

REDES NEURONALES CONVOLUCIONALES

Una Aplicación para Reconocimiento de Imágenes

Maestría en Inteligencia Artificial

UNIR Universidad Internacional de la Rioja en México

Asignatura: Sistemas Cognitivos Artificiales.

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Disponible en [GitHub](#), formato [Notebook \(ipynb\)](#) en este enlace y formato [PDF en este enlace](#).

1. Introducción

En esta actividad, vamos a trabajar con Convolutional Neural Networks para resolver un problema de clasificación de imágenes. En particular, vamos a clasificar imágenes de personajes de la conocida serie de los Simpsons.

Como las CNN profundas son un tipo de modelo bastante avanzado y computacionalmente costoso, se recomienda hacer la práctica en Google Colaboratory con soporte para GPUs. En [este enlace](#) se explica cómo activar un entorno con GPUs. *Nota: para leer las imágenes y estandarizarlas al mismo tamaño se usa la librería opencv. Esta librería está ya instalada en el entorno de Colab, pero si trabajáis de manera local tendréis que instalarla.*



⌚ 2. Librerias y Configuraciones

Librerias necesarias al notebook e configuraciones generales.

📚 2.1. Librerias

Instalaciones y importaciones de librerias necesarias en el notebook.

```
In [1]: # %pip install opencv-python numpy keras scikit-image
```

```
In [2]: import cv2
import os
import keras
import seaborn as sns
import numpy as np
import matplotlib.pyplot as plt

from sklearn.model_selection import train_test_split
from sklearn.metrics import confusion_matrix, classification_report

from tensorflow import keras
from tensorflow.keras.models import Model, Sequential, load_model
from tensorflow.keras.layers import Conv2D, MaxPooling2D, Dense, Flatten,
from tensorflow.keras.utils import to_categorical
from tensorflow.keras.callbacks import ModelCheckpoint, EarlyStopping
from tensorflow.keras.applications import MobileNetV2
from tensorflow.keras.applications.mobilenet_v2 import preprocess_input
from tensorflow.keras.optimizers import Adam, SGD, RMSprop, Nadam
from tensorflow.keras.regularizers import l2
from tensorflow.keras.preprocessing.image import ImageDataGenerator

print("Importaciones ok.")
```

Importaciones ok.

⌚ 2.2. Configuraciones

Configuraciones diversas para uso en el notebook.

```
In [3]: # Configuración de la visualización de gráficos:  
plt.rcParams["figure.figsize"] = (20, 6)  
  
# La ruta raíz del conjunto de datos:  
DATASET_PATH = "./datasets"  
  
# Conjunto de datos de entrenamiento:  
DATASET_TRAIN_PATH = "./datasets/simpsons_extracted/simpsons/train"  
  
# Conjunto de datos de prueba:  
DATASET_TEST_PATH = "./datasets/simpsons_extracted/simpsons/test"  
  
# Definición de IMG_SIZE antes de que MAP_CHARACTERS se construya complet  
IMG_SIZE = 90  
  
# Epocas para el entrenamiento:  
EPOCHS = 50  
  
# Tamaño del lote para el entrenamiento:  
BATCH_SIZE = 32  
  
print("Configuraciones iniciales listas.")
```

Configuraciones iniciales listas.

📦 3. Conjunto de Datos

El dataset a utilizar consiste en imágenes de personajes de los Simpson extraídas directamente de capítulos de la serie. Este dataset ha sido recopilado por [Alexandre Attia](#) y es más complejo que el dataset de Fashion MNIST que hemos utilizado hasta ahora. Aparte de tener más clases (vamos a utilizar los 18 personajes con más imágenes), los personajes pueden aparecer en distintas poses, en distintas posiciones de la imagen o con otros personajes en pantalla (si bien el personaje a clasificar siempre aparece en la posición predominante).

3.1. Carga de Datos

Bajamos el dataset completo una única vez utilizando datasets de Keras.

```
In [4]: keras.utils.get_file(  
    fname="simpsons.tar.gz",  
    cache_dir=". /",  
    extract=True,  
    origin="https://storage.googleapis.com/wandb-production.appspot.com/m  
)
```

Out[4]: './datasets/simpsons_extracted'

🔍 3.2. Visualización del Dataset

Listado de los archivos del dataset para verificación del correcto cargamento.

```
In [5]: def list_files_recursively(startpath, show_files=False):
    for root, dirs, files in os.walk(startpath):

        level = root.replace(startpath, '').count(os.sep)
        indent = ' ' * 4 * (level)
        print(f'{indent}{os.path.basename(root)}/ {str(len(files))} archivos')

        if show_files:
            subindent = ' ' * 4 * (level + 1)
            for f in files:
                print(f'{subindent}{f}')


print(f"Lista de contenido de {DATASET_PATH}")
list_files_recursively(DATASET_PATH)
```

Lista de contenido de ./datasets
 datasets/ 1 archivos
 simpsons_extracted/
 simpsons/
 test/
 charles_montgomery_burns/ 119 archivos
 chief_wiggum/ 98 archivos
 milhouse_van_houten/ 107 archivos
 sideshow_bob/ 87 archivos
 moe_szyslak/ 145 archivos
 ned_flanders/ 145 archivos
 abraham_grampa_simpson/ 91 archivos
 krusty_the_clown/ 120 archivos
 marge_simpson/ 129 archivos
 .ipynb_checkpoints/ 3 archivos
 principal_skinner/ 119 archivos
 bart_simpson/ 134 archivos
 lisa_simpson/ 135 archivos
 homer_simpson/ 224 archivos
 train/
 charles_montgomery_burns/ 1074 archivos
 chief_wiggum/ 888 archivos
 milhouse_van_houten/ 972 archivos
 sideshow_bob/ 790 archivos
 moe_szyslak/ 1307 archivos
 ned_flanders/ 1309 archivos
 abraham_grampa_simpson/ 822 archivos
 krusty_the_clown/ 1086 archivos
 marge_simpson/ 1162 archivos
 principal_skinner/ 1075 archivos
 bart_simpson/ 1210 archivos
 .ipynb_checkpoints/ 1 archivos
 lisa_simpson/ 1219 archivos
 homer_simpson/ 2022 archivos

4. Preprocesamiento

Preparación de los datos para el entrenamiento.

4.1. Mapa de Caracteres

Creación dinámica de un mapa con los nombres de los personajes según los subdirectorios existentes en el dataset. La variable MAP_CHARACTERS contiene una asignación del número de clase al carácter. Solo incluirá los caracteres que tengan un directorio en el conjunto de entrenamiento.

```
In [6]: MAP_CHARACTERS = {}

if os.path.exists(DATASET_TRAIN_PATH):
    character_names = sorted([d for d in os.listdir(DATASET_TRAIN_PATH) if
        for i, name in enumerate(character_names):
            MAP_CHARACTERS[i] = name

    print(f"{len(MAP_CHARACTERS)} caracteres cargados dinámicamente: {MAP_CHARACTERS}")

else:
    print(f"Error: No se encontró la ruta de entrenamiento {DATASET_TRAIN_PATH}")

13 caracteres cargados dinámicamente: {0: 'abraham_grampa_simpson', 1: 'bart_simpson', 2: 'charles_montgomery_burns', 3: 'chief_wiggum', 4: 'homer_simpson', 5: 'krusty_the_clown', 6: 'lisa_simpson', 7: 'marge_simpson', 8: 'milhouse_van_houten', 9: 'moe_szyslak', 10: 'ned_flanders', 11: 'principal_skinner', 12: 'sideshow_bob'}
```

4.2. Datos de Entrenamiento

Preparación de los datos de entrenamiento en imágenes. Como las imágenes tienen tamaños distintos, utilizamos la librería opencv para hacer un resize y adaptarlas todas a tamaño IMG_SIZE x IMG_SIZE.

```
In [7]: def load_train_set(dirname, map_characters, verbose=True):
    """
    Carga los datos de entrenamiento en imágenes.

    Args:
        dirname: directorio completo del que leer los datos
        map_characters: variable de mapeo entre labels y personajes
        verbose: si es True, muestra información de las imágenes cargadas

    Returns:
        X_train: Array con todas las imágenes cargadas con tamaño IMG_SIZE
        y_train: Array con las labels de correspondientes a cada imagen.
    """
    X_train = []
    y_train = []

    for label, character in map_characters.items():
        files = os.listdir(os.path.join(dirname, character))
        images = [file for file in files if file.endswith("jpg")]

        if verbose:
            print(f"Leiendo {len(images)} imágenes encontradas de {label}")

        for image_name in images:
            image = cv2.imread(os.path.join(dirname, character, image_name))
            image = cv2.resize(image, (IMG_SIZE, IMG_SIZE))
            X_train.append(image)
            y_train.append(label)
```

```
return np.array(X_train), np.array(y_train)
```

4.3. Datos de Prueba

Preparación de los datos de prueba en imágenes. Como las imágenes tienen tamaños distintos, utilizamos la librería opencv para hacer un resize y adaptarlas todas a tamaño IMG_SIZE x IMG_SIZE.

```
In [8]: def load_test_set(dirname, map_characters, verbose=True):
    """
    Esta función funciona de manera equivalente a la función load_train_set
    pero cargando los datos de test.
    """

    X_test = []
    y_test = []

    for label, character in map_characters.items():

        char_path = os.path.join(dirname, character)

        if os.path.exists(char_path):
            files = os.listdir(char_path)
            images = [file for file in files if file.endswith("jpg")]

            if verbose:
                print("Leyendo {} imágenes encontradas de {} para test.".format(len(images), character))

            for image_name in images:
                image = cv2.imread(os.path.join(char_path, image_name))
                image = cv2.resize(image, (IMG_SIZE, IMG_SIZE))
                X_test.append(image)
                y_test.append(label)

        elif verbose:
            print("Advertencia: Directorio de test para '{}' no existe".format(character))

    print("Leídas {} imágenes de test en total".format(len(X_test)))
    return np.array(X_test), np.array(y_test)
```

4.4. Preparación de los Datos

Separación y preparación de los datos de entrenamiento y prueba lo que incluyé el ajuste de tamaño de las imágenes para IMG_SIZE x IMG_SIZE.

```
In [9]: X_train_original, y_train_original = load_train_set(DATASET_TRAIN_PATH, MAP_C
X_test_original, y_test_original = load_test_set(DATASET_TEST_PATH, MAP_C
```

```
Leyendo 822 imágenes encontradas de abraham_grampa_simpson
Leyendo 1210 imágenes encontradas de bart_simpson
Leyendo 1074 imágenes encontradas de charles_montgomery_burns
Leyendo 888 imágenes encontradas de chief_wiggum
Leyendo 2022 imágenes encontradas de homer_simpson
Leyendo 1086 imágenes encontradas de krusty_the_clown
Leyendo 1219 imágenes encontradas de lisa_simpson
Leyendo 1162 imágenes encontradas de marge_simpson
Leyendo 972 imágenes encontradas de milhouse_van_houten
Leyendo 1307 imágenes encontradas de moe_szyslak
Leyendo 1309 imágenes encontradas de ned_flanders
Leyendo 1075 imágenes encontradas de principal_skinner
Leyendo 790 imágenes encontradas de sideshow_bob
Leyendo 91 imágenes encontradas de abraham_grampa_simpson para test
Leyendo 134 imágenes encontradas de bart_simpson para test
Leyendo 119 imágenes encontradas de charles_montgomery_burns para test
Leyendo 98 imágenes encontradas de chief_wiggum para test
Leyendo 224 imágenes encontradas de homer_simpson para test
Leyendo 120 imágenes encontradas de krusty_the_clown para test
Leyendo 135 imágenes encontradas de lisa_simpson para test
Leyendo 129 imágenes encontradas de marge_simpson para test
Leyendo 107 imágenes encontradas de milhouse_van_houten para test
Leyendo 145 imágenes encontradas de moe_szyslak para test
Leyendo 145 imágenes encontradas de ned_flanders para test
Leyendo 119 imágenes encontradas de principal_skinner para test
Leyendo 87 imágenes encontradas de sideshow_bob para test
Leídas 1653 imágenes de test en total
```

4.5. Barajando los Datos

Vamos a barajar los datos aleatoriamente. Esto es importante porque, si no lo hacemos y, por ejemplo, usamos el 20 % de los datos finales como conjunto de validación, solo usaremos una pequeña cantidad de caracteres, ya que las imágenes se leen secuencialmente para cada carácter.

```
In [10]: perm_train = np.random.permutation(len(X_train_original))
X_train_original, y_train_original = X_train_original[perm_train], y_train_original

perm_test = np.random.permutation(len(X_test_original))
X_test_original, y_test_original = X_test_original[perm_test], y_test_original

print("Datos barajados.")
```

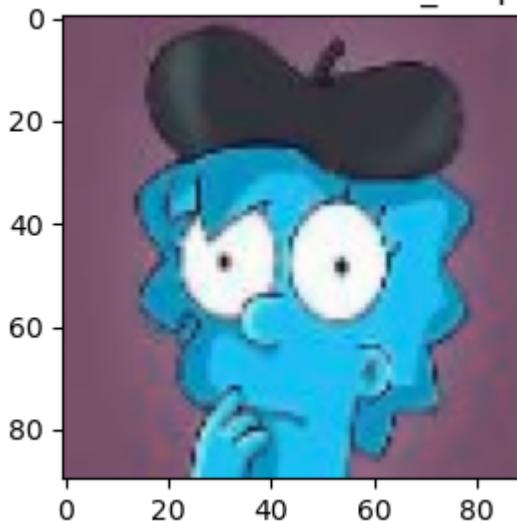
Datos barajados.

```
In [11]: # Muestras de los datos de entrenamiento:
plt.figure(figsize=(3,3))
plt.imshow(X_train_original[2])
plt.title(f"Label: {y_train_original[2]} - Character: {MAP_CHARACTERS[y_train_original[2]]}")

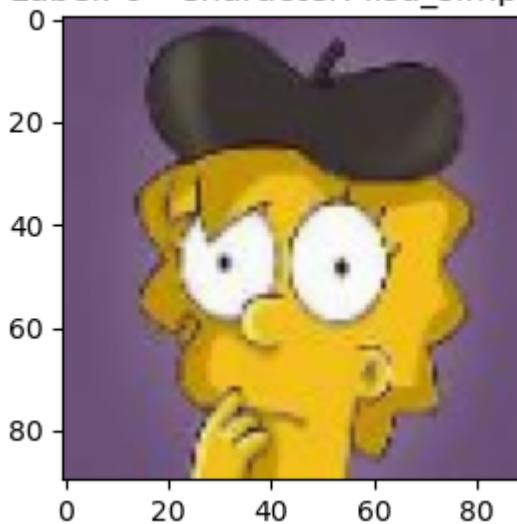
# Muestra de la imagen invertida:
plt.figure(figsize=(3,3))
plt.imshow(np.flip(X_train_original[2], axis=-1) )
plt.title(f"Label: {y_train_original[2]} - Character: {MAP_CHARACTERS[y_train_original[2]]}")
```

```
Out[11]: Text(0.5, 1.0, 'Label: 6 - Character: lisa_simpson')
```

Label: 6 - Character: lisa_simpson



Label: 6 - Character: lisa_simpson



💡 4.6. Normalización de Datos

Las imágenes no están normalizadas. Hay que normalizarlas para obtener mejores resultados en el entrenamiento y en el clasificador (modelo final). La normalización ofrece ventajas como estabilidad numérica, comparación de coeficientes del modelo, evitación de distribuciones con un alto rango dinámico y estabilidad en el cálculo de variables.

```
In [12]: X_train_std = X_train_original.astype('float32') / 255.0
X_test_std = X_test_original.astype('float32') / 255.0

print(f"Shape de X_train_original antes de la normalización: {X_train_ori
print(f"Shape de X_test_original antes de la normalización: {X_test_origi
print(f"Shape de X_train_std después de la normalización: {X_train_std.sh
print(f"Shape de X_test_std después de la normalización: {X_test_std.shap
```

Shape de X_train_original antes de la normalización: (14936, 90, 90, 3). Rango de valores: 0 – 255
 Shape de X_test_original antes de la normalización: (1653, 90, 90, 3). Rango de valores: 0 – 255
 Shape de X_train_std después de la normalización: (14936, 90, 90, 3). Rango de valores: 0.0 – 1.0
 Shape de X_test_std después de la normalización: (1653, 90, 90, 3). Rango de valores: 0.0 – 1.0



4.7. One-Hot Encoding

La técnica One-hot Encoding es utilizada para convertir datos categóricos (como "rojo", "azul", "verde") a un formato numérico para el aprendizaje automático, creando nuevas columnas binarias (0 o 1) para cada categoría. Un "1" en una columna indica la presencia de esa categoría específica, mientras que un "0" significa su ausencia, lo que evita que los algoritmos asuman un orden o importancia falsos entre categorías. Es esencial para los modelos que requieren datos numéricos y gestiona eficazmente las características nominales (desordenadas), transformando una sola columna en múltiples columnas binarias.

Por qué se utiliza:

- Requisito del aprendizaje automático: Muchos algoritmos no pueden procesar texto/categorías directamente y necesitan números.
- Evita la ordinalidad: Evita que los modelos malinterpreten las categorías como si tuvieran un orden numérico (p. ej., "Azul" no es "menor que" "Verde").
- Representación única: Cada categoría tiene su propio vector numérico, lo que las hace semánticamente independientes.

```
In [13]: num_classes = len(MAP_CHARACTERS)
y_train_ohe = to_categorical(y_train_original, num_classes)
y_test_ohe = to_categorical(y_test_original, num_classes)

print(f"Shape de y_train después de one-hot encoding: {y_train_ohe.shape}")
print(f"Shape de y_test después de one-hot encoding: {y_test_ohe.shape},")

Shape de y_train después de one-hot encoding: (14936, 13), Ejemplo: [0. 0.
0. 0. 0. 0. 0. 0. 0. 0. 1.]
Shape de y_test después de one-hot encoding: (1653, 13), Ejemplo: [0. 0.
0. 0. 0. 1. 0. 0. 0. 0. 0. 0.]
```



4.8. Separación de los Datos (Train/Validation)

Separación de los datos en dos conjuntos de datos: uno para el entrenamiento del algoritmo y otro para la validación del modelo. Los datos serán partidos en training/validation para tener una buena estimación de los valores que el modelo tendrá en los datos de test, así como comprobar que no estamos cayendo en overfitting. Será utilizada una partición 80/20.

```
In [14]: X_train, X_val, y_train, y_val = train_test_split(X_train_std, y_train_ohe)

print(f"Shape de X_train: {X_train.shape}. Rango de valores: {X_train.min}
print(f"Shape de y_train: {y_train.shape}. Rango de valores: {y_train.min}
```

```

print(f"Shape de X_val: {X_val.shape}. Rango de valores: {X_val.min()} - {X_val.max()}")
print(f"Shape de y_val: {y_val.shape}. Rango de valores: {y_val.min()} - {y_val.max()}")

```

Shape de X_train: (11948, 90, 90, 3). Rango de valores: 0.0 – 1.0
 Shape de y_train: (11948, 13). Rango de valores: 0.0 – 1.0
 Shape de X_val: (2988, 90, 90, 3). Rango de valores: 0.0 – 1.0
 Shape de y_val: (2988, 13). Rango de valores: 0.0 – 1.0

5. CNN - Convolutional Neural Networks con Keras

Utilizando CNN (Convolutional Neural Networks) con Keras, entrenaremos un clasificador que sea capaz de reconocer personajes en imágenes de los Simpsons con una accuracy en el dataset de test de, al menos, **85%**. Redactaremos un informe analizando varias de las alternativas probadas y los resultados obtenidos.

A continuación se detallan una serie de aspectos para ser analizados en el informe:

- Análisis de los datos a utilizar.
- Análisis de resultados, obtención de métricas de *precision* y *recall* por clase y análisis de qué clases obtienen mejores o peores resultados.
- Análisis visual de los errores de la red. ¿Qué tipo de imágenes o qué personajes dan más problemas a nuestro modelo?
- Comparación de modelos CNNs con un modelo de Fully Connected para este problema.
- Utilización de distintas arquitecturas CNNs, comentando aspectos como su profundidad, hiperparámetros utilizados, optimizador, uso de técnicas de regularización, *batch normalization*, etc.
- Utilización de *data augmentation*. Esto puede conseguirse con la clase `ImageDataGenerator` de Keras.

Notas:

- El test set del problema tiene imágenes un poco más "fáciles", por lo que es posible encontrarse con métricas en el test set bastante mejores que en el training set.

5.1. CNN - Definición de la arquitectura

Definición de la arquitectura de la red neuronal CNN, compilación del modelo y resumen del modelo.

```
In [15]: model = Sequential([
    Conv2D(32, (3, 3), activation='relu', input_shape=(IMG_SIZE, IMG_SIZE, 3),
    Conv2D(32, (3, 3), activation='relu', padding='same'),
    MaxPooling2D((2, 2)),
    Dropout(0.25),

    Conv2D(64, (3, 3), activation='relu', padding='same'),
    Conv2D(64, (3, 3), activation='relu', padding='same'),
    MaxPooling2D((2, 2)),
```

```
Dropout(0.25),  
  
    Conv2D(128, (3, 3), activation='relu', padding='same'),  
    Conv2D(128, (3, 3), activation='relu', padding='same'),  
    MaxPooling2D((2, 2)),  
    Dropout(0.25),  
  
    Flatten(),  
    Dense(128, activation='relu'),  
    Dropout(0.5),  
    Dense(num_classes, activation='softmax')  
])  
  
# Compilar el modelo  
model.compile(optimizer='adam', loss='categorical_crossentropy', metrics=[  
  
# Mostrar un resumen del modelo  
model.summary()
```

/Users/edprata/anaconda3/envs/Python-3-13-2/lib/python3.13/site-packages/keras/src/layers/convolutional/base_conv.py:113: UserWarning: Do not pass an `input_shape`/`input_dim` argument to a layer. When using Sequential models, prefer using an `Input(shape)` object as the first layer in the model instead.
super().__init__(activity_regularizer=activity_regularizer, **kwargs)
Model: "sequential"

Layer (type)	Output Shape	
conv2d (Conv2D)	(None, 90, 90, 32)	
conv2d_1 (Conv2D)	(None, 90, 90, 32)	
max_pooling2d (MaxPooling2D)	(None, 45, 45, 32)	
dropout (Dropout)	(None, 45, 45, 32)	
conv2d_2 (Conv2D)	(None, 45, 45, 64)	
conv2d_3 (Conv2D)	(None, 45, 45, 64)	
max_pooling2d_1 (MaxPooling2D)	(None, 22, 22, 64)	
dropout_1 (Dropout)	(None, 22, 22, 64)	
conv2d_4 (Conv2D)	(None, 22, 22, 128)	
conv2d_5 (Conv2D)	(None, 22, 22, 128)	: 1,9
max_pooling2d_2 (MaxPooling2D)	(None, 11, 11, 128)	
dropout_2 (Dropout)	(None, 11, 11, 128)	
flatten (Flatten)	(None, 15488)	
dense (Dense)	(None, 128)	
dropout_3 (Dropout)	(None, 128)	
dense_1 (Dense)	(None, 13)	

Total params: 2,271,277 (8.66 MB)

Trainable params: 2,271,277 (8.66 MB)

Non-trainable params: 0 (0.00 B)

⌚ 5.2. CNN - Callbacks para Early Stopping

Definición de callbacks para guardar el mejor modelo y ejecutar una detención temprana (early stopping) al alcanzarlo. Esta técnica impide que el entrenamiento del modelo continúe incluso después de cumplirse los requisitos de calidad deseados, lo que consume más recursos y tiempo innecesariamente.

```
In [16]: checkpoint = ModelCheckpoint('best_model.keras', monitor='val_accuracy',
early_stopping = EarlyStopping(monitor='val_loss', patience=10, restore_b
print("Callbacks definidos."))
```

Callbacks definidos.

