2	1	masks	directory	Contains corresponding segmentation masks	811
3	1	Benign	directory	Contains benign tumor data	2
4	2	Benign/images	directory	Ultrasound images of benign tumors	358
5	2	Benign/masks	directory	Segmentation masks for benign tumors	358
6	1	Malignant	directory	Contains malignant tumor data	2
7	2	Malignant/images	directory	Ultrasound images of malignant tumors	453
8	2	Malignant/masks	directory	Segmentation masks for malignant tumors	453

Abaixo vamos listar imagens, máscaras e labels

[ ]:
```
BASE_DIR = "BUS_UC/BUS_UC/BUS_UC"
IMG_PATTERN = "*.png"

# diretórios
dirs = {
    0: (os.path.join(BASE_DIR, "Benign",    "images"),
        os.path.join(BASE_DIR, "Benign",    "masks")),
    1: (os.path.join(BASE_DIR, "Malignant", "images"),
        os.path.join(BASE_DIR, "Malignant", "masks")),
}

all_images, all_masks, all_labels = [], [], []
for label, (img_dir, mask_dir) in dirs.items():
    imgs  = sorted(glob.glob(os.path.join(img_dir,  IMG_PATTERN)))
    masks = sorted(glob.glob(os.path.join(mask_dir, IMG_PATTERN)))
    all_images += imgs
    all_masks  += masks
```

```
    all_labels += [label] * len(imgs)

print(f"Total: {len(all_images)} imagens, {len(all_masks)} máscaras")
print("Distribuição:", pd.Series(all_labels).value_counts().to_dict())
```

```
Total: 811 imagens, 811 máscaras
Distribuição: {1: 453, 0: 358}
```

1.3.3 3.4 Divisão dos Dados

- Treino: 70% (567)
- Validação: 15% (122)
- Teste: 15% (122)

[ ]:
```
imgs, masks, labs = skshuffle(all_images, all_masks, all_labels,␣
 ↪random_state=42)
X_train, X_rem, M_train, M_rem, y_train, y_rem = train_test_split(
    imgs, masks, labs,
    test_size=0.30, stratify=labs, random_state=42
)
X_val, X_test, M_val, M_test, y_val, y_test = train_test_split(
    X_rem, M_rem, y_rem,
    test_size=0.50, stratify=y_rem, random_state=42
)

print(f"Train: {len(X_train)} | Val: {len(X_val)} | Test: {len(X_test)}")
```

```
Train: 567 | Val: 122 | Test: 122
```

1.3.4 3.3 Pré-processamento e Aumentação

- Normalização para [0,1]
- Recorte da região de interesse usando máscaras
- Aumentação aplicada apenas no treino: flips, brilho, contraste e saturação aleatórios

[ ]:
```
IMG_SIZE = (224, 224)

def parse_image_mask(img_path, mask_path, label):
    # lê e normaliza imagem
    img = tf.io.read_file(img_path)
    img = tf.image.decode_png(img, channels=3)
    img = tf.image.resize(img, IMG_SIZE) / 255.0

    # lê máscara e redimensiona
    mask = tf.io.read_file(mask_path)
```

```
    mask = tf.image.decode_png(mask, channels=1)
    mask = tf.image.resize(mask, IMG_SIZE)

    # aplica máscara
    img = img * mask

    # AUGMENTAÇÃO APENAS NO TREINO
    if tf.random.uniform(()) > 0.5:
        img = tf.image.random_flip_left_right(img)
    if tf.random.uniform(()) > 0.5:
        img = tf.image.random_flip_up_down(img)
    if tf.random.uniform(()) > 0.5:
        img = tf.image.random_brightness(img, max_delta=0.15)
    if tf.random.uniform(()) > 0.5:
        img = tf.image.random_contrast(img, lower=0.8, upper=1.2)
    if tf.random.uniform(()) > 0.5:
        img = tf.image.random_saturation(img, lower=0.8, upper=1.2)

    return img, label
```

1.3.5 3.5 Criação do Pipeline com `tf.data`

Construção dos `Dataset` e `DataLoader` para treino, validação e teste.

[ ]:
```
def make_dataset(imgs, masks, labels, batch_size=32, shuffle=True):
    ds = tf.data.Dataset.from_tensor_slices((imgs, masks, labels))
    if shuffle:
        ds = ds.shuffle(len(imgs))
    ds = ds.map(lambda i, m, l: parse_image_mask(i, m, l),
                num_parallel_calls=tf.data.AUTOTUNE)
    ds = ds.batch(batch_size).prefetch(tf.data.AUTOTUNE)
    return ds

train_ds = make_dataset(X_train, M_train, y_train)
val_ds = make_dataset(X_val, M_val, y_val, shuffle=False)
test_ds = make_dataset(X_test, M_test, y_test, shuffle=False)

# verificação rápida
for imgs, labs in train_ds.take(1):
    print("Batch imagens:", imgs.shape, "Batch labels:", labs.numpy())
```

```
I0000 00:00:1745965968.986928  247347 gpu_device.cc:2019] Created device
/job:localhost/replica:0/task:0/device:GPU:0 with 4047 MB memory:  -> device: 0,
name: NVIDIA GeForce RTX 2060, pci bus id: 0000:01:00.0, compute capability: 7.5

Batch imagens: (16, 224, 224, 3) Batch labels: [1 1 1 0 1 0 1 1 0 1 1 0 1 1 0 1]

2025-04-29 19:32:49.525397: I tensorflow/core/framework/local_rendezvous.cc:407]
Local rendezvous is aborting with status: OUT_OF_RANGE: End of sequence
```

