

ML_Final_Cruise_copy

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1 CISC5800: Machine Learning Final Project

1.0.1 *Creating a Convolutional Neural Network using a Plant Leaf Diseases Training Dataset from Kaggle*

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1.2 General Flow of this Notebook:

1. Data Exploration
2. Initial Run of VGG-16 Model
3. Recreating “mock” VGG-16 Model
4. Testing different CNN Layers
5. Reducing Data to only 21 Classes and ~56,000 samples for less runtime and greater accuracy
6. Identifying Data Imbalance Problem
7. Using Class Weights to solve for imbalance
8. Creating Stratified K-Fold to solve for imbalance (different Jupyter-Notebook)
9. Honorable Mention: Augmented data function that I ended up not being able to use because it took up too much memory

```
[22]: #loading all the necessary packages for this project
import os

#silencing warnings from tensorflow re: gpu use
os.environ["GRPC_VERBOSITY"] = "ERROR"
os.environ["GLOG_minloglevel"] = "2"
os.environ['TF_ENABLE_ONEDNN_OPTS'] = '0'

import tensorflow as tf
import numpy as np
import pandas as pd
from tensorflow import keras
from tensorflow.keras import layers, models
from tensorflow.keras.preprocessing.image import ImageDataGenerator
from keras.applications import VGG16
from sklearn.metrics import classification_report, confusion_matrix, \
    ConfusionMatrixDisplay
from sklearn.utils import class_weight
from pathlib import Path
```

```

from PIL import Image
import glob
import time
import matplotlib.pyplot as plt
import seaborn as sns

#verify local GPU being used by Tensorflow
tf.config.list_physical_devices('GPU')

```

[22]: [PhysicalDevice(name='/physical_device:GPU:0', device_type='GPU')]

1.3 1. Data Exploration

The data is from the Kaggle dataset “Plant Leaf Diseases Training Dataset” by Nirmal Sankalana. You can follow this link to the dataset: <https://www.kaggle.com/datasets/nirmalsankalana/plant-diseases-training-dataset>

This first block of code provides a preliminary look at the dataset and creates a dataframe that summarizes the classes. Even at this point it is apparent that there are issues with data imbalances.

```

[20]: #directory path of parent folder of all plant images
dir_path = "/home/ryan/plant_data/plant-diseases-training-dataset"
parent = Path(dir_path)

#list of names of each folder (class)
classes = [entry.name for entry in parent.iterdir() if entry.is_dir()]
class_onehot = [x for x in range(len(classes))]

#creates a list of classes organized by plant healthy vs. unhealthy
#I considered dividing the plants by healthy vs. unhealthy to reduce the num.
↳ classes and improve accuracy
health_dir = []

#initialize empty class df to store classes and class counts
df_class = pd.DataFrame({'class': classes, 'y':class_onehot, 'plant': pd.NA,
↳ 'health': ['unhealthy' for x in range(len(classes))], 'count':np.nan})

#used for class weights in section 7
train_labels = []

#creates df of classes and thier counts
for cls in classes:
    #assigns class plant, health, and class count to each class
    p=Path(f'{dir_path}/{cls}')
    count = sum(1 for entry in p.rglob('*') if entry.is_file())
    df_class.loc[df_class['class'] == cls, 'count'] = count
    temp_list = [cls for x in range(count)]

```

```

train_labels = train_labels + temp_list #for use in class weights in
↳section 7

#assigns plant type
split = cls.split('___',1)
df_class.loc[df_class['class'] == cls, 'plant'] = split[0]

#create dir list to create classes of only <plant>_healthy and
↳<plant>_unhealthy
if split[1] == 'healthy':
    health_dir.append(cls)
elif (split[1] != 'healthy') & (f'{split[0]}___unhealthy' not in
↳health_dir):
    health_dir.append(f'{split[0]}___unhealthy')

#assigns health of class
if split[1] == 'healthy':
    df_class.loc[df_class['class'] == cls, 'health'] = 'healthy'

#gets number of classes
nclasses = len(classes)

print("Num Classes: ", nclasses)
print("Class DataFrame with counts of each class:\n", df_class.
↳sort_values(by='count', ascending=False))

```

Num Classes: 71

Class DataFrame with counts of each class:

	class	y	plant	health	count
45	Cassava___mosaic_disease	45	Cassava	unhealthy	13158.0
51	Orange___citrus_greening	51	Orange	unhealthy	5507.0
57	Tomato___leaf_curl	57	Tomato	unhealthy	5357.0
49	Soybean___healthy	49	Soybean	healthy	5090.0
63	Rose___slug_sawfly	63	Rose	unhealthy	4979.0
..
69	Apple___brown_spot	69	Apple	unhealthy	215.0
2	Watermelon___healthy	2	Watermelon	healthy	205.0
21	Coffee___red_spider_mite	21	Coffee	unhealthy	167.0
65	Watermelon___anthracnose	65	Watermelon	unhealthy	155.0
67	Potato___nematode	67	Potato	unhealthy	68.0

[71 rows x 5 columns]

```

[4]: #prints list of all classes
print(classes)

```

```

['Rice___brown_spot', 'Blueberry___healthy', 'Watermelon___healthy',
'Tomato___bacterial_spot', 'Rose___rust', 'Raspberry___healthy',

```

```
'Sugercane__rust', 'Sugercane__healthy', 'Cassava__healthy', 'Rice__tungro',
'Cherry__healthy', 'Tomato__spider_mites', 'Tomato__mosaic_virus',
'Corn__gray_leaf_spot', 'Rice__bacterial_blight', 'Potato__leafroll_virus',
'Corn__healthy', 'Potato__early_blight', 'Apple__healthy',
'Potato__bacterial_wilt', 'Grape__healthy', 'Coffee__red_spider_mite',
'Bell_pepper__healthy', 'Sugercane__yellow_leaf', 'Peach__bacterial_spot',
'Cassava__green_mottle', 'Apple__alternaria_leaf_spot',
'Bell_pepper__bacterial_spot', 'Apple__scab', 'Tomato__leaf_mold',
'Sugercane__red_rot', 'Cherry__powdery_mildew', 'Tomato__early_blight',
'Peach__healthy', 'Tomato__healthy', 'Potato__healthy',
'Watermelon__mosaic_virus', 'Rice__blast', 'Tomato__septoria_leaf_spot',
'Corn__common_rust', 'Tomato__target_spot', 'Coffee__healthy',
'Watermelon__downy_mildew', 'Potato__mosaic_virus', 'Potato__phytophthora',
'Cassava__mosaic_disease', 'Grape__Leaf_blight', 'Potato__late_blight',
'Apple__black_rot', 'Soybean__healthy', 'Cassava__bacterial_blight',
'Orange__citrus_greening', 'Coffee__rust', 'Squash__powdery_mildew',
'Strawberry__leaf_scorch', 'Tomato__late_blight', 'Grape__black_rot',
'Tomato__leaf_curl', 'Grape__black_measles', 'Corn__northern_leaf_blight',
'Sugercane__mosaic', 'Rose__healthy', 'Apple__rust', 'Rose__slug_sawfly',
'Cassava__brown_streak_disease', 'Watermelon__anthracnose',
'Strawberry__healthy', 'Potato__nematode', 'Apple__gray_spot',
'Apple__brown_spot', 'Potato__pests']
```

1.3.1 Count of Unhealthy vs. Healthy samples per Plant Species

The code block below creates and prints a dataframe containing the sample counts for each plant and whether the sample class is either of a healthy class or an unhealthy class.

```
[5]: #gets count of all unhealthy instances per plant
df_unhealthy = df_class.where(df_class['health']=='unhealthy')
unhealthy = df_unhealthy.groupby('plant')['count'].sum()

#gets count of all healthy instances per plant
df_healthy = df_class.where(df_class['health']=='healthy')
healthy = df_healthy.groupby('plant')['count'].sum()

#list of all plants
plants = list(set(unhealthy.index.to_list() + healthy.index.to_list()))

#initialize df to combine healthy and unhealthy counts per plant
df_health = pd.DataFrame({'plant':plants, 'unhealthy':np.nan, 'healthy':np.nan})

#not all plants have both healthy and unhealthy classes
#this finds the plants that are missing (un)healthy classes

miss_healthy = []
miss_unhealthy = []
```

```

#fills list of all missing healthy classes
for plant in unhealthy.index.to_list():
    if plant not in healthy.index.to_list():
        miss_healthy.append(plant)

#fills list of all missing unhealthy classes
for plant in healthy.index.to_list():
    if plant not in unhealthy.index.to_list():
        miss_unhealthy.append(plant)

#fills df_health
for plant in plants:
    if plant in miss_unhealthy:
        df_health.loc[df_health['plant']==plant, 'unhealthy'] = 0
        df_health.loc[df_health['plant']==plant, 'healthy'] = healthy.at[plant]
    elif plant in miss_healthy:
        df_health.loc[df_health['plant']==plant, 'unhealthy'] = unhealthy.
        ↪at[plant]
        df_health.loc[df_health['plant']==plant, 'healthy'] = 0
    else:
        df_health.loc[df_health['plant']==plant, 'unhealthy'] = unhealthy.
        ↪at[plant]
        df_health.loc[df_health['plant']==plant, 'healthy'] = healthy.at[plant]

df_health['total'] = df_health[['unhealthy', 'healthy']].sum(axis=1)

print(df_health.sort_values(by='total', ascending=False))

```

	plant	unhealthy	healthy	total
9	Cassava	18820.0	2577.0	21397.0
7	Tomato	16569.0	1591.0	18160.0
10	Rose	9932.0	4978.0	14910.0
18	Potato	7503.0	2275.0	9778.0
4	Grape	5727.0	1705.0	7432.0
13	Apple	3972.0	2570.0	6542.0
5	Rice	5932.0	0.0	5932.0
1	Orange	5507.0	0.0	5507.0
6	Soybean	0.0	5090.0	5090.0
16	Corn	2690.0	1162.0	3852.0
8	Peach	2297.0	360.0	2657.0
0	Sugercane	1999.0	522.0	2521.0
19	Bell_pepper	997.0	1478.0	2475.0
15	Cherry	1052.0	854.0	1906.0
17	Squash	1835.0	0.0	1835.0
11	Strawberry	1109.0	456.0	1565.0
3	Coffee	769.0	791.0	1560.0
12	Blueberry	0.0	1502.0	1502.0

2	Watermelon	950.0	205.0	1155.0
14	Raspberry	0.0	371.0	371.0

```
[6]: #validating all cases found for both healthy and unhealthy classes
print('total healthy:', df_health['healthy'].sum())
print('total unhealthy:', df_health['unhealthy'].sum())
print()

#using df_class to validate
print(df_class.groupby('health')['count'].sum())

#all records
nsamp = df_class['count'].sum()
print("Number of samples: ", nsamp)
```

```
total healthy: 28487.0
total unhealthy: 87660.0
```

```
health
healthy      28487.0
unhealthy    87660.0
Name: count, dtype: float64
Number of samples: 116147.0
```

1.4 2. Initial Run of VGG-16 Model

This section is to just prove that my local system could train and run a CNN model using the plant dataset. The code section below is from an example by Subas Paudel using the same dataset. I wanted to make sure my system was running correctly and that I was able to produce a similar result. His code can be found here: <https://www.kaggle.com/code/subaspauldel/plant-disease>. This run of the VGG-16 model gave me a good baseline to compare any adjustments I made to my own CNN models.

```
[7]: #create VGG-16 model object
vgg=VGG16(include_top=True,weights='imagenet',input_shape=(224,224,3))
for layer in vgg.layers:
    layer.trainable=False
x=vgg.layers[-2].output
x=layers.Dense(256,activation='relu')(x)
out=layers.Dense(71,activation='softmax')(x)
model=models.Model(inputs=vgg.input,outputs=out)

#print model summary
model.summary()

#create image generator object and create training and testing datasets
tr_dg=ImageDataGenerator(rescale=1./255, shear_range=.2, zoom_range=.
↪2, horizontal_flip=True, validation_split=.2)
```

```

tr_gen=tr_dg.
    ↪flow_from_directory(dir_path,target_size=(224,224),batch_size=32,class_mode='categorical',s
val_gen=tr_dg.
    ↪flow_from_directory(dir_path,target_size=(224,224),batch_size=32,class_mode='categorical',s

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

#early stopping to prevent unnecessary epochs
es=tf.keras.callbacks.EarlyStopping(
    monitor='val_loss',
    patience=3,
    baseline=None,
    restore_best_weights=True)

#start time
start = time.perf_counter()

#training VGG model
his=model.fit(tr_gen,steps_per_epoch=2000//
    ↪32,epochs=50,validation_data=val_gen,validation_steps=800//32,
    ↪callbacks=[es])

#end time
end = time.perf_counter()

print(f'Execution Time: {round(((end-start)/60),2)} Minutes')

```

WARNING: All log messages before absl::InitializeLog() is called are written to STDERR

I0000 00:00:1765851241.932753 2356 gpu_device.cc:2019] Created device
/job:localhost/replica:0/task:0/device:GPU:0 with 13270 MB memory: -> device:
0, name: NVIDIA GeForce RTX 5060 Ti, pci bus id: 0000:01:00.0, compute
capability: 12.0

Model: "functional"

Layer (type)	Output Shape	Param #
input_layer (InputLayer)	(None, 224, 224, 3)	0
block1_conv1 (Conv2D)	(None, 224, 224, 64)	1,792
block1_conv2 (Conv2D)	(None, 224, 224, 64)	36,928

block1_pool (MaxPooling2D)	(None, 112, 112, 64)	0
block2_conv1 (Conv2D)	(None, 112, 112, 128)	73,856
block2_conv2 (Conv2D)	(None, 112, 112, 128)	147,584
block2_pool (MaxPooling2D)	(None, 56, 56, 128)	0
block3_conv1 (Conv2D)	(None, 56, 56, 256)	295,168
block3_conv2 (Conv2D)	(None, 56, 56, 256)	590,080
block3_conv3 (Conv2D)	(None, 56, 56, 256)	590,080
block3_pool (MaxPooling2D)	(None, 28, 28, 256)	0
block4_conv1 (Conv2D)	(None, 28, 28, 512)	1,180,160
block4_conv2 (Conv2D)	(None, 28, 28, 512)	2,359,808
block4_conv3 (Conv2D)	(None, 28, 28, 512)	2,359,808
block4_pool (MaxPooling2D)	(None, 14, 14, 512)	0
block5_conv1 (Conv2D)	(None, 14, 14, 512)	2,359,808
block5_conv2 (Conv2D)	(None, 14, 14, 512)	2,359,808
block5_conv3 (Conv2D)	(None, 14, 14, 512)	2,359,808
block5_pool (MaxPooling2D)	(None, 7, 7, 512)	0
flatten (Flatten)	(None, 25088)	0
fc1 (Dense)	(None, 4096)	102,764,544
fc2 (Dense)	(None, 4096)	16,781,312
dense (Dense)	(None, 256)	1,048,832
dense_1 (Dense)	(None, 71)	18,247

Total params: 135,327,623 (516.23 MB)

Trainable params: 1,067,079 (4.07 MB)

Non-trainable params: 134,260,544 (512.16 MB)

Found 92942 images belonging to 71 classes.