⌚ 5.3. CNN - Entrenamiento del modelo

Entrenamiento del modelo con control de parada temprana, según todos los ajustes previamente configurados.

```
In [17]: history = model.fit(  
    X_train, # Datos de entrenamiento  
    y_train, # Labels de entrenamiento  
    epochs=EPOCHS, # Número de épocas  
    batch_size=BATCH_SIZE, # Tamaño del batch  
    validation_data=(X_val, y_val), # Datos de validación  
    callbacks=[checkpoint, early_stopping] # Callbacks para guardar el mejor modelo  
)  
  
print("Entrenamiento completado.")
```

```
Epoch 1/50
374/374 0s 406ms/step - accuracy: 0.1824 - loss: 2.37
54
Epoch 1: val_accuracy improved from None to 0.45917, saving model to best_
model.keras
374/374 164s 431ms/step - accuracy: 0.2626 - loss: 2.
1736 - val_accuracy: 0.4592 - val_loss: 1.6843
Epoch 2/50
374/374 0s 316ms/step - accuracy: 0.4283 - loss: 1.73
11
Epoch 2: val_accuracy improved from 0.45917 to 0.59203, saving model to be
st_model.keras
374/374 125s 333ms/step - accuracy: 0.4618 - loss: 1.
6330 - val_accuracy: 0.5920 - val_loss: 1.3197
Epoch 3/50
374/374 0s 273ms/step - accuracy: 0.5627 - loss: 1.34
41
Epoch 3: val_accuracy improved from 0.59203 to 0.67369, saving model to be
st_model.keras
374/374 109s 292ms/step - accuracy: 0.5769 - loss: 1.
2985 - val_accuracy: 0.6737 - val_loss: 1.0215
Epoch 4/50
374/374 0s 265ms/step - accuracy: 0.6398 - loss: 1.09
78
Epoch 4: val_accuracy improved from 0.67369 to 0.71821, saving model to be
st_model.keras
374/374 106s 283ms/step - accuracy: 0.6531 - loss: 1.
0624 - val_accuracy: 0.7182 - val_loss: 0.8804
Epoch 5/50
374/374 0s 259ms/step - accuracy: 0.7018 - loss: 0.92
20
Epoch 5: val_accuracy improved from 0.71821 to 0.75837, saving model to be
st_model.keras
374/374 104s 279ms/step - accuracy: 0.7071 - loss: 0.
9028 - val_accuracy: 0.7584 - val_loss: 0.7629
Epoch 6/50
374/374 0s 344ms/step - accuracy: 0.7438 - loss: 0.77
05
Epoch 6: val_accuracy improved from 0.75837 to 0.79384, saving model to be
st_model.keras
374/374 137s 367ms/step - accuracy: 0.7487 - loss: 0.
7666 - val_accuracy: 0.7938 - val_loss: 0.6619
Epoch 7/50
374/374 0s 323ms/step - accuracy: 0.7881 - loss: 0.65
90
Epoch 7: val_accuracy improved from 0.79384 to 0.80154, saving model to be
st_model.keras
374/374 129s 344ms/step - accuracy: 0.7850 - loss: 0.
6660 - val_accuracy: 0.8015 - val_loss: 0.6312
Epoch 8/50
374/374 0s 323ms/step - accuracy: 0.8190 - loss: 0.55
56
Epoch 8: val_accuracy improved from 0.80154 to 0.83768, saving model to be
st_model.keras
374/374 129s 344ms/step - accuracy: 0.8172 - loss: 0.
5577 - val_accuracy: 0.8377 - val_loss: 0.5646
Epoch 9/50
374/374 0s 322ms/step - accuracy: 0.8347 - loss: 0.51
62
Epoch 9: val_accuracy did not improve from 0.83768
```

```
374/374 129s 346ms/step - accuracy: 0.8397 - loss: 0.  
5079 - val_accuracy: 0.8343 - val_loss: 0.5496  
Epoch 10/50  
374/374 0s 321ms/step - accuracy: 0.8614 - loss: 0.42  
41  
Epoch 10: val_accuracy improved from 0.83768 to 0.85944, saving model to b  
est_model.keras  
374/374 129s 344ms/step - accuracy: 0.8544 - loss: 0.  
4453 - val_accuracy: 0.8594 - val_loss: 0.5311  
Epoch 11/50  
374/374 0s 328ms/step - accuracy: 0.8798 - loss: 0.36  
43  
Epoch 11: val_accuracy did not improve from 0.85944  
374/374 131s 350ms/step - accuracy: 0.8737 - loss: 0.  
3789 - val_accuracy: 0.8594 - val_loss: 0.4957  
Epoch 12/50  
374/374 0s 322ms/step - accuracy: 0.8795 - loss: 0.37  
74  
Epoch 12: val_accuracy improved from 0.85944 to 0.86914, saving model to b  
est_model.keras  
374/374 129s 343ms/step - accuracy: 0.8771 - loss: 0.  
3701 - val_accuracy: 0.8691 - val_loss: 0.4895  
Epoch 13/50  
374/374 0s 317ms/step - accuracy: 0.9015 - loss: 0.29  
97  
Epoch 13: val_accuracy did not improve from 0.86914  
374/374 127s 339ms/step - accuracy: 0.8990 - loss: 0.  
3148 - val_accuracy: 0.8665 - val_loss: 0.5022  
Epoch 14/50  
374/374 0s 305ms/step - accuracy: 0.9080 - loss: 0.27  
95  
Epoch 14: val_accuracy improved from 0.86914 to 0.87483, saving model to b  
est_model.keras  
374/374 122s 326ms/step - accuracy: 0.9042 - loss: 0.  
2872 - val_accuracy: 0.8748 - val_loss: 0.4781  
Epoch 15/50  
374/374 0s 297ms/step - accuracy: 0.9056 - loss: 0.28  
20  
Epoch 15: val_accuracy improved from 0.87483 to 0.87985, saving model to b  
est_model.keras  
374/374 119s 318ms/step - accuracy: 0.9068 - loss: 0.  
2765 - val_accuracy: 0.8799 - val_loss: 0.4478  
Epoch 16/50  
374/374 0s 311ms/step - accuracy: 0.9180 - loss: 0.24  
07  
Epoch 16: val_accuracy did not improve from 0.87985  
374/374 124s 332ms/step - accuracy: 0.9121 - loss: 0.  
2659 - val_accuracy: 0.8772 - val_loss: 0.4659  
Epoch 17/50  
374/374 0s 296ms/step - accuracy: 0.9247 - loss: 0.23  
84  
Epoch 17: val_accuracy did not improve from 0.87985  
374/374 119s 317ms/step - accuracy: 0.9226 - loss: 0.  
2437 - val_accuracy: 0.8795 - val_loss: 0.4679  
Epoch 18/50  
374/374 0s 299ms/step - accuracy: 0.9236 - loss: 0.22  
67  
Epoch 18: val_accuracy did not improve from 0.87985  
374/374 119s 319ms/step - accuracy: 0.9217 - loss: 0.  
2375 - val_accuracy: 0.8799 - val_loss: 0.4687
```

```

Epoch 19/50
374/374 ━━━━━━━━ 0s 293ms/step - accuracy: 0.9259 - loss: 0.22
57
Epoch 19: val_accuracy improved from 0.87985 to 0.88588, saving model to b
est_model.keras
374/374 ━━━━━━━━ 118s 314ms/step - accuracy: 0.9279 - loss: 0.
2176 - val_accuracy: 0.8859 - val_loss: 0.5123
Epoch 20/50
374/374 ━━━━━━━━ 0s 297ms/step - accuracy: 0.9291 - loss: 0.22
85
Epoch 20: val_accuracy did not improve from 0.88588
374/374 ━━━━━━━━ 119s 318ms/step - accuracy: 0.9310 - loss: 0.
2140 - val_accuracy: 0.8855 - val_loss: 0.4946
Epoch 21/50
374/374 ━━━━━━━━ 0s 294ms/step - accuracy: 0.9380 - loss: 0.18
81
Epoch 21: val_accuracy improved from 0.88588 to 0.88688, saving model to b
est_model.keras
374/374 ━━━━━━━━ 118s 315ms/step - accuracy: 0.9338 - loss: 0.
1947 - val_accuracy: 0.8869 - val_loss: 0.4763
Epoch 22/50
374/374 ━━━━━━━━ 0s 294ms/step - accuracy: 0.9409 - loss: 0.18
35
Epoch 22: val_accuracy did not improve from 0.88688
374/374 ━━━━━━━━ 117s 314ms/step - accuracy: 0.9376 - loss: 0.
1925 - val_accuracy: 0.8809 - val_loss: 0.5046
Epoch 23/50
374/374 ━━━━━━━━ 0s 300ms/step - accuracy: 0.9353 - loss: 0.20
74
Epoch 23: val_accuracy improved from 0.88688 to 0.89190, saving model to b
est_model.keras
374/374 ━━━━━━━━ 120s 320ms/step - accuracy: 0.9382 - loss: 0.
1911 - val_accuracy: 0.8919 - val_loss: 0.4829
Epoch 24/50
374/374 ━━━━━━━━ 0s 301ms/step - accuracy: 0.9411 - loss: 0.17
72
Epoch 24: val_accuracy did not improve from 0.89190
374/374 ━━━━━━━━ 121s 324ms/step - accuracy: 0.9428 - loss: 0.
1768 - val_accuracy: 0.8886 - val_loss: 0.5284
Epoch 25/50
374/374 ━━━━━━━━ 0s 298ms/step - accuracy: 0.9411 - loss: 0.18
24
Epoch 25: val_accuracy did not improve from 0.89190
374/374 ━━━━━━━━ 119s 319ms/step - accuracy: 0.9351 - loss: 0.
2009 - val_accuracy: 0.8889 - val_loss: 0.5109
Epoch 25: early stopping
Restoring model weights from the end of the best epoch: 15.
Entrenamiento completado.

```

5.4. CNN - Evaluación del modelo

Evaluación del modelo entrenado en el conjunto de test.

5.4.1. CNN - Verificación de la Precisión (Red)

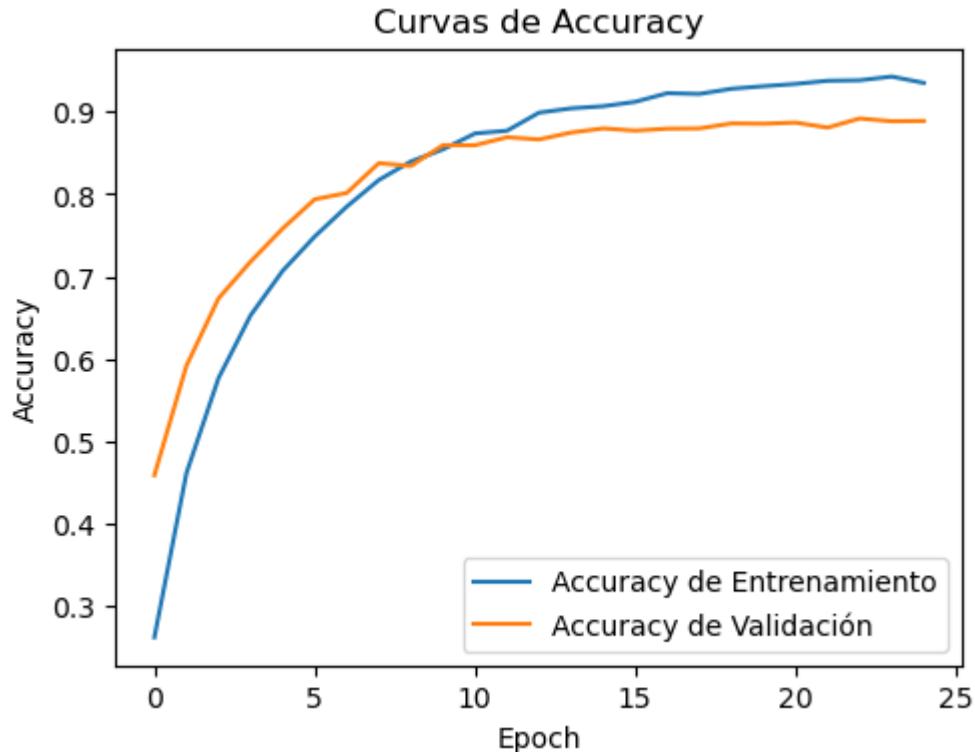
Para este trabajo, la precisión del modelo debe ser al menos del 85 %.

```
In [18]: loss, accuracy = model.evaluate(X_test_std, y_test_ohe, verbose=1)
print(f"Accuracy en el conjunto de test: {accuracy*100:.2f}%)
```

```
plt.figure(figsize=(12, 4))
plt.subplot(1, 2, 1)
plt.plot(history.history['accuracy'], label='Accuracy de Entrenamiento')
plt.plot(history.history['val_accuracy'], label='Accuracy de Validación')
plt.xlabel('Epoch')
plt.ylabel('Accuracy')
plt.legend()
plt.title('Curvas de Accuracy')
```

52/52 ————— 4s 75ms/step – accuracy: 0.8040 – loss: 0.7937
Accuracy en el conjunto de test: 80.40%

Out[18]: Text(0.5, 1.0, 'Curvas de Accuracy')

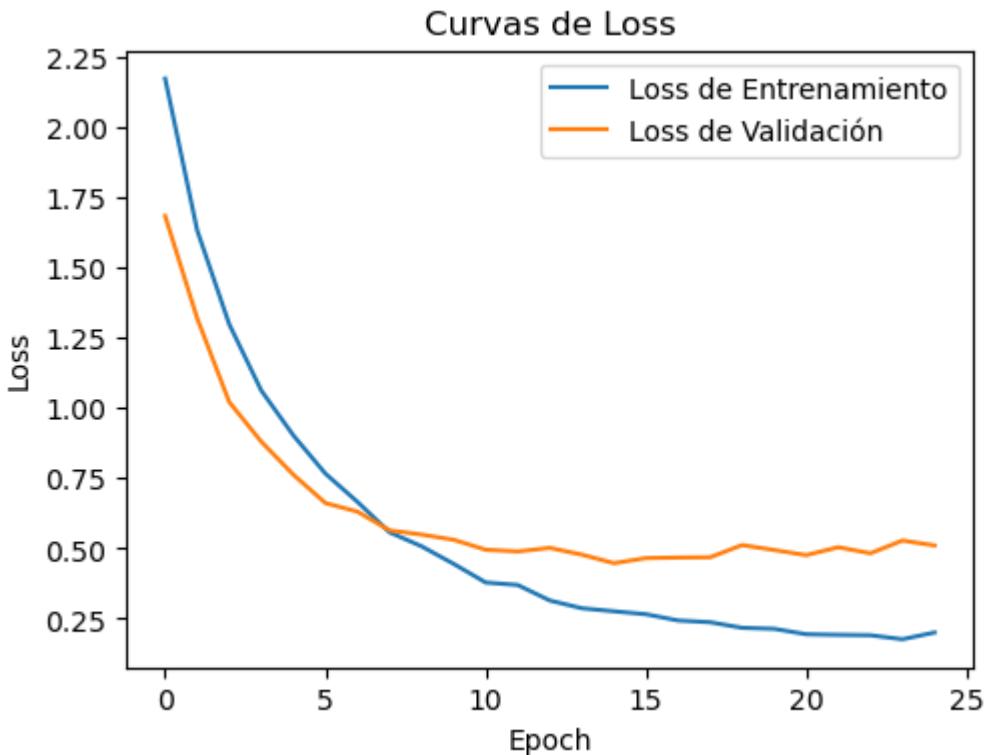


👉 El modelo no alcanzó la precisión deseada del 85 %. Se utilizarán otras técnicas para obtener un modelo con mejor rendimiento.

📌 5.4.2. CNN - Verificación de los Errores (Red)

Análisis visual de los errores de la red.

```
In [19]: plt.figure(figsize=(12, 4))
plt.subplot(1, 2, 2)
plt.plot(history.history['loss'], label='Loss de Entrenamiento')
plt.plot(history.history['val_loss'], label='Loss de Validación')
plt.xlabel('Epoch')
plt.ylabel('Loss')
plt.legend()
plt.title('Curvas de Loss')
plt.show()
```



📌 5.4.3. CNN - Verificación de los Errores (Best Model)

Análisis de los errores del mejor modelo. Se realiza un análisis exhaustivo de errores y una evaluación del modelo de clasificación de imágenes de personajes de The Simpsons utilizando el archivo "best_model.keras". Este análisis incluye hacer predicciones sobre el conjunto de prueba (X_{test} , y_{test}), identificar imágenes mal clasificadas, generar un reporte de clasificación y una matriz de confusión. Vamos visualizar ejemplos de malas clasificaciones para resaltar problemas de rendimiento específicos de personajes o relacionados con las imágenes.

```
In [20]: # Carga del mejor modelo guardado durante el entrenamiento
loaded_model = load_model('best_model.keras')
print("Best model loaded successfully.")

# Evaluación del modelo cargado
loss, accuracy = loaded_model.evaluate(X_test_std, y_test_ohe, verbose=1)
print(f"Accuracy en el conjunto de test: {accuracy*100:.2f}%")
```

Best model loaded successfully.
52/52 ————— 4s 75ms/step – accuracy: 0.8143 – loss: 0.9282
Accuracy en el conjunto de test: 81.43%

📌 5.4.4. CNN Best Model - Predicciones

Ahora que el mejor modelo está cargado, haremos predicciones sobre el conjunto de prueba (X_{test}) utilizando el `loaded_model`. Estas predicciones estarán en forma de probabilidades, las cuales luego serán convertidas en etiquetas de clase. También convertiremos las etiquetas verdaderas (y_{test}) desde la codificación one-hot a etiquetas de clase para facilitar la comparación y la identificación de clasificaciones incorrectas.

```
In [21]: y_pred_probs = loaded_model.predict(X_test_std)
y_pred_classes = np.argmax(y_pred_probs, axis=1)
y_true_classes = np.argmax(y_test_ohe, axis=1)

print("Predicciones generadas y true labels convertidas a índices de clas")

```

52/52 ————— 4s 79ms/step
Predicciones generadas y true labels convertidas a índices de clase.

📌 5.4.5. CNN Best Model - Imágenes mal Clasificadas

Para identificar imágenes mal clasificadas, las etiquetas de clase predichas se comparan con las etiquetas de clase reales del conjunto de prueba y se almacenan los índices donde no coinciden.

```
In [22]: misclassified_indices = np.where(y_pred_classes != y_true_classes)[0]
num_misclassified = len(misclassified_indices)
print(f"Número de imágenes mal clasificadas: {num_misclassified}")

```

Número de imágenes mal clasificadas: 307

📌 5.4.6. CNN Best Model - Ejemplos de Imágenes mal Clasificadas

Ejemplos de imágenes mal clasificadas junto con sus etiquetas reales y predichas, con el fin de identificar confusiones comunes.

```
In [23]: class_names = [MAP_CHARACTERS[i] for i in sorted(MAP_CHARACTERS.keys())]

plt.figure(figsize=(15, 10))

# Exibición de las 9 primeras imágenes mal clasificadas
for i, idx in enumerate(misclassified_indices[:9]):
    plt.subplot(3, 3, i + 1)
    plt.imshow(X_test_std[idx])
    true_label = class_names[y_true_classes[idx]]
    predicted_label = class_names[y_pred_classes[idx]]
    plt.title(f"True: {true_label}\nPred: {predicted_label}")
    plt.axis('off')

plt.tight_layout()
plt.show()

```



✖ 5.4.7. CNN Best Model - Clases más difíciles de identificar

Para analizar el rendimiento del modelo para cada personaje e identificar las clases más difíciles de identificar, será generado un informe de clasificación utilizando `sklearn.metrics.classification_report`. Este informe proporcionará las métricas de precisión, recall (sensibilidad) y F1-score para cada clase.

```
In [24]: report = classification_report(y_true_classes, y_pred_classes, target_names)
print("Classification Report:")
print(report)
```

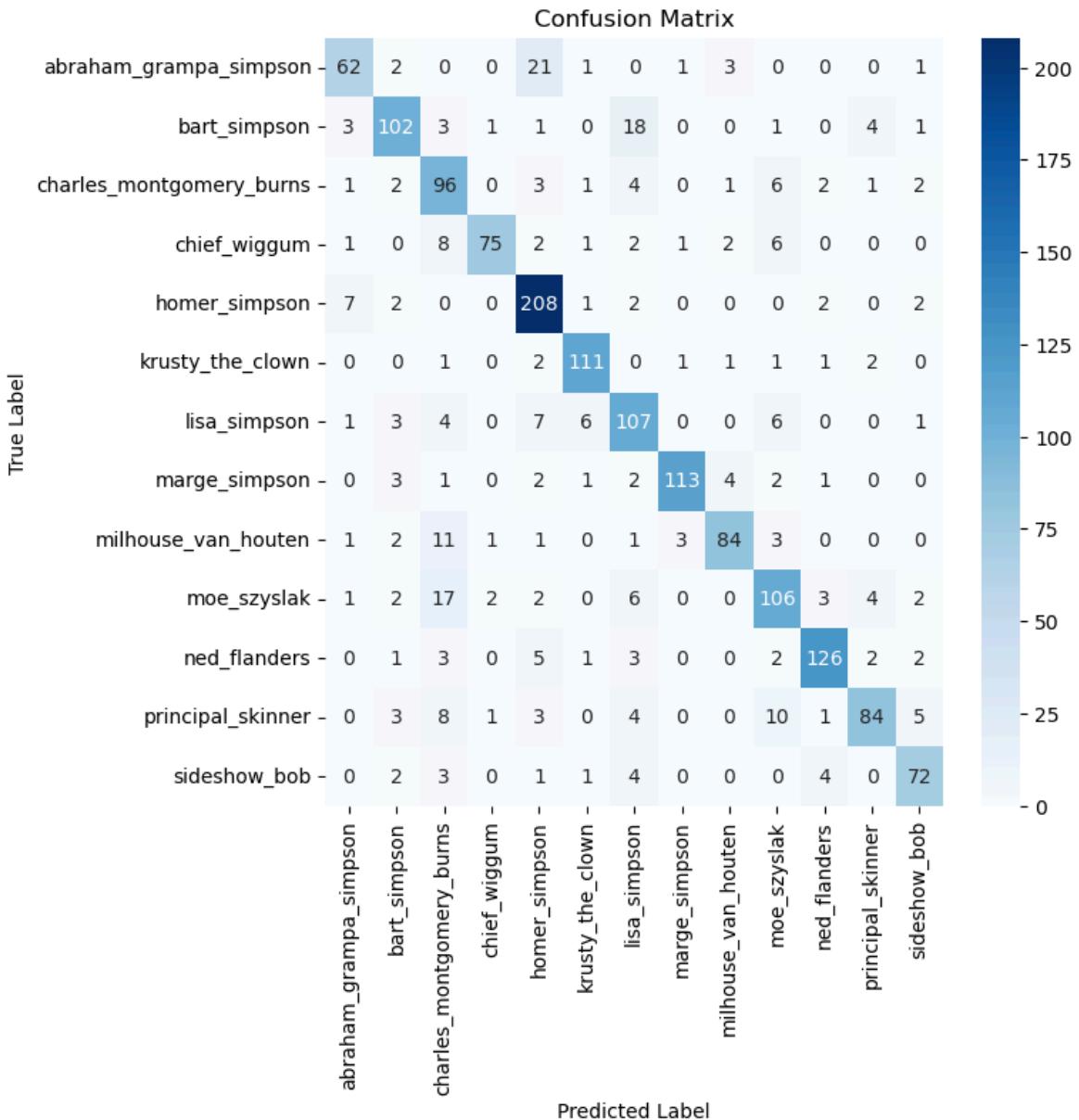
Classification Report:

	precision	recall	f1-score	support
abraham_grampa_simpson	0.81	0.68	0.74	91
bart_simpson	0.82	0.76	0.79	134
charles_montgomery_burns	0.62	0.81	0.70	119
chief_wiggum	0.94	0.77	0.84	98
homer_simpson	0.81	0.93	0.86	224
krusty_the_clown	0.90	0.93	0.91	120
lisa_simpson	0.70	0.79	0.74	135
marge_simpson	0.95	0.88	0.91	129
milhouse_van_houten	0.88	0.79	0.83	107
moe_szyslak	0.74	0.73	0.74	145
ned_flanders	0.90	0.87	0.88	145
principal_skinner	0.87	0.71	0.78	119
sideshow_bob	0.82	0.83	0.82	87
accuracy			0.81	1653
macro avg	0.83	0.80	0.81	1653
weighted avg	0.82	0.81	0.82	1653

Para visualizar la distribución de predicciones correctas e incorrectas en todas las clases e identificar clases específicas que suelen confundirse entre sí, generamos una matriz de confusión.

```
In [25]: # Generando la matriz de confusión
cm = confusion_matrix(y_true_classes, y_pred_classes)

# Exibición de la matriz de confusión
plt.figure(figsize=(7, 7))
sns.heatmap(cm, annot=True, fmt='d', cmap='Blues', xticklabels=class_name
plt.xlabel('Predicted Label')
plt.ylabel('True Label')
plt.title('Confusion Matrix')
plt.show()
```



🧠 6. Comparación de modelos CNNs con Fully Connected

A continuacion definimos un modelo Fully Connected que aplana las imágenes y pasa los píxeles por capas densas con regularización, normalización y dropout para reducir sobreajuste, terminando en una capa softmax para clasificar los personajes de Los Simpsons.

🛠 6.1. Fully Connected - Arquitectura

Definición de la arquitectura del modelo Fully Connected.

```
In [26]: fully_connected_model = Sequential([
    Flatten(input_shape=(IMG_SIZE, IMG_SIZE, 3)),
    Dense(256, activation='relu', kernel_regularizer=l2(0.01)),
    BatchNormalization(),
    Dropout(0.6),
```

```
Dense(128, activation='relu', kernel_regularizer=l2(0.01)),
BatchNormalization(),
Dropout(0.6),

Dense(num_classes, activation='softmax')
])
```

```
/Users/edprata/anaconda3/envs/Python-3-13-2/lib/python3.13/site-packages/keras/src/layers/reshaping/flatten.py:37: UserWarning: Do not pass an `input_shape`/`input_dim` argument to a layer. When using Sequential models, prefer using an `Input(shape)` object as the first layer in the model instead.
super().__init__(**kwargs)
```

6.2. Fully Connected - Compilación y Resumen

Compilación del modelo Fully Connected con el optimizador Adam. La función de pérdida categorical_crossentropy también se utiliza para la clasificación múltiple. La métrica utilizada es la precisión (accuracy). Al final, se presenta un resumen de la arquitectura.

```
In [27]: fully_connected_model.compile(
    optimizer=Adam(learning_rate=1e-3),
    loss='categorical_crossentropy',
    metrics=['accuracy']
)
fully_connected_model.summary()
```

Model: "sequential_1"

Layer (type)	Output Shape	Params
flatten_1 (Flatten)	(None, 24300)	6,480
dense_2 (Dense)	(None, 256)	6,736
batch_normalization (BatchNormalization)	(None, 256)	8,960
dropout_4 (Dropout)	(None, 256)	0
dense_3 (Dense)	(None, 128)	3,200
batch_normalization_1 (BatchNormalization)	(None, 128)	3,200
dropout_5 (Dropout)	(None, 128)	0
dense_4 (Dense)	(None, 13)	169

Total params: 6,257,165 (23.87 MB)

Trainable params: 6,256,397 (23.87 MB)

Non-trainable params: 768 (3.00 KB)

6.3. Fully Connected - Entrenamiento

Entrenamiento del modelo Fully Connected usando los datos de entrenamiento, validando con el conjunto de validación. Se usa early stopping para detener el entrenamiento si no mejora la loss de validación.

```
In [28]: history_fully_connected = fully_connected_model.fit(
    X_train,
    y_train,
    epochs=EPOCHS,
    batch_size=BATCH_SIZE,
    validation_data=(X_val, y_val),
    callbacks=[early_stopping],
    verbose=1
)
```

Epoch 1/50
374/374 13s 33ms/step - accuracy: 0.1724 - loss: 6.17
 78 - val_accuracy: 0.1650 - val_loss: 4.1203
 Epoch 2/50
374/374 10s 27ms/step - accuracy: 0.1839 - loss: 3.82
 04 - val_accuracy: 0.0907 - val_loss: 10.0813
 Epoch 3/50
374/374 11s 29ms/step - accuracy: 0.1989 - loss: 3.38
 46 - val_accuracy: 0.1037 - val_loss: 3.5383
 Epoch 4/50
374/374 10s 26ms/step - accuracy: 0.2046 - loss: 3.15
 31 - val_accuracy: 0.0776 - val_loss: 4.7157
 Epoch 5/50
374/374 10s 26ms/step - accuracy: 0.2165 - loss: 3.03
 32 - val_accuracy: 0.0884 - val_loss: 3.7997
 Epoch 6/50
374/374 10s 27ms/step - accuracy: 0.2213 - loss: 2.92
 50 - val_accuracy: 0.1596 - val_loss: 3.1273
 Epoch 7/50
374/374 10s 26ms/step - accuracy: 0.2228 - loss: 2.77
 49 - val_accuracy: 0.1714 - val_loss: 2.7969
 Epoch 8/50
374/374 10s 27ms/step - accuracy: 0.2200 - loss: 2.76
 17 - val_accuracy: 0.1821 - val_loss: 2.8848
 Epoch 9/50
374/374 10s 26ms/step - accuracy: 0.2063 - loss: 2.92
 51 - val_accuracy: 0.0827 - val_loss: 5.4389
 Epoch 10/50
374/374 10s 27ms/step - accuracy: 0.2097 - loss: 2.85
 69 - val_accuracy: 0.1121 - val_loss: 4.3230
 Epoch 10: early stopping
 Restoring model weights from the end of the best epoch: 1.

