DenkowskiStanislawlab3TF

October 28, 2022

[ ]:
```
import tensorflow as tf
import tensorflow_datasets as tfds
import numpy as np
import matplotlib.pyplot as plt
import time
from PIL import Image
import requests
```

Ze względu na wielkie problemy z pytorchem i pytrochem lightniningiem, zdecydowałem się zrobić tego laba przy pomocy tensorflow i keras.
Problemy miałem następujące: - dataloader bardzo bardzo spowalniał, jeśli zwiększałem liczbę workerów (nie jest to wielki problem) - Mój model, który moim zdaniem jest dobrze zdefiniowany, (nie wykluczam, że się pomyliłem ale porównywałem do bardzo wielu innych modeli w internecie), bardzo słabo się uczył - Obie kwestie nie gwarantują błędów po stronie pytorcha, ale biorąc pod uwagę dosyć specyficzną maszynę na której pracuję i liczbę problemów jaką znalazłem wolałem zmienic framework - potencjalnie będę próbował wrócić do pytorch lightning, ale nie mam teraz czasu szukać problemów

[ ]:
```
cifar10 = tf.keras.datasets.cifar10
(train_images, train_labels), (val_images, val_labels) = cifar10.load_data()
info = tfds.builder('cifar10').info
info
```

```
2022-10-27 11:10:12.223962: W
tensorflow/core/platform/cloud/google_auth_provider.cc:184] All attempts to get
a Google authentication bearer token failed, returning an empty token.
Retrieving token from files failed with "NOT_FOUND: Could not locate the
credentials file.". Retrieving token from GCE failed with "FAILED_PRECONDITION:
Error executing an HTTP request: libcurl code 6 meaning 'Couldn't resolve host
name', error details: Could not resolve host: metadata".
```

[ ]:
```
tfds.core.DatasetInfo(
    name='cifar10',
    full_name='cifar10/3.0.2',
    description="""
    The CIFAR-10 dataset consists of 60000 32x32 colour images in 10 classes,
with 6000 images per class. There are 50000 training images and 10000 test
images.
    """,
```

```
    homepage='https://www.cs.toronto.edu/~kriz/cifar.html',
data_path='/var/folders/8p/_cz7tfws6qj3stcp8jwc282r0000gn/T/tmpts2uasditfds',
    file_format=tfrecord,
    download_size=162.17 MiB,
    dataset_size=132.40 MiB,
    features=FeaturesDict({
        'id': Text(shape=(), dtype=tf.string),
        'image': Image(shape=(32, 32, 3), dtype=tf.uint8),
        'label': ClassLabel(shape=(), dtype=tf.int64, num_classes=10),
    }),
    supervised_keys=('image', 'label'),
    disable_shuffling=False,
    splits={
        'test': <SplitInfo num_examples=10000, num_shards=1>,
        'train': <SplitInfo num_examples=50000, num_shards=1>,
    },
    citation="""@TECHREPORT{Krizhevsky09learningmultiple,
        author = {Alex Krizhevsky},
        title = {Learning multiple layers of features from tiny images},
        institution = {},
        year = {2009}
    }""",
)
```

[ ]:
```
classes = info.features['label'].names
classes
```

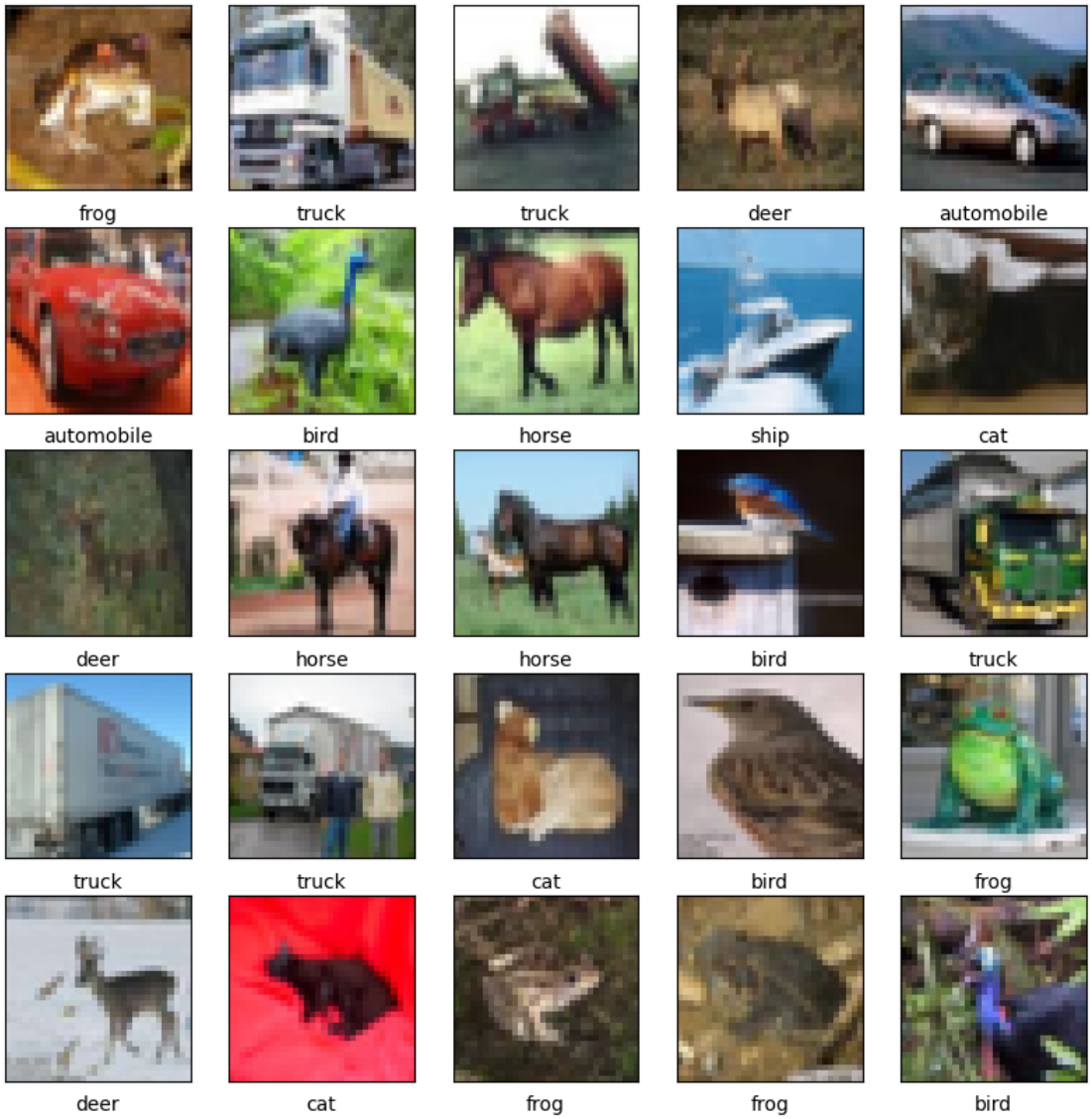
[ ]:
```
['airplane',
 'automobile',
 'bird',
 'cat',
 'deer',
 'dog',
 'frog',
 'horse',
 'ship',
 'truck']
```