1.3.6 3.6 Blocos Customizados

Definição de: - **PDFBlock**: fusão piramidal com convoluções dilatadas
- **SEBlock**: recalibração channel-wise (Squeeze-and-Excitation)

[ ]:
```
class SEBlock(layers.Layer):
    """Squeeze-and-Excitation: recalibra dinamicamente a importância dos canais.
    """
    def __init__(self, channels, reduction=16, **kwargs):
        super().__init__(**kwargs)
        self.global_pool = layers.GlobalAveragePooling2D()
        self.fc1         = layers.Dense(channels // reduction,
    activation="relu")
        self.fc2         = layers.Dense(channels,          activation="sigmoid")
        self.reshape     = layers.Reshape((1, 1, channels))
        self.multiply    = layers.Multiply()

    def call(self, x):
        se = self.global_pool(x)      # [B, C]
        se = self.fc1(se)             # [B, C/r]
        se = self.fc2(se)             # [B, C]
        se = self.reshape(se)         # [B, 1, 1, C]
        return self.multiply([x, se])

class PDFBlock(layers.Layer):
    """Pyramid-Dilated Fusion: múltiplas convoluções dilatadas + projeção 1×1.
    """
    def __init__(self, out_channels, kernel_sizes, dilations, **kwargs):
        super().__init__(**kwargs)
        assert len(kernel_sizes) == len(dilations), "kernel_sizes e dilations
    devem ter mesmo tamanho"
        self.branches = []
        for k, d in zip(kernel_sizes, dilations):
            self.branches.append(
                layers.Conv2D(
                    filters=out_channels,
                    kernel_size=k,
                    padding="same",
                    dilation_rate=d,
                    activation="relu"
                )
            )
        self.project = layers.Conv2D(filters=out_channels, kernel_size=1,
    activation="relu")

    def call(self, x):
        feats = [branch(x) for branch in self.branches]
```

```
        x_cat = tf.concat(feats, axis=-1)
        return self.project(x_cat)
```

1.3.7 3.7 Arquitetura de Classificação

Backbone: EfficientNetB0 pré-treinado
→ PDFBlock → SEBlock → GAP → Dense(256) → Dropout(0.5) → Dense(1, sigmoid)

[ ]:
```
# 1) Backbone ResNet50 sem top layer, retendo mapa espacial
# Usando EfficientNetB0 como backbone por ser mais leve e rápido
backbone = EfficientNetB0(
    include_top=False,
    weights="imagenet",
    input_shape=(*IMG_SIZE, 3)
)
backbone.trainable = False  # congelado no início

# 2) Construção do grafo
inp = Input(shape=(*IMG_SIZE, 3), name="input_image")
x   = backbone(inp)                              # [B, H', W', C=2048]

# 3) Aplicar PDFBlock (multi-escala)
x = PDFBlock(
    out_channels=512,
    kernel_sizes=[1, 3, 5, 7],
    dilations=[1, 2, 3, 4]
)(x)  # agora [B, H', W', 512]

# 4) Recalibração de canais via SEBlock
x = SEBlock(channels=512, reduction=16)(x)      # [B, H', W', 512]

# 5) Agregação e cabeça de classificação
x = layers.GlobalAveragePooling2D(name="gap")(x)  # [B, 512]
x = layers.Dense(256, activation="relu", name="fc1")(x)
x = layers.Dropout(0.5, name="dropout")(x)
out = layers.Dense(1, activation="sigmoid", name="output")(x)

model_clf = Model(inputs=inp, outputs=out, name="MobileNetV2_PDF_SE_Clf")

#Penalizar mais os erros
def focal_loss(alpha=0.55, gamma=2.):
    """
    alpha > 0.5 favorece mais o foco na classe 1 (Malignant).
    """
    def focal_loss_fixed(y_true, y_pred):
        y_true = tf.cast(y_true, tf.float32)
        epsilon = tf.keras.backend.epsilon()
```

```
        y_pred = tf.clip_by_value(y_pred, epsilon, 1. - epsilon)

        cross_entropy = -y_true * tf.math.log(y_pred) - (1 - y_true) * tf.math.
 ↪log(1 - y_pred)
        weight = alpha * tf.pow(1 - y_pred, gamma) * y_true + (1 - alpha) * tf.
 ↪pow(y_pred, gamma) * (1 - y_true)
        loss = weight * cross_entropy
        return tf.reduce_mean(loss)

    return focal_loss_fixed

# 6) Compilação do modelo
model_clf.compile(
    optimizer=tf.keras.optimizers.Adam(learning_rate=1e-4),
    loss=focal_loss(alpha=0.55, gamma=2.),
    metrics=["accuracy", tf.keras.metrics.AUC(name="auc")]
)

model_clf.summary()
```