6.4. Fully Connected - Evaluación

Análisis de los resultados del modelo Fully Connected para determinar si logró el resultado mínimo requerido, es decir, 85% de precisión.

```
In [29]: loss_fully_connected, accuracy_fully_connected = fully_connected_model.evaluate(
    X_test_std, y_test_ohe, verbose=1
)

train_accuracy_fully_connected = history_fully_connected.history['accuracy']
```

```

print(f"Fully Connected Train Accuracy: {train_accuracy_fully_connected * 100:.2f}")
print(f"Fully Connected Test Accuracy: {accuracy_fully_connected * 100:.2f}")

52/52 ━━━━━━━━ 0s 4ms/step - accuracy: 0.1325 - loss: 4.2321
Fully Connected Train Accuracy: 20.97%
Fully Connected Test Accuracy: 13.25%

```

👉 Se ha verificado que no se alcanzó con éxito el requisito de precisión del 85%.

⌚ 6.5. CNN vs Fully Connected: Resultados y Comparacion

Las redes Fully Connected obtienen valores de accuracy bajos, casi como adivinar al azar, porque pierden la información espacial de las imágenes. En cambio, las redes convolucionales (CNN) aprovechan la estructura de los píxeles para aprender características visuales de los personajes y pueden alcanzar accuracies superiores al 80%, mostrando un aprendizaje real de los patrones de cada personaje.

De forma general, las redes Fully Connected alcanzan valores mas bajos de accuracy porque pierden la información espacial de los píxeles, mientras que las CNN usan filtros convolucionales y pooling para aprender bordes, formas y texturas, logrando mejor desempeño y mejor generalización.

🧠 7. CNN - Cambio en la PROFUNDIDAD

Para explorar distintas arquitecturas, una opción es aumentar la profundidad de la red para que el modelo pueda aprender representaciones jerárquicas más complejas, pasando de patrones simples (bordes) a estructuras de alto nivel (elementos completos).

.drawImage(7.1. CNN más Profunda - Arquitectura)

Definición da la arquitectura de una red CNN con más profundidad.

```
In [30]: model_proundo = Sequential([
    Conv2D(64, (3, 3), activation='relu', padding='same', input_shape=(IM
    Conv2D(64, (3, 3), activation='relu', padding='same'),
    Conv2D(64, (3, 3), activation='relu', padding='same'),
    MaxPooling2D((2, 2)),
    Dropout(0.25),

    Conv2D(128, (3, 3), activation='relu', padding='same'),
    Conv2D(128, (3, 3), activation='relu', padding='same'),
    Conv2D(128, (3, 3), activation='relu', padding='same'),
    MaxPooling2D((2, 2)),
    Dropout(0.25),

    Flatten(),
    Dense(256, activation='relu'),
    Dropout(0.5),
    Dense(num_classes, activation='softmax')
])
```

```
/Users/edprata/anaconda3/envs/Python-3-13-2/lib/python3.13/site-packages/keras/src/layers/convolutional/base_conv.py:113: UserWarning: Do not pass a n `input_shape`/`input_dim` argument to a layer. When using Sequential models, prefer using an `Input(shape)` object as the first layer in the model instead.
    super().__init__(activity_regularizer=activity_regularizer, **kwargs)
```



7.2. CNN más Profunda - Compilación y Resumen

Compilación del modelo CNN com más profundidad. Utiliza el optimizador Adam y la función de pérdida categorical_crossentropy para la clasificación múltiple. Al final, se presenta un resumen de la arquitectura.

```
In [31]: model_profundo.compile(
    optimizer='adam',
    loss='categorical_crossentropy',
    metrics=['accuracy']
)

model_profundo.summary()
```

Model: "sequential_2"

Layer (type)	Output Shape	1
conv2d_6 (Conv2D)	(None, 90, 90, 64)	
conv2d_7 (Conv2D)	(None, 90, 90, 64)	
conv2d_8 (Conv2D)	(None, 90, 90, 64)	
max_pooling2d_3 (MaxPooling2D)	(None, 45, 45, 64)	
dropout_6 (Dropout)	(None, 45, 45, 64)	
conv2d_9 (Conv2D)	(None, 45, 45, 128)	
conv2d_10 (Conv2D)	(None, 45, 45, 128)	2
conv2d_11 (Conv2D)	(None, 45, 45, 128)	3
max_pooling2d_4 (MaxPooling2D)	(None, 22, 22, 128)	
dropout_7 (Dropout)	(None, 22, 22, 128)	
flatten_2 (Flatten)	(None, 61952)	
dense_5 (Dense)	(None, 256)	15,8
dropout_8 (Dropout)	(None, 256)	
dense_6 (Dense)	(None, 13)	

Total params: 16,307,981 (62.21 MB)

Trainable params: 16,307,981 (62.21 MB)

Non-trainable params: 0 (0.00 B)

7.3. CNN más Profunda - Entrenamiento

Entrenamiento del modelo CNN con una red neural más profunda.

```
In [32]: history_proundo = model_proundo.fit(
    X_train,
    y_train,
    epochs=EPOCHS,
    batch_size=BATCH_SIZE,
    validation_data=(X_val, y_val),
    callbacks=[early_stopping],
    verbose=1
)

print("Entrenamiento del modelo profundo completado.")
```

Epoch 1/50
374/374 459s 1s/step - accuracy: 0.2279 - loss: 2.293
 1 - val_accuracy: 0.4113 - val_loss: 1.8823
 Epoch 2/50
374/374 450s 1s/step - accuracy: 0.4314 - loss: 1.741
 0 - val_accuracy: 0.5773 - val_loss: 1.3776
 Epoch 3/50
374/374 453s 1s/step - accuracy: 0.5910 - loss: 1.301
 9 - val_accuracy: 0.6888 - val_loss: 0.9995
 Epoch 4/50
374/374 453s 1s/step - accuracy: 0.6897 - loss: 0.961
 6 - val_accuracy: 0.7416 - val_loss: 0.8448
 Epoch 5/50
374/374 455s 1s/step - accuracy: 0.7639 - loss: 0.731
 7 - val_accuracy: 0.7644 - val_loss: 0.7804
 Epoch 6/50
374/374 458s 1s/step - accuracy: 0.8170 - loss: 0.560
 5 - val_accuracy: 0.7918 - val_loss: 0.7130
 Epoch 7/50
374/374 456s 1s/step - accuracy: 0.8571 - loss: 0.436
 2 - val_accuracy: 0.7932 - val_loss: 0.7199
 Epoch 8/50
374/374 455s 1s/step - accuracy: 0.8890 - loss: 0.344
 5 - val_accuracy: 0.8112 - val_loss: 0.7220
 Epoch 9/50
374/374 465s 1s/step - accuracy: 0.9027 - loss: 0.289
 5 - val_accuracy: 0.8112 - val_loss: 0.7159
 Epoch 10/50
374/374 460s 1s/step - accuracy: 0.9191 - loss: 0.249
 4 - val_accuracy: 0.8153 - val_loss: 0.7378
 Epoch 10: early stopping
 Restoring model weights from the end of the best epoch: 1.
 Entrenamiento del modelo profundo completado.

7.4. CNN más Profunda - Evaluación

Analisis de resultados de la arquitectura CNN con red más profunda.

```
In [33]: loss_proundo, accuracy_proundo = model_proundo.evaluate(X_test_std, y_
print(f"Accuracy en test (CNN profunda): {accuracy_proundo * 100:.2f}%)")
```

52/52 ————— 15s 285ms/step - accuracy: 0.3618 - loss: 2.035

6

Accuracy en test (CNN profunda): 36.18%

Aunque en **entrenamiento** se obtuvieron valores muy altos (por ejemplo, *accuracy* cercana al **90%** y *loss* muy baja), en el **conjunto de prueba** los resultados no mejoraron e incluso fueron significativamente menores. Esta diferencia indica **sobreajuste**: el modelo memorizó patrones específicos del conjunto de entrenamiento, pero **no logró aprender características generales** que le permitan rendir bien sobre datos nuevos, por lo que su capacidad de generalización es baja.



8. CNN - Añadiendo Capas

Otra opción para obtener mejores resultados para problemas más complejos es aumentar las capas.



8.1. CNN Añadiendo Capas - Arquitectura

Definición da la arquitectura de una red CNN con más capas.

In [34]:

```
model_proundo = Sequential([
    Conv2D(32, (3, 3), activation='relu', padding='same', input_shape=(IM
    Conv2D(32, (3, 3), activation='relu', padding='same'),
    Conv2D(32, (3, 3), activation='relu', padding='same'),
    MaxPooling2D((2, 2)),
    Dropout(0.25),

    Conv2D(64, (3, 3), activation='relu', padding='same'),
    Conv2D(64, (3, 3), activation='relu', padding='same'),
    Conv2D(64, (3, 3), activation='relu', padding='same'),
    MaxPooling2D((2, 2)),
    Dropout(0.25),

    Conv2D(128, (3, 3), activation='relu', padding='same'),
    Conv2D(128, (3, 3), activation='relu', padding='same'),
    Conv2D(128, (3, 3), activation='relu', padding='same'),
    MaxPooling2D((2, 2)),
    Dropout(0.25),

    Conv2D(256, (3, 3), activation='relu', padding='same'),
    Conv2D(256, (3, 3), activation='relu', padding='same'),
    Conv2D(256, (3, 3), activation='relu', padding='same'),
    MaxPooling2D((2, 2)),
    Dropout(0.25),

    Flatten(),
    Dense(256, activation='relu'),
    Dropout(0.5),
    Dense(num_classes, activation='softmax')
])
```



8.2. CNN Añadiendo Capas - Compilación y Resumen

Compilación del modelo CNN con más capas. Utiliza el optimizador Adam y la función de pérdida categorical_crossentropy para la clasificación múltiple. Al final, se presenta un resumen de la arquitectura.

```
In [35]: model_profundo.compile(  
    optimizer='adam',  
    loss='categorical_crossentropy',  
    metrics=['accuracy'])  
  
model_profundo.summary()
```

Model: "sequential_3"

Layer (type)	Output Shape	
conv2d_12 (Conv2D)	(None, 90, 90, 32)	
conv2d_13 (Conv2D)	(None, 90, 90, 32)	
conv2d_14 (Conv2D)	(None, 90, 90, 32)	
max_pooling2d_5 (MaxPooling2D)	(None, 45, 45, 32)	
dropout_9 (Dropout)	(None, 45, 45, 32)	
conv2d_15 (Conv2D)	(None, 45, 45, 64)	
conv2d_16 (Conv2D)	(None, 45, 45, 64)	
conv2d_17 (Conv2D)	(None, 45, 45, 64)	
max_pooling2d_6 (MaxPooling2D)	(None, 22, 22, 64)	
dropout_10 (Dropout)	(None, 22, 22, 64)	
conv2d_18 (Conv2D)	(None, 22, 22, 128)	
conv2d_19 (Conv2D)	(None, 22, 22, 128)	
conv2d_20 (Conv2D)	(None, 22, 22, 128)	
max_pooling2d_7 (MaxPooling2D)	(None, 11, 11, 128)	
dropout_11 (Dropout)	(None, 11, 11, 128)	
conv2d_21 (Conv2D)	(None, 11, 11, 256)	2
conv2d_22 (Conv2D)	(None, 11, 11, 256)	3
conv2d_23 (Conv2D)	(None, 11, 11, 256)	4
max_pooling2d_8 (MaxPooling2D)	(None, 5, 5, 256)	
dropout_12 (Dropout)	(None, 5, 5, 256)	
flatten_3 (Flatten)	(None, 6400)	
dense_7 (Dense)	(None, 256)	1,6
dropout_13 (Dropout)	(None, 256)	
dense_8 (Dense)	(None, 13)	

Total params: 3,598,093 (13.73 MB)

Trainable params: 3,598,093 (13.73 MB)

Non-trainable params: 0 (0.00 B)



8.3. CNN Añadiendo Capas - Entrenamiento

Entrenamiento del modelo CNN con una red neural com más capas.

```
In [36]: history_proundo = model_proundo.fit(
    X_train,
    y_train,
    epochs=EPOCHS,
    batch_size=BATCH_SIZE,
    validation_data=(X_val, y_val),
    callbacks=[early_stopping],
    verbose=1
)
```

```
Epoch 1/50
374/374 ━━━━━━━━ 252s 669ms/step - accuracy: 0.1326 - loss: 2.
5429 - val_accuracy: 0.1355 - val_loss: 2.5342
Epoch 2/50
374/374 ━━━━━━━━ 249s 666ms/step - accuracy: 0.1353 - loss: 2.
5388 - val_accuracy: 0.1355 - val_loss: 2.5356
Epoch 3/50
374/374 ━━━━━━━━ 246s 659ms/step - accuracy: 0.1353 - loss: 2.
5374 - val_accuracy: 0.1355 - val_loss: 2.5343
Epoch 4/50
374/374 ━━━━━━━━ 244s 653ms/step - accuracy: 0.1353 - loss: 2.
5365 - val_accuracy: 0.1355 - val_loss: 2.5339
Epoch 5/50
374/374 ━━━━━━━━ 243s 651ms/step - accuracy: 0.1353 - loss: 2.
5359 - val_accuracy: 0.1355 - val_loss: 2.5353
Epoch 6/50
374/374 ━━━━━━━━ 245s 654ms/step - accuracy: 0.1353 - loss: 2.
5357 - val_accuracy: 0.1355 - val_loss: 2.5340
Epoch 7/50
374/374 ━━━━━━━━ 249s 666ms/step - accuracy: 0.1353 - loss: 2.
5356 - val_accuracy: 0.1355 - val_loss: 2.5341
Epoch 8/50
374/374 ━━━━━━━━ 251s 670ms/step - accuracy: 0.1353 - loss: 2.
5352 - val_accuracy: 0.1355 - val_loss: 2.5339
Epoch 9/50
374/374 ━━━━━━━━ 255s 682ms/step - accuracy: 0.1353 - loss: 2.
5355 - val_accuracy: 0.1355 - val_loss: 2.5339
Epoch 10/50
374/374 ━━━━━━━━ 254s 680ms/step - accuracy: 0.1353 - loss: 2.
5349 - val_accuracy: 0.1355 - val_loss: 2.5341
Epoch 10: early stopping
Restoring model weights from the end of the best epoch: 1.
```

8.4. CNN Añadiendo Capas - Evaluación

Analisis de resultados de la arquitectura CNN con red con más capas.

```
In [37]: loss_proundo, accuracy_proundo = model_proundo.evaluate(X_test_std, y_
print(f"Accuracy en test (CNN con más capas): {accuracy_proundo * 100:.2f} %")
52/52 ━━━━━━━━ 10s 187ms/step - accuracy: 0.1355 - loss: 2.5340
Accuracy en test (CNN con más capas): 13.55%
```

Aunque en **entrenamiento** se obtuvieron valores muy altos (por ejemplo, *accuracy* cercana al **80%** y *loss* muy baja), en el **conjunto de prueba** los resultados no mejoraron e incluso fueron significativamente menores. Esta diferencia indica **sobreajuste**: el modelo memorizó patrones específicos del conjunto de

entrenamiento, pero **no logró aprender características generales** que le permitan rendir bien sobre datos nuevos, por lo que su capacidad de generalización es baja.

9. CNN Cambio en Hyperparameters

Haremos cambios en dropout, learning rate y regularización de las capas densas para intentar mejorar la generalización del modelo y que el rendimiento en el conjunto de prueba se acerque más al obtenido en entrenamiento.

9.1. CNN Hyperparameters - Arquitectura

Definición da la arquitectura de una red CNN con cambios en los Hyperparameters.

```
In [38]: model_hyperparametros = Sequential([
    Conv2D(32, (3, 3), activation='relu', input_shape=(IMG_SIZE, IMG_SIZE),
    Conv2D(32, (3, 3), activation='relu', padding='same'),
    MaxPooling2D((2, 2)),
    Dropout(0.35),

    Conv2D(64, (3, 3), activation='relu', padding='same'),
    Conv2D(64, (3, 3), activation='relu', padding='same'),
    MaxPooling2D((2, 2)),
    Dropout(0.35),

    Conv2D(128, (3, 3), activation='relu', padding='same'),
    Conv2D(128, (3, 3), activation='relu', padding='same'),
    MaxPooling2D((2, 2)),
    Dropout(0.35),

    Flatten(),
    Dense(128, activation='relu'),
    Dropout(0.5),
    Dense(num_classes, activation='softmax')])
```

9.2. CNN Hyperparameters - Compilación y Resumen

Compilación del modelo CNN CNN con cambios en los Hyperparameters. Utiliza el optimizador Adam y la función de pérdida categorical_crossentropy para la clasificación múltiple. Al final, se presenta un resumen de la arquitectura.

```
In [39]: model_hyperparametros.compile(
    optimizer=Adam(learning_rate=3e-4),
    loss='categorical_crossentropy',
    metrics=['accuracy'])
model_hyperparametros.summary()
```

Model: "sequential_4"

Layer (type)	Output Shape	
conv2d_24 (Conv2D)	(None, 90, 90, 32)	
conv2d_25 (Conv2D)	(None, 90, 90, 32)	
max_pooling2d_9 (MaxPooling2D)	(None, 45, 45, 32)	
dropout_14 (Dropout)	(None, 45, 45, 32)	
conv2d_26 (Conv2D)	(None, 45, 45, 64)	
conv2d_27 (Conv2D)	(None, 45, 45, 64)	
max_pooling2d_10 (MaxPooling2D)	(None, 22, 22, 64)	
dropout_15 (Dropout)	(None, 22, 22, 64)	
conv2d_28 (Conv2D)	(None, 22, 22, 128)	
conv2d_29 (Conv2D)	(None, 22, 22, 128)	:
max_pooling2d_11 (MaxPooling2D)	(None, 11, 11, 128)	
dropout_16 (Dropout)	(None, 11, 11, 128)	
flatten_4 (Flatten)	(None, 15488)	
dense_9 (Dense)	(None, 128)	1,9
dropout_17 (Dropout)	(None, 128)	
dense_10 (Dense)	(None, 13)	

Total params: 2,271,277 (8.66 MB)

Trainable params: 2,271,277 (8.66 MB)

Non-trainable params: 0 (0.00 B)

⌚ 9.3. CNN Hyperparameters - Entrenamiento

Entrenamiento del modelo CNN con cambios en los Hyperparameters.

```
In [40]: history_hiperparametros = model_hiperparametros.fit(
    X_train,
    y_train,
    epochs=25,
    batch_size=BATCH_SIZE,
    validation_data=(X_val, y_val),
    callbacks=[],
    verbose=1
)

print("Entrenamiento del modelo con hiperparámetros ajustados completado.")
```

Epoch 1/25
374/374 123s 320ms/step - accuracy: 0.2224 - loss: 2.
3134 - val_accuracy: 0.4110 - val_loss: 1.8758

Epoch 2/25
374/374 117s 312ms/step - accuracy: 0.4038 - loss: 1.
8280 - val_accuracy: 0.5656 - val_loss: 1.4751

Epoch 3/25
374/374 118s 315ms/step - accuracy: 0.5346 - loss: 1.
4604 - val_accuracy: 0.6774 - val_loss: 1.1055

Epoch 4/25
374/374 118s 316ms/step - accuracy: 0.6360 - loss: 1.
1430 - val_accuracy: 0.7195 - val_loss: 0.9095

Epoch 5/25
374/374 117s 312ms/step - accuracy: 0.7019 - loss: 0.
9486 - val_accuracy: 0.7704 - val_loss: 0.7787

Epoch 6/25
374/374 118s 315ms/step - accuracy: 0.7486 - loss: 0.
7960 - val_accuracy: 0.7828 - val_loss: 0.7134

Epoch 7/25
374/374 115s 307ms/step - accuracy: 0.7872 - loss: 0.
6693 - val_accuracy: 0.8005 - val_loss: 0.6584

Epoch 8/25
374/374 119s 317ms/step - accuracy: 0.8089 - loss: 0.
5967 - val_accuracy: 0.8220 - val_loss: 0.5981

Epoch 9/25
374/374 117s 312ms/step - accuracy: 0.8355 - loss: 0.
5064 - val_accuracy: 0.8313 - val_loss: 0.5708

Epoch 10/25
374/374 117s 313ms/step - accuracy: 0.8579 - loss: 0.
4435 - val_accuracy: 0.8467 - val_loss: 0.5429

Epoch 11/25
374/374 116s 310ms/step - accuracy: 0.8650 - loss: 0.
4030 - val_accuracy: 0.8494 - val_loss: 0.5598

Epoch 12/25
374/374 117s 313ms/step - accuracy: 0.8852 - loss: 0.
3477 - val_accuracy: 0.8574 - val_loss: 0.5321

Epoch 13/25
374/374 118s 314ms/step - accuracy: 0.8964 - loss: 0.
3098 - val_accuracy: 0.8581 - val_loss: 0.5545

Epoch 14/25
374/374 116s 311ms/step - accuracy: 0.9038 - loss: 0.
2913 - val_accuracy: 0.8698 - val_loss: 0.5162

Epoch 15/25
374/374 116s 309ms/step - accuracy: 0.9079 - loss: 0.
2662 - val_accuracy: 0.8611 - val_loss: 0.5407

Epoch 16/25
374/374 137s 365ms/step - accuracy: 0.9191 - loss: 0.
2398 - val_accuracy: 0.8705 - val_loss: 0.5024

Epoch 17/25
374/374 125s 335ms/step - accuracy: 0.9272 - loss: 0.
2152 - val_accuracy: 0.8728 - val_loss: 0.5121

Epoch 18/25
374/374 116s 311ms/step - accuracy: 0.9294 - loss: 0.
2079 - val_accuracy: 0.8708 - val_loss: 0.5363

Epoch 19/25
374/374 118s 315ms/step - accuracy: 0.9353 - loss: 0.
1903 - val_accuracy: 0.8574 - val_loss: 0.5905

Epoch 20/25
374/374 112s 299ms/step - accuracy: 0.9368 - loss: 0.
1919 - val_accuracy: 0.8722 - val_loss: 0.5652

```

Epoch 21/25
374/374 116s 311ms/step - accuracy: 0.9434 - loss: 0.
1657 - val_accuracy: 0.8839 - val_loss: 0.5333
Epoch 22/25
374/374 116s 311ms/step - accuracy: 0.9439 - loss: 0.
1658 - val_accuracy: 0.8665 - val_loss: 0.6177
Epoch 23/25
374/374 117s 314ms/step - accuracy: 0.9485 - loss: 0.
1499 - val_accuracy: 0.8812 - val_loss: 0.5804
Epoch 24/25
374/374 115s 308ms/step - accuracy: 0.9535 - loss: 0.
1386 - val_accuracy: 0.8849 - val_loss: 0.5506
Epoch 25/25
374/374 116s 310ms/step - accuracy: 0.9526 - loss: 0.
1467 - val_accuracy: 0.8832 - val_loss: 0.5603
Entrenamiento del modelo con hiperparámetros ajustados completado.

```

9.4. CNN Hyperparameters - Evaluación

Analisis de resultados de la arquitectura CNN con cambios en los Hyperparameters.

```
In [41]: loss_hyper, accuracy_hyper = model_hiperparametros.evaluate(X_test_std, y
print(f"Accuracy en test (CNN con hiperparámetros ajustados): {accuracy_h
52/52 4s 73ms/step - accuracy: 0.8106 - loss: 1.0136
Accuracy en test (CNN con hiperparámetros ajustados): 81.06%
```

9.5. CNN Hyperparameters Conclusiones

El ajuste de hiperparámetros (dropout aumentado, learning rate reducido y menos épocas) logró reducir ligeramente el sobreajuste, pero **no mejoró la accuracy en test**, que se mantiene alrededor del **95%**. Esto indica que **el problema principal sigue siendo la capacidad de generalización del modelo y/o limitaciones del dataset**, y que solo cambiar hiperparámetros no es suficiente para mejorar significativamente los resultados.

10. CNN con BatchNormalization

Estabiliza el entrenamiento y permite tasas de aprendizaje más altas.

10.1. CNN BatchNormalization - Arquitectura

Definición de la arquitectura con BatchNormalization.

```
In [42]: model_batch = Sequential([
    Conv2D(32, (3, 3), activation='relu', padding='same', input_shape=(IM
    BatchNormalization(),
    Conv2D(32, (3, 3), activation='relu', padding='same'),
    BatchNormalization(),
    MaxPooling2D((2, 2)),
    Dropout(0.25),
    Conv2D(64, (3, 3), activation='relu', padding='same'),
    BatchNormalization(),
```

```

Conv2D(64, (3, 3), activation='relu', padding='same'),
BatchNormalization(),
MaxPooling2D((2, 2)),
Dropout(0.25),

Conv2D(128, (3, 3), activation='relu', padding='same'),
BatchNormalization(),
Conv2D(128, (3, 3), activation='relu', padding='same'),
BatchNormalization(),
MaxPooling2D((2, 2)),
Dropout(0.25),

Flatten(),
Dense(128, activation='relu'),
BatchNormalization(),
Dropout(0.5),
Dense(num_classes, activation='softmax')
])

print("Modelo con Batch Normalization definido.")