[ ]:
```
print(train_images.shape, train_labels.shape, val_images.shape, val_labels.
  ↪shape)
```

```
(50000, 32, 32, 3) (50000, 1) (10000, 32, 32, 3) (10000, 1)
```

[ ]:
```
plt.figure(figsize=(10,10))
for i in range(25):
    plt.subplot(5,5,i+1)
    plt.xticks([])
    plt.yticks([])
```

```
    plt.grid(False)
    plt.imshow(train_images[i])
    plt.xlabel(classes[train_labels[i][0]])
plt.show()
```



Bardzo różnorodne zdjęcia.

[ ]:
```
train_labels = tf.one_hot(tf.reshape(train_labels, train_labels.shape[0]),␣
 ↪depth=10)
val_labels = tf.one_hot(tf.reshape(val_labels, val_labels.shape[0]), depth=10)
train_images = train_images / 255.0
val_images = val_images / 255.0
```

```
train_images[0].shape
```

```
Metal device set to: Apple M1 Pro

systemMemory: 32.00 GB
maxCacheSize: 10.67 GB


2022-10-27 11:10:15.855739: I
tensorflow/core/common_runtime/pluggable_device/pluggable_device_factory.cc:306]
Could not identify NUMA node of platform GPU ID 0, defaulting to 0. Your kernel
may not have been built with NUMA support.
2022-10-27 11:10:15.855866: I
tensorflow/core/common_runtime/pluggable_device/pluggable_device_factory.cc:272]
Created TensorFlow device (/job:localhost/replica:0/task:0/device:GPU:0 with 0
MB memory) -> physical PluggableDevice (device: 0, name: METAL, pci bus id:
<undefined>)
```

[ ]:
```
(32, 32, 3)
```

Wykorzystałem funkcję tf.one_hot do zmiany kodowania labeli na one hot encoding. Dodatkowo normalizuję zbiory danych.

[ ]:
```
minmodel = tf.keras.Sequential([
    tf.keras.layers.Conv2D(5, 3, padding='same', activation='sigmoid',␣
  ↪input_shape=train_images[0].shape),
    tf.keras.layers.Conv2D(5, 3, padding='same', activation='sigmoid'),
    tf.keras.layers.MaxPool2D(pool_size=(8,8), padding='valid'),
    tf.keras.layers.Flatten(),
    tf.keras.layers.Dense(units=10, activation='softmax')
])
```

[ ]:
```
minmodel.summary()
```

```
Model: "sequential"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d (Conv2D)             (None, 32, 32, 5)         140

 conv2d_1 (Conv2D)           (None, 32, 32, 5)         230

 max_pooling2d (MaxPooling2D  (None, 4, 4, 5)          0
 )

 flatten (Flatten)           (None, 80)                0

 dense (Dense)               (None, 10)                810
```

```
=================================================================
Total params: 1,180
Trainable params: 1,180
Non-trainable params: 0
_________________________________________________________________
```

Do implementacji minimalnej architektury wykorzystałem, tf.keras.Sequential - który gwarantuje nam sekwencyjne działanie zdefiniowanych warstw, oraz warst - Conv2D dwa razy, MaxPooling2D, Flatten, Dense.
Zgodnie z poleceniem zadania.
Taki model ma 1180 parametrów.

[ ]:
```
first10 = minmodel(train_images[:10])
print(tf.math.reduce_all(tf.one_hot(tf.math.argmax(first10, axis=1),␣
  ↪depth=10)==train_labels[:10], 1), '\n', tf.math.argmax(first10, axis=1))
print(tf.math.reduce_max(first10, axis=1))
```

```
tf.Tensor([False  True  True False False False False False False False],
shape=(10,), dtype=bool)
 tf.Tensor([9 9 9 9 9 9 9 9 9 9], shape=(10,), dtype=int64)
```

Jak widać model daje bardzo słabe wyniki, ma bardzo duży bias do jednej(czasem kilku konkretrnych) klasy.