Found 23205 images belonging to 71 classes.

Epoch 1/50

2025-12-15 21:14:20.212305: I external/local_xla/xla/service/service.cc:153] XLA service 0x7d3890005790 initialized for platform CUDA (this does not guarantee that XLA will be used). Devices:

2025-12-15 21:14:20.212341: I external/local_xla/xla/service/service.cc:161] StreamExecutor device (0): NVIDIA GeForce RTX 5060 Ti, Compute Capability 12.0

2025-12-15 21:14:20.230412: 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 00:00:1765851260.408041 6823 cuda_dnn.cc:530] Loaded cuDNN version 90800

2025-12-15 21:14:20.921792: I external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_655', 148 bytes spill stores, 148 bytes spill loads

2025-12-15 21:14:21.019650: I external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_669', 76 bytes spill stores, 76 bytes spill loads

2025-12-15 21:14:21.019829: I external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_662', 556 bytes spill stores, 560 bytes spill loads

2025-12-15 21:14:21.124060: I external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_655', 1080 bytes spill stores, 1072 bytes spill loads

2025-12-15 21:14:21.277297: I external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_662', 4120 bytes spill stores, 4120 bytes spill loads

2025-12-15 21:14:24.282443: E external/local_xla/xla/service/slow_operation_alarm.cc:73] Trying algorithm eng0{} for conv %cudnn-conv-bias-activation.40 = (f32[32,224,224,64]{3,2,1,0}, u8[0]{0}) custom-call(%get-tuple-element.13, %bitcast.95, %arg5.6), window={size=3x3 pad=1_1x1_1}, dim_labels=b01f_o01i->b01f, custom_call_target="__cudnn\$convBiasActivationForward", metadata={op_type="Conv2D" op_name="functional_1/block1_conv2_1/convolution"

```
source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-  
packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={  
"operation_queue_id":"0","wait_on_operation_queues":[],"cudnn_conv_backend_config":{"activation_mode":"kRelu","conv_result_scale":1,"side_input_scale":0,"leakyrelu_alpha":0},"force_earliest_schedule":false,"reification_cost":[]}} is taking a  
while...
```

2025-12-15 21:14:25.205299: E

```
external/local_xla/xla/service/slow_operation_alarm.cc:140] The operation took  
1.924807505s
```

```
Trying algorithm eng0{} for conv %cudnn-conv-bias-activation.40 =  
(f32[32,224,224,64]{3,2,1,0}, u8[0]{0}) custom-call(%get-tuple-element.13,  
%bitcast.95, %arg5.6), window={size=3x3 pad=1_1x1_1},  
dim_labels=b01f_o01i->b01f,  
custom_call_target="__cudnn$convBiasActivationForward",  
metadata={op_type="Conv2D" op_name="functional_1/block1_conv2_1/convolution"  
source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-  
packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={  
"operation_queue_id":"0","wait_on_operation_queues":[],"cudnn_conv_backend_config":{"activation_mode":"kRelu","conv_result_scale":1,"side_input_scale":0,"leakyrelu_alpha":0},"force_earliest_schedule":false,"reification_cost":[]}} is taking a  
while...
```

```
2/62          3s 56ms/step - accuracy:  
0.0000e+00 - loss: 4.9238
```

```
I0000 00:00:1765851269.970322    6823 device_compiler.h:196] Compiled cluster  
using XLA! This line is logged at most once for the lifetime of the process.
```

```
62/62          20s 164ms/step -  
accuracy: 0.2203 - loss: 3.5934 - val_accuracy: 0.2900 - val_loss: 3.1951  
Epoch 2/50
```

```
62/62          9s 150ms/step -  
accuracy: 0.2974 - loss: 2.8929 - val_accuracy: 0.3125 - val_loss: 2.8119  
Epoch 3/50
```

```
62/62          9s 149ms/step -  
accuracy: 0.3553 - loss: 2.6230 - val_accuracy: 0.3125 - val_loss: 2.7117  
Epoch 4/50
```

```
18/62          2s 65ms/step -  
accuracy: 0.4191 - loss: 2.3405
```

2025-12-15 21:14:59.743900: W

```
external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All  
configs were filtered out because none of them sufficiently match the hints.  
Maybe the hints set does not contain a good representative set of valid  
configs?Working around this by using the full hints set instead.
```

2025-12-15 21:14:59.743947: W

```
external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All  
configs were filtered out because none of them sufficiently match the hints.  
Maybe the hints set does not contain a good representative set of valid  
configs?Working around this by using the full hints set instead.
```

2025-12-15 21:15:00.119398: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_662', 64 bytes spill stores, 64 bytes spill loads

2025-12-15 21:15:00.203208: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_676', 44 bytes spill stores, 44 bytes spill loads

2025-12-15 21:15:00.553535: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_655', 4768 bytes spill stores, 4692 bytes spill loads

2025-12-15 21:15:00.663603: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_676', 120 bytes spill stores, 120 bytes spill loads

2025-12-15 21:15:00.759774: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_662', 5820 bytes spill stores, 5800 bytes spill loads

2025-12-15 21:15:00.826480: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_901', 96 bytes spill stores, 96 bytes spill loads

2025-12-15 21:15:01.053667: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_676', 356 bytes spill stores, 356 bytes spill loads

2025-12-15 21:15:01.120038: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_676', 940 bytes spill stores, 1044 bytes spill loads

2025-12-15 21:15:01.163154: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_901', 60 bytes spill stores, 60 bytes spill loads

2025-12-15 21:15:01.279710: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function

'gemm_fusion_dot_676', 156 bytes spill stores, 156 bytes spill loads

2025-12-15 21:15:01.485214: I

external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas

warning : Registers are spilled to local memory in function

'gemm_fusion_dot_676', 280 bytes spill stores, 280 bytes spill loads

2025-12-15 21:15:01.548922: I

external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas

warning : Registers are spilled to local memory in function

'gemm_fusion_dot_901', 192 bytes spill stores, 192 bytes spill loads

2025-12-15 21:15:01.612503: I

external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas

warning : Registers are spilled to local memory in function

'gemm_fusion_dot_676', 32 bytes spill stores, 32 bytes spill loads

62/62 14s 227ms/step -

accuracy: 0.4018 - loss: 2.2982 - val_accuracy: 0.4225 - val_loss: 2.3123

Epoch 5/50

62/62 7s 116ms/step -

accuracy: 0.4647 - loss: 2.0763 - val_accuracy: 0.4538 - val_loss: 2.0890

Epoch 6/50

62/62 7s 119ms/step -

accuracy: 0.4839 - loss: 1.9507 - val_accuracy: 0.4850 - val_loss: 1.8614

Epoch 7/50

62/62 7s 119ms/step -

accuracy: 0.4950 - loss: 1.7905 - val_accuracy: 0.5063 - val_loss: 1.8300

Epoch 8/50

62/62 7s 110ms/step -

accuracy: 0.5106 - loss: 1.7167 - val_accuracy: 0.4988 - val_loss: 1.7832

Epoch 9/50

62/62 7s 110ms/step -

accuracy: 0.5136 - loss: 1.7474 - val_accuracy: 0.5675 - val_loss: 1.5439

Epoch 10/50

62/62 7s 111ms/step -

accuracy: 0.5348 - loss: 1.5745 - val_accuracy: 0.5213 - val_loss: 1.6127

Epoch 11/50

62/62 7s 116ms/step -

accuracy: 0.5645 - loss: 1.5275 - val_accuracy: 0.5063 - val_loss: 1.6621

Epoch 12/50

62/62 7s 114ms/step -

accuracy: 0.5973 - loss: 1.4091 - val_accuracy: 0.5250 - val_loss: 1.5378

Epoch 13/50

62/62 7s 112ms/step -

accuracy: 0.5892 - loss: 1.4070 - val_accuracy: 0.5825 - val_loss: 1.4598

Epoch 14/50

62/62 7s 115ms/step -
accuracy: 0.5922 - loss: 1.3726 - val_accuracy: 0.5525 - val_loss: 1.4585
Epoch 15/50

62/62 7s 118ms/step -
accuracy: 0.6028 - loss: 1.3785 - val_accuracy: 0.6150 - val_loss: 1.3647
Epoch 16/50

62/62 7s 115ms/step -
accuracy: 0.6023 - loss: 1.3540 - val_accuracy: 0.5638 - val_loss: 1.5544
Epoch 17/50

62/62 7s 114ms/step -
accuracy: 0.6064 - loss: 1.2828 - val_accuracy: 0.6375 - val_loss: 1.2330
Epoch 18/50

62/62 7s 113ms/step -
accuracy: 0.6250 - loss: 1.2391 - val_accuracy: 0.6162 - val_loss: 1.3294
Epoch 19/50

62/62 7s 113ms/step -
accuracy: 0.6326 - loss: 1.2028 - val_accuracy: 0.6413 - val_loss: 1.2442
Epoch 20/50

62/62 7s 113ms/step -
accuracy: 0.6386 - loss: 1.1915 - val_accuracy: 0.6325 - val_loss: 1.2431
Epoch 21/50

62/62 8s 133ms/step -
accuracy: 0.6426 - loss: 1.2084 - val_accuracy: 0.6762 - val_loss: 1.1908
Epoch 22/50

62/62 7s 108ms/step -
accuracy: 0.6583 - loss: 1.1073 - val_accuracy: 0.6587 - val_loss: 1.1950
Epoch 23/50

62/62 7s 107ms/step -
accuracy: 0.6598 - loss: 1.1045 - val_accuracy: 0.6212 - val_loss: 1.2230
Epoch 24/50

62/62 8s 135ms/step -
accuracy: 0.6401 - loss: 1.1378 - val_accuracy: 0.6475 - val_loss: 1.1765
Epoch 25/50

62/62 7s 112ms/step -
accuracy: 0.6663 - loss: 1.0975 - val_accuracy: 0.6463 - val_loss: 1.3198
Epoch 26/50

62/62 7s 120ms/step -
accuracy: 0.6588 - loss: 1.1159 - val_accuracy: 0.6388 - val_loss: 1.1691
Epoch 27/50

62/62 7s 115ms/step -
accuracy: 0.6764 - loss: 1.0265 - val_accuracy: 0.6875 - val_loss: 1.0655
Epoch 28/50

62/62 7s 106ms/step -
accuracy: 0.6568 - loss: 1.0893 - val_accuracy: 0.6413 - val_loss: 1.2022
Epoch 29/50

62/62 7s 115ms/step -
accuracy: 0.6840 - loss: 1.0245 - val_accuracy: 0.6850 - val_loss: 1.0045
Epoch 30/50

```

62/62          7s 109ms/step -
accuracy: 0.7102 - loss: 0.9671 - val_accuracy: 0.6687 - val_loss: 1.0546
Epoch 31/50
62/62          7s 110ms/step -
accuracy: 0.6915 - loss: 0.9932 - val_accuracy: 0.6313 - val_loss: 1.1709
Epoch 32/50
62/62          7s 109ms/step -
accuracy: 0.6860 - loss: 0.9803 - val_accuracy: 0.6737 - val_loss: 1.1546
Execution Time: 4.18 Minutes

```

```

[10]: #gets the validation loss and accuracy and prints
val_loss, val_acc = model.evaluate(val_gen, verbose=1)
print(f"Validation loss: {val_loss:.3f}")
print(f"Validation accuracy: {val_acc:.3f}")

```

```

726/726        71s 98ms/step -
accuracy: 0.6592 - loss: 1.1196
Validation loss: 1.120
Validation accuracy: 0.659

```

1.5 3. Recreating “mock” VGG-16 Model

I noticed that the VGG model uses 224x224 pixels instead of 256x256 pixels, which is the dimension of most of my photos. So, I tried to recreate the VGG-16 model, but using the 256x256 image dimension.