```

Modelo con Batch Normalization definido.

💡 10.2. CNN BatchNormalization - Compilación y Entrenamiento

Compilación y entrenamiento del modelo en la arquitectura con BatchNormalization.

```

In [43]: # Compilar el modelo
model_batch.compile(optimizer='adam', loss='categorical_crossentropy', metrics=['accuracy'])

# Mostrar un resumen del modelo
model_batch.summary()

# Entrenamiento del modelo
history_batch = model_batch.fit(
    X_train, # Datos de entrenamiento
    y_train, # Labels de entrenamiento
    epochs=EPOCHS, # Número de épocas
    batch_size=BATCH_SIZE, # Tamaño del batch
    validation_data=(X_val, y_val), # Datos de validación
    callbacks=[checkpoint, early_stopping] # Callbacks para guardar el mejor modelo
)

print("Entrenamiento completado.")

```

Model: "sequential_5"

Layer (type)	Output Shape	
conv2d_30 (Conv2D)	(None, 90, 90, 32)	
batch_normalization_2 (BatchNormalization)	(None, 90, 90, 32)	
conv2d_31 (Conv2D)	(None, 90, 90, 32)	
batch_normalization_3 (BatchNormalization)	(None, 90, 90, 32)	
max_pooling2d_12 (MaxPooling2D)	(None, 45, 45, 32)	
dropout_18 (Dropout)	(None, 45, 45, 32)	
conv2d_32 (Conv2D)	(None, 45, 45, 64)	
batch_normalization_4 (BatchNormalization)	(None, 45, 45, 64)	
conv2d_33 (Conv2D)	(None, 45, 45, 64)	
batch_normalization_5 (BatchNormalization)	(None, 45, 45, 64)	
max_pooling2d_13 (MaxPooling2D)	(None, 22, 22, 64)	
dropout_19 (Dropout)	(None, 22, 22, 64)	
conv2d_34 (Conv2D)	(None, 22, 22, 128)	
batch_normalization_6 (BatchNormalization)	(None, 22, 22, 128)	
conv2d_35 (Conv2D)	(None, 22, 22, 128)	:
batch_normalization_7 (BatchNormalization)	(None, 22, 22, 128)	
max_pooling2d_14 (MaxPooling2D)	(None, 11, 11, 128)	
dropout_20 (Dropout)	(None, 11, 11, 128)	
flatten_5 (Flatten)	(None, 15488)	
dense_11 (Dense)	(None, 128)	1,9
batch_normalization_8 (BatchNormalization)	(None, 128)	
dropout_21 (Dropout)	(None, 128)	
dense_12 (Dense)	(None, 13)	

Total params: 2,273,581 (8.67 MB)

Trainable params: 2,272,429 (8.67 MB)

Non-trainable params: 1,152 (4.50 KB)

```
Epoch 1/50
374/374 0s 406ms/step - accuracy: 0.3349 - loss: 2.30
02
Epoch 1: val_accuracy did not improve from 0.89190
374/374 164s 432ms/step - accuracy: 0.4429 - loss: 1.
8766 - val_accuracy: 0.3333 - val_loss: 2.1298
Epoch 2/50
374/374 0s 407ms/step - accuracy: 0.6180 - loss: 1.22
16
Epoch 2: val_accuracy did not improve from 0.89190
374/374 160s 428ms/step - accuracy: 0.6450 - loss: 1.
1403 - val_accuracy: 0.6386 - val_loss: 1.2037
Epoch 3/50
374/374 0s 401ms/step - accuracy: 0.6814 - loss: 1.03
68
Epoch 3: val_accuracy did not improve from 0.89190
374/374 158s 421ms/step - accuracy: 0.6958 - loss: 0.
9807 - val_accuracy: 0.7246 - val_loss: 1.0485
Epoch 4/50
374/374 0s 403ms/step - accuracy: 0.8010 - loss: 0.63
52
Epoch 4: val_accuracy did not improve from 0.89190
374/374 159s 424ms/step - accuracy: 0.8067 - loss: 0.
6288 - val_accuracy: 0.7871 - val_loss: 0.7019
Epoch 5/50
374/374 0s 408ms/step - accuracy: 0.8430 - loss: 0.50
34
Epoch 5: val_accuracy did not improve from 0.89190
374/374 161s 429ms/step - accuracy: 0.8502 - loss: 0.
4742 - val_accuracy: 0.8256 - val_loss: 0.5595
Epoch 6/50
374/374 0s 411ms/step - accuracy: 0.8768 - loss: 0.38
99
Epoch 6: val_accuracy did not improve from 0.89190
374/374 161s 432ms/step - accuracy: 0.8801 - loss: 0.
3824 - val_accuracy: 0.8598 - val_loss: 0.4672
Epoch 7/50
374/374 0s 399ms/step - accuracy: 0.9085 - loss: 0.30
01
Epoch 7: val_accuracy did not improve from 0.89190
374/374 157s 421ms/step - accuracy: 0.9076 - loss: 0.
3029 - val_accuracy: 0.8574 - val_loss: 0.5024
Epoch 8/50
374/374 0s 404ms/step - accuracy: 0.9339 - loss: 0.21
88
Epoch 8: val_accuracy did not improve from 0.89190
374/374 159s 425ms/step - accuracy: 0.9222 - loss: 0.
2471 - val_accuracy: 0.8775 - val_loss: 0.3915
Epoch 9/50
374/374 0s 400ms/step - accuracy: 0.9406 - loss: 0.19
40
Epoch 9: val_accuracy did not improve from 0.89190
374/374 157s 421ms/step - accuracy: 0.9354 - loss: 0.
2060 - val_accuracy: 0.8712 - val_loss: 0.4479
Epoch 10/50
374/374 0s 404ms/step - accuracy: 0.9438 - loss: 0.18
64
Epoch 10: val_accuracy did not improve from 0.89190
374/374 159s 425ms/step - accuracy: 0.9404 - loss: 0.
1929 - val_accuracy: 0.8568 - val_loss: 0.5091
```

```
Epoch 11/50
374/374 0s 400ms/step - accuracy: 0.9562 - loss: 0.13
29
Epoch 11: val_accuracy did not improve from 0.89190
374/374 157s 421ms/step - accuracy: 0.9558 - loss: 0.
1392 - val_accuracy: 0.8738 - val_loss: 0.4640
Epoch 12/50
374/374 0s 428ms/step - accuracy: 0.9614 - loss: 0.12
13
Epoch 12: val_accuracy did not improve from 0.89190
374/374 169s 451ms/step - accuracy: 0.9569 - loss: 0.
1315 - val_accuracy: 0.8865 - val_loss: 0.4249
Epoch 13/50
374/374 0s 403ms/step - accuracy: 0.9645 - loss: 0.11
86
Epoch 13: val_accuracy did not improve from 0.89190
374/374 159s 424ms/step - accuracy: 0.9571 - loss: 0.
1401 - val_accuracy: 0.8892 - val_loss: 0.4127
Epoch 14/50
374/374 0s 401ms/step - accuracy: 0.9628 - loss: 0.11
46
Epoch 14: val_accuracy did not improve from 0.89190
374/374 158s 422ms/step - accuracy: 0.9638 - loss: 0.
1127 - val_accuracy: 0.8892 - val_loss: 0.4414
Epoch 15/50
374/374 0s 411ms/step - accuracy: 0.9730 - loss: 0.08
78
Epoch 15: val_accuracy improved from 0.89190 to 0.91432, saving model to b
est_model.keras
374/374 162s 432ms/step - accuracy: 0.9718 - loss: 0.
0908 - val_accuracy: 0.9143 - val_loss: 0.3363
Epoch 16/50
374/374 0s 413ms/step - accuracy: 0.9687 - loss: 0.09
58
Epoch 16: val_accuracy did not improve from 0.91432
374/374 163s 435ms/step - accuracy: 0.9664 - loss: 0.
1008 - val_accuracy: 0.9120 - val_loss: 0.3269
Epoch 17/50
374/374 0s 407ms/step - accuracy: 0.9724 - loss: 0.08
66
Epoch 17: val_accuracy did not improve from 0.91432
374/374 160s 428ms/step - accuracy: 0.9699 - loss: 0.
0959 - val_accuracy: 0.9100 - val_loss: 0.3595
Epoch 18/50
374/374 0s 415ms/step - accuracy: 0.9707 - loss: 0.08
58
Epoch 18: val_accuracy did not improve from 0.91432
374/374 163s 436ms/step - accuracy: 0.9732 - loss: 0.
0838 - val_accuracy: 0.9093 - val_loss: 0.3518
Epoch 19/50
374/374 0s 409ms/step - accuracy: 0.9798 - loss: 0.06
62
Epoch 19: val_accuracy did not improve from 0.91432
374/374 162s 432ms/step - accuracy: 0.9772 - loss: 0.
0718 - val_accuracy: 0.8896 - val_loss: 0.4428
Epoch 20/50
374/374 0s 418ms/step - accuracy: 0.9765 - loss: 0.07
22
Epoch 20: val_accuracy improved from 0.91432 to 0.91533, saving model to b
est_model.keras
```

```
374/374 ━━━━━━━━━━ 165s 441ms/step - accuracy: 0.9769 - loss: 0.
0732 - val_accuracy: 0.9153 - val_loss: 0.3758
Epoch 21/50
374/374 ━━━━━━━━ 0s 416ms/step - accuracy: 0.9783 - loss: 0.07
03
Epoch 21: val_accuracy did not improve from 0.91533
374/374 ━━━━━━ 164s 439ms/step - accuracy: 0.9758 - loss: 0.
0735 - val_accuracy: 0.7875 - val_loss: 0.9363
Epoch 22/50
374/374 ━━━━━━ 0s 405ms/step - accuracy: 0.9721 - loss: 0.08
60
Epoch 22: val_accuracy did not improve from 0.91533
374/374 ━━━━━━ 160s 426ms/step - accuracy: 0.9739 - loss: 0.
0800 - val_accuracy: 0.9113 - val_loss: 0.3907
Epoch 23/50
374/374 ━━━━━━ 0s 417ms/step - accuracy: 0.9756 - loss: 0.07
83
Epoch 23: val_accuracy did not improve from 0.91533
374/374 ━━━━━━ 164s 439ms/step - accuracy: 0.9762 - loss: 0.
0734 - val_accuracy: 0.9046 - val_loss: 0.3960
Epoch 24/50
374/374 ━━━━━━ 0s 400ms/step - accuracy: 0.9836 - loss: 0.05
15
Epoch 24: val_accuracy did not improve from 0.91533
374/374 ━━━━━━ 158s 422ms/step - accuracy: 0.9828 - loss: 0.
0545 - val_accuracy: 0.9120 - val_loss: 0.3625
Epoch 25/50
374/374 ━━━━━━ 0s 401ms/step - accuracy: 0.9836 - loss: 0.05
55
Epoch 25: val_accuracy did not improve from 0.91533
374/374 ━━━━━━ 158s 422ms/step - accuracy: 0.9808 - loss: 0.
0623 - val_accuracy: 0.9006 - val_loss: 0.4543
Epoch 26/50
374/374 ━━━━━━ 0s 403ms/step - accuracy: 0.9836 - loss: 0.05
29
Epoch 26: val_accuracy did not improve from 0.91533
374/374 ━━━━━━ 159s 424ms/step - accuracy: 0.9806 - loss: 0.
0608 - val_accuracy: 0.8842 - val_loss: 0.4940
Epoch 26: early stopping
Restoring model weights from the end of the best epoch: 16.
Entrenamiento completado.
```

10.3. CNN BatchNormalization - Evaluación

Analisis de resultados de la arquitectura CNN con BatchNormalization.

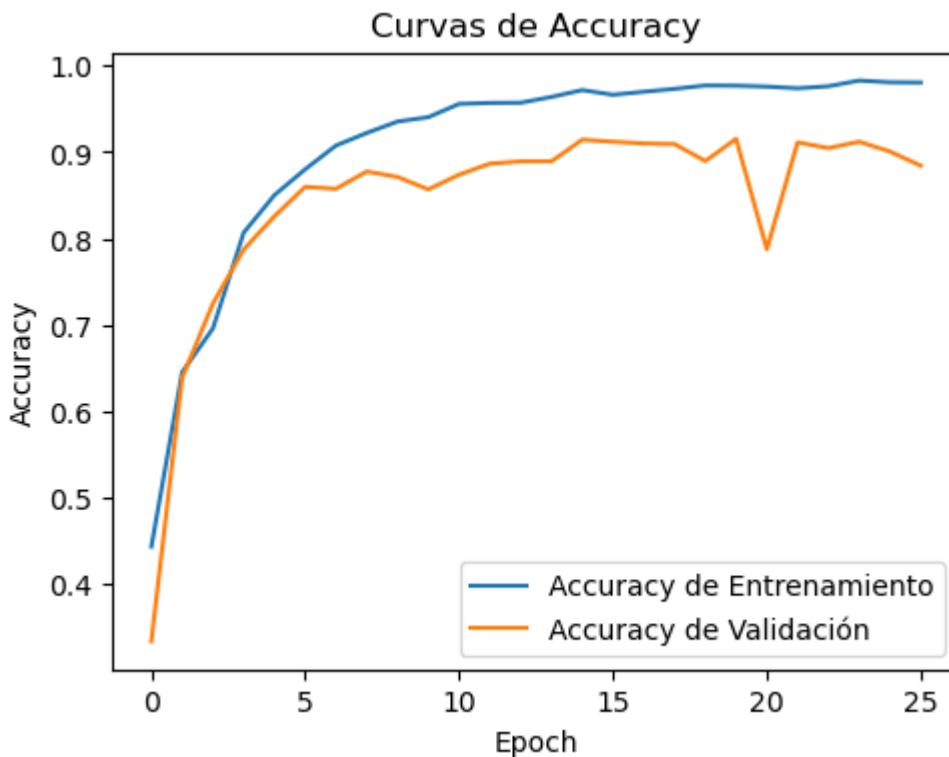
```
In [44]: loss_batch, accuracy_batch = model_batch.evaluate(X_test_std, y_test_ohe,
print(f"Accuracy en test: {accuracy_batch*100:.2f}%")
```

52/52 ━━━━━━ 4s 81ms/step - accuracy: 0.8469 - loss: 0.6237
Accuracy en test: 84.69%

```
In [45]: plt.figure(figsize=(12, 4))
plt.subplot(1, 2, 1)
plt.plot(history_batch.history['accuracy'], label='Accuracy de Entrenamiento')
plt.plot(history_batch.history['val_accuracy'], label='Accuracy de Validación')
plt.xlabel('Epoch')
plt.ylabel('Accuracy')
```

```
plt.legend()
plt.title('Curvas de Accuracy')
```

Out [45]: Text(0.5, 1.0, 'Curvas de Accuracy')



🧠 11. Data Augmentation

Técnica para aumentar artificialmente la cantidad y diversidad de datos de entrenamiento. Esta diversidad de datos se obtiene aplicando transformaciones aleatorias a las imágenes originales (rotaciones, desplazamientos, zoom, flip horizontal, etc.) para generar nuevas variaciones sin recopilar más datos reales.

Ventajas

- Más datos: El modelo ve variaciones del mismo objeto en diferentes contextos
- Mejor generalización: Aprende patrones más robustos, no memoriza específicamente
- Menos overfitting: Reduce la brecha entre entrenamiento y validación
- Eficiencia: Sin costo de recolección adicional

Con la clase `ImageDataGenerator` aplicas transformaciones a las imágenes, cómo los ejemplos:

- Rotaciones $\pm 15^\circ$
- Desplazamientos horizontales/verticales $\pm 10\%$
- Zoom $\pm 15\%$
- Flip horizontal

El resultado es que el modelo entrena con ~3-4x más ejemplos variados del mismo dataset, mejorando su capacidad de reconocer personajes en diferentes poses y

posiciones.

⚙️ 11.1. Data Augmentation - Image Generator y Entrenamiento

Creación del Image Generator configurado para crear las variaciones en las imágenes y utilización del modelo CNN Basico de la primera arquitectura experimentada para empezar el entrenamiento.

```
In [46]: # Creación del generador de datos con aumentos
datagen_aug = ImageDataGenerator(
    rotation_range=20,
    width_shift_range=0.2,
    height_shift_range=0.2,
    horizontal_flip=True,
    zoom_range=0.2,
    shear_range=0.15,
    fill_mode='nearest'
)

# Utiliza el modelo CNN Basico de la primera arquitectura experimentada y
history_aug = model.fit(
    datagen_aug.flow(X_train, y_train, batch_size=BATCH_SIZE),
    epochs=EPOCHS,
    validation_data=(X_val, y_val),
    callbacks=[checkpoint, early_stopping],
    steps_per_epoch=len(X_train)//BATCH_SIZE
)
```

```
Epoch 1/50
373/373 ━━━━━━━━━━━━ 0s 292ms/step - accuracy: 0.6737 - loss: 1.13
82
```

```
Epoch 1: val_accuracy did not improve from 0.91533
373/373 ━━━━━━━━━━━━ 119s 316ms/step - accuracy: 0.6981 - loss: 1.
0045 - val_accuracy: 0.8718 - val_loss: 0.4626
```

```
Epoch 2/50
1/373 ━━━━━━━━━ 2:02 328ms/step - accuracy: 0.7500 - loss: 0.
7531
```

```
/Users/edprata/anaconda3/envs/Python-3-13-2/lib/python3.13/site-packages/k
eras/src/trainers/epoch_iterator.py:116: UserWarning: Your input ran out o
f data; interrupting training. Make sure that your dataset or generator ca
n generate at least `steps_per_epoch * epochs` batches. You may need to us
e the `repeat()` function when building your dataset.
  self._interrupted_warning()
```

```

Epoch 2: val_accuracy did not improve from 0.91533
373/373 7s 19ms/step - accuracy: 0.7500 - loss: 0.753
1 - val_accuracy: 0.8715 - val_loss: 0.4689
Epoch 3/50
373/373 7s 19ms/step - accuracy: 0.7500 - loss: 0.753
1 - val_accuracy: 0.8715 - val_loss: 0.4689
Epoch 3/50
373/373 0s 246ms/step - accuracy: 0.7441 - loss: 0.8643
Epoch 3: val_accuracy did not improve from 0.91533
373/373 98s 263ms/step - accuracy: 0.7464 - loss: 0.8533 - val_accuracy: 0.8825 - val_loss: 0.4259
Epoch 4/50
1/373 1:48 291ms/step - accuracy: 0.8125 - loss: 0.6779
Epoch 4: val_accuracy did not improve from 0.91533
373/373 6s 17ms/step - accuracy: 0.8125 - loss: 0.6779 - val_accuracy: 0.8869 - val_loss: 0.4202
Epoch 5/50
373/373 0s 242ms/step - accuracy: 0.7663 - loss: 0.7578
Epoch 5: val_accuracy did not improve from 0.91533
373/373 96s 258ms/step - accuracy: 0.7684 - loss: 0.7576 - val_accuracy: 0.8909 - val_loss: 0.3922
Epoch 6/50
1/373 1:58 318ms/step - accuracy: 0.8125 - loss: 0.5820
Epoch 6: val_accuracy did not improve from 0.91533
373/373 7s 17ms/step - accuracy: 0.8125 - loss: 0.5820 - val_accuracy: 0.8892 - val_loss: 0.3930
Epoch 7/50
373/373 0s 243ms/step - accuracy: 0.7814 - loss: 0.7059
Epoch 7: val_accuracy did not improve from 0.91533
373/373 97s 259ms/step - accuracy: 0.7827 - loss: 0.7200 - val_accuracy: 0.8815 - val_loss: 0.4345
Epoch 8/50
1/373 1:35 257ms/step - accuracy: 0.8125 - loss: 0.5858
Epoch 8: val_accuracy did not improve from 0.91533
373/373 6s 16ms/step - accuracy: 0.8125 - loss: 0.5858 - val_accuracy: 0.8842 - val_loss: 0.4316
Epoch 9/50
373/373 0s 243ms/step - accuracy: 0.8029 - loss: 0.6611
Epoch 9: val_accuracy did not improve from 0.91533
373/373 97s 259ms/step - accuracy: 0.8013 - loss: 0.6634 - val_accuracy: 0.8902 - val_loss: 0.3778
Epoch 10/50
1/373 1:59 320ms/step - accuracy: 0.7812 - loss: 0.7670
Epoch 10: val_accuracy did not improve from 0.91533
373/373 6s 16ms/step - accuracy: 0.7812 - loss: 0.7670 - val_accuracy: 0.8906 - val_loss: 0.3755
Epoch 10: early stopping
Restoring model weights from the end of the best epoch: 1.

```

11.2. Data Augmentation - Evaluación

Analisis de resultados del modelo CNN entrenado con Data Augmentation.

```
In [70]: loss_aug, accuracy_aug = model.evaluate(X_test_std, y_test_ohe, verbose=1)
print(f"Accuracy en test (CNN con hiperparámetros ajustados): {accuracy_a
52/52 ━━━━━━━━━━ 4s 81ms/step - accuracy: 0.8252 - loss: 0.6449
Accuracy en test (CNN con hiperparámetros ajustados): 82.52%
```

13. CNN con Optimizers

Experimentación de Optimizers para intentar obtener resultados mejores. Un Optimizer es un algoritmo que actualiza los pesos de la red neuronal durante el entrenamiento para minimizar la función de pérdida (error). Los Optimizers utilizados:

- Adam: Adaptativo, combina momentum y RMSprop, convergencia rápida, eficiente, ideal para deep learning.
- RMSprop: Adaptativo, ajusta learning rate por parámetro, es estable, bueno para redes recurrentes.
- Nadam: Adam + Nesterov momentum, mejor convergencia que Adam en algunos casos.
- SGD: Descenso de gradiente estocástico clásico, simple, pero necesita ajuste fino del learning rate.

Optimizers adaptativos (Adam, RMSprop, Nadam) ajustan automáticamente el learning rate para cada parámetro. Son más robustos y generalizan mejor. Los clásicos (como SGD) usan un learning rate fijo y requieren más configuraciones, pero puede ser muy preciso si se ajusta bien.

13.1. CNN con Optimizers - Configuración y Entrenamiento

Configuración de diferentes optimizadores para comparar los resultados.

```
In [48]: # Configuración de diferentes optimizadores para comparar
optimizers = {
    "Adam": Adam(learning_rate=0.001),
    "RMSprop": RMSprop(learning_rate=0.001),
    "Nadam": Nadam(learning_rate=0.001),
    "SGD": SGD(learning_rate=0.002, momentum=0.9)
}

# Diccionario para guardar resultados
results = {}

# Early stopping para evitar overfitting
early_stopping = EarlyStopping(monitor='val_loss', patience=15, restore_b

# Bucle para entrenar y evaluar el modelo con cada optimizador
for name, opt in optimizers.items():
    print(f"\n==== Entrenando con {name} ====")

    # Copiamos la arquitectura profunda
    model_compare = Sequential([
        Conv2D(32, (3,3), activation='relu', padding='same', input_shape=
```

```
Conv2D(32, (3,3), activation='relu', padding='same'),
MaxPooling2D((2,2)),
Dropout(0.25),

Conv2D(64, (3,3), activation='relu', padding='same'),
Conv2D(64, (3,3), activation='relu', padding='same'),
MaxPooling2D((2,2)),
Dropout(0.25),

Conv2D(128, (3,3), activation='relu', padding='same'),
Conv2D(128, (3,3), activation='relu', padding='same'),
MaxPooling2D((2,2)),
Dropout(0.25),

Flatten(),
Dense(128, activation='relu'),
Dropout(0.5),
Dense(num_classes, activation='softmax')
)

# Compilamos el modelo con el optimizador actual
model_compare.compile(optimizer=opt, loss='categorical_crossentropy',

# Entrenamos el modelo
history = model_compare.fit(
    X_train, y_train,
    validation_data=(X_val, y_val),
    epochs=EPOCHS,
    batch_size=BATCH_SIZE,
    callbacks=[early_stopping],
    verbose=1
)

# Evaluamos el modelo en el conjunto de test
loss, acc = model_compare.evaluate(X_test_std, y_test_ohe, verbose=1)
results[name] = {"history": history, "test_accuracy": acc}
print(f"Test accuracy con {name}: {acc*100:.2f}%")
```