[ ]:
```
minmodel.compile(
    optimizer=tf.keras.optimizers.SGD(learning_rate=0.001, momentum=0.9),
    loss=tf.keras.losses.CategoricalCrossentropy(),
    metrics=['accuracy']
)
```

[ ]:
```
start_time=time.time()
minhistory = minmodel.fit(
    x=train_images,
    y=train_labels,
    batch_size=64,
    epochs=150,
    verbose=1,
    validation_data=(val_images, val_labels)
)
print(f"time: {time.time()-start_time}")
```

```
Epoch 1/150

2022-10-27 11:10:22.840351: W
tensorflow/core/platform/profile_utils/cpu_utils.cc:128] Failed to get CPU
frequency: 0 Hz
2022-10-27 11:10:23.076174: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114]
Plugin optimizer for device_type GPU is enabled.
```

```
780/782 [============================>.] - ETA: 0s - loss: 2.3099 - accuracy:
0.1015

2022-10-27 11:10:33.350608: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114]
Plugin optimizer for device_type GPU is enabled.

782/782 [==============================] - 11s 14ms/step - loss: 2.3099 -
accuracy: 0.1014 - val_loss: 2.3022 - val_accuracy: 0.0999
Epoch 2/150
782/782 [==============================] - 10s 13ms/step - loss: 2.3018 -
accuracy: 0.1057 - val_loss: 2.3015 - val_accuracy: 0.1062
Epoch 3/150
782/782 [==============================] - 10s 13ms/step - loss: 2.3006 -
accuracy: 0.1091 - val_loss: 2.2996 - val_accuracy: 0.1402
Epoch 4/150
782/782 [==============================] - 10s 13ms/step - loss: 2.2987 -
accuracy: 0.1183 - val_loss: 2.2978 - val_accuracy: 0.1433
Epoch 5/150
782/782 [==============================] - 10s 13ms/step - loss: 2.2966 -
accuracy: 0.1284 - val_loss: 2.2950 - val_accuracy: 0.1022
Epoch 6/150
782/782 [==============================] - 10s 13ms/step - loss: 2.2929 -
accuracy: 0.1408 - val_loss: 2.2899 - val_accuracy: 0.1665
Epoch 7/150
782/782 [==============================] - 10s 13ms/step - loss: 2.2865 -
accuracy: 0.1493 - val_loss: 2.2819 - val_accuracy: 0.1681
Epoch 8/150
782/782 [==============================] - 10s 13ms/step - loss: 2.2752 -
accuracy: 0.1681 - val_loss: 2.2665 - val_accuracy: 0.1726
Epoch 9/150
782/782 [==============================] - 10s 13ms/step - loss: 2.2556 -
accuracy: 0.1844 - val_loss: 2.2413 - val_accuracy: 0.1896
Epoch 10/150
782/782 [==============================] - 10s 13ms/step - loss: 2.2233 -
accuracy: 0.2015 - val_loss: 2.1997 - val_accuracy: 0.2120
Epoch 11/150
782/782 [==============================] - 10s 13ms/step - loss: 2.1747 -
accuracy: 0.2247 - val_loss: 2.1422 - val_accuracy: 0.2356
Epoch 12/150
782/782 [==============================] - 10s 13ms/step - loss: 2.1180 -
accuracy: 0.2457 - val_loss: 2.0843 - val_accuracy: 0.2628
Epoch 13/150
782/782 [==============================] - 10s 13ms/step - loss: 2.0684 -
accuracy: 0.2684 - val_loss: 2.0402 - val_accuracy: 0.2783
Epoch 14/150
782/782 [==============================] - 10s 13ms/step - loss: 2.0324 -
accuracy: 0.2811 - val_loss: 2.0085 - val_accuracy: 0.2958
Epoch 15/150
```

```
782/782 [==============================] - 10s 13ms/step - loss: 2.0066 -
accuracy: 0.2902 - val_loss: 1.9840 - val_accuracy: 0.3011
Epoch 16/150
782/782 [==============================] - 10s 13ms/step - loss: 1.9859 -
accuracy: 0.2969 - val_loss: 1.9647 - val_accuracy: 0.2990
Epoch 17/150
782/782 [==============================] - 11s 14ms/step - loss: 1.9685 -
accuracy: 0.3008 - val_loss: 1.9479 - val_accuracy: 0.3137
Epoch 18/150
782/782 [==============================] - 10s 13ms/step - loss: 1.9526 -
accuracy: 0.3089 - val_loss: 1.9319 - val_accuracy: 0.3185
Epoch 19/150
782/782 [==============================] - 10s 13ms/step - loss: 1.9374 -
accuracy: 0.3125 - val_loss: 1.9169 - val_accuracy: 0.3307
Epoch 20/150
782/782 [==============================] - 10s 13ms/step - loss: 1.9229 -
accuracy: 0.3181 - val_loss: 1.9029 - val_accuracy: 0.3307
Epoch 21/150
782/782 [==============================] - 10s 13ms/step - loss: 1.9091 -
accuracy: 0.3217 - val_loss: 1.8899 - val_accuracy: 0.3319
Epoch 22/150
782/782 [==============================] - 10s 13ms/step - loss: 1.8956 -
accuracy: 0.3286 - val_loss: 1.8769 - val_accuracy: 0.3356
Epoch 23/150
782/782 [==============================] - 10s 13ms/step - loss: 1.8831 -
accuracy: 0.3323 - val_loss: 1.8648 - val_accuracy: 0.3427
Epoch 24/150
782/782 [==============================] - 10s 13ms/step - loss: 1.8706 -
accuracy: 0.3380 - val_loss: 1.8539 - val_accuracy: 0.3461
Epoch 25/150
782/782 [==============================] - 10s 13ms/step - loss: 1.8586 -
accuracy: 0.3420 - val_loss: 1.8429 - val_accuracy: 0.3495
Epoch 26/150
782/782 [==============================] - 10s 13ms/step - loss: 1.8473 -
accuracy: 0.3457 - val_loss: 1.8317 - val_accuracy: 0.3516
Epoch 27/150
782/782 [==============================] - 10s 13ms/step - loss: 1.8362 -
accuracy: 0.3515 - val_loss: 1.8210 - val_accuracy: 0.3620
Epoch 28/150
782/782 [==============================] - 10s 13ms/step - loss: 1.8259 -
accuracy: 0.3532 - val_loss: 1.8124 - val_accuracy: 0.3584
Epoch 29/150
782/782 [==============================] - 10s 13ms/step - loss: 1.8161 -
accuracy: 0.3573 - val_loss: 1.8020 - val_accuracy: 0.3619
Epoch 30/150
782/782 [==============================] - 10s 13ms/step - loss: 1.8063 -
accuracy: 0.3600 - val_loss: 1.7928 - val_accuracy: 0.3681
Epoch 31/150
```

```
782/782 [==============================] - 10s 13ms/step - loss: 1.7971 -