Model: "MobileNetV2_PDF_SE_Clf"

Layer (type)	Output Shape	Param #
input_image (InputLayer)	(None, 224, 224, 3)	0
efficientnetb0 (Functional)	(None, 7, 7, 1280)	4,049,571
pdf_block (PDFBlock)	(None, 7, 7, 512)	56,101,376
se_block (SEBlock)	(None, 7, 7, 512)	33,312
gap (GlobalAveragePooling2D)	(None, 512)	0
fc1 (Dense)	(None, 256)	131,328
dropout (Dropout)	(None, 256)	0
output (Dense)	(None, 1)	257

Total params: 60,315,844 (230.09 MB)

Trainable params: 56,266,273 (214.64 MB)

```
Non-trainable params: 4,049,571 (15.45 MB)
```

1.4 4. Treinamento

Configuração de callbacks, loss e otimização.

[ ]:
```
callbacks_list = [
    callbacks.EarlyStopping(
        monitor="val_auc",
        patience=4,
        mode="max",
        restore_best_weights=True,
        verbose=1
    ),
]
```

1.4.1 4.1 Ajuste de Pesos das Classes

Cálculo de `class_weight` para balancear as classes no treino.

[ ]:
```
from sklearn.utils.class_weight import compute_class_weight
import numpy as np

# Calcular pesos
class_weights = compute_class_weight(
    class_weight="balanced",
    classes=np.array([0, 1]),
    y=y_train  # (usa os labels do treino)
)

class_weights_dict = {0: class_weights[0], 1: class_weights[1]}
print(class_weights_dict)
```

```
{0: np.float64(1.134), 1: np.float64(0.8943217665615142)}
```

1.4.2 4.2 Treino Inicial

Execução do `.fit()` com Focal Loss, Adam e pesos de classe.