==== Entrenando con Adam ====
Epoch 1/50
374/374 99s 259ms/step - accuracy: 0.2031 - loss: 2.3
408 - val_accuracy: 0.3929 - val_loss: 1.9302
Epoch 2/50
374/374 95s 254ms/step - accuracy: 0.4137 - loss: 1.7
984 - val_accuracy: 0.5847 - val_loss: 1.3457
Epoch 3/50
374/374 95s 254ms/step - accuracy: 0.5389 - loss: 1.4
165 - val_accuracy: 0.6178 - val_loss: 1.1965
Epoch 4/50
374/374 95s 253ms/step - accuracy: 0.6193 - loss: 1.1
572 - val_accuracy: 0.7299 - val_loss: 0.8654
Epoch 5/50
374/374 96s 256ms/step - accuracy: 0.6981 - loss: 0.9
285 - val_accuracy: 0.7597 - val_loss: 0.7420
Epoch 6/50
374/374 98s 261ms/step - accuracy: 0.7451 - loss: 0.7
794 - val_accuracy: 0.8119 - val_loss: 0.6214
Epoch 7/50
374/374 95s 255ms/step - accuracy: 0.7827 - loss: 0.6
589 - val_accuracy: 0.8320 - val_loss: 0.5721
Epoch 8/50
374/374 97s 260ms/step - accuracy: 0.8226 - loss: 0.5
434 - val_accuracy: 0.8447 - val_loss: 0.5545
Epoch 9/50
374/374 96s 257ms/step - accuracy: 0.8411 - loss: 0.4
947 - val_accuracy: 0.8464 - val_loss: 0.5058
Epoch 10/50
374/374 95s 253ms/step - accuracy: 0.8611 - loss: 0.4
178 - val_accuracy: 0.8511 - val_loss: 0.5287
Epoch 11/50
374/374 95s 254ms/step - accuracy: 0.8736 - loss: 0.3
753 - val_accuracy: 0.8638 - val_loss: 0.4894
Epoch 12/50
374/374 95s 254ms/step - accuracy: 0.8822 - loss: 0.3
526 - val_accuracy: 0.8661 - val_loss: 0.4668
Epoch 13/50
374/374 95s 253ms/step - accuracy: 0.8975 - loss: 0.3
099 - val_accuracy: 0.8665 - val_loss: 0.4979
Epoch 14/50
374/374 96s 256ms/step - accuracy: 0.9064 - loss: 0.2
872 - val_accuracy: 0.8849 - val_loss: 0.5245
Epoch 15/50
374/374 96s 257ms/step - accuracy: 0.9104 - loss: 0.2
685 - val_accuracy: 0.8762 - val_loss: 0.5333
Epoch 16/50
374/374 95s 254ms/step - accuracy: 0.9195 - loss: 0.2
412 - val_accuracy: 0.8832 - val_loss: 0.4857
Epoch 17/50
374/374 95s 253ms/step - accuracy: 0.9246 - loss: 0.2
274 - val_accuracy: 0.8772 - val_loss: 0.4963
Epoch 18/50
374/374 94s 252ms/step - accuracy: 0.9263 - loss: 0.2
270 - val_accuracy: 0.8752 - val_loss: 0.5199
Epoch 19/50
374/374 94s 253ms/step - accuracy: 0.9282 - loss: 0.2
186 - val_accuracy: 0.8792 - val_loss: 0.5354
Epoch 20/50
374/374 95s 254ms/step - accuracy: 0.9391 - loss: 0.1

```
821 - val_accuracy: 0.8926 - val_loss: 0.5090
Epoch 21/50
374/374 95s 253ms/step - accuracy: 0.9353 - loss: 0.2
024 - val_accuracy: 0.8872 - val_loss: 0.4927
Epoch 22/50
374/374 95s 254ms/step - accuracy: 0.9403 - loss: 0.1
904 - val_accuracy: 0.8886 - val_loss: 0.4895
Epoch 23/50
374/374 95s 253ms/step - accuracy: 0.9438 - loss: 0.1
699 - val_accuracy: 0.8845 - val_loss: 0.5582
Epoch 24/50
374/374 96s 256ms/step - accuracy: 0.9467 - loss: 0.1
707 - val_accuracy: 0.8966 - val_loss: 0.5064
Epoch 25/50
374/374 95s 253ms/step - accuracy: 0.9484 - loss: 0.1
595 - val_accuracy: 0.8896 - val_loss: 0.4969
Epoch 26/50
374/374 95s 254ms/step - accuracy: 0.9510 - loss: 0.1
525 - val_accuracy: 0.8902 - val_loss: 0.5961
Epoch 27/50
374/374 97s 259ms/step - accuracy: 0.9480 - loss: 0.1
617 - val_accuracy: 0.8869 - val_loss: 0.6075
Epoch 27: early stopping
Restoring model weights from the end of the best epoch: 12.
52/52 3s 64ms/step - accuracy: 0.7973 - loss: 0.7256
Test accuracy con Adam: 79.73%
```

== Entrenando con RMSprop ==

```
Epoch 1/50
374/374 101s 266ms/step - accuracy: 0.2261 - loss: 2.
2893 - val_accuracy: 0.4475 - val_loss: 1.7927
Epoch 2/50
374/374 95s 255ms/step - accuracy: 0.4824 - loss: 1.6
198 - val_accuracy: 0.5987 - val_loss: 1.2711
Epoch 3/50
374/374 95s 254ms/step - accuracy: 0.6359 - loss: 1.1
694 - val_accuracy: 0.7400 - val_loss: 0.8446
Epoch 4/50
374/374 98s 262ms/step - accuracy: 0.7268 - loss: 0.8
858 - val_accuracy: 0.7323 - val_loss: 1.0580
Epoch 5/50
374/374 95s 253ms/step - accuracy: 0.7833 - loss: 0.7
101 - val_accuracy: 0.8072 - val_loss: 0.7105
Epoch 6/50
374/374 96s 257ms/step - accuracy: 0.8186 - loss: 0.6
040 - val_accuracy: 0.8384 - val_loss: 0.5448
Epoch 7/50
374/374 96s 256ms/step - accuracy: 0.8482 - loss: 0.5
000 - val_accuracy: 0.8444 - val_loss: 0.5284
Epoch 8/50
374/374 95s 255ms/step - accuracy: 0.8682 - loss: 0.4
491 - val_accuracy: 0.8614 - val_loss: 0.4639
Epoch 9/50
374/374 96s 256ms/step - accuracy: 0.8760 - loss: 0.4
253 - val_accuracy: 0.8745 - val_loss: 0.4368
Epoch 10/50
374/374 95s 254ms/step - accuracy: 0.8868 - loss: 0.3
993 - val_accuracy: 0.8253 - val_loss: 1.0652
Epoch 11/50
374/374 96s 257ms/step - accuracy: 0.8932 - loss: 0.3
```

757 - val_accuracy: 0.8645 - val_loss: 0.6293
Epoch 12/50
374/374 96s 257ms/step - accuracy: 0.8930 - loss: 0.3
671 - val_accuracy: 0.8551 - val_loss: 0.7419
Epoch 13/50
374/374 95s 255ms/step - accuracy: 0.8971 - loss: 0.3
696 - val_accuracy: 0.8922 - val_loss: 0.5058
Epoch 14/50
374/374 95s 255ms/step - accuracy: 0.8983 - loss: 0.3
568 - val_accuracy: 0.8855 - val_loss: 0.7072
Epoch 15/50
374/374 95s 254ms/step - accuracy: 0.8980 - loss: 0.3
755 - val_accuracy: 0.8835 - val_loss: 0.7475
Epoch 16/50
374/374 96s 257ms/step - accuracy: 0.9062 - loss: 0.3
708 - val_accuracy: 0.8681 - val_loss: 1.0282
Epoch 17/50
374/374 96s 257ms/step - accuracy: 0.9038 - loss: 0.3
887 - val_accuracy: 0.8799 - val_loss: 0.8042
Epoch 18/50
374/374 96s 258ms/step - accuracy: 0.8996 - loss: 0.3
954 - val_accuracy: 0.8979 - val_loss: 0.5128
Epoch 19/50
374/374 96s 257ms/step - accuracy: 0.9053 - loss: 0.3
690 - val_accuracy: 0.8598 - val_loss: 0.5327
Epoch 20/50
374/374 98s 260ms/step - accuracy: 0.9046 - loss: 0.3
749 - val_accuracy: 0.8842 - val_loss: 0.5626
Epoch 21/50
374/374 96s 257ms/step - accuracy: 0.9024 - loss: 0.3
825 - val_accuracy: 0.8531 - val_loss: 0.8421
Epoch 22/50
374/374 96s 256ms/step - accuracy: 0.9072 - loss: 0.3
801 - val_accuracy: 0.9023 - val_loss: 0.5745
Epoch 23/50
374/374 95s 255ms/step - accuracy: 0.9025 - loss: 0.4
000 - val_accuracy: 0.8608 - val_loss: 0.6022
Epoch 24/50
374/374 95s 255ms/step - accuracy: 0.9024 - loss: 0.4
126 - val_accuracy: 0.8450 - val_loss: 0.6663
Epoch 24: early stopping
Restoring model weights from the end of the best epoch: 9.
52/52 3s 65ms/step - accuracy: 0.8179 - loss: 0.6790
Test accuracy con RMSprop: 81.79%

==== Entrenando con Nadam ====
Epoch 1/50
374/374 100s 263ms/step - accuracy: 0.2714 - loss: 2.
1736 - val_accuracy: 0.5375 - val_loss: 1.5432
Epoch 2/50
374/374 96s 257ms/step - accuracy: 0.5244 - loss: 1.4
708 - val_accuracy: 0.6958 - val_loss: 1.0577
Epoch 3/50
374/374 97s 259ms/step - accuracy: 0.6584 - loss: 1.0
833 - val_accuracy: 0.7456 - val_loss: 0.8477
Epoch 4/50
374/374 98s 263ms/step - accuracy: 0.7364 - loss: 0.8
129 - val_accuracy: 0.7811 - val_loss: 0.7253
Epoch 5/50
374/374 98s 261ms/step - accuracy: 0.7954 - loss: 0.6

```
403 - val_accuracy: 0.8283 - val_loss: 0.5831
Epoch 6/50
374/374 96s 258ms/step - accuracy: 0.8335 - loss: 0.5
237 - val_accuracy: 0.8497 - val_loss: 0.5249
Epoch 7/50
374/374 96s 258ms/step - accuracy: 0.8635 - loss: 0.4
256 - val_accuracy: 0.8668 - val_loss: 0.4949
Epoch 8/50
374/374 96s 257ms/step - accuracy: 0.8778 - loss: 0.3
747 - val_accuracy: 0.8825 - val_loss: 0.4563
Epoch 9/50
374/374 96s 257ms/step - accuracy: 0.9003 - loss: 0.3
148 - val_accuracy: 0.8832 - val_loss: 0.4133
Epoch 10/50
374/374 96s 256ms/step - accuracy: 0.9101 - loss: 0.2
723 - val_accuracy: 0.8825 - val_loss: 0.4691
Epoch 11/50
374/374 96s 256ms/step - accuracy: 0.9230 - loss: 0.2
492 - val_accuracy: 0.8979 - val_loss: 0.4381
Epoch 12/50
374/374 97s 259ms/step - accuracy: 0.9293 - loss: 0.2
276 - val_accuracy: 0.8929 - val_loss: 0.4193
Epoch 13/50
374/374 97s 261ms/step - accuracy: 0.9345 - loss: 0.2
040 - val_accuracy: 0.9023 - val_loss: 0.4473
Epoch 14/50
374/374 96s 258ms/step - accuracy: 0.9402 - loss: 0.1
871 - val_accuracy: 0.8976 - val_loss: 0.4236
Epoch 15/50
374/374 96s 257ms/step - accuracy: 0.9442 - loss: 0.1
782 - val_accuracy: 0.8952 - val_loss: 0.5046
Epoch 16/50
374/374 96s 257ms/step - accuracy: 0.9464 - loss: 0.1
671 - val_accuracy: 0.9023 - val_loss: 0.4321
Epoch 17/50
374/374 97s 258ms/step - accuracy: 0.9514 - loss: 0.1
581 - val_accuracy: 0.8956 - val_loss: 0.4711
Epoch 18/50
374/374 96s 258ms/step - accuracy: 0.9510 - loss: 0.1
544 - val_accuracy: 0.9009 - val_loss: 0.4794
Epoch 19/50
374/374 97s 259ms/step - accuracy: 0.9556 - loss: 0.1
440 - val_accuracy: 0.9023 - val_loss: 0.4692
Epoch 20/50
374/374 99s 264ms/step - accuracy: 0.9575 - loss: 0.1
378 - val_accuracy: 0.8946 - val_loss: 0.5046
Epoch 21/50
374/374 97s 258ms/step - accuracy: 0.9534 - loss: 0.1
465 - val_accuracy: 0.8993 - val_loss: 0.4899
Epoch 22/50
374/374 96s 257ms/step - accuracy: 0.9580 - loss: 0.1
286 - val_accuracy: 0.9076 - val_loss: 0.4428
Epoch 23/50
374/374 97s 259ms/step - accuracy: 0.9606 - loss: 0.1
248 - val_accuracy: 0.9076 - val_loss: 0.5006
Epoch 24/50
374/374 97s 260ms/step - accuracy: 0.9618 - loss: 0.1
186 - val_accuracy: 0.9013 - val_loss: 0.5020
Epoch 24: early stopping
Restoring model weights from the end of the best epoch: 9.
```

```

52/52 3s 64ms/step - accuracy: 0.8294 - loss: 0.6665
Test accuracy con Nadam: 82.94%

== Entrenando con SGD ==
Epoch 1/50
374/374 102s 264ms/step - accuracy: 0.1373 - loss: 2.
5173 - val_accuracy: 0.2172 - val_loss: 2.4157
Epoch 2/50
374/374 95s 254ms/step - accuracy: 0.2603 - loss: 2.2
296 - val_accuracy: 0.3869 - val_loss: 1.9927
Epoch 3/50
374/374 100s 267ms/step - accuracy: 0.3582 - loss: 1.
9668 - val_accuracy: 0.4618 - val_loss: 1.7532
Epoch 4/50
374/374 97s 259ms/step - accuracy: 0.4297 - loss: 1.7
609 - val_accuracy: 0.5442 - val_loss: 1.4754
Epoch 5/50
374/374 95s 254ms/step - accuracy: 0.4910 - loss: 1.5
988 - val_accuracy: 0.5693 - val_loss: 1.4222
Epoch 6/50
374/374 94s 251ms/step - accuracy: 0.5294 - loss: 1.4
632 - val_accuracy: 0.6188 - val_loss: 1.2456
Epoch 7/50
374/374 95s 255ms/step - accuracy: 0.5789 - loss: 1.3
246 - val_accuracy: 0.6118 - val_loss: 1.2323
Epoch 8/50
374/374 95s 253ms/step - accuracy: 0.6134 - loss: 1.2
110 - val_accuracy: 0.6814 - val_loss: 1.0186
Epoch 9/50
374/374 95s 255ms/step - accuracy: 0.6544 - loss: 1.0
884 - val_accuracy: 0.7075 - val_loss: 0.9326
Epoch 10/50
374/374 97s 259ms/step - accuracy: 0.6832 - loss: 0.9
906 - val_accuracy: 0.7279 - val_loss: 0.8886
Epoch 11/50
374/374 96s 256ms/step - accuracy: 0.7231 - loss: 0.8
648 - val_accuracy: 0.7604 - val_loss: 0.7811
Epoch 12/50
374/374 94s 252ms/step - accuracy: 0.7373 - loss: 0.7
986 - val_accuracy: 0.7614 - val_loss: 0.7813
Epoch 13/50
374/374 95s 254ms/step - accuracy: 0.7656 - loss: 0.7
107 - val_accuracy: 0.8039 - val_loss: 0.6699
Epoch 14/50
374/374 95s 254ms/step - accuracy: 0.7895 - loss: 0.6
477 - val_accuracy: 0.8129 - val_loss: 0.6227
Epoch 15/50
374/374 95s 254ms/step - accuracy: 0.8093 - loss: 0.5
752 - val_accuracy: 0.7972 - val_loss: 0.6635
Epoch 15: early stopping
Restoring model weights from the end of the best epoch: 1.
52/52 3s 65ms/step - accuracy: 0.1960 - loss: 2.4379
Test accuracy con SGD: 19.60%

```

13.2. CNN con Optimizers - Evaluación

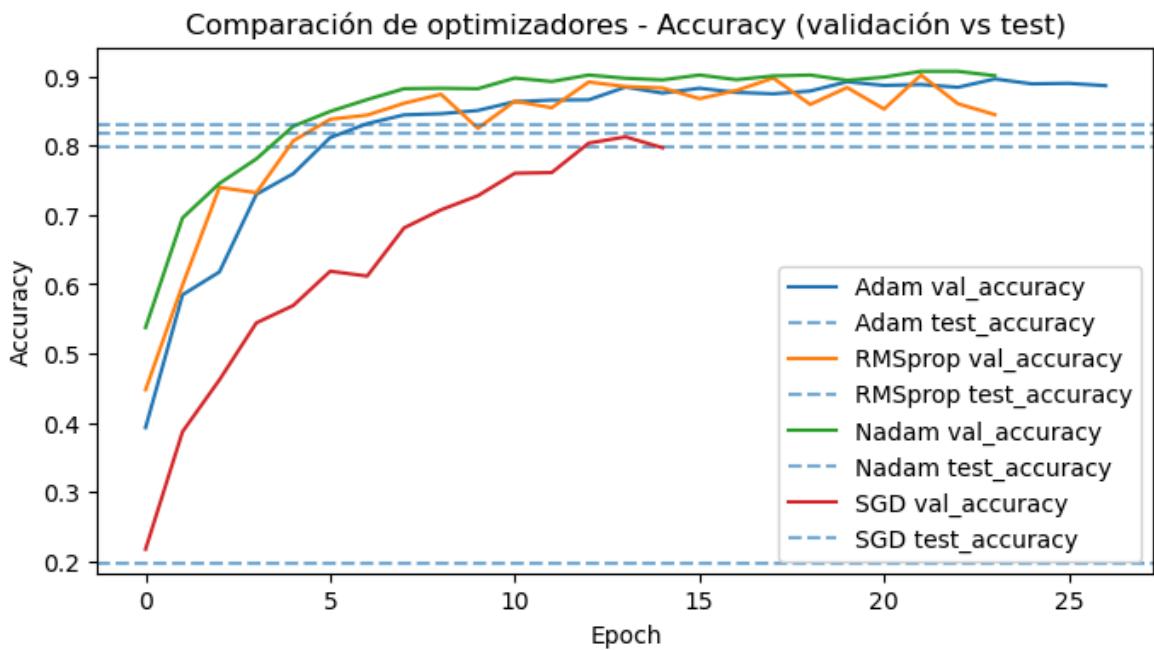
Analisis de resultados de la arquitectura CNN con diferentes Optimizers.

```
In [49]: plt.figure(figsize=(8,4))

for name, res in results.items():
    # Curva de validación
    plt.plot(
        res["history"].history['val_accuracy'],
        label=f"{name} val_accuracy"
    )

    # Línea horizontal de test accuracy
    plt.axhline(
        y=res["test_accuracy"],
        linestyle='--',
        alpha=0.6,
        label=f"{name} test_accuracy"
    )

plt.title("Comparación de optimizadores – Accuracy (validación vs test)")
plt.xlabel("Epoch")
plt.ylabel("Accuracy")
plt.legend()
plt.show()
```



⌚ 13.3. CNN con Optimizers - Conclusión

Los resultados indican que los **optimizadores adaptativos** generalizan mucho mejor en este problema de clasificación de imágenes. Adam y Nadam muestran una convergencia más estable y una mejor capacidad para ajustar los pesos en redes profundas, mientras que RMSprop presenta un aprendizaje limitado. Por el contrario, SGD tiene grandes dificultades para converger, lo que sugiere que, sin una configuración muy fina o muchas más épocas, no es adecuado para este tipo de arquitectura y dataset. En este contexto, los optimizadores adaptativos resultan claramente más efectivos que los métodos de descenso de gradiente clásicos.

14. CNN Tuned (+BatchNormalization +DA +Nadam)

Con el objetivo de lograr una precisión superior al 85%, se utilizarán junto con las técnicas más exitosas hasta ahora con CNN: BatchNormalization, Data Augmentation y Optimizer Nadam.



14.1. CNN Tuned - Definición de la arquitectura

Se utilizará la primera arquitectura intentada, porque logró la mayor accuracy, añadiendo capas de BatchNormalization porque aumentó el accuracy en otro experimento.

```
In [71]: model_tunned = Sequential([
    Conv2D(32, (3, 3), activation='relu', padding='same', input_shape=(IM
    BatchNormalization(),
    Conv2D(32, (3, 3), activation='relu', padding='same'),
    BatchNormalization(),
    MaxPooling2D((2, 2)),
    Dropout(0.25),

    Conv2D(64, (3, 3), activation='relu', padding='same'),
    BatchNormalization(),
    Conv2D(64, (3, 3), activation='relu', padding='same'),
    BatchNormalization(),
    MaxPooling2D((2, 2)),
    Dropout(0.25),

    Conv2D(128, (3, 3), activation='relu', padding='same'),
    BatchNormalization(),
    Conv2D(128, (3, 3), activation='relu', padding='same'),
    BatchNormalization(),
    MaxPooling2D((2, 2)),
    Dropout(0.25),

    Flatten(),
    Dense(128, activation='relu'),
    BatchNormalization(),
    Dropout(0.5),
    Dense(num_classes, activation='softmax')
])
print("Modelo con Batch Normalization definido.")
```

Modelo con Batch Normalization definido.



14.2. CNN Tuned - Data Augmentation

Creación del Image Generator configurado para crear las variaciones en las imágenes y utilización del modelo CNN Basico de la primera arquitectura experimentada para empezar el entrenamiento.

```
In [72]: datagen_aug2 = ImageDataGenerator(
    rotation_range=20,
```

```
width_shift_range=0.2,  
height_shift_range=0.2,  
horizontal_flip=True,  
zoom_range=0.2,  
shear_range=0.15,  
fill_mode='nearest'  
)
```

14.3. CNN Tunned - Compilación con Optimizer Nadan

Compilación utilizando Optimizer Nadan que presentó mejor resultado en experimentos anteriores.

```
In [73]: # Compilar el modelo  
model_tunned.compile(optimizer=Nadam(learning_rate=0.001), loss='categori  
  
# Mostrar un resumen del modelo  
model_tunned.summary()
```

Model: "sequential_11"

Layer (type)	Output Shape	
conv2d_60 (Conv2D)	(None, 90, 90, 32)	
batch_normalization_9 (BatchNormalization)	(None, 90, 90, 32)	
conv2d_61 (Conv2D)	(None, 90, 90, 32)	
batch_normalization_10 (BatchNormalization)	(None, 90, 90, 32)	
max_pooling2d_27 (MaxPooling2D)	(None, 45, 45, 32)	
dropout_40 (Dropout)	(None, 45, 45, 32)	
conv2d_62 (Conv2D)	(None, 45, 45, 64)	
batch_normalization_11 (BatchNormalization)	(None, 45, 45, 64)	
conv2d_63 (Conv2D)	(None, 45, 45, 64)	
batch_normalization_12 (BatchNormalization)	(None, 45, 45, 64)	
max_pooling2d_28 (MaxPooling2D)	(None, 22, 22, 64)	
dropout_41 (Dropout)	(None, 22, 22, 64)	
conv2d_64 (Conv2D)	(None, 22, 22, 128)	
batch_normalization_13 (BatchNormalization)	(None, 22, 22, 128)	
conv2d_65 (Conv2D)	(None, 22, 22, 128)	:
batch_normalization_14 (BatchNormalization)	(None, 22, 22, 128)	
max_pooling2d_29 (MaxPooling2D)	(None, 11, 11, 128)	
dropout_42 (Dropout)	(None, 11, 11, 128)	
flatten_10 (Flatten)	(None, 15488)	
dense_25 (Dense)	(None, 128)	1,9
batch_normalization_15 (BatchNormalization)	(None, 128)	
dropout_43 (Dropout)	(None, 128)	
dense_26 (Dense)	(None, 13)	

Total params: 2,273,581 (8.67 MB)

Trainable params: 2,272,429 (8.67 MB)

Non-trainable params: 1,152 (4.50 KB)

14.4. CNN Tuned - Compilación y Entrenamiento

Compilación y entrenamiento del modelo en la arquitectura CNN utilizando BatchNormalization, Data Augmentation y Optimizer Nadan.

```
In [75]: history_aug = model_tunned.fit(  
    datagen_aug2.flow(X_train, y_train, batch_size=BATCH_SIZE),  
    epochs=EPOCHS,  
    batch_size=BATCH_SIZE,  
    validation_data=(X_val, y_val),  
    callbacks=[checkpoint, early_stopping],  
    steps_per_epoch=len(X_train)//BATCH_SIZE  
)  
  
print("Entrenamiento completado.")
```

Epoch 1/50
373/373 0s 506ms/step - accuracy: 0.3051 - loss: 2.33
68
Epoch 1: val_accuracy did not improve from 0.91533
373/373 200s 531ms/step - accuracy: 0.3453 - loss: 2.
1822 - val_accuracy: 0.2982 - val_loss: 2.1525
Epoch 2/50
1/373 2:52 465ms/step - accuracy: 0.4375 - loss: 1.
8625

```
/Users/edprata/anaconda3/envs/Python-3-13-2/lib/python3.13/site-packages/k  
eras/src/trainers/epoch_iterator.py:116: UserWarning: Your input ran out o  
f data; interrupting training. Make sure that your dataset or generator ca  
n generate at least `steps_per_epoch * epochs` batches. You may need to us  
e the `repeat()` function when building your dataset.  
    self._interrupted_warning()
```

```
Epoch 2: val_accuracy did not improve from 0.91533
373/373 8s 21ms/step - accuracy: 0.4375 - loss: 1.862
5 - val_accuracy: 0.2992 - val_loss: 2.1409
Epoch 3/50
373/373 8s 21ms/step - accuracy: 0.4375 - loss: 1.862
5 - val_accuracy: 0.2992 - val_loss: 2.1409
Epoch 3/50
373/373 0s 403ms/step - accuracy: 0.4696 - loss: 1.72
29
Epoch 3: val_accuracy did not improve from 0.91533
373/373 158s 424ms/step - accuracy: 0.4982 - loss: 1.
6191 - val_accuracy: 0.5077 - val_loss: 1.5421
Epoch 4/50
1/373 2:57 478ms/step - accuracy: 0.4375 - loss: 2.
0483
Epoch 4: val_accuracy did not improve from 0.91533
373/373 7s 19ms/step - accuracy: 0.4375 - loss: 2.048
3 - val_accuracy: 0.5810 - val_loss: 1.3036
Epoch 5/50
373/373 0s 357ms/step - accuracy: 0.5728 - loss: 1.35
24
Epoch 5: val_accuracy did not improve from 0.91533
373/373 140s 375ms/step - accuracy: 0.5964 - loss: 1.
2764 - val_accuracy: 0.7239 - val_loss: 0.8562
Epoch 6/50
1/373 2:58 481ms/step - accuracy: 0.6250 - loss: 1.
1282
Epoch 6: val_accuracy did not improve from 0.91533
373/373 8s 19ms/step - accuracy: 0.6250 - loss: 1.128
2 - val_accuracy: 0.7262 - val_loss: 0.8646
Epoch 7/50
373/373 0s 359ms/step - accuracy: 0.6866 - loss: 1.00
52
Epoch 7: val_accuracy did not improve from 0.91533
373/373 141s 378ms/step - accuracy: 0.7012 - loss: 0.
9509 - val_accuracy: 0.7741 - val_loss: 0.7228
Epoch 8/50
1/373 2:47 451ms/step - accuracy: 0.6875 - loss: 0.
8289
Epoch 8: val_accuracy did not improve from 0.91533
373/373 7s 19ms/step - accuracy: 0.6875 - loss: 0.828
9 - val_accuracy: 0.7631 - val_loss: 0.7605
Epoch 9/50
373/373 0s 364ms/step - accuracy: 0.7509 - loss: 0.78
31
Epoch 9: val_accuracy did not improve from 0.91533
373/373 143s 384ms/step - accuracy: 0.7582 - loss: 0.
7642 - val_accuracy: 0.8069 - val_loss: 0.6229
Epoch 10/50
1/373 3:09 508ms/step - accuracy: 0.7500 - loss: 0.
8200
Epoch 10: val_accuracy did not improve from 0.91533
373/373 7s 19ms/step - accuracy: 0.7500 - loss: 0.820
0 - val_accuracy: 0.8139 - val_loss: 0.6041
Epoch 11/50
373/373 0s 383ms/step - accuracy: 0.7805 - loss: 0.70
52
Epoch 11: val_accuracy did not improve from 0.91533
373/373 150s 402ms/step - accuracy: 0.7878 - loss: 0.
6843 - val_accuracy: 0.8628 - val_loss: 0.4478
```

```

Epoch 12/50
 1/373 ━━━━━━━━━━ 3:24 549ms/step - accuracy: 0.8125 - loss: 0.
5116
Epoch 12: val_accuracy did not improve from 0.91533
373/373 ━━━━━━━━ 8s 20ms/step - accuracy: 0.8125 - loss: 0.511
6 - val_accuracy: 0.8661 - val_loss: 0.4360
Epoch 13/50
373/373 ━━━━━━ 0s 399ms/step - accuracy: 0.8127 - loss: 0.61
58
Epoch 13: val_accuracy did not improve from 0.91533
373/373 ━━━━━━ 156s 418ms/step - accuracy: 0.8127 - loss: 0.
6060 - val_accuracy: 0.8484 - val_loss: 0.5039
Epoch 14/50
 1/373 ━━━━━━ 3:14 522ms/step - accuracy: 0.9062 - loss: 0.
4621
Epoch 14: val_accuracy did not improve from 0.91533
373/373 ━━━━━━ 8s 21ms/step - accuracy: 0.9062 - loss: 0.462
1 - val_accuracy: 0.8521 - val_loss: 0.5016
Epoch 15/50
373/373 ━━━━━━ 0s 404ms/step - accuracy: 0.8291 - loss: 0.55
69
Epoch 15: val_accuracy did not improve from 0.91533
373/373 ━━━━━━ 158s 423ms/step - accuracy: 0.8296 - loss: 0.
5549 - val_accuracy: 0.8082 - val_loss: 0.6067
Epoch 15: early stopping
Restoring model weights from the end of the best epoch: 1.
Entrenamiento completado.