accuracy: 0.3643 - val_loss: 1.7854 - val_accuracy: 0.3689
Epoch 32/150
782/782 [==============================] - 10s 13ms/step - loss: 1.7887 -
accuracy: 0.3658 - val_loss: 1.7802 - val_accuracy: 0.3720
Epoch 33/150
782/782 [==============================] - 10s 13ms/step - loss: 1.7805 -
accuracy: 0.3690 - val_loss: 1.7699 - val_accuracy: 0.3774
Epoch 34/150
782/782 [==============================] - 10s 13ms/step - loss: 1.7725 -
accuracy: 0.3721 - val_loss: 1.7621 - val_accuracy: 0.3758
Epoch 35/150
782/782 [==============================] - 10s 13ms/step - loss: 1.7647 -
accuracy: 0.3737 - val_loss: 1.7560 - val_accuracy: 0.3807
Epoch 36/150
782/782 [==============================] - 10s 13ms/step - loss: 1.7575 -
accuracy: 0.3770 - val_loss: 1.7475 - val_accuracy: 0.3835
Epoch 37/150
782/782 [==============================] - 10s 13ms/step - loss: 1.7500 -
accuracy: 0.3789 - val_loss: 1.7404 - val_accuracy: 0.3852
Epoch 38/150
782/782 [==============================] - 10s 13ms/step - loss: 1.7429 -
accuracy: 0.3826 - val_loss: 1.7354 - val_accuracy: 0.3886
Epoch 39/150
782/782 [==============================] - 10s 13ms/step - loss: 1.7362 -
accuracy: 0.3850 - val_loss: 1.7274 - val_accuracy: 0.3886
Epoch 40/150
782/782 [==============================] - 10s 13ms/step - loss: 1.7291 -
accuracy: 0.3861 - val_loss: 1.7210 - val_accuracy: 0.3898
Epoch 41/150
782/782 [==============================] - 10s 13ms/step - loss: 1.7222 -
accuracy: 0.3892 - val_loss: 1.7139 - val_accuracy: 0.3958
Epoch 42/150
782/782 [==============================] - 10s 13ms/step - loss: 1.7154 -
accuracy: 0.3914 - val_loss: 1.7066 - val_accuracy: 0.3953
Epoch 43/150
782/782 [==============================] - 10s 13ms/step - loss: 1.7086 -
accuracy: 0.3940 - val_loss: 1.7009 - val_accuracy: 0.3952
Epoch 44/150
782/782 [==============================] - 10s 13ms/step - loss: 1.7020 -
accuracy: 0.3976 - val_loss: 1.6940 - val_accuracy: 0.3979
Epoch 45/150
782/782 [==============================] - 10s 13ms/step - loss: 1.6953 -
accuracy: 0.3995 - val_loss: 1.6876 - val_accuracy: 0.4010
Epoch 46/150
782/782 [==============================] - 11s 13ms/step - loss: 1.6884 -
accuracy: 0.4021 - val_loss: 1.6804 - val_accuracy: 0.4042
Epoch 47/150
```

```
782/782 [==============================] - 10s 13ms/step - loss: 1.6813 -
accuracy: 0.4045 - val_loss: 1.6745 - val_accuracy: 0.4060
Epoch 48/150
782/782 [==============================] - 10s 13ms/step - loss: 1.6742 -
accuracy: 0.4081 - val_loss: 1.6681 - val_accuracy: 0.4056
Epoch 49/150
782/782 [==============================] - 10s 13ms/step - loss: 1.6672 -
accuracy: 0.4099 - val_loss: 1.6598 - val_accuracy: 0.4105
Epoch 50/150
782/782 [==============================] - 10s 13ms/step - loss: 1.6603 -
accuracy: 0.4128 - val_loss: 1.6544 - val_accuracy: 0.4141
Epoch 51/150
782/782 [==============================] - 10s 13ms/step - loss: 1.6536 -
accuracy: 0.4147 - val_loss: 1.6469 - val_accuracy: 0.4162
Epoch 52/150
782/782 [==============================] - 10s 13ms/step - loss: 1.6465 -
accuracy: 0.4170 - val_loss: 1.6402 - val_accuracy: 0.4171
Epoch 53/150
782/782 [==============================] - 10s 13ms/step - loss: 1.6404 -
accuracy: 0.4199 - val_loss: 1.6341 - val_accuracy: 0.4178
Epoch 54/150
782/782 [==============================] - 10s 13ms/step - loss: 1.6331 -
accuracy: 0.4230 - val_loss: 1.6274 - val_accuracy: 0.4236
Epoch 55/150
782/782 [==============================] - 10s 13ms/step - loss: 1.6270 -
accuracy: 0.4251 - val_loss: 1.6214 - val_accuracy: 0.4226
Epoch 56/150
782/782 [==============================] - 11s 13ms/step - loss: 1.6207 -
accuracy: 0.4280 - val_loss: 1.6150 - val_accuracy: 0.4260
Epoch 57/150
782/782 [==============================] - 10s 13ms/step - loss: 1.6143 -
accuracy: 0.4306 - val_loss: 1.6106 - val_accuracy: 0.4287
Epoch 58/150
782/782 [==============================] - 10s 13ms/step - loss: 1.6088 -
accuracy: 0.4318 - val_loss: 1.6045 - val_accuracy: 0.4301
Epoch 59/150
782/782 [==============================] - 10s 13ms/step - loss: 1.6028 -
accuracy: 0.4344 - val_loss: 1.5995 - val_accuracy: 0.4303
Epoch 60/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5976 -
accuracy: 0.4351 - val_loss: 1.5946 - val_accuracy: 0.4323
Epoch 61/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5922 -
accuracy: 0.4377 - val_loss: 1.5891 - val_accuracy: 0.4350
Epoch 62/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5868 -
accuracy: 0.4396 - val_loss: 1.5843 - val_accuracy: 0.4359
Epoch 63/150
```

```
782/782 [==============================] - 10s 13ms/step - loss: 1.5819 -
accuracy: 0.4427 - val_loss: 1.5801 - val_accuracy: 0.4371
Epoch 64/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5774 -
accuracy: 0.4453 - val_loss: 1.5756 - val_accuracy: 0.4362
Epoch 65/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5725 -
accuracy: 0.4453 - val_loss: 1.5709 - val_accuracy: 0.4421
Epoch 66/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5680 -
accuracy: 0.4479 - val_loss: 1.5669 - val_accuracy: 0.4449
Epoch 67/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5639 -
accuracy: 0.4499 - val_loss: 1.5637 - val_accuracy: 0.4458
Epoch 68/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5596 -
accuracy: 0.4506 - val_loss: 1.5594 - val_accuracy: 0.4465