[ ]:
```
history = model_clf.fit(
    train_ds,
    validation_data=val_ds,
    epochs=30,
    callbacks=callbacks_list,
    class_weight=class_weights_dict
)
```

```
Epoch 1/30
```

```
WARNING: All log messages before absl::InitializeLog() is called are written to
STDERR
I0000 00:00:1745965980.715930  247426 service.cc:152] XLA service 0x7fcaa40039f0
initialized for platform CUDA (this does not guarantee that XLA will be used).
Devices:
I0000 00:00:1745965980.715961  247426 service.cc:160]   StreamExecutor device
(0): NVIDIA GeForce RTX 2060, Compute Capability 7.5
2025-04-29 19:33:01.172587: I
tensorflow/compiler/mlir/tensorflow/utils/dump_mlir_util.cc:269] disabling MLIR
crash reproducer, set env var `MLIR_CRASH_REPRODUCER_DIRECTORY` to enable.
I0000 00:00:1745965982.911359  247426 cuda_dnn.cc:529] Loaded cuDNN version
90501
2025-04-29 19:33:11.043673: W
external/local_xla/xla/tsl/framework/bfc_allocator.cc:310] Allocator (GPU_0_bfc)
ran out of memory trying to allocate 3.72GiB with freed_by_count=0. The caller
indicates that this is not a failure, but this may mean that there could be
performance gains if more memory were available.
2025-04-29 19:33:11.661514: W
external/local_xla/xla/tsl/framework/bfc_allocator.cc:310] Allocator (GPU_0_bfc)
ran out of memory trying to allocate 4.53GiB with freed_by_count=0. The caller
indicates that this is not a failure, but this may mean that there could be
performance gains if more memory were available.
I0000 00:00:1745965998.043135  247426 device_compiler.h:188] Compiled cluster
using XLA!  This line is logged at most once for the lifetime of the process.

35/36             0s 96ms/step -
accuracy: 0.5233 - auc: 0.5256 - loss: 0.0901

2025-04-29 19:33:26.670108: W
external/local_xla/xla/tsl/framework/bfc_allocator.cc:310] Allocator (GPU_0_bfc)
ran out of memory trying to allocate 2.88GiB with freed_by_count=0. The caller
indicates that this is not a failure, but this may mean that there could be
performance gains if more memory were available.
2025-04-29 19:33:31.028286: E
external/local_xla/xla/service/slow_operation_alarm.cc:73] Trying algorithm
eng28{k2=1,k3=0} for conv %cudnn-conv.177 = (f32[1280,512,5,5]{3,2,1,0},
u8[0]{0}) custom-call(f32[1280,63,7,7]{3,2,1,0} %bitcast.37214,
f32[512,63,3,3]{3,2,1,0} %bitcast.39069), window={size=3x3},
dim_labels=bf01_oi01->bf01, custom_call_target="__cudnn$convForward",
metadata={op_type="Conv2DBackpropFilter" op_name="gradient_tape/MobileNetV2_PDF_
SE_Clf_1/pdf_block_1/conv2d_2_1/convolution/Conv2DBackpropFilter"
source_file="/home/gustavo/projetoFinal-DeepLearning/venv/lib/python3.9/site-
packages/tensorflow/python/framework/ops.py" source_line=1200}, backend_config={
"operation_queue_id":"0","wait_on_operation_queues":[],"cudnn_conv_backend_confi
g":{"conv_result_scale":1,"activation_mode":"kNone","side_input_scale":0,"leakyr
elu_alpha":0},"force_earliest_schedule":false} is taking a while…
2025-04-29 19:33:31.050234: E
external/local_xla/xla/service/slow_operation_alarm.cc:140] The operation took
2.618629154s
```

```
Trying algorithm eng28{k2=1,k3=0} for conv %cudnn-conv.177 =
(f32[1280,512,5,5]{3,2,1,0}, u8[0]{0}) custom-call(f32[1280,63,7,7]{3,2,1,0}
%bitcast.37214, f32[512,63,3,3]{3,2,1,0} %bitcast.39069), window={size=3x3},
dim_labels=bf01_oi01->bf01, custom_call_target="__cudnn$convForward",
metadata={op_type="Conv2DBackpropFilter" op_name="gradient_tape/MobileNetV2_PDF_
SE_Clf_1/pdf_block_1/conv2d_2_1/convolution/Conv2DBackpropFilter"
source_file="/home/gustavo/projetoFinal-DeepLearning/venv/lib/python3.9/site-
packages/tensorflow/python/framework/ops.py" source_line=1200}, backend_config={
"operation_queue_id":"0","wait_on_operation_queues":[],"cudnn_conv_backend_confi
g":{"conv_result_scale":1,"activation_mode":"kNone","side_input_scale":0,"leakyr
elu_alpha":0},"force_earliest_schedule":false} is taking a while…
2025-04-29 19:33:31.107876: W
external/local_xla/xla/tsl/framework/bfc_allocator.cc:310] Allocator (GPU_0_bfc)
ran out of memory trying to allocate 3.13GiB with freed_by_count=0. The caller
indicates that this is not a failure, but this may mean that there could be
performance gains if more memory were available.
2025-04-29 19:33:31.547349: W
external/local_xla/xla/tsl/framework/bfc_allocator.cc:310] Allocator (GPU_0_bfc)
ran out of memory trying to allocate 3.49GiB with freed_by_count=0. The caller
indicates that this is not a failure, but this may mean that there could be
performance gains if more memory were available.

36/36            0s 551ms/step -
accuracy: 0.5240 - auc: 0.5267 - loss: 0.0901

2025-04-29 19:33:46.100930: W
external/local_xla/xla/tsl/framework/bfc_allocator.cc:310] Allocator (GPU_0_bfc)
ran out of memory trying to allocate 2.96GiB with freed_by_count=0. The caller
indicates that this is not a failure, but this may mean that there could be
performance gains if more memory were available.

36/36            59s 922ms/step -
accuracy: 0.5247 - auc: 0.5276 - loss: 0.0901 - val_accuracy: 0.5902 - val_auc:
0.6469 - val_loss: 0.0835
Epoch 2/30
36/36            4s 114ms/step -
accuracy: 0.6347 - auc: 0.6584 - loss: 0.0796 - val_accuracy: 0.5984 - val_auc:
0.6940 - val_loss: 0.0793
Epoch 3/30
36/36            4s 105ms/step -
accuracy: 0.6623 - auc: 0.7483 - loss: 0.0744 - val_accuracy: 0.5820 - val_auc:
0.6367 - val_loss: 0.0817
Epoch 4/30
36/36            4s 119ms/step -
accuracy: 0.6907 - auc: 0.7681 - loss: 0.0725 - val_accuracy: 0.6721 - val_auc:
0.7206 - val_loss: 0.0761
Epoch 5/30
36/36            7s 124ms/step -
accuracy: 0.7261 - auc: 0.7617 - loss: 0.0728 - val_accuracy: 0.6639 - val_auc:
```

```
0.7530 - val_loss: 0.0726
Epoch 6/30
36/36             4s 109ms/step -
accuracy: 0.7796 - auc: 0.8489 - loss: 0.0634 - val_accuracy: 0.5082 - val_auc:
0.6404 - val_loss: 0.0983
Epoch 7/30
36/36             4s 111ms/step -
accuracy: 0.6869 - auc: 0.7768 - loss: 0.0735 - val_accuracy: 0.6311 - val_auc:
0.7034 - val_loss: 0.0784
Epoch 8/30
36/36             4s 106ms/step -
accuracy: 0.7797 - auc: 0.8534 - loss: 0.0604 - val_accuracy: 0.6639 - val_auc:
0.7053 - val_loss: 0.0810
Epoch 9/30
36/36             4s 105ms/step -
accuracy: 0.7871 - auc: 0.8705 - loss: 0.0587 - val_accuracy: 0.6066 - val_auc:
0.6962 - val_loss: 0.0867
Epoch 9: early stopping
Restoring model weights from the end of the best epoch: 5.
```

1.5 5. Resultados Iniciais

Avaliação do modelo treinado originalmente.