I essentially just used the same number of convolutional layers and FC layers. I also froze some of the initial convolutional layers and froze the first two FC layers, which is similar to the VGG-16 model. This model also takes a very long time to run, which is not great for experimentation.

```

[11]: def mock_VGG16(input_shape, nclasses):

    #input layer
    inputs = keras.Input(shape=input_shape)

    #rescale layer - pixels to [0,1]
    x = layers.Rescaling(1./255)(inputs)

    #Stack 1 - convolution round 1, maxpooling
    x = layers.Conv2D(filters=32, kernel_size=(3,3), padding="same",
↳activation="relu", trainable=False)(x)
    x = layers.Conv2D(filters=32, kernel_size=(3,3), padding="same",
↳activation="relu", trainable=False)(x)
    x = layers.MaxPooling2D(pool_size=(2,2), strides=2)(x)

    #Stack 2 - convolution round 2, maxpooling
    x = layers.Conv2D(filters=64, kernel_size=(3,3), padding="same",
↳activation="relu", trainable=False)(x)

```

```

x = layers.Conv2D(filters=64, kernel_size=(3,3), padding="same",
↳activation="relu", trainable=False)(x)
x = layers.MaxPooling2D(pool_size=(2,2), strides=2)(x)

#Stack 3 - Convolution round 3, maxpooling
x = layers.Conv2D(filters=128, kernel_size=(3,3), padding="same",
↳activation="relu", trainable=False)(x)
x = layers.Conv2D(filters=128, kernel_size=(3,3), padding="same",
↳activation="relu", trainable=False)(x)
x = layers.Conv2D(filters=128, kernel_size=(3,3), padding="same",
↳activation="relu", trainable=False)(x)
x = layers.MaxPooling2D(pool_size=(2,2), strides=2)(x)

# #Stack 4 - Convolutional round 4, maxpooling
x = layers.Conv2D(filters=512, kernel_size=(3,3), padding="same",
↳activation="relu")(x)
x = layers.Conv2D(filters=512, kernel_size=(3,3), padding="same",
↳activation="relu")(x)
x = layers.Conv2D(filters=512, kernel_size=(3,3), padding="same",
↳activation="relu")(x)
x = layers.MaxPooling2D(pool_size=(2,2), strides=2)(x)

# #Stack 5 - Convolutional round 5, maxpooling
x = layers.Conv2D(filters=512, kernel_size=(3,3), padding="same",
↳activation="relu")(x)
x = layers.Conv2D(filters=512, kernel_size=(3,3), padding="same",
↳activation="relu")(x)
x = layers.Conv2D(filters=512, kernel_size=(3,3), padding="same",
↳activation="relu")(x)
x = layers.MaxPooling2D(pool_size=(2,2), strides=2)(x)

#Flatten layer
x = layers.Flatten()(x)

#Stack 6 - Fully Connected Layers
x = layers.Dropout(0.2)(x)      #drop 20% neurons to prevent overfitting
↳before sending to FC layers
x = layers.Dense(1024, activation="relu", trainable=False)(x)

x = layers.Dropout(0.2)(x)      #drop 20% neurons to prevent overfitting
↳before sending to FC layers
x = layers.Dense(512, activation="relu", trainable=False)(x)

x = layers.Dropout(0.2)(x)      #drop 20% neurons to prevent overfitting
↳before sending to FC layers
x = layers.Dense(256, activation="relu")(x)

```

```

x = layers.Dropout(0.2)(x) #drop 20% neurons before sending to output layer

#output layer using softmax function
outputs = layers.Dense(nclasses, activation="softmax")(x)

model = keras.Model(inputs=inputs, outputs=outputs)

return model

#initialize input shape
input_shape = (256,256,3)
nclasses = 71

#create model object
model = mock_VGG16(input_shape, nclasses)

#compile model
model.compile(
    optimizer=keras.optimizers.Adam(learning_rate=1e-3),
    loss="sparse_categorical_crossentropy",
    metrics=["accuracy"])

#print model summary
model.summary()

```

Model: "functional_1"

Layer (type)	Output Shape	Param #
input_layer_1 (InputLayer)	(None, 256, 256, 3)	0
rescaling (Rescaling)	(None, 256, 256, 3)	0
conv2d (Conv2D)	(None, 256, 256, 32)	896
conv2d_1 (Conv2D)	(None, 256, 256, 32)	9,248
max_pooling2d (MaxPooling2D)	(None, 128, 128, 32)	0
conv2d_2 (Conv2D)	(None, 128, 128, 64)	18,496
conv2d_3 (Conv2D)	(None, 128, 128, 64)	36,928
max_pooling2d_1 (MaxPooling2D)	(None, 64, 64, 64)	0
conv2d_4 (Conv2D)	(None, 64, 64, 128)	73,856

conv2d_5 (Conv2D)	(None, 64, 64, 128)	147,584
conv2d_6 (Conv2D)	(None, 64, 64, 128)	147,584
max_pooling2d_2 (MaxPooling2D)	(None, 32, 32, 128)	0
conv2d_7 (Conv2D)	(None, 32, 32, 512)	590,336
conv2d_8 (Conv2D)	(None, 32, 32, 512)	2,359,808
conv2d_9 (Conv2D)	(None, 32, 32, 512)	2,359,808
max_pooling2d_3 (MaxPooling2D)	(None, 16, 16, 512)	0
conv2d_10 (Conv2D)	(None, 16, 16, 512)	2,359,808
conv2d_11 (Conv2D)	(None, 16, 16, 512)	2,359,808
conv2d_12 (Conv2D)	(None, 16, 16, 512)	2,359,808
max_pooling2d_4 (MaxPooling2D)	(None, 8, 8, 512)	0
flatten (Flatten)	(None, 32768)	0
dropout (Dropout)	(None, 32768)	0
dense_2 (Dense)	(None, 1024)	33,555,456
dropout_1 (Dropout)	(None, 1024)	0
dense_3 (Dense)	(None, 512)	524,800
dropout_2 (Dropout)	(None, 512)	0
dense_4 (Dense)	(None, 256)	131,328
dropout_3 (Dropout)	(None, 256)	0
dense_5 (Dense)	(None, 71)	18,247

Total params: 47,053,799 (179.50 MB)

Trainable params: 12,538,951 (47.83 MB)

Non-trainable params: 34,514,848 (131.66 MB)

```
[13]: plant_dir="/home/ryan/plant_data/plant-diseases-training-dataset"

data_tr, data_ts = tf.keras.preprocessing.image_dataset_from_directory(
    plant_dir,
    labels='inferred',
    label_mode = 'int',
    batch_size=64,
    image_size=(256,256),
    shuffle=True,
    seed = 42,
    validation_split=0.2,
    subset='both',
    interpolation='lanczos3',
    crop_to_aspect_ratio=True,
    verbose=True)

#Early Stopping for efficiency
callbacks = [
    keras.callbacks.EarlyStopping(
        monitor = "val_loss",
        patience = 3,
        restore_best_weights=True)]

#start time
start = time.perf_counter()

#fit model and store epoch history
history = model.fit(
    data_tr,
    validation_data = data_ts,
    epochs=50,
    callbacks=callbacks)

#end time
end = time.perf_counter()

print(f'Execution Time: {round(((end-start)/60),2)} Minutes')
```

Found 116147 files belonging to 71 classes.

Using 92918 files for training.

Using 23229 files for validation.

Epoch 1/50

2025-12-15 21:34:19.508089: W

external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
configs were filtered out because none of them sufficiently match the hints.

Maybe the hints set does not contain a good representative set of valid configs?Working around this by using the full hints set instead.

2025-12-15 21:34:19.508141: W
external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All configs were filtered out because none of them sufficiently match the hints. Maybe the hints set does not contain a good representative set of valid configs?Working around this by using the full hints set instead.

2025-12-15 21:34:19.880651: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_1430', 172 bytes spill stores, 172 bytes spill loads

2025-12-15 21:34:19.962982: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_1481', 1016 bytes spill stores, 1004 bytes spill loads

2025-12-15 21:34:19.963571: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_1430', 1032 bytes spill stores, 1008 bytes spill loads

2025-12-15 21:34:19.964124: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_2482', 116 bytes spill stores, 116 bytes spill loads

2025-12-15 21:34:20.063419: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_2482', 4 bytes spill stores, 4 bytes spill loads

2025-12-15 21:34:20.150442: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_2213', 24 bytes spill stores, 24 bytes spill loads

2025-12-15 21:34:20.292491: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_2322', 140 bytes spill stores, 140 bytes spill loads

2025-12-15 21:34:20.479104: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_2213', 204 bytes spill stores, 204 bytes spill loads

2025-12-15 21:34:20.885419: I

```
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas  
warning : Registers are spilled to local memory in function  
'gemm_fusion_dot_2463', 412 bytes spill stores, 428 bytes spill loads
```

```
2025-12-15 21:34:20.938860: I  
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas  
warning : Registers are spilled to local memory in function  
'gemm_fusion_dot_2463', 148 bytes spill stores, 148 bytes spill loads
```

```
2025-12-15 21:34:21.115132: I  
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas  
warning : Registers are spilled to local memory in function  
'gemm_fusion_dot_2482', 776 bytes spill stores, 768 bytes spill loads
```

```
2025-12-15 21:34:21.124999: I  
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas  
warning : Registers are spilled to local memory in function  
'gemm_fusion_dot_2322', 40 bytes spill stores, 40 bytes spill loads
```

```
2025-12-15 21:34:21.242245: I  
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas  
warning : Registers are spilled to local memory in function  
'gemm_fusion_dot_2213', 632 bytes spill stores, 776 bytes spill loads
```

```
2025-12-15 21:34:21.245721: I  
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas  
warning : Registers are spilled to local memory in function  
'gemm_fusion_dot_2322', 56 bytes spill stores, 56 bytes spill loads
```

```
2025-12-15 21:34:23.695488: E  
external/local_xla/xla/service/slow_operation_alarm.cc:73] Trying algorithm  
eng0{} for conv %cudnn-conv-bias-activation.40 = (f32[64,256,256,32]{3,2,1,0},  
u8[0]{0}) custom-call(%get-tuple-element.32, %bitcast.477, %arg5.6),  
window={size=3x3 pad=1_1x1_1}, dim_labels=b01f_o01i->b01f,  
custom_call_target="_cudnn$convBiasActivationForward",  
metadata={op_type="Conv2D" op_name="functional_1_1/conv2d_1_2/convolution"  
source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-  
packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={  
"operation_queue_id":"0","wait_on_operation_queues":[],"cudnn_conv_backend_config":  
{"activation_mode":"kRelu","conv_result_scale":1,"side_input_scale":0,"leakyrelu_alpha":0},  
"force_earliest_schedule":false,"reification_cost":[]}] is taking a  
while...
```

```
2025-12-15 21:34:23.961159: E  
external/local_xla/xla/service/slow_operation_alarm.cc:140] The operation took  
1.265761134s
```

```
Trying algorithm eng0{} for conv %cudnn-conv-bias-activation.40 =  
(f32[64,256,256,32]{3,2,1,0}, u8[0]{0}) custom-call(%get-tuple-element.32,  
%bitcast.477, %arg5.6), window={size=3x3 pad=1_1x1_1},
```

```

dim_labels=b01f_o01i->b01f,
custom_call_target="__cudnn$convBiasActivationForward",
metadata={op_type="Conv2D" op_name="functional_1_1/conv2d_1_2/convolution"
source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-
packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={
"operation_queue_id":"0","wait_on_operation_queues":[],"cudnn_conv_backend_conf
ig":{"activation_mode":"kRelu","conv_result_scale":1,"side_input_scale":0,"leaky
relu_alpha":0},"force_earliest_schedule":false,"reification_cost":[]}} is taking a
while...
2025-12-15 21:34:26.798706: E
external/local_xla/xla/service/slow_operation_alarm.cc:73] Trying algorithm
eng0{} for conv %cudnn-conv-bias-activation.42 = (f32[64,128,128,64]{3,2,1,0},
u8[0]{0}) custom-call(%get-tuple-element.34, %bitcast.481, %arg9.10),
window={size=3x3 pad=1_1x1_1}, dim_labels=b01f_o01i->b01f,
custom_call_target="__cudnn$convBiasActivationForward",
metadata={op_type="Conv2D" op_name="functional_1_1/conv2d_3_1/convolution"
source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-
packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={
"operation_queue_id":"0","wait_on_operation_queues":[],"cudnn_conv_backend_conf
ig":{"activation_mode":"kRelu","conv_result_scale":1,"side_input_scale":0,"leaky
relu_alpha":0},"force_earliest_schedule":false,"reification_cost":[]}} is taking a
while...
2025-12-15 21:34:27.029827: E
external/local_xla/xla/service/slow_operation_alarm.cc:140] The operation took
1.231563801s
Trying algorithm eng0{} for conv %cudnn-conv-bias-activation.42 =
(f32[64,128,128,64]{3,2,1,0}, u8[0]{0}) custom-call(%get-tuple-element.34,
%bitcast.481, %arg9.10), window={size=3x3 pad=1_1x1_1},
dim_labels=b01f_o01i->b01f,
custom_call_target="__cudnn$convBiasActivationForward",
metadata={op_type="Conv2D" op_name="functional_1_1/conv2d_3_1/convolution"
source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-
packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={
"operation_queue_id":"0","wait_on_operation_queues":[],"cudnn_conv_backend_conf
ig":{"activation_mode":"kRelu","conv_result_scale":1,"side_input_scale":0,"leaky
relu_alpha":0},"force_earliest_schedule":false,"reification_cost":[]}} is taking a
while...

1451/1452          0s 164ms/step -
accuracy: 0.2353 - loss: 3.2243

2025-12-15 21:38:34.513058: W
external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
configs were filtered out because none of them sufficiently match the hints.
Maybe the hints set does not contain a good representative set of valid
configs?Working around this by using the full hints set instead.
2025-12-15 21:38:34.513148: W
external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
configs were filtered out because none of them sufficiently match the hints.

```

Maybe the hints set does not contain a good representative set of valid configs? Working around this by using the full hints set instead.

```

2025-12-15 21:38:34.905802: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1430', 252 bytes spill stores, 256 bytes spill loads

2025-12-15 21:38:35.015468: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_2213', 32 bytes spill stores, 32 bytes spill loads

2025-12-15 21:38:35.072861: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_2213', 156 bytes spill stores, 156 bytes spill loads

2025-12-15 21:38:35.191912: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1481', 920 bytes spill stores, 908 bytes spill loads

2025-12-15 21:38:35.228796: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1430', 4948 bytes spill stores, 4848 bytes spill loads

2025-12-15 21:38:35.259140: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_2463', 184 bytes spill stores, 184 bytes spill loads

2025-12-15 21:38:35.364989: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_2213', 72 bytes spill stores, 64 bytes spill loads

2025-12-15 21:38:35.561420: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_2482', 188 bytes spill stores, 188 bytes spill loads

2025-12-15 21:38:35.663639: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_2322', 60 bytes spill stores, 60 bytes spill loads

2025-12-15 21:38:35.688308: I