Epoch 69/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5558 -
accuracy: 0.4532 - val_loss: 1.5551 - val_accuracy: 0.4504
Epoch 70/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5514 -
accuracy: 0.4538 - val_loss: 1.5518 - val_accuracy: 0.4497
Epoch 71/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5477 -
accuracy: 0.4551 - val_loss: 1.5483 - val_accuracy: 0.4495
Epoch 72/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5439 -
accuracy: 0.4565 - val_loss: 1.5446 - val_accuracy: 0.4494
Epoch 73/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5405 -
accuracy: 0.4578 - val_loss: 1.5420 - val_accuracy: 0.4509
Epoch 74/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5368 -
accuracy: 0.4581 - val_loss: 1.5384 - val_accuracy: 0.4562
Epoch 75/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5336 -
accuracy: 0.4591 - val_loss: 1.5369 - val_accuracy: 0.4547
Epoch 76/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5308 -
accuracy: 0.4606 - val_loss: 1.5329 - val_accuracy: 0.4557
Epoch 77/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5275 -
accuracy: 0.4607 - val_loss: 1.5307 - val_accuracy: 0.4582
Epoch 78/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5244 -
accuracy: 0.4615 - val_loss: 1.5272 - val_accuracy: 0.4600
Epoch 79/150
```

```
782/782 [==============================] - 10s 13ms/step - loss: 1.5215 -
accuracy: 0.4621 - val_loss: 1.5264 - val_accuracy: 0.4594
Epoch 80/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5184 -
accuracy: 0.4636 - val_loss: 1.5224 - val_accuracy: 0.4612
Epoch 81/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5158 -
accuracy: 0.4644 - val_loss: 1.5216 - val_accuracy: 0.4602
Epoch 82/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5132 -
accuracy: 0.4651 - val_loss: 1.5160 - val_accuracy: 0.4623
Epoch 83/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5107 -
accuracy: 0.4675 - val_loss: 1.5150 - val_accuracy: 0.4657
Epoch 84/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5083 -
accuracy: 0.4670 - val_loss: 1.5115 - val_accuracy: 0.4662
Epoch 85/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5056 -
accuracy: 0.4674 - val_loss: 1.5098 - val_accuracy: 0.4666
Epoch 86/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5034 -
accuracy: 0.4692 - val_loss: 1.5065 - val_accuracy: 0.4674
Epoch 87/150
782/782 [==============================] - 10s 13ms/step - loss: 1.5010 -
accuracy: 0.4687 - val_loss: 1.5050 - val_accuracy: 0.4659
Epoch 88/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4989 -
accuracy: 0.4700 - val_loss: 1.5030 - val_accuracy: 0.4695
Epoch 89/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4965 -
accuracy: 0.4710 - val_loss: 1.5010 - val_accuracy: 0.4693
Epoch 90/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4944 -
accuracy: 0.4720 - val_loss: 1.4997 - val_accuracy: 0.4701
Epoch 91/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4923 -
accuracy: 0.4717 - val_loss: 1.4967 - val_accuracy: 0.4702
Epoch 92/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4904 -
accuracy: 0.4736 - val_loss: 1.4952 - val_accuracy: 0.4746
Epoch 93/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4883 -
accuracy: 0.4738 - val_loss: 1.4933 - val_accuracy: 0.4738
Epoch 94/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4862 -
accuracy: 0.4744 - val_loss: 1.4908 - val_accuracy: 0.4735
Epoch 95/150
```

```
782/782 [==============================] - 10s 13ms/step - loss: 1.4844 -
accuracy: 0.4748 - val_loss: 1.4891 - val_accuracy: 0.4762
Epoch 96/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4826 -
accuracy: 0.4749 - val_loss: 1.4870 - val_accuracy: 0.4779
Epoch 97/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4809 -
accuracy: 0.4745 - val_loss: 1.4861 - val_accuracy: 0.4771
Epoch 98/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4790 -
accuracy: 0.4765 - val_loss: 1.4856 - val_accuracy: 0.4776
Epoch 99/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4773 -
accuracy: 0.4768 - val_loss: 1.4832 - val_accuracy: 0.4761
Epoch 100/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4757 -
accuracy: 0.4773 - val_loss: 1.4812 - val_accuracy: 0.4793
Epoch 101/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4740 -
accuracy: 0.4782 - val_loss: 1.4794 - val_accuracy: 0.4770
Epoch 102/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4724 -
accuracy: 0.4779 - val_loss: 1.4780 - val_accuracy: 0.4789
Epoch 103/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4706 -
accuracy: 0.4789 - val_loss: 1.4759 - val_accuracy: 0.4774
Epoch 104/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4693 -
accuracy: 0.4794 - val_loss: 1.4748 - val_accuracy: 0.4824
Epoch 105/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4676 -
accuracy: 0.4807 - val_loss: 1.4726 - val_accuracy: 0.4803
Epoch 106/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4662 -
accuracy: 0.4809 - val_loss: 1.4716 - val_accuracy: 0.4798
Epoch 107/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4643 -
accuracy: 0.4805 - val_loss: 1.4690 - val_accuracy: 0.4811
Epoch 108/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4631 -
accuracy: 0.4816 - val_loss: 1.4687 - val_accuracy: 0.4836
Epoch 109/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4614 -
accuracy: 0.4831 - val_loss: 1.4682 - val_accuracy: 0.4835
Epoch 110/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4600 -