[ ]:
```
test_loss, test_acc, test_auc = model_clf.evaluate(test_ds)
print(f"Test Loss:     {test_loss:.4f}")
print(f"Test Accuracy: {test_acc:.4f}")
print(f"Test AUC:      {test_auc:.4f}")
```

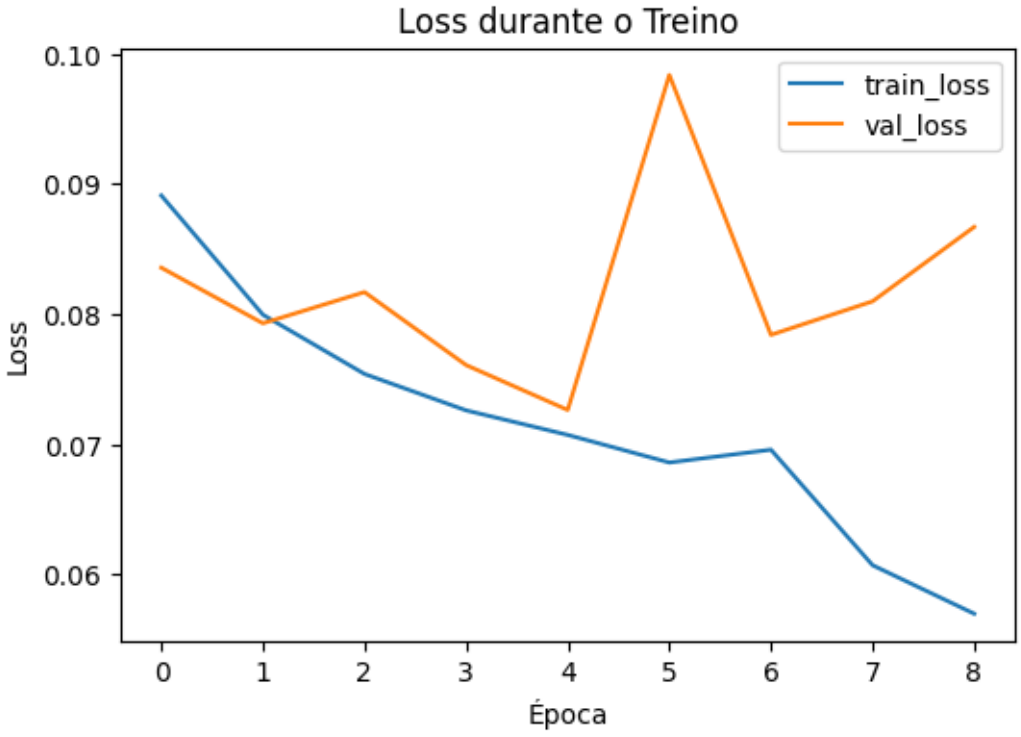
```
8/8             0s 52ms/step -
accuracy: 0.5938 - auc: 0.6312 - loss: 0.0839
Test Loss:     0.0835
Test Accuracy: 0.5902
Test AUC:      0.6442
```

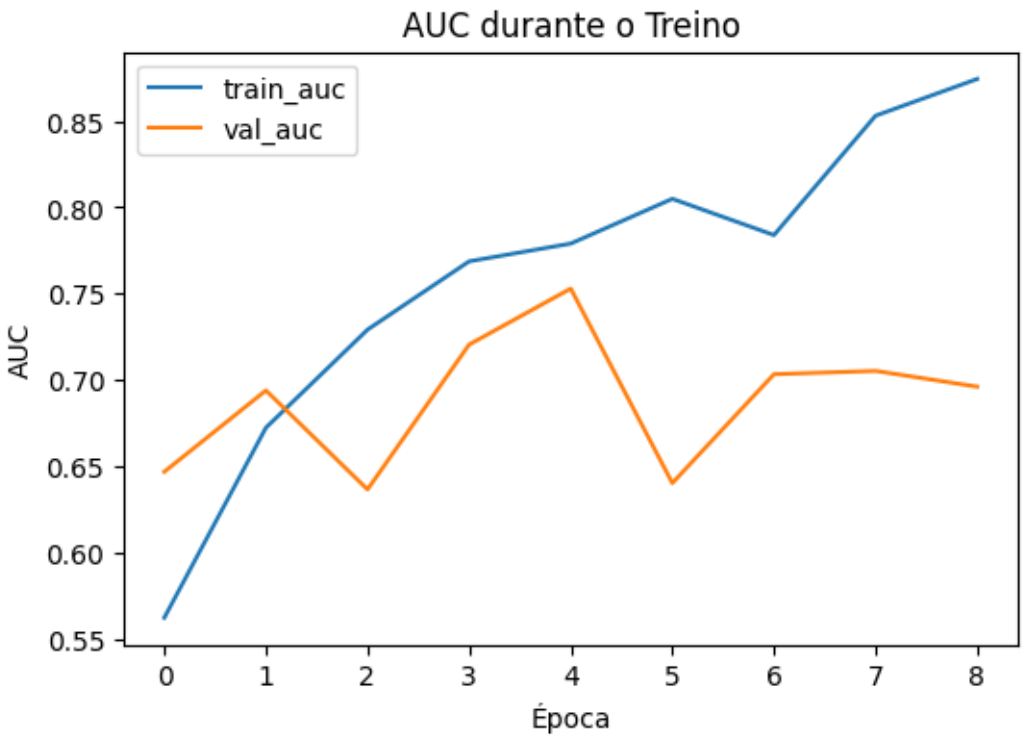
1.5.1 5.1 Curvas de Loss e AUC durante o Treino