```

```
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_2213', 48 bytes spill stores, 48 bytes spill loads
```

```
2025-12-15 21:38:35.844369: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_2482', 12 bytes spill stores, 12 bytes spill loads
```

```
2025-12-15 21:38:35.973963: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_2482', 5508 bytes spill stores, 4380 bytes spill loads
```

```
2025-12-15 21:38:36.090669: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_2463', 352 bytes spill stores, 364 bytes spill loads
```

```
2025-12-15 21:38:36.174327: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_2322', 96 bytes spill stores, 96 bytes spill loads
```

```
2025-12-15 21:38:36.326150: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_2322', 192 bytes spill stores, 192 bytes spill loads
```

```
2025-12-15 21:38:36.326483: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_2213', 740 bytes spill stores, 876 bytes spill loads
```

```
2025-12-15 21:38:38.466250: E
external/local_xla/xla/service/slow_operation_alarm.cc:73] Trying algorithm
eng0{} for conv %cudnn-conv-bias-activation.40 = (f32[54,256,256,32]{3,2,1,0},
u8[0]{0}) custom-call(%get-tuple-element.32, %bitcast.477, %arg5.6),
window={size=3x3 pad=1_1x1_1}, dim_labels=b01f_o01i->b01f,
custom_call_target="__cudnn$convBiasActivationForward",
metadata={op_type="Conv2D" op_name="functional_1_1/conv2d_1_2/convolution"
source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-
packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={
"operation_queue_id": "0", "wait_on_operation_queues": [], "cudnn_conv_backend_conf
ig": {"activation_mode": "kRelu", "conv_result_scale": 1, "side_input_scale": 0, "leaky
relu_alpha": 0}, "force_earliest_schedule": false, "reification_cost": []} is taking a
while...
```

```
2025-12-15 21:38:38.539928: E
```

```

external/local_xla/xla/service/slow_operation_alarm.cc:140] The operation took
1.079482931s
Trying algorithm eng0{} for conv %cudnn-conv-bias-activation.40 =
(f32[54,256,256,32]{3,2,1,0}, u8[0]{0}) custom-call(%get-tuple-element.32,
%bitcast.477, %arg5.6), window={size=3x3 pad=1_1x1_1},
dim_labels=b01f_o01i->b01f,
custom_call_target="__cudnn$convBiasActivationForward",
metadata={op_type="Conv2D" op_name="functional_1_1/conv2d_1_2/convolution"
source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-
packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={
"operation_queue_id":"0","wait_on_operation_queues":[],"cudnn_conv_backend_conf
ig":{"activation_mode":"kRelu","conv_result_scale":1,"side_input_scale":0,"leaky
relu_alpha":0},"force_earliest_schedule":false,"reification_cost":[]}} is taking a
while...
2025-12-15 21:38:41.148964: E
external/local_xla/xla/service/slow_operation_alarm.cc:73] Trying algorithm
eng0{} for conv %cudnn-conv-bias-activation.42 = (f32[54,128,128,64]{3,2,1,0},
u8[0]{0}) custom-call(%get-tuple-element.34, %bitcast.481, %arg9.10),
window={size=3x3 pad=1_1x1_1}, dim_labels=b01f_o01i->b01f,
custom_call_target="__cudnn$convBiasActivationForward",
metadata={op_type="Conv2D" op_name="functional_1_1/conv2d_3_1/convolution"
source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-
packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={
"operation_queue_id":"0","wait_on_operation_queues":[],"cudnn_conv_backend_conf
ig":{"activation_mode":"kRelu","conv_result_scale":1,"side_input_scale":0,"leaky
relu_alpha":0},"force_earliest_schedule":false,"reification_cost":[]}} is taking a
while...
2025-12-15 21:38:41.190358: E
external/local_xla/xla/service/slow_operation_alarm.cc:140] The operation took
1.044815421s
Trying algorithm eng0{} for conv %cudnn-conv-bias-activation.42 =
(f32[54,128,128,64]{3,2,1,0}, u8[0]{0}) custom-call(%get-tuple-element.34,
%bitcast.481, %arg9.10), window={size=3x3 pad=1_1x1_1},
dim_labels=b01f_o01i->b01f,
custom_call_target="__cudnn$convBiasActivationForward",
metadata={op_type="Conv2D" op_name="functional_1_1/conv2d_3_1/convolution"
source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-
packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={
"operation_queue_id":"0","wait_on_operation_queues":[],"cudnn_conv_backend_conf
ig":{"activation_mode":"kRelu","conv_result_scale":1,"side_input_scale":0,"leaky
relu_alpha":0},"force_earliest_schedule":false,"reification_cost":[]}} is taking a
while...

1452/1452          0s 174ms/step -
accuracy: 0.2354 - loss: 3.2238

2025-12-15 21:38:49.804849: W
external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
configs were filtered out because none of them sufficiently match the hints.

```


Maybe the hints set does not contain a good representative set of valid configs? Working around this by using the full hints set instead.

```

2025-12-15 21:38:50.164316: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_238', 36 bytes spill stores, 36 bytes spill loads

2025-12-15 21:38:50.208484: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_217', 172 bytes spill stores, 172 bytes spill loads

2025-12-15 21:38:50.273593: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_238', 80 bytes spill stores, 80 bytes spill loads

2025-12-15 21:38:50.292428: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_217', 1032 bytes spill stores, 1008 bytes spill loads

2025-12-15 21:38:50.327923: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_238', 4 bytes spill stores, 4 bytes spill loads

2025-12-15 21:38:50.406322: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_238', 4 bytes spill stores, 4 bytes spill loads

2025-12-15 21:38:50.534305: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_238', 320 bytes spill stores, 324 bytes spill loads

2025-12-15 21:38:50.585908: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_238', 20 bytes spill stores, 20 bytes spill loads

2025-12-15 21:38:50.608673: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_224', 4180 bytes spill stores, 4188 bytes spill loads

2025-12-15 21:38:50.628188: I

```

external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_238', 4 bytes spill stores, 4 bytes spill loads

2025-12-15 21:38:50.724741: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_238', 52 bytes spill stores, 52 bytes spill loads

2025-12-15 21:38:50.809867: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_238', 80 bytes spill stores, 80 bytes spill loads

2025-12-15 21:38:50.865354: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_238', 1008 bytes spill stores, 1164 bytes spill loads

2025-12-15 21:39:22.051239: W
external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
configs were filtered out because none of them sufficiently match the hints.
Maybe the hints set does not contain a good representative set of valid
configs?Working around this by using the full hints set instead.

2025-12-15 21:39:22.447024: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_217', 252 bytes spill stores, 256 bytes spill loads

2025-12-15 21:39:22.639908: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_238', 32 bytes spill stores, 32 bytes spill loads

2025-12-15 21:39:22.778389: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_217', 4948 bytes spill stores, 4848 bytes spill loads

2025-12-15 21:39:22.936551: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_224', 5840 bytes spill stores, 5840 bytes spill loads

2025-12-15 21:39:23.003105: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_238', 416 bytes spill stores, 416 bytes spill loads

```

2025-12-15 21:39:23.003320: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_238', 124 bytes spill stores, 124 bytes spill loads

2025-12-15 21:39:23.004327: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_238', 296 bytes spill stores, 296 bytes spill loads

2025-12-15 21:39:23.005418: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_238', 924 bytes spill stores, 1032 bytes spill loads

2025-12-15 21:39:23.022848: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_238', 44 bytes spill stores, 44 bytes spill loads

2025-12-15 21:39:23.145971: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_238', 168 bytes spill stores, 168 bytes spill loads

2025-12-15 21:39:25.378539: E
external/local_xla/xla/service/slow_operation_alarm.cc:73] Trying algorithm
eng0{} for conv %cudnn-conv-bias-activation.40 = (f32[61,256,256,32]{3,2,1,0},
u8[0]{0}) custom-call(%get-tuple-element.13, %bitcast.95, %arg5.6),
window={size=3x3 pad=1_1x1_1}, dim_labels=b01f_o01i->b01f,
custom_call_target="__cudnn$convBiasActivationForward",
metadata={op_type="Conv2D" op_name="functional_1_1/conv2d_1_2/convolution"
source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-
packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={
"operation_queue_id": "0", "wait_on_operation_queues": [], "cudnn_conv_backend_conf
ig": {"activation_mode": "kRelu", "conv_result_scale": 1, "side_input_scale": 0, "leaky
relu_alpha": 0}, "force_earliest_schedule": false, "reification_cost": []} is taking a
while...
2025-12-15 21:39:25.599889: E
external/local_xla/xla/service/slow_operation_alarm.cc:140] The operation took
1.222293133s
Trying algorithm eng0{} for conv %cudnn-conv-bias-activation.40 =
(f32[61,256,256,32]{3,2,1,0}, u8[0]{0}) custom-call(%get-tuple-element.13,
%bitcast.95, %arg5.6), window={size=3x3 pad=1_1x1_1},
dim_labels=b01f_o01i->b01f,
custom_call_target="__cudnn$convBiasActivationForward",
metadata={op_type="Conv2D" op_name="functional_1_1/conv2d_1_2/convolution"

```

```
source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-  
packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={  
"operation_queue_id":"0","wait_on_operation_queues":[],"cudnn_conv_backend_conf  
g":{"activation_mode":"kRelu","conv_result_scale":1,"side_input_scale":0,"leaky  
relu_alpha":0},"force_earliest_schedule":false,"reification_cost":[]}} is taking a  
while...
```

2025-12-15 21:39:28.395853: E

```
external/local_xla/xla/service/slow_operation_alarm.cc:73] Trying algorithm  
eng0{} for conv %cudnn-conv-bias-activation.42 = (f32[61,128,128,64]{3,2,1,0},  
u8[0]{0}) custom-call(%get-tuple-element.15, %bitcast.99, %arg9.10),  
window={size=3x3 pad=1_1x1_1}, dim_labels=b01f_o01i->b01f,  
custom_call_target="__cudnn$convBiasActivationForward",  
metadata={op_type="Conv2D" op_name="functional_1_1/conv2d_3_1/convolution"  
source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-  
packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={  
"operation_queue_id":"0","wait_on_operation_queues":[],"cudnn_conv_backend_conf  
g":{"activation_mode":"kRelu","conv_result_scale":1,"side_input_scale":0,"leaky  
relu_alpha":0},"force_earliest_schedule":false,"reification_cost":[]}} is taking a  
while...
```

2025-12-15 21:39:28.566910: E

```
external/local_xla/xla/service/slow_operation_alarm.cc:140] The operation took  
1.171149965s
```

```
Trying algorithm eng0{} for conv %cudnn-conv-bias-activation.42 =  
(f32[61,128,128,64]{3,2,1,0}, u8[0]{0}) custom-call(%get-tuple-element.15,  
%bitcast.99, %arg9.10), window={size=3x3 pad=1_1x1_1},  
dim_labels=b01f_o01i->b01f,  
custom_call_target="__cudnn$convBiasActivationForward",  
metadata={op_type="Conv2D" op_name="functional_1_1/conv2d_3_1/convolution"  
source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-  
packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={  
"operation_queue_id":"0","wait_on_operation_queues":[],"cudnn_conv_backend_conf  
g":{"activation_mode":"kRelu","conv_result_scale":1,"side_input_scale":0,"leaky  
relu_alpha":0},"force_earliest_schedule":false,"reification_cost":[]}} is taking a  
while...
```

1452/1452 316s 205ms/step

- accuracy: 0.3686 - loss: 2.5087 - val_accuracy: 0.5681 - val_loss: 1.5318

Epoch 2/50

1452/1452 267s 184ms/step

- accuracy: 0.5760 - loss: 1.4609 - val_accuracy: 0.6701 - val_loss: 1.0834

Epoch 3/50

1452/1452 267s 184ms/step

- accuracy: 0.6425 - loss: 1.1911 - val_accuracy: 0.6940 - val_loss: 0.9855

Epoch 4/50

1452/1452 267s 184ms/step

- accuracy: 0.6835 - loss: 1.0264 - val_accuracy: 0.7507 - val_loss: 0.7892

Epoch 5/50

1452/1452 268s 184ms/step

```

- accuracy: 0.7123 - loss: 0.9150 - val_accuracy: 0.7653 - val_loss: 0.7346
Epoch 6/50
1452/1452          267s 184ms/step
- accuracy: 0.7350 - loss: 0.8319 - val_accuracy: 0.7773 - val_loss: 0.6859
Epoch 7/50
1452/1452          267s 184ms/step
- accuracy: 0.7507 - loss: 0.7720 - val_accuracy: 0.7892 - val_loss: 0.6390
Epoch 8/50
1452/1452          267s 184ms/step
- accuracy: 0.7641 - loss: 0.7224 - val_accuracy: 0.7966 - val_loss: 0.6236
Epoch 9/50
1452/1452          267s 184ms/step
- accuracy: 0.7742 - loss: 0.6879 - val_accuracy: 0.8085 - val_loss: 0.5799
Epoch 10/50
1452/1452          267s 184ms/step
- accuracy: 0.7827 - loss: 0.6563 - val_accuracy: 0.8025 - val_loss: 0.5928
Epoch 11/50
1452/1452          268s 184ms/step
- accuracy: 0.7907 - loss: 0.6338 - val_accuracy: 0.8136 - val_loss: 0.5666
Epoch 12/50
1452/1452          267s 184ms/step
- accuracy: 0.7973 - loss: 0.6063 - val_accuracy: 0.8211 - val_loss: 0.5367
Epoch 13/50
1452/1452          268s 184ms/step
- accuracy: 0.8035 - loss: 0.5877 - val_accuracy: 0.8294 - val_loss: 0.5143
Epoch 14/50
1452/1452          267s 184ms/step
- accuracy: 0.8095 - loss: 0.5714 - val_accuracy: 0.8260 - val_loss: 0.5177
Epoch 15/50
1452/1452          267s 184ms/step
- accuracy: 0.8146 - loss: 0.5506 - val_accuracy: 0.8246 - val_loss: 0.5309
Epoch 16/50
1452/1452          267s 184ms/step
- accuracy: 0.8182 - loss: 0.5344 - val_accuracy: 0.8287 - val_loss: 0.5244
Execution Time: 72.15 Minutes

```

```

[15]: #predicting and storing values in y and y_hat
y = []
y_hat = []
for images, label in data_ts:
    pred = model.predict(images, verbose=0)
    y.extend(label.numpy())
    y_hat.extend(np.argmax(pred, axis=1))