```

14.5. CNN Tuned - Evaluación del modelo

Evaluación del modelo entrenado en el conjunto de test.

```

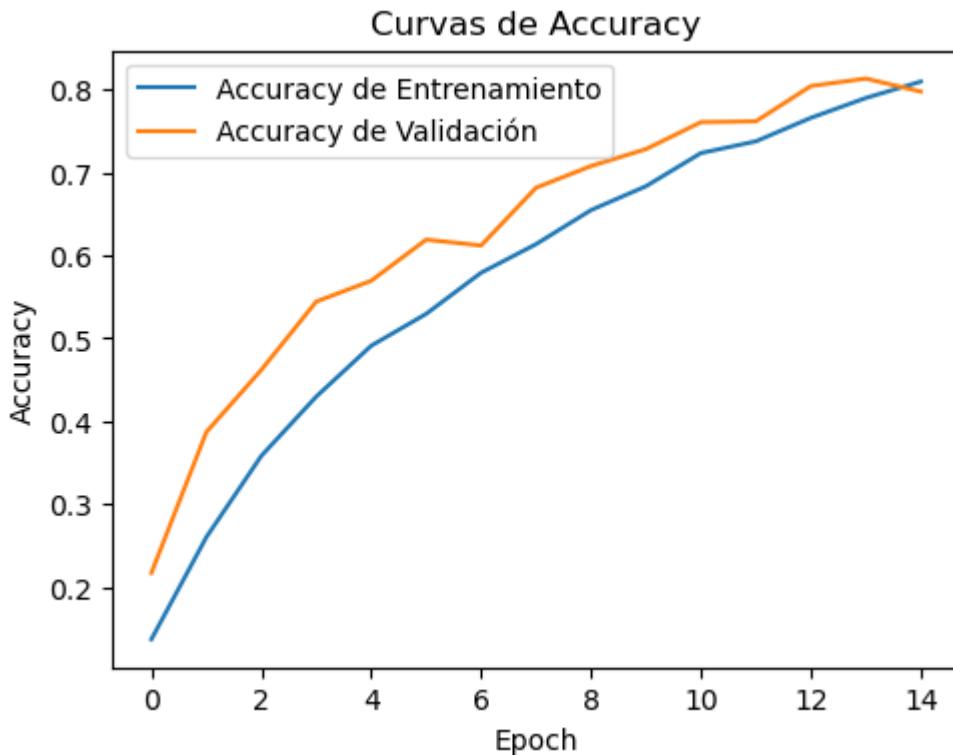
In [76]: # Carga del mejor modelo guardado durante el entrenamiento
loaded_model = load_model('best_model.keras')
print("Best model loaded successfully.")

# Evaluación del modelo cargado
loss, accuracy = loaded_model.evaluate(X_test_std, y_test_ohe, verbose=1)
print(f"Accuracy en el conjunto de test: {accuracy*100:.2f}%")

plt.figure(figsize=(12, 4))
plt.subplot(1, 2, 1)
plt.plot(history.history['accuracy'], label='Accuracy de Entrenamiento')
plt.plot(history.history['val_accuracy'], label='Accuracy de Validación')
plt.xlabel('Epoch')
plt.ylabel('Accuracy')
plt.legend()
plt.title('Curvas de Accuracy')

Best model loaded successfully.
52/52 ━━━━━━━━ 6s 85ms/step - accuracy: 0.8627 - loss: 0.6835
Accuracy en el conjunto de test: 86.27%
Out[76]: Text(0.5, 1.0, 'Curvas de Accuracy')

```



🧠 15. Transfer Learning

Transfer Learning es una técnica de aprendizaje automático donde utilizas un modelo pre-entrenado (ya entrenado en un dataset grande) como punto de partida para resolver un problema nuevo. En lugar de entrenar un modelo desde cero, reutilizas características ya aprendidas por otro modelo y las adaptas a tu problema específico. Algunas de las ventajas son:

- Requiere menos datos de entrenamiento
- Entrenamiento más rápido
- Mejor generalización
- Ideal para datasets pequeños

⌚ 15.1. Transfer Learning - Rango de Datos

Para el entrenamiento del modelo con Transfer Learning es necesario que el rango de los datos sean ajustados como sigue.

```
In [50]: # Rango original:
print("Rango X_train:", X_train.min(), X_train.max())
print("Rango X_val:", X_val.min(), X_val.max())
print("Rango X_test:", X_test_std.min(), X_test_std.max())

# Copias para Transfer Learning:
X_train_tl = preprocess_input((X_train * 255).astype("float32"))
X_val_tl = preprocess_input((X_val * 255).astype("float32"))
X_test_tl = preprocess_input((X_test_std * 255).astype("float32"))

# Rango de las copias para Transfer Learning:
print("Rango X_train_tl:", X_train_tl.min(), X_train_tl.max())
```

```

print("Rango X_val_tl:", X_val_tl.min(), X_val_tl.max())
print("Rango X_test_tl:", X_test_tl.min(), X_test_tl.max())

Rango X_train: 0.0 1.0
Rango X_val: 0.0 1.0
Rango X_test: 0.0 1.0
Rango X_train_tl: -1.0 1.0
Rango X_val_tl: -1.0 1.0
Rango X_test_tl: -1.0 1.0

```

💡 15.2. Transfer Learning - Configuración

Configuración del modelo pre-entrenado con todas las capas congeladas. La opción "base_model.trainable = False" es una configuración para el congelamiento de todas las capas del modelo pre-entrenado, lo que significa que sus pesos no se actualizarán durante el entrenamiento.

Esto preserva las características útiles ya aprendidas en el modelo pre-entrenado (MobileNetV2), por ejemplo bordes, texturas y formas en ImageNet. Congelarlo evita que esos conocimientos se pierdan. Solo las capas nuevas agregadas al final (Dense, Dropout) se entrena con los datos específicos (personajes de Los Simpson).

Con esto se gana en eficiencia computacional, entrenamiento mucho más rápido, usa menos memoria, menos parámetros que actualizar y evita sobreajuste, con menos parámetros entrenables, el modelo es menos propenso a memorizar datos.

```

In [51]: # Modelo base preentrenado
base_model = MobileNetV2(
    input_shape=(IMG_SIZE, IMG_SIZE, 3),
    include_top=False,
    weights="imagenet"
)

# Fase 1: congelamos TODAS las capas
base_model.trainable = False

print("Modelo base cargado y capas congeladas para Transfer Learning.")

```

```

/var/folders/7g/ch5l_np56q51q3c4q01r2hs00000gn/T/ipykernel_29902/198752085
9.py:2: UserWarning: `input_shape` is undefined or non-square, or `rows` i
s not in [96, 128, 160, 192, 224]. Weights for input shape (224, 224) will
be loaded as the default.
base_model = MobileNetV2()

```

Modelo base cargado y capas congeladas para Transfer Learning.

💡 15.3. Transfer Learning - Compilación y Resumen

Compilación del modelo pre-entrenado y resumen de la arquitectura.

```

In [52]: num_classes = len(MAP_CHARACTERS)

model_tl = Sequential([
    base_model,
    GlobalAveragePooling2D(),
    Dense(256, activation="relu"),

```

```

        Dropout(0.5),
        Dense(num_classes, activation="softmax")
    ])

model_tl.compile(
    optimizer=Adam(learning_rate=1e-3),
    loss="categorical_crossentropy",
    metrics=["accuracy"]
)

model_tl.summary()

```

Model: "sequential_10"

Layer (type)	Output Shape	
mobilenetv2_1.00_224 (Functional)	(None, 3, 3, 1280)	2,2
global_average_pooling2d (GlobalAveragePooling2D)	(None, 1280)	
dense_21 (Dense)	(None, 256)	3
dropout_38 (Dropout)	(None, 256)	
dense_22 (Dense)	(None, 13)	

Total params: 2,589,261 (9.88 MB)

Trainable params: 331,277 (1.26 MB)

Non-trainable params: 2,257,984 (8.61 MB)

⌚ 15.4. Transfer Learning - Callbacks

Configuración de callbacks para el control del entrenamiento del modelo pre-entrenado.

```
In [53]: callbacks = [
    EarlyStopping(monitor="val_loss", patience=10, restore_best_weights=True),
    ModelCheckpoint("best_model_transfer_learning.h5", monitor="val_accuracy")]

print("Callbacks configurados para Transfer Learning.")
```

Callbacks configurados para Transfer Learning.

⌚ 15.5. Transfer Learning - Entrenamiento

Entrenamiento del modelo pre-entrenado.

```
In [54]: history_tl = model_tl.fit(
    X_train_tl, y_train,
    validation_data=(X_val_tl, y_val),
    epochs=EPOCHS,
    batch_size=BATCH_SIZE,
    callbacks=callbacks)
```

```
)  
  
print("Entrenamiento con Transfer Learning completado.")  
  
Epoch 1/50  
374/374 0s 39ms/step - accuracy: 0.2247 - loss: 2.475  
0  
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.  
374/374 23s 53ms/step - accuracy: 0.3021 - loss: 2.14  
03 - val_accuracy: 0.5100 - val_loss: 1.5520  
Epoch 2/50  
374/374 0s 40ms/step - accuracy: 0.4496 - loss: 1.686  
1  
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.  
374/374 18s 49ms/step - accuracy: 0.4599 - loss: 1.65  
57 - val_accuracy: 0.5776 - val_loss: 1.3497  
Epoch 3/50  
374/374 0s 40ms/step - accuracy: 0.5177 - loss: 1.472  
1  
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.  
374/374 18s 49ms/step - accuracy: 0.5196 - loss: 1.46  
53 - val_accuracy: 0.5950 - val_loss: 1.3074  
Epoch 4/50  
374/374 0s 38ms/step - accuracy: 0.5594 - loss: 1.352  
0  
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.  
374/374 18s 47ms/step - accuracy: 0.5616 - loss: 1.34  
15 - val_accuracy: 0.6091 - val_loss: 1.2493  
Epoch 5/50  
374/374 0s 40ms/step - accuracy: 0.5908 - loss: 1.231  
3  
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.  
374/374 19s 52ms/step - accuracy: 0.5921 - loss: 1.24  
63 - val_accuracy: 0.6252 - val_loss: 1.2033  
Epoch 6/50  
373/374 0s 41ms/step - accuracy: 0.6227 - loss: 1.146  
8  
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
```

```
374/374 ━━━━━━━━ 19s 51ms/step - accuracy: 0.6197 - loss: 1.16
23 - val_accuracy: 0.6275 - val_loss: 1.2044
Epoch 7/50
374/374 ━━━━━━━━ 0s 40ms/step - accuracy: 0.6324 - loss: 1.099
9
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
374/374 ━━━━━━━━ 18s 49ms/step - accuracy: 0.6306 - loss: 1.11
01 - val_accuracy: 0.6315 - val_loss: 1.1705
Epoch 8/50
374/374 ━━━━━━━━ 0s 40ms/step - accuracy: 0.6576 - loss: 1.032
0
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
374/374 ━━━━━━━━ 19s 49ms/step - accuracy: 0.6525 - loss: 1.04
46 - val_accuracy: 0.6339 - val_loss: 1.1831
Epoch 9/50
374/374 ━━━━━━━━ 0s 39ms/step - accuracy: 0.6779 - loss: 0.975
8
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
374/374 ━━━━━━━━ 18s 48ms/step - accuracy: 0.6698 - loss: 0.99
35 - val_accuracy: 0.6439 - val_loss: 1.1542
Epoch 10/50
374/374 ━━━━━━━━ 0s 40ms/step - accuracy: 0.6964 - loss: 0.925
5
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
374/374 ━━━━━━━━ 19s 50ms/step - accuracy: 0.6924 - loss: 0.93
23 - val_accuracy: 0.6503 - val_loss: 1.1548
Epoch 11/50
374/374 ━━━━━━━━ 0s 38ms/step - accuracy: 0.6979 - loss: 0.876
5
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
374/374 ━━━━━━━━ 18s 48ms/step - accuracy: 0.6969 - loss: 0.88
70 - val_accuracy: 0.6556 - val_loss: 1.1465
Epoch 12/50
374/374 ━━━━━━━━ 0s 39ms/step - accuracy: 0.7173 - loss: 0.844
1
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
```

```

374/374 _____ 18s 49ms/step - accuracy: 0.7087 - loss: 0.86
46 - val_accuracy: 0.6623 - val_loss: 1.1683
Epoch 13/50
374/374 _____ 18s 48ms/step - accuracy: 0.7217 - loss: 0.80
50 - val_accuracy: 0.6573 - val_loss: 1.1491
Epoch 14/50
374/374 _____ 18s 47ms/step - accuracy: 0.7332 - loss: 0.77
94 - val_accuracy: 0.6479 - val_loss: 1.1594
Epoch 15/50
374/374 _____ 18s 47ms/step - accuracy: 0.7436 - loss: 0.75
49 - val_accuracy: 0.6563 - val_loss: 1.1955
Epoch 16/50
374/374 _____ 18s 49ms/step - accuracy: 0.7537 - loss: 0.71
88 - val_accuracy: 0.6576 - val_loss: 1.1749
Epoch 17/50
374/374 _____ 18s 48ms/step - accuracy: 0.7614 - loss: 0.70
49 - val_accuracy: 0.6583 - val_loss: 1.1833
Epoch 18/50
374/374 _____ 18s 48ms/step - accuracy: 0.7657 - loss: 0.66
69 - val_accuracy: 0.6516 - val_loss: 1.2447
Epoch 19/50
374/374 _____ 18s 47ms/step - accuracy: 0.7818 - loss: 0.62
89 - val_accuracy: 0.6616 - val_loss: 1.2053
Epoch 20/50
374/374 _____ 18s 48ms/step - accuracy: 0.7789 - loss: 0.63
23 - val_accuracy: 0.6563 - val_loss: 1.2465
Epoch 21/50
374/374 _____ 0s 38ms/step - accuracy: 0.7900 - loss: 0.600
5

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

374/374 _____ 18s 49ms/step - accuracy: 0.7872 - loss: 0.61
22 - val_accuracy: 0.6667 - val_loss: 1.2304
Entrenamiento con Transfer Learning completado.

```

15.6. Transfer Learning - Evaluación

Analís de resultados del modelo pre-entrenado para Transfer Learning.

```
In [55]: loss_tl, accuracy_tl = model_tl.evaluate(X_test_tl, y_test_ohe, verbose=1)
print(f"Accuracy en test (Transfer Learning): {accuracy_tl*100:.2f}%")
```

```
52/52 _____ 2s 36ms/step - accuracy: 0.5039 - loss: 1.7725
Accuracy en test (Transfer Learning): 50.39%
```

🧠 16. Transfer Learning - Congelamiento de las Primeras Capas

Utilización de la técnica Transfer Learning, pero utilizando el congelamiento de solo las primeras capas (CPC), dejando entrenar las últimas (fine tuning).

⚙️ 16.1. Transfer Learning CPC - Configuración

Configuración del modelo pre-entrenado congelando solo las primeras capas.

```
In [56]: # Abre todas las capas del modelo base
base_model.trainable = True

# Congela las primeras capas y dejamos entrenar las últimas
for layer in base_model.layers[:-30]:
    layer.trainable = False

print("Algunas capas del modelo base descongeladas para fine-tuning.")
```

Algunas capas del modelo base descongeladas para fine-tuning.

⚙️ 16.2. Transfer Learning CPC - Compilación y Resumen

Compilación del modelo pre-entrenado y resumen de la arquitectura.

```
In [57]: model_tl.compile(
    optimizer=Adam(learning_rate=1e-4),
    loss="categorical_crossentropy",
    metrics=["accuracy"]
)

model_tl.summary()
```

Model: "sequential_10"

Layer (type)	Output Shape	
mobilenetv2_1.00_224 (Functional)	(None, 3, 3, 1280)	2,2
global_average_pooling2d (GlobalAveragePooling2D)	(None, 1280)	
dense_21 (Dense)	(None, 256)	3
dropout_38 (Dropout)	(None, 256)	
dense_22 (Dense)	(None, 13)	

Total params: 2,589,261 (9.88 MB)

Trainable params: 1,857,677 (7.09 MB)

Non-trainable params: 731,584 (2.79 MB)

16.3. Transfer Learning CPC - Entrenamiento

Entrenamiento del modelo pre-entrenado.

```
In [58]: history_ft = model_tl.fit(  
    X_train_tl, y_train,  
    validation_data=(X_val_tl, y_val),  
    epochs=EPOCHS,  
    batch_size=BATCH_SIZE,  
    callbacks=callbacks  
)
```

Epoch 1/50
374/374 33s 75ms/step - accuracy: 0.4897 - loss: 1.63
25 - val_accuracy: 0.5773 - val_loss: 2.0558
Epoch 2/50
374/374 25s 67ms/step - accuracy: 0.6794 - loss: 1.02
03 - val_accuracy: 0.6466 - val_loss: 1.6641
Epoch 3/50
373/374 0s 58ms/step - accuracy: 0.7626 - loss: 0.748
7
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
374/374 25s 68ms/step - accuracy: 0.7660 - loss: 0.7418 - val_accuracy: 0.6941 - val_loss: 1.4651
Epoch 4/50
374/374 0s 58ms/step - accuracy: 0.8308 - loss: 0.5303
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
374/374 25s 67ms/step - accuracy: 0.8312 - loss: 0.5319 - val_accuracy: 0.7333 - val_loss: 1.1742
Epoch 5/50
374/374 0s 57ms/step - accuracy: 0.8660 - loss: 0.4169
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
374/374 25s 67ms/step - accuracy: 0.8709 - loss: 0.4081 - val_accuracy: 0.7697 - val_loss: 1.0526
Epoch 6/50
373/374 0s 59ms/step - accuracy: 0.8949 - loss: 0.3210
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.

```
374/374 ━━━━━━━━ 26s 68ms/step - accuracy: 0.8953 - loss: 0.31  
96 - val_accuracy: 0.7838 - val_loss: 0.9457  
Epoch 7/50  
374/374 ━━━━━━━━ 25s 68ms/step - accuracy: 0.9199 - loss: 0.24  
54 - val_accuracy: 0.7798 - val_loss: 1.0056  
Epoch 8/50  
373/374 ━━━━━━ 0s 57ms/step - accuracy: 0.9372 - loss: 0.194  
1  
WARNING:absl:You are saving your model as an HDF5 file via `model.save()`  
or `keras.saving.save_model(model)`. This file format is considered legacy.  
We recommend using instead the native Keras format, e.g. `model.save('m  
y_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.  
374/374 ━━━━━━━━ 25s 66ms/step - accuracy: 0.9357 - loss: 0.20  
01 - val_accuracy: 0.7868 - val_loss: 1.0421  
Epoch 9/50  
373/374 ━━━━━━ 0s 58ms/step - accuracy: 0.9467 - loss: 0.169  
7  
WARNING:absl:You are saving your model as an HDF5 file via `model.save()`  
or `keras.saving.save_model(model)`. This file format is considered legacy.  
We recommend using instead the native Keras format, e.g. `model.save('m  
y_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.  
374/374 ━━━━━━━━ 25s 67ms/step - accuracy: 0.9458 - loss: 0.16  
97 - val_accuracy: 0.7962 - val_loss: 1.0386  
Epoch 10/50  
374/374 ━━━━━━━━ 26s 69ms/step - accuracy: 0.9595 - loss: 0.12  
95 - val_accuracy: 0.7892 - val_loss: 1.0794  
Epoch 11/50  
374/374 ━━━━━━━━ 25s 66ms/step - accuracy: 0.9591 - loss: 0.12  
75 - val_accuracy: 0.7932 - val_loss: 1.1185  
Epoch 12/50  
373/374 ━━━━━━ 0s 58ms/step - accuracy: 0.9694 - loss: 0.107  
1  
WARNING:absl:You are saving your model as an HDF5 file via `model.save()`  
or `keras.saving.save_model(model)`. This file format is considered legacy.  
We recommend using instead the native Keras format, e.g. `model.save('m  
y_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.  
374/374 ━━━━━━━━ 26s 68ms/step - accuracy: 0.9655 - loss: 0.11  
72 - val_accuracy: 0.8089 - val_loss: 1.0430  
Epoch 13/50  
374/374 ━━━━━━━━ 25s 68ms/step - accuracy: 0.9675 - loss: 0.10  
43 - val_accuracy: 0.8062 - val_loss: 1.0618  
Epoch 14/50  
373/374 ━━━━━━ 0s 57ms/step - accuracy: 0.9764 - loss: 0.081  
3  
WARNING:absl:You are saving your model as an HDF5 file via `model.save()`  
or `keras.saving.save_model(model)`. This file format is considered legacy.  
We recommend using instead the native Keras format, e.g. `model.save('m  
y_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.  
374/374 ━━━━━━━━ 25s 67ms/step - accuracy: 0.9730 - loss: 0.08  
89 - val_accuracy: 0.8133 - val_loss: 1.0732  
Epoch 15/50  
Epoch 15/50  
374/374 ━━━━━━━━ 25s 68ms/step - accuracy: 0.9716 - loss: 0.08  
77 - val_accuracy: 0.8049 - val_loss: 1.1396  
Epoch 16/50  
374/374 ━━━━━━━━ 25s 66ms/step - accuracy: 0.9772 - loss: 0.07  
78 - val_accuracy: 0.8059 - val_loss: 1.2058
```

⌚ 16.4. Transfer Learning CPC - Evaluación

Analís de resultados del modelo pre-entrenado para Transfer Learning.

```
In [59]: loss_tl, accuracy_tl = model_tl.evaluate(X_test_tl, y_test_ohe, verbose=1
print(f"Accuracy en test (Transfer Learning + Fine-Tuning): {accuracy_tl*100}%")
```

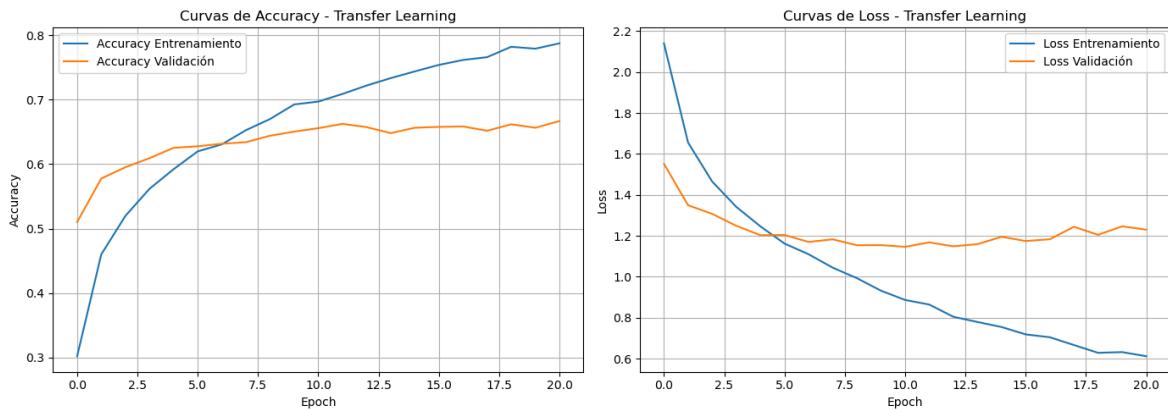
52/52 ━━━━━━━━ 2s 35ms/step – accuracy: 0.6679 – loss: 1.7242
Accuracy en test (Transfer Learning + Fine-Tuning): 66.79%

```
In [60]: plt.figure(figsize=(14, 5))
```

```
# Accuracy
plt.subplot(1, 2, 1)
plt.plot(history_tl.history['accuracy'], label='Accuracy Entrenamiento')
plt.plot(history_tl.history['val_accuracy'], label='Accuracy Validación')
plt.xlabel('Epoch')
plt.ylabel('Accuracy')
plt.title('Curvas de Accuracy – Transfer Learning')
plt.legend()
plt.grid(True)

# Loss
plt.subplot(1, 2, 2)
plt.plot(history_tl.history['loss'], label='Loss Entrenamiento')
plt.plot(history_tl.history['val_loss'], label='Loss Validación')
plt.xlabel('Epoch')
plt.ylabel('Loss')
plt.title('Curvas de Loss – Transfer Learning')
plt.legend()
plt.grid(True)

plt.tight_layout()
plt.show()
```



⌚ 16.5. Transfer Learning CPC - Conclusión

En este experimento se aplicó la técnica Transfer Learning utilizando MobileNetV2 como modelo base preentrenado. Las imágenes fueron normalizadas y adaptadas al tamaño requerido por la red, pero no se aplicaron técnicas de data augmentation en esta etapa.