[ ]:
```
# 1) Loss
plt.figure(figsize=(6,4))
plt.plot(history.history["loss"],   label="train_loss")
plt.plot(history.history["val_loss"], label="val_loss")
plt.title("Loss durante o Treino")
plt.xlabel("Época")
plt.ylabel("Loss")
plt.legend()
plt.show()

# 2) AUC
```

```
plt.figure(figsize=(6,4))
plt.plot(history.history["auc"],     label="train_auc")
plt.plot(history.history["val_auc"], label="val_auc")
plt.title("AUC durante o Treino")
plt.xlabel("Época")
plt.ylabel("AUC")
plt.legend()
plt.show()
```





1.5.2 5.2 Avaliação no Conjunto de Teste

- Classification Report
- Matriz de Confusão

[ ]:
```
# Previsões
y_pred_prob = model_clf.predict(test_ds)
y_pred = (y_pred_prob > 0.5).astype(int).reshape(-1)
y_true = np.concatenate([labels.numpy() for imgs, labels in test_ds], axis=0)

# Classification Report
print(classification_report(y_true, y_pred, target_names=["Benign",␣
 ↪"Malignant"]))

# Confusion Matrix
cm = confusion_matrix(y_true, y_pred)
plt.figure(figsize=(6,5))
sns.heatmap(cm, annot=True, fmt="d", cmap="Blues", xticklabels=["Benign",␣
 ↪"Malignant"], yticklabels=["Benign", "Malignant"])
plt.xlabel("Predicted")
plt.ylabel("True")
plt.title("Confusion Matrix")
```

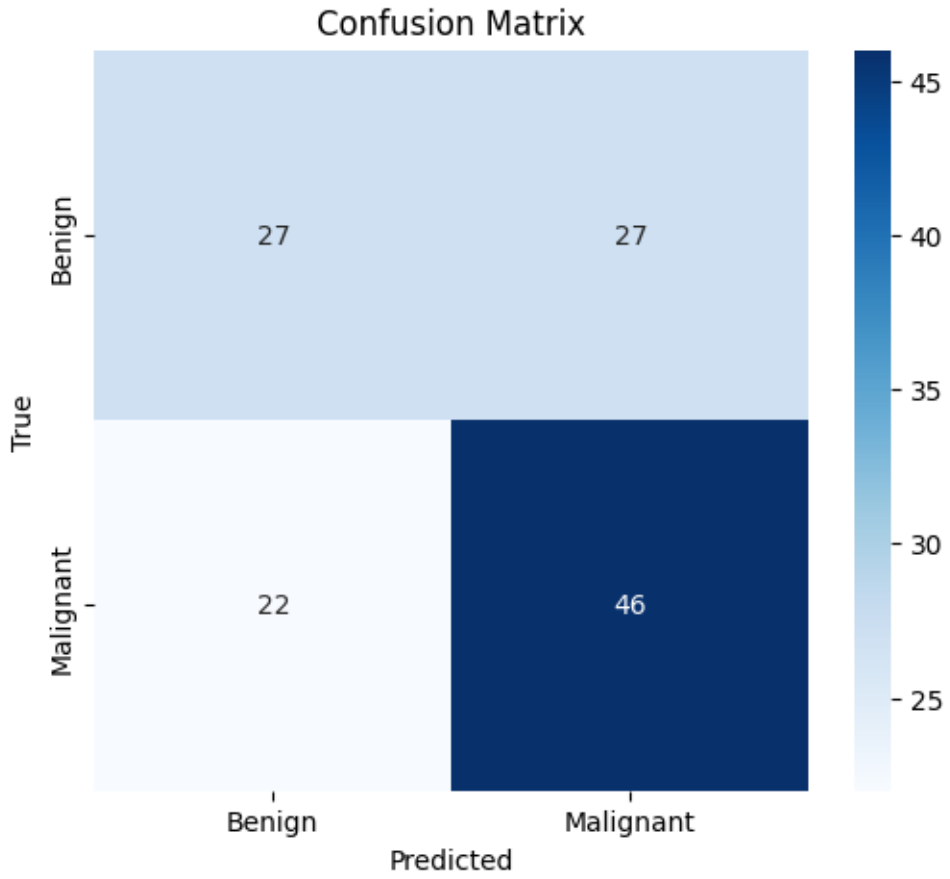
```
plt.show()
```

```
8/8             9s 648ms/step
              precision    recall  f1-score   support

      Benign       0.55      0.50      0.52        54
   Malignant       0.63      0.68      0.65        68

    accuracy                           0.60       122
   macro avg       0.59      0.59      0.59       122
weighted avg       0.60      0.60      0.60       122
```

```
2025-04-29 19:34:36.547066: I tensorflow/core/framework/local_rendezvous.cc:407]
Local rendezvous is aborting with status: OUT_OF_RANGE: End of sequence
```



1.6 6. Ajuste Fino (Fine-tuning)

Descongelamento dos últimos 30% das camadas do backbone e re-treinamento.