```

```

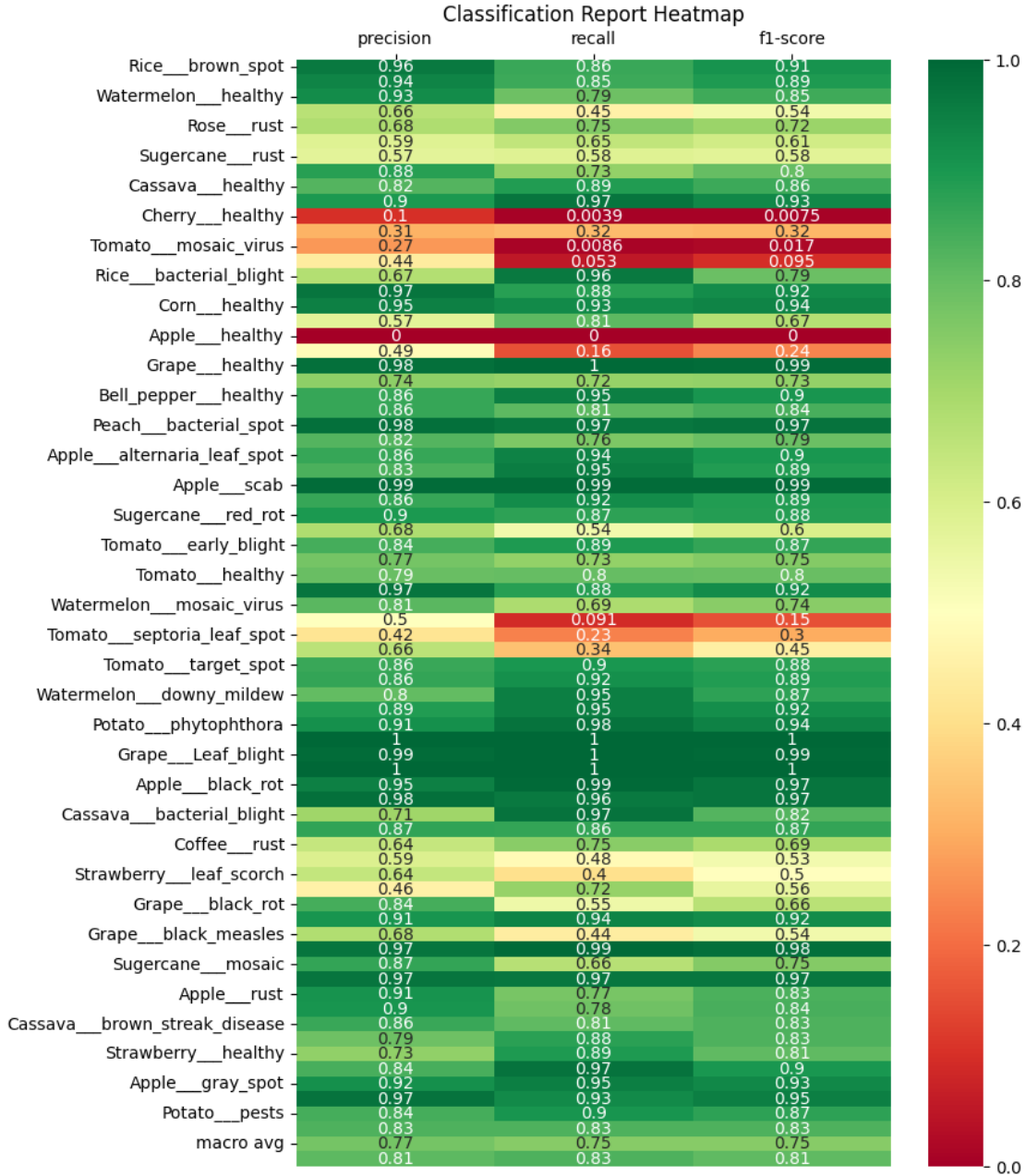
2025-12-15 22:48:43.004530: I tensorflow/core/framework/local_rendezvous.cc:407]
Local rendezvous is aborting with status: OUT_OF_RANGE: End of sequence

```

```
[17]: #generate and display Classification Report
class_report = classification_report(y, y_hat, target_names=classes,
    ↪output_dict=True)

plt.figure(figsize=(8, 12))
sns.heatmap(pd.DataFrame(class_report).iloc[: -1, :].T, annot=True,
    ↪cmap="RdYlGn")
plt.title("Mock VGG-16 Classification Report")
plt.gca().xaxis.set_label_position('top')
plt.gca().xaxis.tick_top()
plt.show()
```

```
/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-
packages/sklearn/metrics/_classification.py:1731: UndefinedMetricWarning:
Precision is ill-defined and being set to 0.0 in labels with no predicted
samples. Use `zero_division` parameter to control this behavior.
    _warn_prf(average, modifier, f"{metric.capitalize()} is", result.shape[0])
/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-
packages/sklearn/metrics/_classification.py:1731: UndefinedMetricWarning:
Precision is ill-defined and being set to 0.0 in labels with no predicted
samples. Use `zero_division` parameter to control this behavior.
    _warn_prf(average, modifier, f"{metric.capitalize()} is", result.shape[0])
/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-
packages/sklearn/metrics/_classification.py:1731: UndefinedMetricWarning:
Precision is ill-defined and being set to 0.0 in labels with no predicted
samples. Use `zero_division` parameter to control this behavior.
    _warn_prf(average, modifier, f"{metric.capitalize()} is", result.shape[0])
```



1.6 4. Testing different CNN Layers

I iteratively tested using different layers within the CNN, including changing the number of convolutional and FC layers and which layers to freeze, before I landed upon the CNN below as being the best balance between performance and efficiency. I found that there were too many convolutional layers in the VGG-16 model for the amount of data that I had. I also reduced the number of filters for each convolutional stack and traded layers.flatten for layers.GlobalAveragePooling2D to reduce dimensionality even more.

```

[8]: def custom_cnn(input_shape, nclasses):

    inputs = keras.Input(shape=input_shape)

    #Rescale pixels to [-1,1]
    x = layers.Rescaling(1./127.5, offset=-1.0)(inputs)

    #Stack 1 - convolution round 1, maxpooling
    x = layers.Conv2D(32, (3,3), padding="same", activation="relu")(x)
    x = layers.Conv2D(32, (3,3), padding="same", activation="relu")(x)
    x = layers.MaxPooling2D((2,2))(x)

    #Stack 2 - convolution round 2, maxpooling
    x = layers.Conv2D(64, (3,3), padding="same", activation="relu")(x)
    x = layers.Conv2D(64, (3,3), padding="same", activation="relu")(x)
    x = layers.MaxPooling2D((2,2))(x)

    #Stack 3 - Convolution round 3, maxpooling
    x = layers.Conv2D(128, (3,3), padding="same", activation="relu")(x)
    x = layers.Conv2D(128, (3,3), padding="same", activation="relu")(x)
    x = layers.Conv2D(128, (3,3), padding="same", activation="relu")(x)
    x = layers.MaxPooling2D((2,2))(x)

    #reduces dimensionality
    x = layers.GlobalAveragePooling2D()(x)

    #drop 50% neurons to prevent overfitting before sending to FC layer
    x = layers.Dropout(0.5)(x)
    x = layers.Dense(128, activation="relu")(x) #the only FC layer outside of
    ↪ the output layer
    x = layers.Dropout(0.5)(x) #drop 50% neurons to prevent overfitting before
    ↪ sending to output layer

    #output layer - softmax function
    outputs = layers.Dense(nclasses, activation="softmax")(x)

    model = keras.Model(inputs=inputs, outputs=outputs)

    return model

#initialize input shape
input_shape = (256,256,3)
nclasses = 71

#create model object
cust_model = custom_cnn(input_shape, nclasses)

```



```
#compile model
cust_model.compile(
    optimizer=keras.optimizers.Adam(learning_rate=1e-3),
    loss="sparse_categorical_crossentropy",
    metrics=["accuracy"])

#print model summary
cust_model.summary()
```

Model: "functional"

Layer (type)	Output Shape	Param #
input_layer (InputLayer)	(None, 256, 256, 3)	0
rescaling (Rescaling)	(None, 256, 256, 3)	0
conv2d (Conv2D)	(None, 256, 256, 32)	896
conv2d_1 (Conv2D)	(None, 256, 256, 32)	9,248
max_pooling2d (MaxPooling2D)	(None, 128, 128, 32)	0
conv2d_2 (Conv2D)	(None, 128, 128, 64)	18,496
conv2d_3 (Conv2D)	(None, 128, 128, 64)	36,928
max_pooling2d_1 (MaxPooling2D)	(None, 64, 64, 64)	0
conv2d_4 (Conv2D)	(None, 64, 64, 128)	73,856
conv2d_5 (Conv2D)	(None, 64, 64, 128)	147,584
conv2d_6 (Conv2D)	(None, 64, 64, 128)	147,584
max_pooling2d_2 (MaxPooling2D)	(None, 32, 32, 128)	0
global_average_pooling2d (GlobalAveragePooling2D)	(None, 128)	0
dropout (Dropout)	(None, 128)	0
dense (Dense)	(None, 128)	16,512
dropout_1 (Dropout)	(None, 128)	0

dense_1 (Dense)

(None, 71)

9,159

Total params: 460,263 (1.76 MB)

Trainable params: 460,263 (1.76 MB)

Non-trainable params: 0 (0.00 B)

```
[ ]: #Early Stopping for efficiency
cust_callbacks = [
    keras.callbacks.EarlyStopping(
        monitor = "val_loss",
        patience = 3,
        mode='min',
        restore_best_weights=True)]

#start time
start = time.perf_counter()

#fit model and store epoch history
cust_history = cust_model.fit(
    data_tr,
    validation_data = data_ts,
    epochs=50,
    callbacks=cust_callbacks)

#end time
end = time.perf_counter()

print(f'Execution Time: {round(((end-start)/60),2)} Minutes')
```

Epoch 1/50

1452/1452 240s 165ms/step

- accuracy: 0.4776 - loss: 1.8073 - val_accuracy: 0.6107 - val_loss: 1.3519

Epoch 2/50

1452/1452 240s 165ms/step

- accuracy: 0.5532 - loss: 1.5094 - val_accuracy: 0.6771 - val_loss: 1.0989

Epoch 3/50

1452/1452 240s 165ms/step

- accuracy: 0.6086 - loss: 1.2950 - val_accuracy: 0.7187 - val_loss: 0.9309

Epoch 4/50

1452/1452 240s 165ms/step

- accuracy: 0.6576 - loss: 1.1186 - val_accuracy: 0.7554 - val_loss: 0.7883

Epoch 5/50

1452/1452 239s 165ms/step

- accuracy: 0.6920 - loss: 0.9932 - val_accuracy: 0.7909 - val_loss: 0.6756
Epoch 6/50
1452/1452 240s 165ms/step
- accuracy: 0.7151 - loss: 0.9094 - val_accuracy: 0.8129 - val_loss: 0.5800
Epoch 7/50
1452/1452 240s 165ms/step
- accuracy: 0.7344 - loss: 0.8395 - val_accuracy: 0.8192 - val_loss: 0.5583
Epoch 8/50
1452/1452 240s 165ms/step
- accuracy: 0.7516 - loss: 0.7785 - val_accuracy: 0.8300 - val_loss: 0.5261
Epoch 9/50
1452/1452 240s 165ms/step
- accuracy: 0.7632 - loss: 0.7395 - val_accuracy: 0.8421 - val_loss: 0.4892
Epoch 10/50
1452/1452 240s 165ms/step
- accuracy: 0.7741 - loss: 0.6970 - val_accuracy: 0.8393 - val_loss: 0.4777
Epoch 11/50
1452/1452 240s 165ms/step
- accuracy: 0.7852 - loss: 0.6633 - val_accuracy: 0.8514 - val_loss: 0.4447
Epoch 12/50
1452/1452 240s 166ms/step
- accuracy: 0.7933 - loss: 0.6368 - val_accuracy: 0.8538 - val_loss: 0.4366
Epoch 13/50
1452/1452 240s 165ms/step
- accuracy: 0.8036 - loss: 0.6022 - val_accuracy: 0.8596 - val_loss: 0.4223
Epoch 14/50
1452/1452 240s 165ms/step
- accuracy: 0.8108 - loss: 0.5810 - val_accuracy: 0.8692 - val_loss: 0.3942
Epoch 15/50
1452/1452 240s 165ms/step
- accuracy: 0.8153 - loss: 0.5629 - val_accuracy: 0.8725 - val_loss: 0.3752
Epoch 16/50
1452/1452 239s 165ms/step
- accuracy: 0.8218 - loss: 0.5375 - val_accuracy: 0.8741 - val_loss: 0.3801
Epoch 17/50
1452/1452 240s 165ms/step
- accuracy: 0.8274 - loss: 0.5272 - val_accuracy: 0.8769 - val_loss: 0.3761
Epoch 18/50
1452/1452 240s 165ms/step
- accuracy: 0.8323 - loss: 0.5055 - val_accuracy: 0.8796 - val_loss: 0.3572
Epoch 19/50
1452/1452 240s 165ms/step
- accuracy: 0.8364 - loss: 0.4955 - val_accuracy: 0.8825 - val_loss: 0.3382
Epoch 20/50
1163/1452 45s 156ms/step
- accuracy: 0.8373 - loss: 0.4886

1.6.1 Browser Crash above ~~~

The browser crashed as it was running, but this model was having the best run I have seen yet. Unfortunately, when the browser crashed I lost all of the y-values and predictions as well. So, I cannot see what the precision/recall was like on this run. I will not run it again because I am assuming it will crash again due to insufficient memory.

```
[ ]: #predicting and storing values in y and y_hat
y_custom = []
yhat_custom = []
for images, label in data_ts:
    pred = model.predict(images, verbose=1)
    y_custom.extend(label.numpy())
    yhat_custom.extend(np.argmax(pred, axis=1))

#generate and display Classification Report
cust_class_report = classification_report(y_custom, yhat_custom,
    ↪target_names=classes, output_dict=True)

plt.figure(figsize=(8, 12))
sns.heatmap(pd.DataFrame(cust_class_report).iloc[: -1, :].T, annot=True,
    ↪cmap="RdYlGn")
plt.title("Custom CNN Classification Report")
plt.gca().xaxis.set_label_position('top')
plt.gca().xaxis.tick_top()
plt.show()
```

1.7 5. Reducing Data to only 21 Classes and ~56,000 samples

I decided to reduce the data to only 21 classes for three reasons: 1. It reduces the runtime of the model, so I could test more hyperparameters. 2. It improve the model performance by not needing to focus on underrepresented classes. 3. Fewer classes made it a little easier to investigate other ways in which performance was being impacted.