accuracy: 0.4824 - val_loss: 1.4662 - val_accuracy: 0.4848
Epoch 111/150
```

```
782/782 [==============================] - 10s 13ms/step - loss: 1.4587 -
accuracy: 0.4835 - val_loss: 1.4641 - val_accuracy: 0.4849
Epoch 112/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4568 -
accuracy: 0.4839 - val_loss: 1.4623 - val_accuracy: 0.4831
Epoch 113/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4555 -
accuracy: 0.4850 - val_loss: 1.4617 - val_accuracy: 0.4846
Epoch 114/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4542 -
accuracy: 0.4856 - val_loss: 1.4600 - val_accuracy: 0.4831
Epoch 115/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4527 -
accuracy: 0.4863 - val_loss: 1.4583 - val_accuracy: 0.4832
Epoch 116/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4515 -
accuracy: 0.4859 - val_loss: 1.4581 - val_accuracy: 0.4847
Epoch 117/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4500 -
accuracy: 0.4858 - val_loss: 1.4593 - val_accuracy: 0.4820
Epoch 118/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4488 -
accuracy: 0.4875 - val_loss: 1.4548 - val_accuracy: 0.4850
Epoch 119/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4472 -
accuracy: 0.4889 - val_loss: 1.4545 - val_accuracy: 0.4877
Epoch 120/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4465 -
accuracy: 0.4891 - val_loss: 1.4520 - val_accuracy: 0.4854
Epoch 121/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4447 -
accuracy: 0.4888 - val_loss: 1.4513 - val_accuracy: 0.4855
Epoch 122/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4435 -
accuracy: 0.4892 - val_loss: 1.4497 - val_accuracy: 0.4869
Epoch 123/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4423 -
accuracy: 0.4906 - val_loss: 1.4476 - val_accuracy: 0.4849
Epoch 124/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4408 -
accuracy: 0.4913 - val_loss: 1.4472 - val_accuracy: 0.4876
Epoch 125/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4399 -
accuracy: 0.4906 - val_loss: 1.4457 - val_accuracy: 0.4886
Epoch 126/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4384 -
accuracy: 0.4922 - val_loss: 1.4442 - val_accuracy: 0.4904
Epoch 127/150
```

```
782/782 [==============================] - 10s 13ms/step - loss: 1.4370 -
accuracy: 0.4922 - val_loss: 1.4442 - val_accuracy: 0.4893
Epoch 128/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4359 -
accuracy: 0.4927 - val_loss: 1.4420 - val_accuracy: 0.4891
Epoch 129/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4350 -
accuracy: 0.4947 - val_loss: 1.4416 - val_accuracy: 0.4908
Epoch 130/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4338 -
accuracy: 0.4939 - val_loss: 1.4427 - val_accuracy: 0.4868
Epoch 131/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4324 -
accuracy: 0.4957 - val_loss: 1.4391 - val_accuracy: 0.4917
Epoch 132/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4311 -
accuracy: 0.4958 - val_loss: 1.4420 - val_accuracy: 0.4893
Epoch 133/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4302 -
accuracy: 0.4954 - val_loss: 1.4384 - val_accuracy: 0.4888
Epoch 134/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4290 -
accuracy: 0.4961 - val_loss: 1.4353 - val_accuracy: 0.4938
Epoch 135/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4277 -
accuracy: 0.4961 - val_loss: 1.4344 - val_accuracy: 0.4931
Epoch 136/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4266 -
accuracy: 0.4967 - val_loss: 1.4337 - val_accuracy: 0.4918
Epoch 137/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4253 -
accuracy: 0.4974 - val_loss: 1.4326 - val_accuracy: 0.4956
Epoch 138/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4239 -
accuracy: 0.4982 - val_loss: 1.4335 - val_accuracy: 0.4925
Epoch 139/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4231 -
accuracy: 0.4987 - val_loss: 1.4298 - val_accuracy: 0.4942
Epoch 140/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4221 -
accuracy: 0.4992 - val_loss: 1.4295 - val_accuracy: 0.4950
Epoch 141/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4210 -
accuracy: 0.4998 - val_loss: 1.4284 - val_accuracy: 0.4961
Epoch 142/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4195 -
accuracy: 0.5002 - val_loss: 1.4308 - val_accuracy: 0.4938
Epoch 143/150
```

```
782/782 [==============================] - 10s 13ms/step - loss: 1.4185 -
accuracy: 0.5007 - val_loss: 1.4274 - val_accuracy: 0.4949
Epoch 144/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4177 -
accuracy: 0.5016 - val_loss: 1.4255 - val_accuracy: 0.4961
Epoch 145/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4164 -
accuracy: 0.5013 - val_loss: 1.4243 - val_accuracy: 0.4943
Epoch 146/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4159 -
accuracy: 0.5021 - val_loss: 1.4252 - val_accuracy: 0.4956
Epoch 147/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4146 -
accuracy: 0.5022 - val_loss: 1.4220 - val_accuracy: 0.4957
Epoch 148/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4131 -
accuracy: 0.5028 - val_loss: 1.4215 - val_accuracy: 0.4963
Epoch 149/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4125 -
accuracy: 0.5036 - val_loss: 1.4198 - val_accuracy: 0.4966
Epoch 150/150
782/782 [==============================] - 10s 13ms/step - loss: 1.4113 -
accuracy: 0.5043 - val_loss: 1.4192 - val_accuracy: 0.4969
time: 1541.3710536956787
```