[ ]:
```python
# Descongelar EfficientNetB0 a partir de 70% das camadas
fine_tune_at = int(len(backbone.layers) * 0.7)

for layer in backbone.layers[fine_tune_at:]:
    layer.trainable = True

# Recompilar o modelo com learning rate menor
model_clf.compile(
    optimizer=tf.keras.optimizers.Adam(learning_rate=1e-5),
    loss="binary_crossentropy",
    metrics=["accuracy", tf.keras.metrics.AUC(name="auc")]
)
```

1.6.1 6.1 Treino após Fine-tuning

[ ]:
```python
# Treinar mais algumas épocas após liberar as camadas
history_finetune = model_clf.fit(
    train_ds,
    validation_data=val_ds,
    epochs=5,
    callbacks=callbacks_list,
    class_weight=class_weights_dict  # Mantém pesos!
)
```

```
Epoch 1/5
```

```
2025-04-29 19:34:55.817116: W
external/local_xla/xla/tsl/framework/bfc_allocator.cc:310] Allocator (GPU_0_bfc)
ran out of memory trying to allocate 3.14GiB with freed_by_count=0. The caller
indicates that this is not a failure, but this may mean that there could be
performance gains if more memory were available.
2025-04-29 19:34:55.817186: W
external/local_xla/xla/tsl/framework/bfc_allocator.cc:310] Allocator (GPU_0_bfc)
ran out of memory trying to allocate 3.14GiB with freed_by_count=0. The caller
indicates that this is not a failure, but this may mean that there could be
performance gains if more memory were available.
2025-04-29 19:34:56.923807: W
external/local_xla/xla/tsl/framework/bfc_allocator.cc:310] Allocator (GPU_0_bfc)
ran out of memory trying to allocate 3.72GiB with freed_by_count=0. The caller
indicates that this is not a failure, but this may mean that there could be
performance gains if more memory were available.
2025-04-29 19:34:57.533447: W
external/local_xla/xla/tsl/framework/bfc_allocator.cc:310] Allocator (GPU_0_bfc)
ran out of memory trying to allocate 4.53GiB with freed_by_count=0. The caller
indicates that this is not a failure, but this may mean that there could be
performance gains if more memory were available.
```

```
36/36            68s 1s/step -
accuracy: 0.6489 - auc: 0.7012 - loss: 0.6339 - val_accuracy: 0.6148 - val_auc:
```

```
0.7367 - val_loss: 0.6108
Epoch 2/5
36/36             8s 217ms/step -
accuracy: 0.6741 - auc: 0.7590 - loss: 0.6024 - val_accuracy: 0.6148 - val_auc:
0.7166 - val_loss: 0.6114
Epoch 3/5
36/36             5s 140ms/step -
accuracy: 0.7009 - auc: 0.7629 - loss: 0.5920 - val_accuracy: 0.6311 - val_auc:
0.6923 - val_loss: 0.6200
Epoch 4/5
36/36             5s 140ms/step -
accuracy: 0.7199 - auc: 0.8058 - loss: 0.5613 - val_accuracy: 0.5820 - val_auc:
0.6859 - val_loss: 0.6208
Epoch 5/5
36/36             5s 142ms/step -
accuracy: 0.6902 - auc: 0.7840 - loss: 0.5667 - val_accuracy: 0.6148 - val_auc:
0.6857 - val_loss: 0.6246
Epoch 5: early stopping
Restoring model weights from the end of the best epoch: 1.
```

1.6.2 6.2 Avaliação no Teste após Fine-tuning

[ ]:
```python
# Avaliar no conjunto de teste
loss, accuracy, auc = model_clf.evaluate(test_ds)
print(f"Test Loss: {loss:.4f}")
print(f"Test Accuracy: {accuracy:.4f}")
print(f"Test AUC: {auc:.4f}")
```

```
8/8             0s 54ms/step -
accuracy: 0.5840 - auc: 0.6049 - loss: 0.6497
Test Loss: 0.6470
Test Accuracy: 0.5820
Test AUC: 0.6382
```

1.6.3 6.3 Matriz de Confusão e Classification Report

[ ]:
```python
# Previsões
y_pred_prob = model_clf.predict(test_ds)
y_pred = (y_pred_prob > 0.5).astype(int).reshape(-1)
y_true = np.concatenate([labels.numpy() for imgs, labels in test_ds], axis=0)

# Classification Report
from sklearn.metrics import classification_report
print(classification_report(y_true, y_pred, target_names=["Benign",␣
 ↪"Malignant"]))

# Confusion Matrix
from sklearn.metrics import confusion_matrix
```