The small dataset only uses classes from the following plants: Cassava, Tomato, Potato, Rice, and Soybean. I chose these classes primarily for their class count, but also for their agricultural relevance. I used the custom_cnn for this dataset since it has a good balance between performance and efficiency.

```
[6]: #list of plants used in small dataset
small_lst = ["Cassava", "Tomato", "Potato", "Rice", "Soybean"]

#creates the dataframe that summarizes the small dataset
df_small = df_class[df_class['plant'].isin(small_lst)]

#reduces the classes to only those that have over 1,000 samples
df_small = df_small[df_small['count'] >= 1000]

print(f"small nclasses: {len(df_small)}, nsamples= {df_small['count'].sum()}")
```

```
print(df_small.sort_values(by='count', ascending=False))
print(df_small['class'].tolist())
```

```
small nclasses: 21, nsamples= 56244.0
```

	class	y	plant	health	count
45	Cassava__mosaic_disease	45	Cassava	unhealthy	13158.0
57	Tomato__leaf_curl	57	Tomato	unhealthy	5357.0
49	Soybean__healthy	49	Soybean	healthy	5090.0
17	Potato__early_blight	17	Potato	unhealthy	2628.0
8	Cassava__healthy	8	Cassava	healthy	2577.0
25	Cassava__green_mottle	25	Cassava	unhealthy	2386.0
35	Potato__healthy	35	Potato	healthy	2275.0
64	Cassava__brown_streak_disease	64	Cassava	unhealthy	2189.0
3	Tomato__bacterial_spot	3	Tomato	unhealthy	2127.0
47	Potato__late_blight	47	Potato	unhealthy	2087.0
55	Tomato__late_blight	55	Tomato	unhealthy	1909.0
38	Tomato__septoria_leaf_spot	38	Tomato	unhealthy	1771.0
11	Tomato__spider_mites	11	Tomato	unhealthy	1676.0
0	Rice__brown_spot	0	Rice	unhealthy	1600.0
34	Tomato__healthy	34	Tomato	healthy	1591.0
14	Rice__bacterial_blight	14	Rice	unhealthy	1584.0
37	Rice__blast	37	Rice	unhealthy	1440.0
40	Tomato__target_spot	40	Tomato	unhealthy	1404.0
9	Rice__tungro	9	Rice	unhealthy	1308.0
50	Cassava__bacterial_blight	50	Cassava	unhealthy	1087.0
32	Tomato__early_blight	32	Tomato	unhealthy	1000.0

```
['Rice__brown_spot', 'Tomato__bacterial_spot', 'Cassava__healthy',
'Rice__tungro', 'Tomato__spider_mites', 'Rice__bacterial_blight',
'Potato__early_blight', 'Cassava__green_mottle', 'Tomato__early_blight',
'Tomato__healthy', 'Potato__healthy', 'Rice__blast',
'Tomato__septoria_leaf_spot', 'Tomato__target_spot',
'Cassava__mosaic_disease', 'Potato__late_blight', 'Soybean__healthy',
'Cassava__bacterial_blight', 'Tomato__late_blight', 'Tomato__leaf_curl',
'Cassava__brown_streak_disease']
```

```
[11]: small_dir = "/home/ryan/plants_small"
```

```
#initialize the train and test sets for the small dataset
small_tr, small_ts = tf.keras.preprocessing.image_dataset_from_directory(
    small_dir,
    labels='inferred',
    label_mode = 'int',
    batch_size=64,
    image_size=(256,256),
    shuffle=True,
    seed = 42,
    validation_split=0.2,
```

```

subset='both',
interpolation='lanczos3',
crop_to_aspect_ratio=True,
verbose=True)

#initialize input shape
input_shape = (256,256,3)
small_nclasses = len(df_small)
small_classes = small_tr.class_names

#create model object
small_model = custom_cnn(input_shape, small_nclasses)

#compile model
small_model.compile(
    optimizer=keras.optimizers.Adam(learning_rate=1e-3),
    loss="sparse_categorical_crossentropy",
    metrics=["accuracy"])

#Early Stopping for efficiency
callbacks = [
    keras.callbacks.EarlyStopping(
        monitor = "val_loss",
        patience = 3,
        mode='min',
        restore_best_weights=True)]

#fit model and store epoch history
history = small_model.fit(
    small_tr,
    validation_data = small_ts,
    epochs=50,
    callbacks=callbacks)

```

Found 56244 files belonging to 21 classes.

Using 44996 files for training.

Using 11248 files for validation.

Epoch 1/50

703/704 0s 156ms/step -

accuracy: 0.3539 - loss: 2.2176

2025-12-16 00:38:04.037037: W

external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
 configs were filtered out because none of them sufficiently match the hints.
 Maybe the hints set does not contain a good representative set of valid
 configs?Working around this by using the full hints set instead.

2025-12-16 00:38:04.037138: W

external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All

configs were filtered out because none of them sufficiently match the hints.
 Maybe the hints set does not contain a good representative set of valid
 configs?Working around this by using the full hints set instead.

2025-12-16 00:38:04.037150: W
 external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
 configs were filtered out because none of them sufficiently match the hints.
 Maybe the hints set does not contain a good representative set of valid
 configs?Working around this by using the full hints set instead.

2025-12-16 00:38:04.037155: W
 external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
 configs were filtered out because none of them sufficiently match the hints.
 Maybe the hints set does not contain a good representative set of valid
 configs?Working around this by using the full hints set instead.

2025-12-16 00:38:04.037160: W
 external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
 configs were filtered out because none of them sufficiently match the hints.
 Maybe the hints set does not contain a good representative set of valid
 configs?Working around this by using the full hints set instead.

2025-12-16 00:38:04.037164: W
 external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
 configs were filtered out because none of them sufficiently match the hints.
 Maybe the hints set does not contain a good representative set of valid
 configs?Working around this by using the full hints set instead.

2025-12-16 00:38:04.909313: I
 external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
 warning : Registers are spilled to local memory in function
 'gemm_fusion_dot_1299', 664 bytes spill stores, 808 bytes spill loads

2025-12-16 00:38:04.912820: I
 external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
 warning : Registers are spilled to local memory in function
 'gemm_fusion_dot_947', 16 bytes spill stores, 16 bytes spill loads

2025-12-16 00:38:05.107840: I
 external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
 warning : Registers are spilled to local memory in function
 'gemm_fusion_dot_947', 24 bytes spill stores, 24 bytes spill loads

2025-12-16 00:38:05.276011: I
 external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
 warning : Registers are spilled to local memory in function
 'gemm_fusion_dot_1530', 8 bytes spill stores, 8 bytes spill loads

2025-12-16 00:38:05.285876: I
 external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
 warning : Registers are spilled to local memory in function
 'gemm_fusion_dot_1408', 104 bytes spill stores, 104 bytes spill loads

2025-12-16 00:38:05.701842: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1408', 112 bytes spill stores, 112 bytes spill loads

2025-12-16 00:38:06.224837: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1299', 136 bytes spill stores, 248 bytes spill loads

2025-12-16 00:38:06.324178: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1408', 120 bytes spill stores, 120 bytes spill loads

2025-12-16 00:38:06.409026: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1530', 20 bytes spill stores, 20 bytes spill loads

2025-12-16 00:38:06.763603: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1749', 168 bytes spill stores, 168 bytes spill loads

2025-12-16 00:38:06.909739: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1530', 128 bytes spill stores, 128 bytes spill loads

2025-12-16 00:38:07.164468: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1530', 56 bytes spill stores, 56 bytes spill loads

2025-12-16 00:38:07.221911: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1749', 108 bytes spill stores, 108 bytes spill loads

2025-12-16 00:38:07.766216: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1497', 736 bytes spill stores, 1032 bytes spill loads

704/704 0s 167ms/step -
accuracy: 0.3540 - loss: 2.2170


```

2025-12-16 00:38:12.090812: W
external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
configs were filtered out because none of them sufficiently match the hints.
Maybe the hints set does not contain a good representative set of valid
configs?Working around this by using the full hints set instead.
2025-12-16 00:38:12.090858: W
external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
configs were filtered out because none of them sufficiently match the hints.
Maybe the hints set does not contain a good representative set of valid
configs?Working around this by using the full hints set instead.
2025-12-16 00:38:12.595038: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_154', 4 bytes spill stores, 4 bytes spill loads

2025-12-16 00:38:12.774282: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_154', 4 bytes spill stores, 4 bytes spill loads

2025-12-16 00:38:12.896221: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_154', 128 bytes spill stores, 156 bytes spill loads

2025-12-16 00:38:13.071386: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_154', 1008 bytes spill stores, 1164 bytes spill loads

2025-12-16 00:38:13.160239: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_154', 52 bytes spill stores, 52 bytes spill loads

2025-12-16 00:38:13.213419: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_154', 72 bytes spill stores, 72 bytes spill loads

2025-12-16 00:38:15.427983: E
external/local_xla/xla/service/slow_operation_alarm.cc:73] Trying algorithm
eng0{} for conv %cudnn-conv-bias-activation.22 = (f32[64,256,256,32]{3,2,1,0},
u8[0]{0}) custom-call(%get-tuple-element.7, %bitcast.52, %arg5.6),
window={size=3x3 pad=1_1x1_1}, dim_labels=b01f_o01i->b01f,
custom_call_target="__cudnn$convBiasActivationForward",
metadata={op_type="Conv2D" op_name="functional_3_1/conv2d_22_1/convolution"
source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-

```

packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={"operation_queue_id": "0", "wait_on_operation_queues": [], "cudnn_conv_backend_config": {"activation_mode": "kRelu", "conv_result_scale": 1, "side_input_scale": 0, "leakyrelu_alpha": 0}, "force_earliest_schedule": false, "reification_cost": []} is taking a while...

2025-12-16 00:38:15.689570: E

external/local_xla/xla/service/slow_operation_alarm.cc:140] The operation took 1.261644252s

Trying algorithm eng0{} for conv %cudnn-conv-bias-activation.22 = (f32[64,256,256,32]{3,2,1,0}, u8[0]{0}) custom-call(%get-tuple-element.7, %bitcast.52, %arg5.6), window={size=3x3 pad=1_1x1_1}, dim_labels=b01f_o01i->b01f, custom_call_target="__cudnn\$convBiasActivationForward", metadata={op_type="Conv2D" op_name="functional_3_1/conv2d_22_1/convolution" source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={"operation_queue_id": "0", "wait_on_operation_queues": [], "cudnn_conv_backend_config": {"activation_mode": "kRelu", "conv_result_scale": 1, "side_input_scale": 0, "leakyrelu_alpha": 0}, "force_earliest_schedule": false, "reification_cost": []} is taking a while...

2025-12-16 00:38:17.021252: W

external/local_xla/xla/tsl/framework/bfc_allocator.cc:310] Allocator (GPU_0_bfc) ran out of memory trying to allocate 4.55GiB 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.

2025-12-16 00:38:18.356814: E

external/local_xla/xla/service/slow_operation_alarm.cc:73] Trying algorithm eng0{} for conv %cudnn-conv-bias-activation.24 = (f32[64,128,128,64]{3,2,1,0}, u8[0]{0}) custom-call(%get-tuple-element.9, %bitcast.56, %arg9.10), window={size=3x3 pad=1_1x1_1}, dim_labels=b01f_o01i->b01f, custom_call_target="__cudnn\$convBiasActivationForward", metadata={op_type="Conv2D" op_name="functional_3_1/conv2d_24_1/convolution" source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={"operation_queue_id": "0", "wait_on_operation_queues": [], "cudnn_conv_backend_config": {"activation_mode": "kRelu", "conv_result_scale": 1, "side_input_scale": 0, "leakyrelu_alpha": 0}, "force_earliest_schedule": false, "reification_cost": []} is taking a while...

2025-12-16 00:38:18.596648: E

external/local_xla/xla/service/slow_operation_alarm.cc:140] The operation took 1.240498781s

Trying algorithm eng0{} for conv %cudnn-conv-bias-activation.24 = (f32[64,128,128,64]{3,2,1,0}, u8[0]{0}) custom-call(%get-tuple-element.9, %bitcast.56, %arg9.10), window={size=3x3 pad=1_1x1_1}, dim_labels=b01f_o01i->b01f, custom_call_target="__cudnn\$convBiasActivationForward", metadata={op_type="Conv2D" op_name="functional_3_1/conv2d_24_1/convolution" source_file="/home/ryan/anaconda3/envs/nightly_gpu/lib/python3.12/site-

packages/tensorflow/python/framework/ops.py" source_line=1221}, backend_config={"operation_queue_id": "0", "wait_on_operation_queues": [], "cudnn_conv_backend_config": {"activation_mode": "kRelu", "conv_result_scale": 1, "side_input_scale": 0, "leakyrelu_alpha": 0}, "force_earliest_schedule": false, "reification_cost": []} is taking a while...

2025-12-16 00:38:26.979462: W

external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All configs were filtered out because none of them sufficiently match the hints. Maybe the hints set does not contain a good representative set of valid configs?Working around this by using the full hints set instead.

2025-12-16 00:38:26.979511: W

external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All configs were filtered out because none of them sufficiently match the hints. Maybe the hints set does not contain a good representative set of valid configs?Working around this by using the full hints set instead.

2025-12-16 00:38:27.431307: I

external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_147', 4 bytes spill stores, 4 bytes spill loads

2025-12-16 00:38:27.444086: I

external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_147', 16 bytes spill stores, 16 bytes spill loads

2025-12-16 00:38:27.652406: I

external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_154', 56 bytes spill stores, 56 bytes spill loads

2025-12-16 00:38:27.974349: I

external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_147', 24 bytes spill stores, 24 bytes spill loads

2025-12-16 00:38:27.974459: I

external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_154', 12 bytes spill stores, 12 bytes spill loads

2025-12-16 00:38:28.058230: I

external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function 'gemm_fusion_dot_154', 92 bytes spill stores, 92 bytes spill loads

2025-12-16 00:38:28.120783: I

external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas warning : Registers are spilled to local memory in function