Los resultados obtenidos muestran que el modelo aprende correctamente los patrones del conjunto de entrenamiento, alcanzando una accuracy muy alta (98%). Sin embargo, la accuracy en el conjunto de validación se estabiliza alrededor del 80%, observándose una brecha creciente entre entrenamiento y validación. Este comportamiento, junto con la evolución de la función de pérdida, indica la aparición de overfitting moderado: mientras la pérdida de entrenamiento disminuye de forma continua, la pérdida de validación se mantiene prácticamente constante.

Este fenómeno sugiere que, aunque el modelo es capaz de ajustarse bien a los datos de entrenamiento, las representaciones aprendidas no generalizan adecuadamente a datos no vistos.

En conclusión, el uso de transfer learning sin data augmentation no resulta suficiente para alcanzar el objetivo de una accuracy superior al 85% en el conjunto de teste.

17. Transfer Learning + Data Augmentation

Es una combinación de dos técnicas poderosas:

1. Transfer Learning: Reutilizas un modelo pre-entrenado (MobileNetV2 en ImageNet) como base, congelando sus capas para preservar características genéricas ya aprendidas (bordes, texturas, formas).
2. Data Augmentation: Aplicas transformaciones a las imágenes de entrenamiento (rotaciones, desplazamientos, zoom, flip) para aumentar la diversidad de datos sin recopilar más imágenes.

Las ventajas son:

- Menos overfitting, más variedad de ejemplos.
- Mejor generalización porque el modelo aprende patrones más robustos.
- Entrenamientos más estables, curvas de train/val más cercanas.
- Computacionalmente eficiente, reutilizas características pre-entrenadas

En este ejemplo se utiliza MobileNetV2 congelado más transformaciones de imágenes, lo que resulta en modelo más robusto para clasificar personajes de Los Simpson, reduciendo la brecha entre entrenamiento y validación.

17.1. Transfer Learning DA - Configuración

Cargando Data augmentation para Transfer Learning y regresando rango de datos para 0-255.

```
In [61]: # Data Augmentation específico para MobileNetV2
train_datagen = ImageDataGenerator(
    preprocessing_function=preprocess_input,
    rotation_range=15,
    width_shift_range=0.1,
    height_shift_range=0.1,
    zoom_range=0.15,
```

```

        horizontal_flip=True
    )

# Data Augmentation para el conjunto de validación (solo preprocesamiento)
val_datagen = ImageDataGenerator(
    preprocessing_function=preprocess_input
)

# Generadores de datos
train_generator = train_datagen.flow(
    X_train * 255,
    y_train,
    batch_size=BATCH_SIZE
)

val_generator = val_datagen.flow(
    X_val * 255,
    y_val,
    batch_size=BATCH_SIZE,
    shuffle=False
)

print("Data generators configurados para Transfer Learning con Data Augme

```

Data generators configurados para Transfer Learning con Data Augmentation.

⌚ 17.2. Transfer Learning DA - Modelo y Capas

Carga del modelo pre-entrenado MobileNetV2 y congelamiento de las capas convolucionales.

In [62]:

```

# Modelo base preentrenado
base_model = MobileNetV2(
    weights="imagenet",
    include_top=False,
    input_shape=(IMG_SIZE, IMG_SIZE, 3)
)

# Congelar capas convolucionales
for layer in base_model.layers:
    layer.trainable = False

print("Modelo base cargado y capas congeladas para Transfer Learning con

```

```

/var/folders/7g/ch5l_np56q51q3c4q01r2hs00000gn/T/ipykernel_29902/218356730
9.py:2: UserWarning: `input_shape` is undefined or non-square, or `rows` i
s not in [96, 128, 160, 192, 224]. Weights for input shape (224, 224) will
be loaded as the default.
    base_model = MobileNetV2(
Modelo base cargado y capas congeladas para Transfer Learning con Data Aug
mentation.

```

⌚ 17.3. Transfer Learning DA - Añadindo Capas

Añadindo capas al modelo pre-entrenado para Data Augmentation.

In [63]:

```

x = base_model.output
x = GlobalAveragePooling2D()(x)

```

```
x = Dense(256, activation="relu")(x)
x = Dropout(0.5)(x)

output = Dense(num_classes, activation="softmax")(x)
model_tl = Model(inputs=base_model.input, outputs=output)

print("Modelo completo con nuevas capas densas creado.")
```

Modelo completo con nuevas capas densas creado.

💡 17.4. Transfer Learning DA - Compilación y Resumen

Compilación del modelo pre-entrenado y resumen de la arquitectura.

```
In [64]: model_tl.compile(
    optimizer=Adam(learning_rate=1e-3),
    loss="categorical_crossentropy",
    metrics=["accuracy"]
)

model_tl.summary()
```

Model: "functional_27"

Layer (type)	Output Shape	Param #	Connected To
input_layer_12 (InputLayer)	(None, 90, 90, 3)	0	-
Conv1 (Conv2D)	(None, 45, 45, 32)	864	input_layer_12
bn_Conv1 (BatchNormalization)	(None, 45, 45, 32)	128	Conv1[0][0]
Conv1_relu (ReLU)	(None, 45, 45, 32)	0	bn_Conv1[0]
expanded_conv_dept... (DepthwiseConv2D)	(None, 45, 45, 32)	288	Conv1_relu
expanded_conv_dept... (BatchNormalization)	(None, 45, 45, 32)	128	expanded_conv_dept...
expanded_conv_dept... (ReLU)	(None, 45, 45, 32)	0	expanded_conv_dept...
expanded_conv_proj... (Conv2D)	(None, 45, 45, 16)	512	expanded_conv_dept...
expanded_conv_proj... (BatchNormalization)	(None, 45, 45, 16)	64	expanded_conv_dept...
block_1_expand (Conv2D)	(None, 45, 45, 96)	1,536	expanded_conv_dept...
block_1_expand_BN (BatchNormalization)	(None, 45, 45, 96)	384	block_1_expand
block_1_expand_relu (ReLU)	(None, 45, 45, 96)	0	block_1_expand
block_1_pad (ZeroPadding2D)	(None, 47, 47, 96)	0	block_1_expand
block_1_depthwise (DepthwiseConv2D)	(None, 23, 23, 96)	864	block_1_pad
block_1_depthwise_... (BatchNormalization)	(None, 23, 23, 96)	384	block_1_depthwise
block_1_depthwise_... (ReLU)	(None, 23, 23, 96)	0	block_1_depthwise
block_1_project (Conv2D)	(None, 23, 23, 24)	2,304	block_1_depthwise
block_1_project_BN (BatchNormalization)	(None, 23, 23, 24)	96	block_1_project
block_2_expand (Conv2D)	(None, 23, 23, 144)	3,456	block_1_project
block_2_expand_BN (BatchNormalization)	(None, 23, 23, 144)	576	block_2_expand
block_2_expand_relu	(None, 23, 23,	0	block_2_expand

(ReLU)	144)		
block_2_depthwise (DepthwiseConv2D)	(None, 23, 23, 144)	1,296	block_2_ex
block_2_depthwise_... (BatchNormalizatio...)	(None, 23, 23, 144)	576	block_2_de
block_2_depthwise_... (ReLU)	(None, 23, 23, 144)	0	block_2_de
block_2_project (Conv2D)	(None, 23, 23, 24)	3,456	block_2_de
block_2_project_BN (BatchNormalizatio...)	(None, 23, 23, 24)	96	block_2_pro
block_2_add (Add)	(None, 23, 23, 24)	0	block_1_pro block_2_pro
block_3_expand (Conv2D)	(None, 23, 23, 144)	3,456	block_2_adv
block_3_expand_BN (BatchNormalizatio...)	(None, 23, 23, 144)	576	block_3_ex
block_3_expand_relu (ReLU)	(None, 23, 23, 144)	0	block_3_ex
block_3_pad (ZeroPadding2D)	(None, 25, 25, 144)	0	block_3_ex
block_3_depthwise (DepthwiseConv2D)	(None, 12, 12, 144)	1,296	block_3_pac
block_3_depthwise_... (BatchNormalizatio...)	(None, 12, 12, 144)	576	block_3_de
block_3_depthwise_... (ReLU)	(None, 12, 12, 144)	0	block_3_de
block_3_project (Conv2D)	(None, 12, 12, 32)	4,608	block_3_de
block_3_project_BN (BatchNormalizatio...)	(None, 12, 12, 32)	128	block_3_pro
block_4_expand (Conv2D)	(None, 12, 12, 192)	6,144	block_3_pro
block_4_expand_BN (BatchNormalizatio...)	(None, 12, 12, 192)	768	block_4_ex
block_4_expand_relu (ReLU)	(None, 12, 12, 192)	0	block_4_ex
block_4_depthwise (DepthwiseConv2D)	(None, 12, 12, 192)	1,728	block_4_ex
block_4_depthwise_... (BatchNormalizatio...)	(None, 12, 12, 192)	768	block_4_de
block_4_depthwise_... (ReLU)	(None, 12, 12, 192)	0	block_4_de

block_4_project (Conv2D)	(None, 12, 12, 32)	6,144	block_4_depthwise
block_4_project_BN (BatchNormalization)	(None, 12, 12, 32)	128	block_4_project_BN
block_4_add (Add)	(None, 12, 12, 32)	0	block_3_project block_4_project
block_5_expand (Conv2D)	(None, 12, 12, 192)	6,144	block_4_add block_5_expand
block_5_expand_BN (BatchNormalization)	(None, 12, 12, 192)	768	block_5_expand_BN
block_5_expand_relu (ReLU)	(None, 12, 12, 192)	0	block_5_expand block_5_expand_relu
block_5_depthwise (DepthwiseConv2D)	(None, 12, 12, 192)	1,728	block_5_expand block_5_depthwise
block_5_depthwise_BN (BatchNormalization)	(None, 12, 12, 192)	768	block_5_depthwise block_5_depthwise_BN
block_5_depthwise_ReLU (ReLU)	(None, 12, 12, 192)	0	block_5_depthwise block_5_depthwise_ReLU
block_5_project (Conv2D)	(None, 12, 12, 32)	6,144	block_5_depthwise block_5_project
block_5_project_BN (BatchNormalization)	(None, 12, 12, 32)	128	block_5_project_BN
block_5_add (Add)	(None, 12, 12, 32)	0	block_4_add block_5_project
block_6_expand (Conv2D)	(None, 12, 12, 192)	6,144	block_5_add block_6_expand
block_6_expand_BN (BatchNormalization)	(None, 12, 12, 192)	768	block_6_expand_BN
block_6_expand_relu (ReLU)	(None, 12, 12, 192)	0	block_6_expand block_6_expand_relu
block_6_pad (ZeroPadding2D)	(None, 13, 13, 192)	0	block_6_expand block_6_pad
block_6_depthwise (DepthwiseConv2D)	(None, 6, 6, 192)	1,728	block_6_pad block_6_depthwise
block_6_depthwise_BN (BatchNormalization)	(None, 6, 6, 192)	768	block_6_depthwise block_6_depthwise_BN
block_6_depthwise_ReLU (ReLU)	(None, 6, 6, 192)	0	block_6_depthwise block_6_depthwise_ReLU
block_6_project (Conv2D)	(None, 6, 6, 64)	12,288	block_6_depthwise block_6_project
block_6_project_BN (BatchNormalization)	(None, 6, 6, 64)	256	block_6_project_BN

block_7_expand (Conv2D)	(None, 6, 6, 384)	24,576	block_6_pr
block_7_expand_BN (BatchNormalizatio...)	(None, 6, 6, 384)	1,536	block_7_ex
block_7_expand_relu (ReLU)	(None, 6, 6, 384)	0	block_7_ex
block_7_depthwise (DepthwiseConv2D)	(None, 6, 6, 384)	3,456	block_7_ex
block_7_depthwise_... (BatchNormalizatio...)	(None, 6, 6, 384)	1,536	block_7_de
block_7_depthwise_... (ReLU)	(None, 6, 6, 384)	0	block_7_de
block_7_project (Conv2D)	(None, 6, 6, 64)	24,576	block_7_de
block_7_project_BN (BatchNormalizatio...)	(None, 6, 6, 64)	256	block_7_pr
block_7_add (Add)	(None, 6, 6, 64)	0	block_6_pr block_7_pr
block_8_expand (Conv2D)	(None, 6, 6, 384)	24,576	block_7_adv
block_8_expand_BN (BatchNormalizatio...)	(None, 6, 6, 384)	1,536	block_8_ex
block_8_expand_relu (ReLU)	(None, 6, 6, 384)	0	block_8_ex
block_8_depthwise (DepthwiseConv2D)	(None, 6, 6, 384)	3,456	block_8_ex
block_8_depthwise_... (BatchNormalizatio...)	(None, 6, 6, 384)	1,536	block_8_de
block_8_depthwise_... (ReLU)	(None, 6, 6, 384)	0	block_8_de
block_8_project (Conv2D)	(None, 6, 6, 64)	24,576	block_8_de
block_8_project_BN (BatchNormalizatio...)	(None, 6, 6, 64)	256	block_8_pr
block_8_add (Add)	(None, 6, 6, 64)	0	block_7_adv block_8_pr
block_9_expand (Conv2D)	(None, 6, 6, 384)	24,576	block_8_adv
block_9_expand_BN (BatchNormalizatio...)	(None, 6, 6, 384)	1,536	block_9_ex
block_9_expand_relu (ReLU)	(None, 6, 6, 384)	0	block_9_ex
block_9_depthwise	(None, 6, 6, 384)	3,456	block_9_ex

(DepthwiseConv2D)			
block_9_depthwise... (BatchNormalizatio...)	(None, 6, 6, 384)	1,536	block_9_de...
block_9_depthwise... (ReLU)	(None, 6, 6, 384)	0	block_9_de...
block_9_project (Conv2D)	(None, 6, 6, 64)	24,576	block_9_de...
block_9_project_BN (BatchNormalizatio...)	(None, 6, 6, 64)	256	block_9_pro...
block_9_add (Add)	(None, 6, 6, 64)	0	block_8_add block_9_pro...
block_10_expand (Conv2D)	(None, 6, 6, 384)	24,576	block_9_adv...
block_10_expand_BN (BatchNormalizatio...)	(None, 6, 6, 384)	1,536	block_10_e...
block_10_expand_re... (ReLU)	(None, 6, 6, 384)	0	block_10_e...
block_10_depthwise (DepthwiseConv2D)	(None, 6, 6, 384)	3,456	block_10_e...
block_10_depthwise... (BatchNormalizatio...)	(None, 6, 6, 384)	1,536	block_10_de...
block_10_depthwise... (ReLU)	(None, 6, 6, 384)	0	block_10_de...
block_10_project (Conv2D)	(None, 6, 6, 96)	36,864	block_10_de...
block_10_project_BN (BatchNormalizatio...)	(None, 6, 6, 96)	384	block_10_pi...
block_11_expand (Conv2D)	(None, 6, 6, 576)	55,296	block_10_pi...
block_11_expand_BN (BatchNormalizatio...)	(None, 6, 6, 576)	2,304	block_11_e...
block_11_expand_re... (ReLU)	(None, 6, 6, 576)	0	block_11_e...
block_11_depthwise (DepthwiseConv2D)	(None, 6, 6, 576)	5,184	block_11_e...
block_11_depthwise... (BatchNormalizatio...)	(None, 6, 6, 576)	2,304	block_11_de...
block_11_depthwise... (ReLU)	(None, 6, 6, 576)	0	block_11_de...
block_11_project (Conv2D)	(None, 6, 6, 96)	55,296	block_11_de...
block_11_project_BN (BatchNormalizatio...)	(None, 6, 6, 96)	384	block_11_pi...

block_11_add (Add)	(None, 6, 6, 96)	0	block_10_p1 block_11_p1
block_12_expand (Conv2D)	(None, 6, 6, 576)	55,296	block_11_ac
block_12_expand_BN (BatchNormalizatio...)	(None, 6, 6, 576)	2,304	block_12_e1
block_12_expand_re... (ReLU)	(None, 6, 6, 576)	0	block_12_e2
block_12_depthwise (DepthwiseConv2D)	(None, 6, 6, 576)	5,184	block_12_e3
block_12_depthwise... (BatchNormalizatio...)	(None, 6, 6, 576)	2,304	block_12_de1
block_12_depthwise... (ReLU)	(None, 6, 6, 576)	0	block_12_de2
block_12_project (Conv2D)	(None, 6, 6, 96)	55,296	block_12_de3
block_12_project_BN (BatchNormalizatio...)	(None, 6, 6, 96)	384	block_12_pi
block_12_add (Add)	(None, 6, 6, 96)	0	block_11_ac block_12_p1
block_13_expand (Conv2D)	(None, 6, 6, 576)	55,296	block_12_ac
block_13_expand_BN (BatchNormalizatio...)	(None, 6, 6, 576)	2,304	block_13_e1
block_13_expand_re... (ReLU)	(None, 6, 6, 576)	0	block_13_e2
block_13_pad (ZeroPadding2D)	(None, 7, 7, 576)	0	block_13_e3
block_13_depthwise (DepthwiseConv2D)	(None, 3, 3, 576)	5,184	block_13_pa
block_13_depthwise... (BatchNormalizatio...)	(None, 3, 3, 576)	2,304	block_13_de1
block_13_depthwise... (ReLU)	(None, 3, 3, 576)	0	block_13_de2
block_13_project (Conv2D)	(None, 3, 3, 160)	92,160	block_13_de3
block_13_project_BN (BatchNormalizatio...)	(None, 3, 3, 160)	640	block_13_pi
block_14_expand (Conv2D)	(None, 3, 3, 960)	153,600	block_13_pi
block_14_expand_BN (BatchNormalizatio...)	(None, 3, 3, 960)	3,840	block_14_e1

block_14_expand_re... (ReLU)	(None, 3, 3, 960)	0	block_14_e
block_14_depthwise (DepthwiseConv2D)	(None, 3, 3, 960)	8,640	block_14_e
block_14_depthwise... (BatchNormalizatio...)	(None, 3, 3, 960)	3,840	block_14_de
block_14_depthwise... (ReLU)	(None, 3, 3, 960)	0	block_14_de
block_14_project (Conv2D)	(None, 3, 3, 160)	153,600	block_14_de
block_14_project_BN (BatchNormalizatio...)	(None, 3, 3, 160)	640	block_14_pi
block_14_add (Add)	(None, 3, 3, 160)	0	block_13_pi block_14_pi
block_15_expand (Conv2D)	(None, 3, 3, 960)	153,600	block_14_ac
block_15_expand_BN (BatchNormalizatio...)	(None, 3, 3, 960)	3,840	block_15_e
block_15_expand_re... (ReLU)	(None, 3, 3, 960)	0	block_15_e
block_15_depthwise (DepthwiseConv2D)	(None, 3, 3, 960)	8,640	block_15_e
block_15_depthwise... (BatchNormalizatio...)	(None, 3, 3, 960)	3,840	block_15_de
block_15_depthwise... (ReLU)	(None, 3, 3, 960)	0	block_15_de
block_15_project (Conv2D)	(None, 3, 3, 160)	153,600	block_15_de
block_15_project_BN (BatchNormalizatio...)	(None, 3, 3, 160)	640	block_15_pi
block_15_add (Add)	(None, 3, 3, 160)	0	block_14_ac block_15_pi
block_16_expand (Conv2D)	(None, 3, 3, 960)	153,600	block_15_ac
block_16_expand_BN (BatchNormalizatio...)	(None, 3, 3, 960)	3,840	block_16_e
block_16_expand_re... (ReLU)	(None, 3, 3, 960)	0	block_16_e
block_16_depthwise (DepthwiseConv2D)	(None, 3, 3, 960)	8,640	block_16_e
block_16_depthwise... (BatchNormalizatio...)	(None, 3, 3, 960)	3,840	block_16_de
block_16_depthwise...	(None, 3, 3, 960)	0	block_16_de

(ReLU)			
block_16_project (Conv2D)	(None, 3, 3, 320)	307,200	block_16_de...
block_16_project_BN (BatchNormalizatio...)	(None, 3, 3, 320)	1,280	block_16_pi...
Conv_1 (Conv2D)	(None, 3, 3, 1280)	409,600	block_16_pi...
Conv_1_bn (BatchNormalizatio...)	(None, 3, 3, 1280)	5,120	Conv_1[0] [6]
out_relu (ReLU)	(None, 3, 3, 1280)	0	Conv_1_bn[6]
global_average_poo... (GlobalAveragePool...)	(None, 1280)	0	out_relu[0]
dense_23 (Dense)	(None, 256)	327,936	global_ave...
dropout_39 (Dropout)	(None, 256)	0	dense_23[0]
dense_24 (Dense)	(None, 13)	3,341	dropout_39

Total params: 2,589,261 (9.88 MB)

Trainable params: 331,277 (1.26 MB)

Non-trainable params: 2,257,984 (8.61 MB)

⌚ 17.5. Transfer Learning DA - Entrenamiento

Entrenamiento del modelo con Transfer Learning y Data Augmentation.

```
In [65]: history_tl = model_tl.fit(
    train_generator,
    validation_data=val_generator,
    epochs=EP0CHS,
    callbacks=callbacks
)

print("Entrenamiento con Transfer Learning y Data Augmentation completado")
```

```

Epoch 1/50
374/374 24s 55ms/step - accuracy: 0.2713 - loss: 2.22
31 - val_accuracy: 0.4796 - val_loss: 1.6820
Epoch 2/50
374/374 19s 52ms/step - accuracy: 0.3890 - loss: 1.89
07 - val_accuracy: 0.5301 - val_loss: 1.5237
Epoch 3/50
374/374 20s 52ms/step - accuracy: 0.4087 - loss: 1.80
36 - val_accuracy: 0.5335 - val_loss: 1.4744
Epoch 4/50
374/374 19s 52ms/step - accuracy: 0.4388 - loss: 1.72
90 - val_accuracy: 0.5807 - val_loss: 1.3532
Epoch 5/50
374/374 20s 53ms/step - accuracy: 0.4609 - loss: 1.67
19 - val_accuracy: 0.5679 - val_loss: 1.3553
Epoch 6/50
374/374 20s 53ms/step - accuracy: 0.4560 - loss: 1.67
02 - val_accuracy: 0.5840 - val_loss: 1.3192
Epoch 7/50
374/374 20s 55ms/step - accuracy: 0.4710 - loss: 1.63
47 - val_accuracy: 0.5760 - val_loss: 1.3450
Epoch 8/50
374/374 20s 54ms/step - accuracy: 0.4853 - loss: 1.59
25 - val_accuracy: 0.5947 - val_loss: 1.2903
Epoch 9/50
374/374 21s 56ms/step - accuracy: 0.4873 - loss: 1.57
62 - val_accuracy: 0.6021 - val_loss: 1.2682
Epoch 10/50
374/374 20s 54ms/step - accuracy: 0.4979 - loss: 1.55
30 - val_accuracy: 0.5991 - val_loss: 1.2881
Entrenamiento con Transfer Learning y Data Augmentation completado.