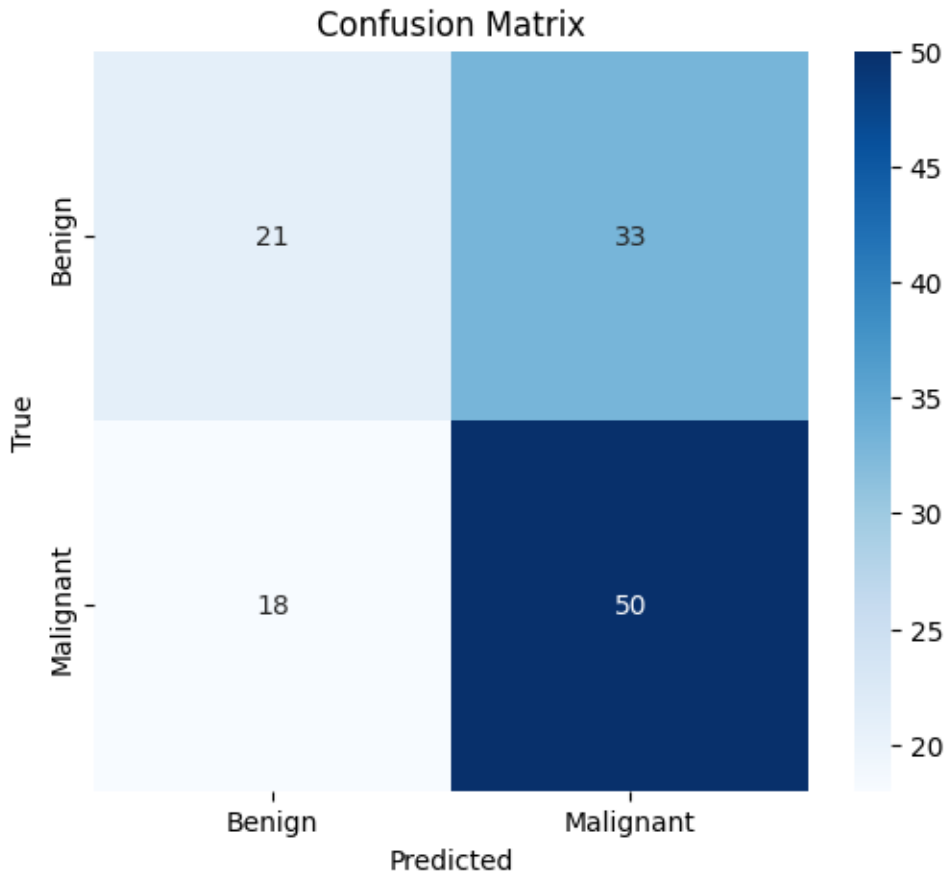
```
import seaborn as sns
import matplotlib.pyplot as plt

cm = confusion_matrix(y_true, y_pred)
plt.figure(figsize=(6,5))
sns.heatmap(cm, annot=True, fmt="d", cmap="Blues", xticklabels=["Benign",␣
 ↪"Malignant"], yticklabels=["Benign", "Malignant"])
plt.xlabel("Predicted")
plt.ylabel("True")
plt.title("Confusion Matrix")
plt.show()
```

```
8/8             9s 713ms/step
              precision    recall  f1-score   support

      Benign       0.54      0.39      0.45        54
   Malignant       0.60      0.74      0.66        68

    accuracy                           0.58       122
   macro avg       0.57      0.56      0.56       122
weighted avg       0.57      0.58      0.57       122
```



1.7 7. Análise Crítica

O modelo apresenta recall mais alto para malignos, o que é desejável em diagnóstico precoce, mesmo que a acurácia geral fique em ~60%. Consideramos que o modelo falhou em seu objetivo, considerando que sua AUC é perto de 60%, o que em análises médicas é abaixo do esperado (85%)

1.8 8. Conclusões e Recomendações

- Máscaras, Distorções de Imagem e Penalização de erros melhoram o pré-processamento.

- EfficientNetB0 + PDFBlock/SEBlock extraiu bons recursos das imagens, que tem poucos detalhes.

Recomendações:
2. Tuning de hiperparâmetros.
3. Aumentar o dataset e diversificar augmentations.

[9]:
```
!jupyter nbconvert --to pdf ProjetoFinal.ipynb
```

```
[NbConvertApp] Converting notebook ProjetoFinal.ipynb to pdf
[NbConvertApp] Support files will be in ProjetoFinal_files/
[NbConvertApp] Making directory ./ProjetoFinal_files
[NbConvertApp] Writing 93158 bytes to notebook.tex
[NbConvertApp] Building PDF
[NbConvertApp] Running xelatex 3 times: ['xelatex', 'notebook.tex', '-quiet']
[NbConvertApp] Running bibtex 1 time: ['bibtex', 'notebook']
[NbConvertApp] WARNING | bibtex had problems, most likely because there were no
citations
[NbConvertApp] PDF successfully created
[NbConvertApp] Writing 190674 bytes to ProjetoFinal.pdf
```