'gemm_fusion_dot_154', 128 bytes spill stores, 156 bytes spill loads

2025-12-16 00:38:28.132753: I

external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas

warning : Registers are spilled to local memory in function

'gemm_fusion_dot_154', 964 bytes spill stores, 1120 bytes spill loads

704/704 143s 199ms/step -

accuracy: 0.4345 - loss: 1.8439 - val_accuracy: 0.5384 - val_loss: 1.3316

Epoch 2/50

704/704 117s 166ms/step -

accuracy: 0.5533 - loss: 1.3157 - val_accuracy: 0.6034 - val_loss: 1.1330

Epoch 3/50

704/704 116s 165ms/step -

accuracy: 0.6124 - loss: 1.1264 - val_accuracy: 0.6749 - val_loss: 0.9602

Epoch 4/50

704/704 117s 165ms/step -

accuracy: 0.6526 - loss: 1.0123 - val_accuracy: 0.6987 - val_loss: 0.8490

Epoch 5/50

704/704 116s 165ms/step -

accuracy: 0.6871 - loss: 0.9054 - val_accuracy: 0.7438 - val_loss: 0.7239

Epoch 6/50

704/704 116s 165ms/step -

accuracy: 0.7108 - loss: 0.8322 - val_accuracy: 0.7475 - val_loss: 0.7243

Epoch 7/50

704/704 116s 165ms/step -

accuracy: 0.7308 - loss: 0.7677 - val_accuracy: 0.7877 - val_loss: 0.5940

Epoch 8/50

704/704 116s 165ms/step -

accuracy: 0.7510 - loss: 0.7108 - val_accuracy: 0.7758 - val_loss: 0.6497

Epoch 9/50

704/704 116s 165ms/step -

accuracy: 0.7619 - loss: 0.6783 - val_accuracy: 0.8021 - val_loss: 0.5433

Epoch 10/50

704/704 116s 165ms/step -

accuracy: 0.7763 - loss: 0.6320 - val_accuracy: 0.8177 - val_loss: 0.5071

Epoch 11/50

704/704 116s 165ms/step -

accuracy: 0.7880 - loss: 0.6058 - val_accuracy: 0.8225 - val_loss: 0.5031

Epoch 12/50

704/704 116s 165ms/step -

accuracy: 0.8045 - loss: 0.5570 - val_accuracy: 0.8257 - val_loss: 0.4726

Epoch 13/50

704/704 116s 165ms/step -

accuracy: 0.8052 - loss: 0.5471 - val_accuracy: 0.8180 - val_loss: 0.4978

Epoch 14/50

704/704 116s 165ms/step -

```

accuracy: 0.8156 - loss: 0.5248 - val_accuracy: 0.8396 - val_loss: 0.4264
Epoch 15/50
704/704          116s 165ms/step -
accuracy: 0.8209 - loss: 0.5074 - val_accuracy: 0.8510 - val_loss: 0.4111
Epoch 16/50
704/704          116s 165ms/step -
accuracy: 0.8310 - loss: 0.4723 - val_accuracy: 0.8562 - val_loss: 0.3890
Epoch 17/50
704/704          116s 165ms/step -
accuracy: 0.8339 - loss: 0.4710 - val_accuracy: 0.8409 - val_loss: 0.4454
Epoch 18/50
704/704          116s 165ms/step -
accuracy: 0.8409 - loss: 0.4476 - val_accuracy: 0.8626 - val_loss: 0.3814
Epoch 19/50
704/704          116s 165ms/step -
accuracy: 0.8450 - loss: 0.4372 - val_accuracy: 0.8562 - val_loss: 0.3866
Epoch 20/50
704/704          116s 165ms/step -
accuracy: 0.8472 - loss: 0.4269 - val_accuracy: 0.8637 - val_loss: 0.3728
Epoch 21/50
704/704          116s 165ms/step -
accuracy: 0.8524 - loss: 0.4140 - val_accuracy: 0.8686 - val_loss: 0.3617
Epoch 22/50
704/704          116s 165ms/step -
accuracy: 0.8579 - loss: 0.4036 - val_accuracy: 0.8625 - val_loss: 0.3896
Epoch 23/50
704/704          116s 165ms/step -
accuracy: 0.8595 - loss: 0.3919 - val_accuracy: 0.8639 - val_loss: 0.3747
Epoch 24/50
704/704          116s 165ms/step -
accuracy: 0.8675 - loss: 0.3770 - val_accuracy: 0.8690 - val_loss: 0.3632
Epoch 25/50
704/704          116s 165ms/step -
accuracy: 0.8698 - loss: 0.3638 - val_accuracy: 0.8621 - val_loss: 0.3889
Epoch 26/50
704/704          116s 165ms/step -
accuracy: 0.8725 - loss: 0.3505 - val_accuracy: 0.8742 - val_loss: 0.3604
Epoch 27/50
704/704          116s 165ms/step -
accuracy: 0.8759 - loss: 0.3549 - val_accuracy: 0.8767 - val_loss: 0.3442
Epoch 28/50
704/704          116s 165ms/step -
accuracy: 0.8819 - loss: 0.3367 - val_accuracy: 0.8787 - val_loss: 0.3413
Epoch 29/50
704/704          116s 165ms/step -
accuracy: 0.8827 - loss: 0.3323 - val_accuracy: 0.8624 - val_loss: 0.3904
Epoch 30/50
704/704          116s 165ms/step -

```

```

accuracy: 0.8898 - loss: 0.3108 - val_accuracy: 0.8672 - val_loss: 0.3871
Epoch 31/50
704/704          116s 165ms/step -
accuracy: 0.8923 - loss: 0.3051 - val_accuracy: 0.8578 - val_loss: 0.3979
Epoch 32/50
704/704          116s 165ms/step -
accuracy: 0.8933 - loss: 0.2981 - val_accuracy: 0.8752 - val_loss: 0.3771
Epoch 33/50
704/704          116s 165ms/step -
accuracy: 0.8998 - loss: 0.2853 - val_accuracy: 0.8810 - val_loss: 0.3595

```

```
[13]: small_model.save("/home/ryan/cnn_small_final.keras")
```

1.8 6. Identifying the Data Imbalance Problem

Looking at the classification report and confusion matrix for only 21 classes made it a lot clearer that the model was struggling with classifying Cassava classes. This is because the Cassava_mosaic_disease class has so many more samples than any other class, so the model is leaning toward assigning any Cassava image as being part of the mosaic disease class.

```

[16]: #predicting and storing values in y and y_hat
y_small = []
yhat_small = []
for images, label in small_ts:
    pred = small_model.predict(images, verbose=0)
    y_small.extend(label.numpy())
    yhat_small.extend(np.argmax(pred, axis=1))

#generates and display Classification Report
small_class_report = classification_report(y_small, yhat_small,
    ↪target_names=small_classes, output_dict=True)

plt.figure(figsize=(8, 6))
sns.heatmap(pd.DataFrame(small_class_report).iloc[:-1, :].T, annot=True,
    ↪cmap="RdYlGn")
plt.title("Small Dataset Classification Report")
plt.gca().xaxis.set_label_position('top')
plt.gca().xaxis.tick_top()
plt.show()

```

```

2025-12-16 01:41:25.657562: W
external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
configs were filtered out because none of them sufficiently match the hints.
Maybe the hints set does not contain a good representative set of valid
configs?Working around this by using the full hints set instead.
2025-12-16 01:41:25.657813: W
external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
configs were filtered out because none of them sufficiently match the hints.

```

Maybe the hints set does not contain a good representative set of valid configs? Working around this by using the full hints set instead.

2025-12-16 01:41:26.135436: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_135', 4 bytes spill stores, 4 bytes spill loads

2025-12-16 01:41:26.401834: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_128', 4 bytes spill stores, 4 bytes spill loads

2025-12-16 01:41:26.667693: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_135', 52 bytes spill stores, 52 bytes spill loads

2025-12-16 01:41:26.676653: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_128', 40 bytes spill stores, 40 bytes spill loads

2025-12-16 01:41:26.677828: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_128', 16 bytes spill stores, 16 bytes spill loads

2025-12-16 01:41:26.719653: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_135', 72 bytes spill stores, 72 bytes spill loads

2025-12-16 01:41:26.815625: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_135', 1008 bytes spill stores, 1164 bytes spill loads

2025-12-16 01:41:26.853467: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_135', 12 bytes spill stores, 12 bytes spill loads

2025-12-16 01:41:26.983142: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_135', 128 bytes spill stores, 156 bytes spill loads

2025-12-16 01:41:45.705133: W

```

external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
configs were filtered out because none of them sufficiently match the hints.
Maybe the hints set does not contain a good representative set of valid
configs?Working around this by using the full hints set instead.
2025-12-16 01:41:45.705177: W
external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
configs were filtered out because none of them sufficiently match the hints.
Maybe the hints set does not contain a good representative set of valid
configs?Working around this by using the full hints set instead.
2025-12-16 01:41:46.025404: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_128', 16 bytes spill stores, 16 bytes spill loads

2025-12-16 01:41:46.137311: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_128', 4 bytes spill stores, 4 bytes spill loads

2025-12-16 01:41:46.667531: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_135', 12 bytes spill stores, 12 bytes spill loads

2025-12-16 01:41:46.716625: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_135', 960 bytes spill stores, 1116 bytes spill loads

2025-12-16 01:41:46.718605: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_128', 12 bytes spill stores, 12 bytes spill loads

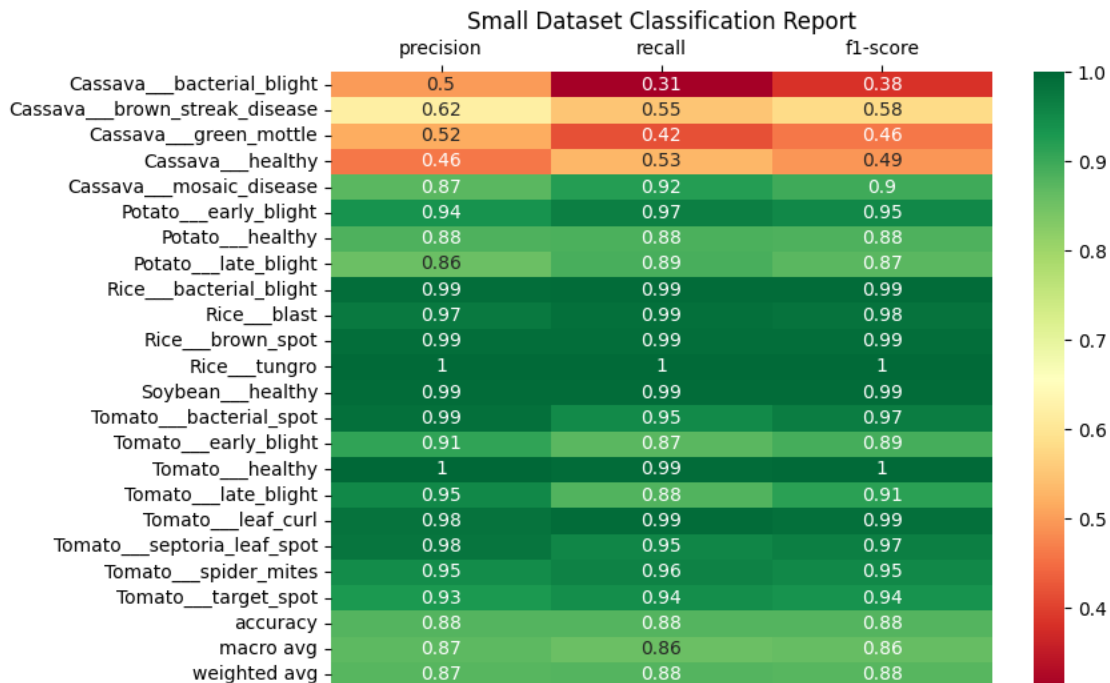
2025-12-16 01:41:46.808312: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_135', 128 bytes spill stores, 156 bytes spill loads

2025-12-16 01:41:46.816422: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_135', 52 bytes spill stores, 52 bytes spill loads

2025-12-16 01:41:46.887987: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_135', 76 bytes spill stores, 76 bytes spill loads

```


2025-12-16 01:41:49.324968: I tensorflow/core/framework/local_rendezvous.cc:407] Local rendezvous is aborting with status: OUT_OF_RANGE: End of sequence

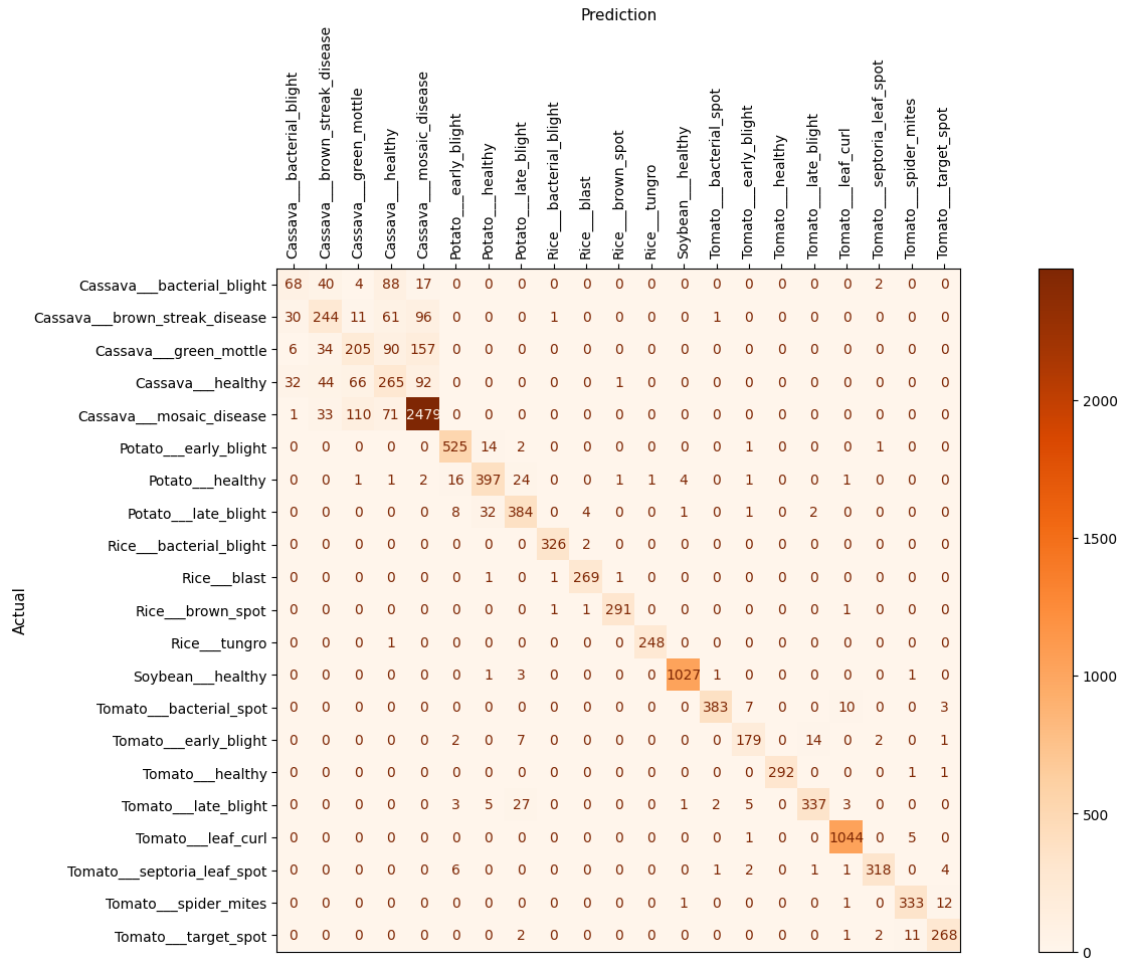


```
[17]: #generates and display confusion matrix
cm = confusion_matrix(y_small, yhat_small)
disp = ConfusionMatrixDisplay(confusion_matrix=cm, display_labels=small_classes)

fig, ax = plt.subplots(figsize=(20,10))
disp.plot(ax=ax,cmap='Oranges')
ax.tick_params(axis='x',labelrotation=90)
plt.title('Small Dataset Confusion Matrix', fontsize=15, pad=20)
plt.xlabel('Prediction', fontsize=11)
plt.ylabel('Actual', fontsize=11)
plt.gca().xaxis.set_label_position('top')
plt.gca().xticks_rotation=90
plt.gca().xaxis.tick_top()
plt.gca().figure.subplots_adjust(bottom=0.2)

plt.show()
```