```

17.6. Transfer Learning DA - Evaluación

Analisis de resultados de la arquitectura Transfer Learning con Data Augmentation.

```
In [66]: loss_tl, accuracy_tl = model_tl.evaluate(X_test_tl, y_test_ohe, verbose=1
print(f"Accuracy en test (Transfer Learning + Data Augmentation): {accuracy}")
52/52 3s 39ms/step - accuracy: 0.3908 - loss: 1.8738
Accuracy en test (Transfer Learning + Data Augmentation): 39.08%
```

17.7. Transfer Learning DA - Descongelando Capas

Descongelando las últimas capas para nuevo entrenamiento.

```
In [67]: # Descongelar las últimas capas
for layer in base_model.layers[-30:]:
    layer.trainable = True

# Compilar el modelo nuevamente
model_tl.compile(
    optimizer=Adam(learning_rate=1e-4),
    loss="categorical_crossentropy",
    metrics=["accuracy"]
)

# Resumen del modelo
```

```
model_tl.summary()

# Entrenamiento con fine-tuning usando data augmentation
history_ft = model_tl.fit(
    train_generator,
    validation_data=val_generator,
    epochs=15,
    callbacks=callbacks
)
```

Model: "functional_27"

Layer (type)	Output Shape	Param #	Connected To
input_layer_12 (InputLayer)	(None, 90, 90, 3)	0	-
Conv1 (Conv2D)	(None, 45, 45, 32)	864	input_layer_12
bn_Conv1 (BatchNormalization)	(None, 45, 45, 32)	128	Conv1[0][0]
Conv1_relu (ReLU)	(None, 45, 45, 32)	0	bn_Conv1[0]
expanded_conv_dept... (DepthwiseConv2D)	(None, 45, 45, 32)	288	Conv1_relu
expanded_conv_dept... (BatchNormalization)	(None, 45, 45, 32)	128	expanded_conv_dept...
expanded_conv_dept... (ReLU)	(None, 45, 45, 32)	0	expanded_conv_dept...
expanded_conv_proj... (Conv2D)	(None, 45, 45, 16)	512	expanded_conv_dept...
expanded_conv_proj... (BatchNormalization)	(None, 45, 45, 16)	64	expanded_conv_dept...
block_1_expand (Conv2D)	(None, 45, 45, 96)	1,536	expanded_conv_dept...
block_1_expand_BN (BatchNormalization)	(None, 45, 45, 96)	384	block_1_expand
block_1_expand_relu (ReLU)	(None, 45, 45, 96)	0	block_1_expand
block_1_pad (ZeroPadding2D)	(None, 47, 47, 96)	0	block_1_expand
block_1_depthwise (DepthwiseConv2D)	(None, 23, 23, 96)	864	block_1_pad
block_1_depthwise_... (BatchNormalization)	(None, 23, 23, 96)	384	block_1_depthwise
block_1_depthwise_... (ReLU)	(None, 23, 23, 96)	0	block_1_depthwise
block_1_project (Conv2D)	(None, 23, 23, 24)	2,304	block_1_depthwise
block_1_project_BN (BatchNormalization)	(None, 23, 23, 24)	96	block_1_project
block_2_expand (Conv2D)	(None, 23, 23, 144)	3,456	block_1_project
block_2_expand_BN (BatchNormalization)	(None, 23, 23, 144)	576	block_2_expand
block_2_expand_relu	(None, 23, 23,	0	block_2_expand

(ReLU)	144)		
block_2_depthwise (DepthwiseConv2D)	(None, 23, 23, 144)	1,296	block_2_ex
block_2_depthwise_... (BatchNormalizatio...)	(None, 23, 23, 144)	576	block_2_de
block_2_depthwise_... (ReLU)	(None, 23, 23, 144)	0	block_2_de
block_2_project (Conv2D)	(None, 23, 23, 24)	3,456	block_2_de
block_2_project_BN (BatchNormalizatio...)	(None, 23, 23, 24)	96	block_2_pro
block_2_add (Add)	(None, 23, 23, 24)	0	block_1_pro block_2_pro
block_3_expand (Conv2D)	(None, 23, 23, 144)	3,456	block_2_adv
block_3_expand_BN (BatchNormalizatio...)	(None, 23, 23, 144)	576	block_3_ex
block_3_expand_relu (ReLU)	(None, 23, 23, 144)	0	block_3_ex
block_3_pad (ZeroPadding2D)	(None, 25, 25, 144)	0	block_3_ex
block_3_depthwise (DepthwiseConv2D)	(None, 12, 12, 144)	1,296	block_3_pac
block_3_depthwise_... (BatchNormalizatio...)	(None, 12, 12, 144)	576	block_3_de
block_3_depthwise_... (ReLU)	(None, 12, 12, 144)	0	block_3_de
block_3_project (Conv2D)	(None, 12, 12, 32)	4,608	block_3_de
block_3_project_BN (BatchNormalizatio...)	(None, 12, 12, 32)	128	block_3_pro
block_4_expand (Conv2D)	(None, 12, 12, 192)	6,144	block_3_pro
block_4_expand_BN (BatchNormalizatio...)	(None, 12, 12, 192)	768	block_4_ex
block_4_expand_relu (ReLU)	(None, 12, 12, 192)	0	block_4_ex
block_4_depthwise (DepthwiseConv2D)	(None, 12, 12, 192)	1,728	block_4_ex
block_4_depthwise_... (BatchNormalizatio...)	(None, 12, 12, 192)	768	block_4_de
block_4_depthwise_... (ReLU)	(None, 12, 12, 192)	0	block_4_de

block_4_project (Conv2D)	(None, 12, 12, 32)	6,144	block_4_de
block_4_project_BN (BatchNormalizatio...)	(None, 12, 12, 32)	128	block_4_pro
block_4_add (Add)	(None, 12, 12, 32)	0	block_3_pro block_4_pro
block_5_expand (Conv2D)	(None, 12, 12, 192)	6,144	block_4_adv
block_5_expand_BN (BatchNormalizatio...)	(None, 12, 12, 192)	768	block_5_exp
block_5_expand_relu (ReLU)	(None, 12, 12, 192)	0	block_5_exp
block_5_depthwise (DepthwiseConv2D)	(None, 12, 12, 192)	1,728	block_5_exp
block_5_depthwise_... (BatchNormalizatio...)	(None, 12, 12, 192)	768	block_5_de
block_5_depthwise_... (ReLU)	(None, 12, 12, 192)	0	block_5_de
block_5_project (Conv2D)	(None, 12, 12, 32)	6,144	block_5_de
block_5_project_BN (BatchNormalizatio...)	(None, 12, 12, 32)	128	block_5_pro
block_5_add (Add)	(None, 12, 12, 32)	0	block_4_adv block_5_pro
block_6_expand (Conv2D)	(None, 12, 12, 192)	6,144	block_5_adv
block_6_expand_BN (BatchNormalizatio...)	(None, 12, 12, 192)	768	block_6_ex
block_6_expand_relu (ReLU)	(None, 12, 12, 192)	0	block_6_ex
block_6_pad (ZeroPadding2D)	(None, 13, 13, 192)	0	block_6_ex
block_6_depthwise (DepthwiseConv2D)	(None, 6, 6, 192)	1,728	block_6_pa
block_6_depthwise_... (BatchNormalizatio...)	(None, 6, 6, 192)	768	block_6_de
block_6_depthwise_... (ReLU)	(None, 6, 6, 192)	0	block_6_de
block_6_project (Conv2D)	(None, 6, 6, 64)	12,288	block_6_de
block_6_project_BN (BatchNormalizatio...)	(None, 6, 6, 64)	256	block_6_pro

block_7_expand (Conv2D)	(None, 6, 6, 384)	24,576	block_6_pr
block_7_expand_BN (BatchNormalizatio...)	(None, 6, 6, 384)	1,536	block_7_ex
block_7_expand_relu (ReLU)	(None, 6, 6, 384)	0	block_7_ex
block_7_depthwise (DepthwiseConv2D)	(None, 6, 6, 384)	3,456	block_7_ex
block_7_depthwise_... (BatchNormalizatio...)	(None, 6, 6, 384)	1,536	block_7_de
block_7_depthwise_... (ReLU)	(None, 6, 6, 384)	0	block_7_de
block_7_project (Conv2D)	(None, 6, 6, 64)	24,576	block_7_de
block_7_project_BN (BatchNormalizatio...)	(None, 6, 6, 64)	256	block_7_pr
block_7_add (Add)	(None, 6, 6, 64)	0	block_6_pr block_7_pr
block_8_expand (Conv2D)	(None, 6, 6, 384)	24,576	block_7_adv
block_8_expand_BN (BatchNormalizatio...)	(None, 6, 6, 384)	1,536	block_8_ex
block_8_expand_relu (ReLU)	(None, 6, 6, 384)	0	block_8_ex
block_8_depthwise (DepthwiseConv2D)	(None, 6, 6, 384)	3,456	block_8_ex
block_8_depthwise_... (BatchNormalizatio...)	(None, 6, 6, 384)	1,536	block_8_de
block_8_depthwise_... (ReLU)	(None, 6, 6, 384)	0	block_8_de
block_8_project (Conv2D)	(None, 6, 6, 64)	24,576	block_8_de
block_8_project_BN (BatchNormalizatio...)	(None, 6, 6, 64)	256	block_8_pr
block_8_add (Add)	(None, 6, 6, 64)	0	block_7_adv block_8_pr
block_9_expand (Conv2D)	(None, 6, 6, 384)	24,576	block_8_adv
block_9_expand_BN (BatchNormalizatio...)	(None, 6, 6, 384)	1,536	block_9_ex
block_9_expand_relu (ReLU)	(None, 6, 6, 384)	0	block_9_ex
block_9_depthwise	(None, 6, 6, 384)	3,456	block_9_ex

(DepthwiseConv2D)			
block_9_depthwise... (BatchNormalizatio...)	(None, 6, 6, 384)	1,536	block_9_de...
block_9_depthwise... (ReLU)	(None, 6, 6, 384)	0	block_9_de...
block_9_project (Conv2D)	(None, 6, 6, 64)	24,576	block_9_de...
block_9_project_BN (BatchNormalizatio...)	(None, 6, 6, 64)	256	block_9_pro...
block_9_add (Add)	(None, 6, 6, 64)	0	block_8_add block_9_pro...
block_10_expand (Conv2D)	(None, 6, 6, 384)	24,576	block_9_adv...
block_10_expand_BN (BatchNormalizatio...)	(None, 6, 6, 384)	1,536	block_10_e...
block_10_expand_re... (ReLU)	(None, 6, 6, 384)	0	block_10_e...
block_10_depthwise (DepthwiseConv2D)	(None, 6, 6, 384)	3,456	block_10_e...
block_10_depthwise... (BatchNormalizatio...)	(None, 6, 6, 384)	1,536	block_10_de...
block_10_depthwise... (ReLU)	(None, 6, 6, 384)	0	block_10_de...
block_10_project (Conv2D)	(None, 6, 6, 96)	36,864	block_10_de...
block_10_project_BN (BatchNormalizatio...)	(None, 6, 6, 96)	384	block_10_pi...
block_11_expand (Conv2D)	(None, 6, 6, 576)	55,296	block_10_pi...
block_11_expand_BN (BatchNormalizatio...)	(None, 6, 6, 576)	2,304	block_11_e...
block_11_expand_re... (ReLU)	(None, 6, 6, 576)	0	block_11_e...
block_11_depthwise (DepthwiseConv2D)	(None, 6, 6, 576)	5,184	block_11_e...
block_11_depthwise... (BatchNormalizatio...)	(None, 6, 6, 576)	2,304	block_11_de...
block_11_depthwise... (ReLU)	(None, 6, 6, 576)	0	block_11_de...
block_11_project (Conv2D)	(None, 6, 6, 96)	55,296	block_11_de...
block_11_project_BN (BatchNormalizatio...)	(None, 6, 6, 96)	384	block_11_pi...

block_11_add (Add)	(None, 6, 6, 96)	0	block_10_p1 block_11_p1
block_12_expand (Conv2D)	(None, 6, 6, 576)	55,296	block_11_ac
block_12_expand_BN (BatchNormalizatio...)	(None, 6, 6, 576)	2,304	block_12_e1
block_12_expand_re... (ReLU)	(None, 6, 6, 576)	0	block_12_e2
block_12_depthwise (DepthwiseConv2D)	(None, 6, 6, 576)	5,184	block_12_e3
block_12_depthwise... (BatchNormalizatio...)	(None, 6, 6, 576)	2,304	block_12_de1
block_12_depthwise... (ReLU)	(None, 6, 6, 576)	0	block_12_de2
block_12_project (Conv2D)	(None, 6, 6, 96)	55,296	block_12_de3
block_12_project_BN (BatchNormalizatio...)	(None, 6, 6, 96)	384	block_12_p1
block_12_add (Add)	(None, 6, 6, 96)	0	block_11_ac block_12_p1
block_13_expand (Conv2D)	(None, 6, 6, 576)	55,296	block_12_ac
block_13_expand_BN (BatchNormalizatio...)	(None, 6, 6, 576)	2,304	block_13_e1
block_13_expand_re... (ReLU)	(None, 6, 6, 576)	0	block_13_e2
block_13_pad (ZeroPadding2D)	(None, 7, 7, 576)	0	block_13_e3
block_13_depthwise (DepthwiseConv2D)	(None, 3, 3, 576)	5,184	block_13_pa
block_13_depthwise... (BatchNormalizatio...)	(None, 3, 3, 576)	2,304	block_13_de1
block_13_depthwise... (ReLU)	(None, 3, 3, 576)	0	block_13_de2
block_13_project (Conv2D)	(None, 3, 3, 160)	92,160	block_13_de3
block_13_project_BN (BatchNormalizatio...)	(None, 3, 3, 160)	640	block_13_p1
block_14_expand (Conv2D)	(None, 3, 3, 960)	153,600	block_13_p1
block_14_expand_BN (BatchNormalizatio...)	(None, 3, 3, 960)	3,840	block_14_e1

block_14_expand_re... (ReLU)	(None, 3, 3, 960)	0	block_14_e
block_14_depthwise (DepthwiseConv2D)	(None, 3, 3, 960)	8,640	block_14_e
block_14_depthwise... (BatchNormalizatio...)	(None, 3, 3, 960)	3,840	block_14_de
block_14_depthwise... (ReLU)	(None, 3, 3, 960)	0	block_14_de
block_14_project (Conv2D)	(None, 3, 3, 160)	153,600	block_14_de
block_14_project_BN (BatchNormalizatio...)	(None, 3, 3, 160)	640	block_14_pi
block_14_add (Add)	(None, 3, 3, 160)	0	block_13_pi block_14_pi
block_15_expand (Conv2D)	(None, 3, 3, 960)	153,600	block_14_ac
block_15_expand_BN (BatchNormalizatio...)	(None, 3, 3, 960)	3,840	block_15_e
block_15_expand_re... (ReLU)	(None, 3, 3, 960)	0	block_15_e
block_15_depthwise (DepthwiseConv2D)	(None, 3, 3, 960)	8,640	block_15_e
block_15_depthwise... (BatchNormalizatio...)	(None, 3, 3, 960)	3,840	block_15_de
block_15_depthwise... (ReLU)	(None, 3, 3, 960)	0	block_15_de
block_15_project (Conv2D)	(None, 3, 3, 160)	153,600	block_15_de
block_15_project_BN (BatchNormalizatio...)	(None, 3, 3, 160)	640	block_15_pi
block_15_add (Add)	(None, 3, 3, 160)	0	block_14_ac block_15_pi
block_16_expand (Conv2D)	(None, 3, 3, 960)	153,600	block_15_ac
block_16_expand_BN (BatchNormalizatio...)	(None, 3, 3, 960)	3,840	block_16_e
block_16_expand_re... (ReLU)	(None, 3, 3, 960)	0	block_16_e
block_16_depthwise (DepthwiseConv2D)	(None, 3, 3, 960)	8,640	block_16_e
block_16_depthwise... (BatchNormalizatio...)	(None, 3, 3, 960)	3,840	block_16_de
block_16_depthwise...	(None, 3, 3, 960)	0	block_16_de

(ReLU)			
block_16_project (Conv2D)	(None, 3, 3, 320)	307,200	block_16_de
block_16_project_BN (BatchNormalizatio...)	(None, 3, 3, 320)	1,280	block_16_pi
Conv_1 (Conv2D)	(None, 3, 3, 1280)	409,600	block_16_pi
Conv_1_bn (BatchNormalizatio...)	(None, 3, 3, 1280)	5,120	Conv_1[0] [6]
out_relu (ReLU)	(None, 3, 3, 1280)	0	Conv_1_bn[6]
global_average_poo... (GlobalAveragePool...)	(None, 1280)	0	out_relu[0]
dense_23 (Dense)	(None, 256)	327,936	global_ave
dropout_39 (Dropout)	(None, 256)	0	dense_23[0]
dense_24 (Dense)	(None, 13)	3,341	dropout_39

Total params: 2,589,261 (9.88 MB)

Trainable params: 1,857,677 (7.09 MB)

Non-trainable params: 731,584 (2.79 MB)

Epoch 1/15

374/374 32s 74ms/step - accuracy: 0.4133 - loss: 1.81
78 - val_accuracy: 0.5382 - val_loss: 1.8646

Epoch 2/15

374/374 27s 73ms/step - accuracy: 0.5911 - loss: 1.29
94 - val_accuracy: 0.6499 - val_loss: 1.4240

Epoch 3/15

374/374 29s 77ms/step - accuracy: 0.6663 - loss: 1.08
52 - val_accuracy: 0.7185 - val_loss: 1.1413

Epoch 4/15

374/374 29s 77ms/step - accuracy: 0.7053 - loss: 0.94
28 - val_accuracy: 0.7597 - val_loss: 0.8887

Epoch 5/15

374/374 27s 72ms/step - accuracy: 0.7408 - loss: 0.84
65 - val_accuracy: 0.7885 - val_loss: 0.7791

Epoch 6/15

374/374 27s 71ms/step - accuracy: 0.7636 - loss: 0.76
99 - val_accuracy: 0.8035 - val_loss: 0.7069

Epoch 7/15

374/374 0s 61ms/step - accuracy: 0.7797 - loss: 0.709
2

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

```

374/374 _____ 27s 71ms/step - accuracy: 0.7805 - loss: 0.70
69 - val_accuracy: 0.8206 - val_loss: 0.6381
Epoch 8/15
374/374 _____ 0s 64ms/step - accuracy: 0.7968 - loss: 0.655
1
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
374/374 _____ 28s 74ms/step - accuracy: 0.7949 - loss: 0.66
33 - val_accuracy: 0.8283 - val_loss: 0.5852
Epoch 9/15
374/374 _____ 0s 64ms/step - accuracy: 0.8127 - loss: 0.602
6
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
374/374 _____ 28s 74ms/step - accuracy: 0.8093 - loss: 0.61
72 - val_accuracy: 0.8420 - val_loss: 0.5570
Epoch 10/15
374/374 _____ 28s 75ms/step - accuracy: 0.8228 - loss: 0.58
85 - val_accuracy: 0.8263 - val_loss: 0.5995
Epoch 11/15
374/374 _____ 27s 71ms/step - accuracy: 0.8308 - loss: 0.54
96 - val_accuracy: 0.8417 - val_loss: 0.5576
Epoch 12/15
374/374 _____ 26s 69ms/step - accuracy: 0.8369 - loss: 0.53
36 - val_accuracy: 0.8153 - val_loss: 0.6437
Epoch 13/15
374/374 _____ 26s 71ms/step - accuracy: 0.8497 - loss: 0.48
36 - val_accuracy: 0.8397 - val_loss: 0.5713
Epoch 14/15
374/374 _____ 26s 70ms/step - accuracy: 0.8503 - loss: 0.48
23 - val_accuracy: 0.8327 - val_loss: 0.6034
Epoch 15/15
374/374 _____ 0s 64ms/step - accuracy: 0.8582 - loss: 0.462
8
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.
374/374 _____ 28s 74ms/step - accuracy: 0.8590 - loss: 0.46
12 - val_accuracy: 0.8507 - val_loss: 0.5181

```

17.8. Transfer Learning DA - Evaluación

Analisis de resultados de la arquitectura Transfer Learning con Data Augmentation y capas descongeladas.

```
In [68]: loss_tl, accuracy_tl = model_tl.evaluate(X_test_tl, y_test_ohe, verbose=1
print(f"Accuracy en test (Transfer Learning + Data Augmentation): {accuracy}
```

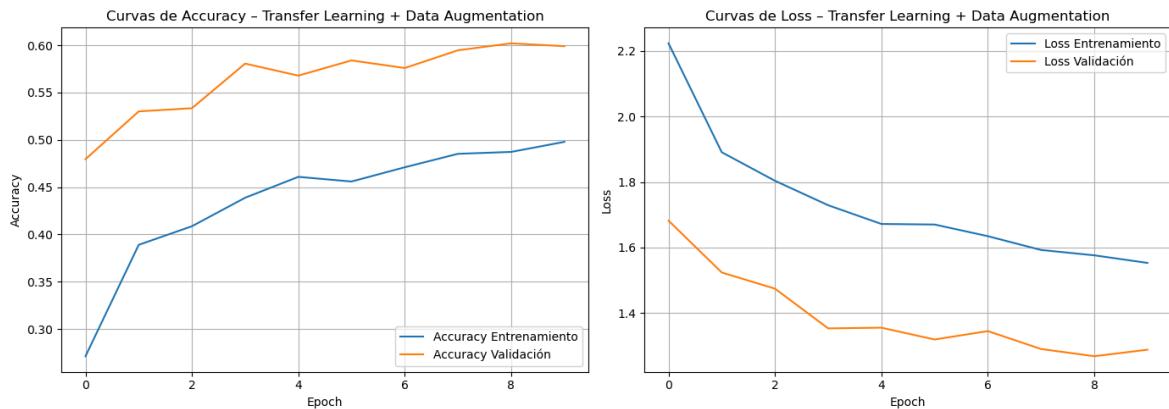
```
52/52 _____ 3s 36ms/step - accuracy: 0.7574 - loss: 1.0252
Accuracy en test (Transfer Learning + Data Augmentation): 75.74%
```

```
In [69]: plt.figure(figsize=(14, 5))
```

```
# Accuracy
plt.subplot(1, 2, 1)
plt.plot(history_tl.history["accuracy"], label="Accuracy Entrenamiento")
plt.plot(history_tl.history["val_accuracy"], label="Accuracy Validación")
plt.xlabel("Epoch")
plt.ylabel("Accuracy")
plt.title("Curvas de Accuracy – Transfer Learning + Data Augmentation")
plt.legend()
plt.grid(True)

# Loss
plt.subplot(1, 2, 2)
plt.plot(history_tl.history["loss"], label="Loss Entrenamiento")
plt.plot(history_tl.history["val_loss"], label="Loss Validación")
plt.xlabel("Epoch")
plt.ylabel("Loss")
plt.title("Curvas de Loss – Transfer Learning + Data Augmentation")
plt.legend()
plt.grid(True)

plt.tight_layout()
plt.show()
```



⌚ 17.9. Transfer Learning DA - Conclusión

En esta fase del trabajo se evaluó el impacto de la aplicación de data augmentation sobre un modelo de transfer learning basado en MobileNetV2, con el objetivo de mejorar la capacidad de generalización del clasificador.

Los resultados muestran que, al aplicar data augmentation, las curvas de *accuracy* de entrenamiento y validación se mantienen muy próximas entre sí a lo largo de las épocas. Este comportamiento indica que el modelo reduce el sobreajuste observado en la versión sin data augmentation, ya que la brecha entre entrenamiento y validación es menor y las pérdidas evolucionan de forma similar en ambos conjuntos.

Sin embargo, esta mejora en la regularización no se traduce en un incremento significativo del rendimiento absoluto del modelo. Este resultado refuerza la hipótesis de que el principal factor limitante no es la falta de datos efectivos, sino la adecuación del modelo preentrenado al dominio del problema. Las transformaciones aplicadas mediante data augmentation pueden introducir variaciones útiles en imágenes fotográficas reales, pero en el caso de imágenes tipo *cartoon* como las de

The Simpsons, algunas de estas transformaciones generan ejemplos poco realistas que no aportan información relevante al aprendizaje.

En conclusión, el uso de data augmentation en combinación con transfer learning mejora la estabilidad del entrenamiento y reduce el sobreajuste, pero no permite alcanzar el objetivo de una accuracy superior al 85% en el conjunto de test.

18. Conclusión del Trabajo

Este trabajo comienza con la carga de datos, una base de datos de imágenes de la famosa serie "Los Simpson". A continuación, se realiza el procesamiento de datos, que incluye:

- Normalización de datos, para obtener estabilidad numérica, entre otras ventajas;
- One-hot Encoding, para convertir datos categóricos a un formato numérico;
- Separación de los datos en dos conjuntos, uno para el entrenamiento y otro para la validación del modelo.

18.1. Experimentos Realizados

Se realizaron experimentos con diferentes arquitecturas de redes neuronales:

1. CNN Convolutional Neural Networks con Keras, utilizando una arquitectura básica para el primer entrenamiento.
2. Fully Connected, modelo que aplana las imágenes y pasa los píxeles por capas densas con regularización, normalización y dropout para reducir sobreajuste.
3. CNN más profunda, aumentada la profundidad de la red para que el modelo pueda aprender representaciones jerárquicas más complejas.
4. CNN con más capas, experimento con más capas en la arquitectura para intentar obtener resultados mejores.
5. CNN con Cambio en Hyperparameters, cambios en dropout, learning rate y regularización de las capas densas para intentar mejorar la generalización del modelo.
6. CNN con BatchNormalization, estabiliza el entrenamiento y permite tasas de aprendizaje más altas.
7. CNN con Data Augmentation: Aumenta la diversidad de datos de entrenamiento.
8. CNN con Optimizers: Actualizan los pesos de la red neuronal durante el entrenamiento.
9. CNN con BatchNormalization, Data Augmentation y Optimizer Nadam: Combinación de las técnicas que presentaron mejores resultados.
10. Transfer Learning: Utilización de un modelo pre-entrenado como punto de partida para resolver un problema nuevo.
11. Transfer Learning con Data Augmentation y Congelamiento: Congelamiento de las primeras capas.
12. Transfer Learning con Data Augmentation sin Congelamiento: Descongelamiento de las últimas capas para nuevo entrenamiento.

18.2. Tabla Comparativa

A continuación se muestra una tabla comparativa con todas las variaciones o arquitecturas probadas y los resultados obtenidos:

N	Red	Accuracy Train	Accuracy Test	Loss
01	CNN Basica	93,5%	81,4%	0,92
02	Fully Connected	20,9%	13,2%	4,23
03	CNN +Profunda	91,9%	36,2%	2,03
04	CNN +Capas	13,5%	13,5%	2,53
05	CNN +Hyperparameters	95,3%	81,0%	1,01
06	CNN +BatchNormalization	98,0%	84,7%	0,62
07	CNN +Data Augmentation	81,2%	82,5%	0,64
08	CNN +Optimizer Adam	94,8%	79,7%	0,72
09	CNN +Optimizer RMSprop	90,5%	81,7%	0,68
10	CNN +Optimizer Nadam	96,1%	82,9%	0,66
11	CNN +Optimizer SGD	80,9%	19,6%	2,44
12	CNN +BN +DA +Nadam 🚀	90,6%	86.3%	0,68
13	Transfer Learning	79,0%	50,4%	1,77
14	Transfer Learning +Congelamiento	97,7%	66,8%	1,72
15	Transfer Learning +DA Congelado	49,8%	39,0%	1,87
16	Transfer Learning +DA Descongelado	85,8%	75,7%	1,02

🚀 La combinación de la arquitectura CNN y las técnicas BatchNormalization, Data Augmentation y Optimizer Nadan dieron como resultado la mayor precisión (accuracy), alcanzando hasta el 86,3% en el dataset de prueba.

18.3. 🧘 Consideraciones Finales

Este trabajo presentó desafíos interesantes que requirieron una considerable investigación y experimentación. Entre ellos, destacan los siguientes:

1. Era necesario encontrar una resolución de imagen ligera, pero suficiente para que la red neuronal identificara con precisión los elementos de interés. Se probaron varias resoluciones diferentes. Cabe destacar que resoluciones superiores a la utilizada en la versión final resultaron en un entrenamiento más lento y un menor rendimiento.
2. La experimentación con diferentes arquitecturas ayudó a demostrar que más capas y más neuronas no necesariamente implican mejores resultados. En cierto modo, este hecho contradice el sentido común.

3. Experimentar con diferentes técnicas por separado fue fundamental para identificar las que más contribuían al objetivo y para seleccionar las más exitosas en el modelo que lograron la precisión deseada.

El objetivo de obtener una precisión mínima del 85% se logró, lo que requirió combinar la arquitectura y las técnicas que ofrecieron el mejor rendimiento durante los experimentos.