Small Dataset Confusion Matrix



1.9 7. Using Class Weights to solve for imbalance

```
[24]: #gets the training label for each sample
train_labels = np.array(train_labels)

#computes the class weights
class_weights = class_weight.compute_class_weight(
    class_weight = "balanced",
    classes = np.unique(train_labels),
    y = train_labels)

#creates dictionary of class weights
class_weights = dict(enumerate(class_weights))

#initialize input shape
```

```

input_shape = (256,256,3)
small_nclasses = len(df_small)
small_classes = small_tr.class_names

# #create model object
# weighted_model = custom_cnn(input_shape, small_nclasses)

# #compile model
# weighted_model.compile(
#     optimizer=keras.optimizers.Adam(learning_rate=1e-3),
#     loss="sparse_categorical_crossentropy",
#     metrics=["accuracy"])

#Early Stopping for efficiency
callbacks = [
    keras.callbacks.EarlyStopping(
        monitor = "val_loss",
        patience = 2,
        mode='min',
        restore_best_weights=True)]

#fit model and store epoch history
history =small_model.fit(
    small_tr,
    validation_data = small_ts,
    epochs=50,
    class_weight=class_weights, #uses class weights to fit model
    callbacks=callbacks)

```

Epoch 1/50

```

2025-12-16 01:44:43.444500: W
external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
configs were filtered out because none of them sufficiently match the hints.
Maybe the hints set does not contain a good representative set of valid
configs?Working around this by using the full hints set instead.
2025-12-16 01:44:43.444552: W
external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
configs were filtered out because none of them sufficiently match the hints.
Maybe the hints set does not contain a good representative set of valid
configs?Working around this by using the full hints set instead.
2025-12-16 01:44:44.292342: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1516', 120 bytes spill stores, 120 bytes spill loads

2025-12-16 01:44:44.358458: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas

```

warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1516', 128 bytes spill stores, 128 bytes spill loads

2025-12-16 01:44:44.585855: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1518', 1140 bytes spill stores, 1284 bytes spill loads

2025-12-16 01:44:44.701451: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1518', 224 bytes spill stores, 224 bytes spill loads

2025-12-16 01:44:44.833487: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1518', 32 bytes spill stores, 32 bytes spill loads

703/704 0s 156ms/step -
accuracy: 0.7604 - loss: 1.4509

2025-12-16 01:46:36.680276: W
external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
configs were filtered out because none of them sufficiently match the hints.
Maybe the hints set does not contain a good representative set of valid
configs?Working around this by using the full hints set instead.

2025-12-16 01:46:36.680324: W
external/local_xla/xla/service/gpu/autotuning/dot_search_space.cc:200] All
configs were filtered out because none of them sufficiently match the hints.
Maybe the hints set does not contain a good representative set of valid
configs?Working around this by using the full hints set instead.

2025-12-16 01:46:37.131630: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1516', 120 bytes spill stores, 120 bytes spill loads

2025-12-16 01:46:37.401329: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1516', 104 bytes spill stores, 104 bytes spill loads

2025-12-16 01:46:38.264754: I
external/local_xla/xla/stream_executor/cuda/subprocess_compilation.cc:346] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1518', 736 bytes spill stores, 1032 bytes spill loads

704/704 124s 170ms/step -

```

accuracy: 0.7798 - loss: 1.3097 - val_accuracy: 0.8132 - val_loss: 0.5665
Epoch 2/50
704/704          116s 165ms/step -
accuracy: 0.8181 - loss: 1.0752 - val_accuracy: 0.8137 - val_loss: 0.5204
Epoch 3/50
704/704          116s 165ms/step -
accuracy: 0.8344 - loss: 0.9814 - val_accuracy: 0.8423 - val_loss: 0.4441
Epoch 4/50
704/704          116s 165ms/step -
accuracy: 0.8413 - loss: 0.9484 - val_accuracy: 0.8363 - val_loss: 0.4750
Epoch 5/50
704/704          116s 165ms/step -
accuracy: 0.8529 - loss: 0.8906 - val_accuracy: 0.8247 - val_loss: 0.5032

```

```

[27]: #predicting and storing values in y and y_hat
y_weighted = []
yhat_weighted = []
for images, label in small_ts:
    pred = small_model.predict(images, verbose=0)
    y_weighted.extend(label.numpy())
    yhat_weighted.extend(np.argmax(pred, axis=1))

#generates and display Classification Report
weighted_class_report = classification_report(y_weighted, yhat_weighted,
    ↪target_names=small_classes, output_dict=True)

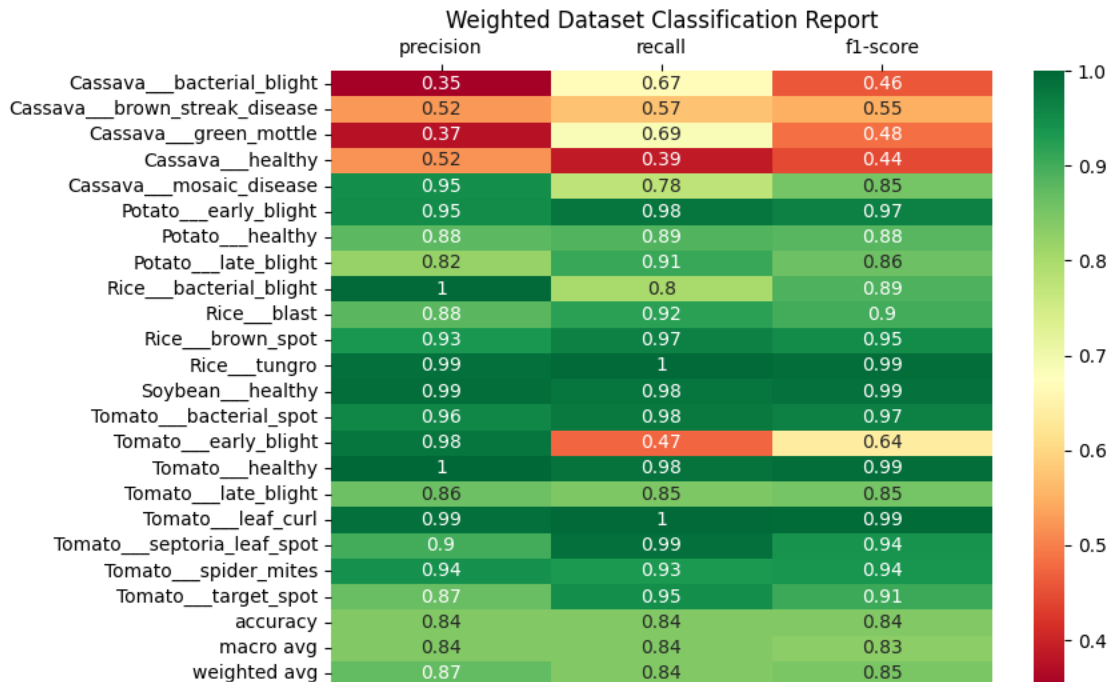
plt.figure(figsize=(8, 6))
sns.heatmap(pd.DataFrame(weighted_class_report).iloc[: -1, :].T, annot=True,
    ↪cmap="RdYlGn")
plt.title("Weighted Dataset Classification Report")
plt.gca().xaxis.set_label_position('top')
plt.gca().xaxis.tick_top()
plt.show()

```

```

2025-12-16 01:56:08.134987: I tensorflow/core/framework/local_rendezvous.cc:407]
Local rendezvous is aborting with status: OUT_OF_RANGE: End of sequence

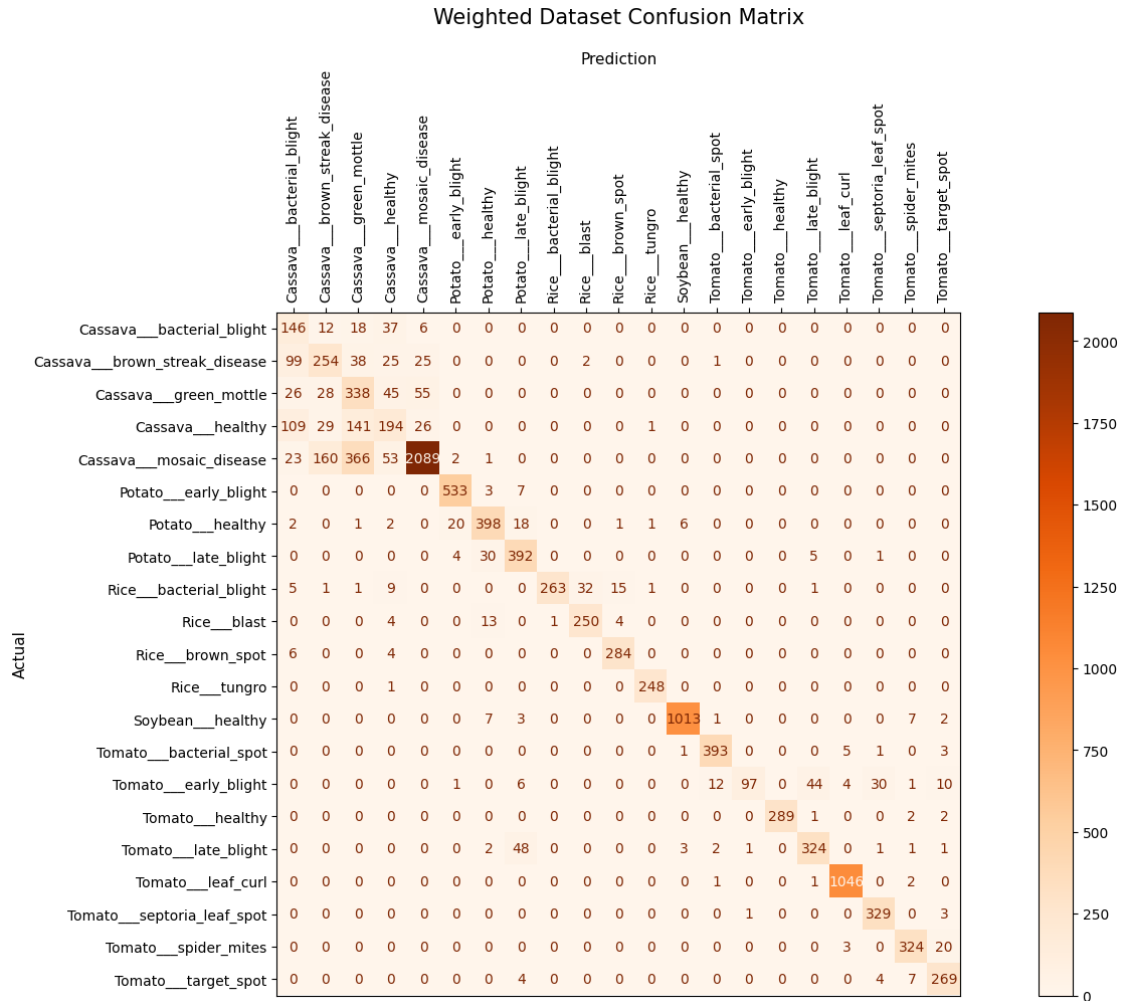
```



```
[28]: #generates and display confusion matrix
cm = confusion_matrix(y_weighted, yhat_weighted)
disp = ConfusionMatrixDisplay(confusion_matrix=cm, display_labels=small_classes)

fig, ax = plt.subplots(figsize=(20,10))
disp.plot(ax=ax, cmap='Oranges')
ax.tick_params(axis='x', labelrotation=90)
plt.title('Weighted Dataset Confusion Matrix', fontsize=15, pad=20)
plt.xlabel('Prediction', fontsize=11)
plt.ylabel('Actual', fontsize=11)
plt.gca().xaxis.set_label_position('top')
plt.gca().xticks_rotation=90
plt.gca().xaxis.tick_top()
plt.gca().figure.subplots_adjust(bottom=0.2)

plt.show()
```



1.9.1 Weighted Confusion Matrix Above ~~~

The weighted classes fixed the problem with many non-mosaic disease cassava classes being assigned to mosaic disease, but now it has caused the Cassava Mosaic Disease to misclassify as all of the other Cassava classes. In some sense, the behavior is the opposite of what it was before the class weighting. And, the different Cassava classes are still being misclassified, now they just aren't all gravitating toward the mosaic disease misclassification.

1.10 8. Creating Stratified K-Fold to solve for imbalance (different Jupyter-Notebook)

I created this model in a different Jupyter Notebook because it was different enough than the above code, and so that it would not cause any issues with this notebook if anything were to go wrong during training (it took ~14 hours).

1.11 9. Augmented Data Function

I created this function to increase the training dataset by adding translations and rotations to the images. I ended up not being able to use this augmented data because my computer did not have enough memory to store the significantly larger dataset.

```
[ ]: autotune = tf.data.AUTOTUNE #used for dynamic adjustment of parallel calls for
    ↳ CPU

def augment_data(data_tr, data_ts):
    #reflect over y-axis (left-right)
    fliphor_tr = data_tr.map(lambda x,y: (tf.image.flip_left_right(x),y),
    ↳ num_parallel_calls=autotune)

    #flip image over x-axis (up-down)
    flipvert_tr = data_tr.map(lambda x,y: (tf.image.flip_up_down(x),y),
    ↳ num_parallel_calls=autotune)

    #rotate image 90 degrees (counter-clockwise)
    rot90_tr = data_tr.map(lambda x,y: (tf.image.rot90(x,k=1),y),
    ↳ num_parallel_calls=autotune)

    #rotate image 180 degrees
    rot180_tr = data_tr.map(lambda x,y: (tf.image.rot90(x,k=2),y),
    ↳ num_parallel_calls=autotune)

    #rotate image -90 degrees (clock-wise)
    rotneg90_tr = data_tr.map(lambda x,y: (tf.image.rot90(x,k=-1),y),
    ↳ num_parallel_calls=autotune)

    #combine original and transformed images to create one augmented dataset
    aug_tr = data_tr.concatenate(fliphor_tr).concatenate(flipvert_tr).
    ↳ concatenate(rot90_tr).concatenate(rot180_tr).concatenate(rotneg90_tr)

    #shuffle data and prefetch so CPU gets data while GPU calculates - reduces
    ↳ i/o latency
    aug_tr = aug_tr.shuffle(1000,seed=seed).prefetch(buffer_size=autotune)

    #cache stores dataset in memory and prefetch to reduce i/o latency
    data_ts = data_ts.cache().prefetch(buffer_size=autotune)

    return aug_tr, data_ts

aug_tr, aug_ts = augment_data(data_tr, data_ts)

print(f"Augmented dataset size: {len(aug_tr)*batch}")
```