Model liczy mniej więcej 30 min.
Trochę mniej jak nie korzystam z komputera, trochę więcej jeśli np. słucham wykładu.

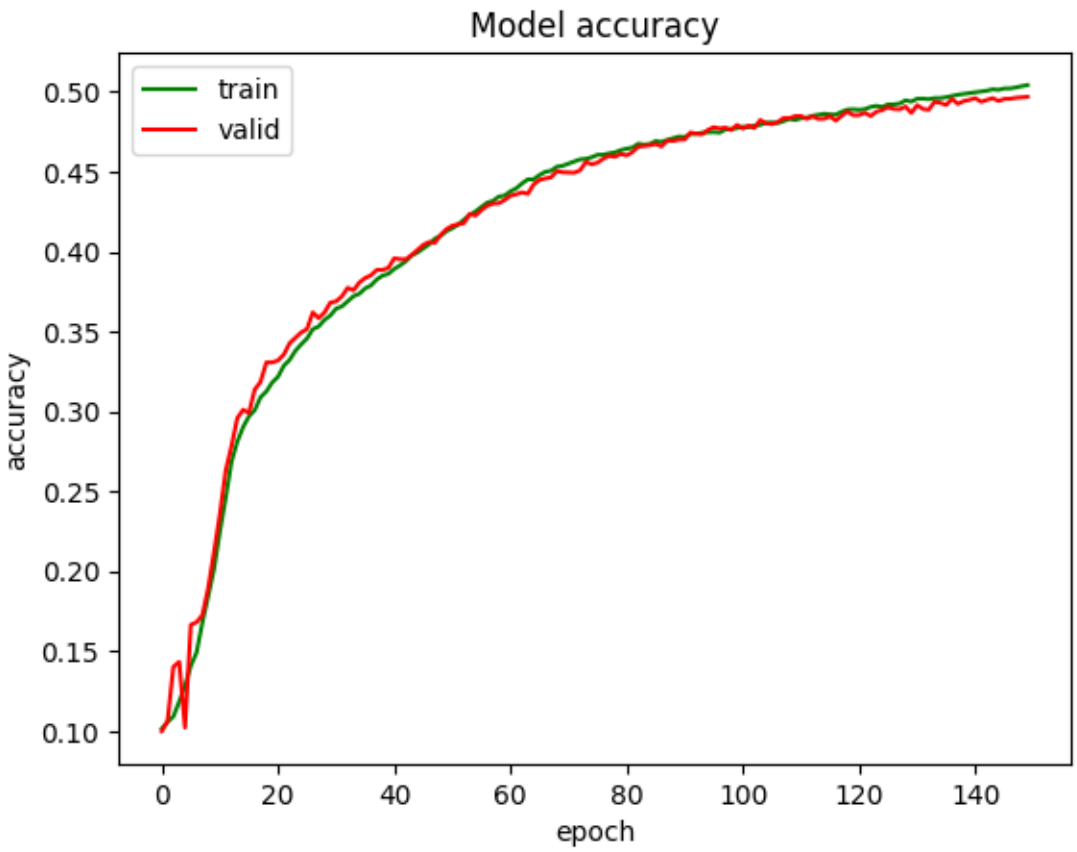
[ ]:
```
minhistory.history.keys()
```

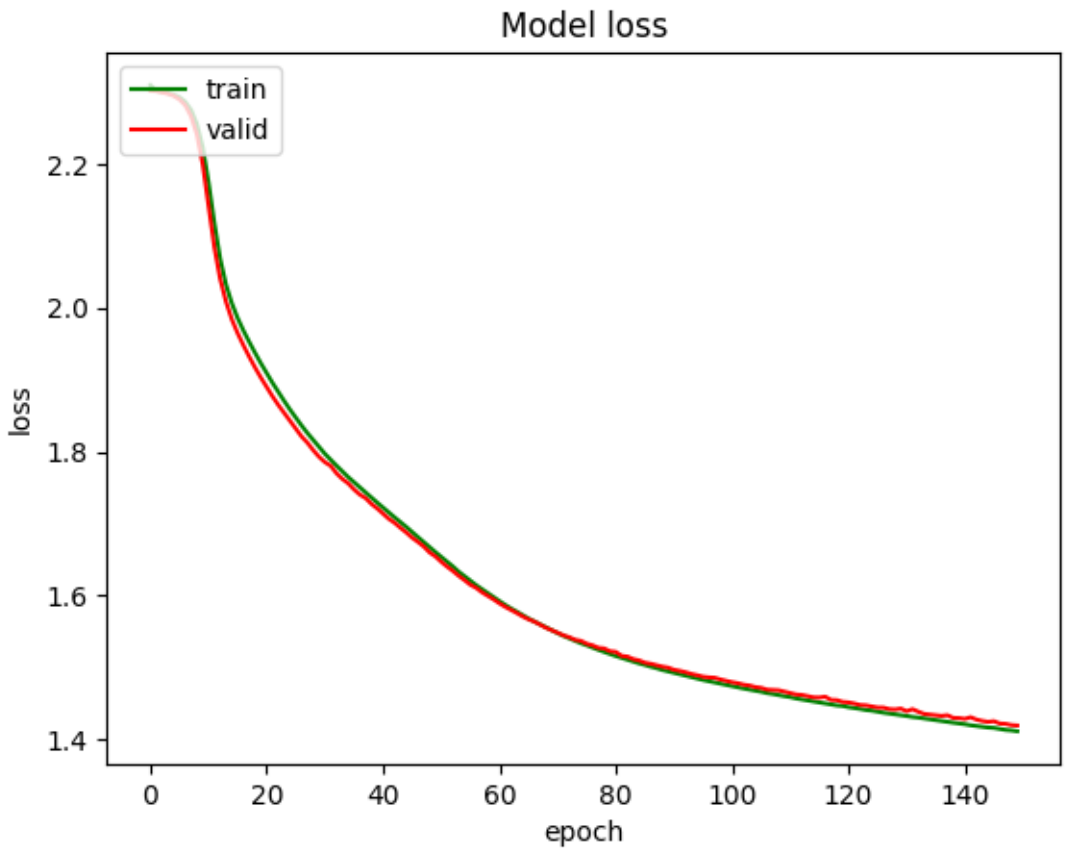
[ ]:
```
dict_keys(['loss', 'accuracy', 'val_loss', 'val_accuracy'])
```

[ ]:
```
def print_train_and_val(history, gtype):
    plt.plot(history[gtype], 'g')
    plt.plot(history['val_'+gtype], 'r')
    plt.title('Model '+gtype)
    plt.ylabel(gtype)
    plt.xlabel('epoch')
    plt.legend(['train', 'valid'], loc='upper left')
    plt.show()

def print_history(history):
    print_train_and_val(history, 'accuracy')
    print_train_and_val(history, 'loss')

print_history(minhistory.history)
```


Model accuracy
train
valid
accuracy
epoch
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0
20
40
60
80
100
120
140



[ ]:
```
first10 = minmodel(train_images[:10])
print(tf.math.reduce_all(tf.one_hot(tf.math.argmax(first10, axis=1),␣
 ↪depth=10)==train_labels[:10], 1), '\n', tf.math.argmax(first10, axis=1))
print(tf.math.reduce_max(first10, axis=1))
```

```
tf.Tensor([False  True  True False  True False False  True  True False],
shape=(10,), dtype=bool)
 tf.Tensor([7 9 9 6 1 7 7 7 8 7], shape=(10,), dtype=int64)
tf.Tensor(
[0.28862807 0.52612484 0.197822   0.41355667 0.37701195 0.28073245
 0.50594556 0.3302498  0.7759927  0.25490594], shape=(10,), dtype=float32)
```

Jak widać, po uczeniu, nasz model znacznie lepiej rozpoznaje klasy, choć dalej nieperfekcyjnie i wciąż możemy zaobserwować pewne biasy co do niektórych klas.
Widać, że często przy pomyłkach, pewność modelu est stosunkowo niska.

[ ]:
```
minmodel2 = tf.keras.Sequential([
    tf.keras.layers.Conv2D(20, 3, padding='same', activation='sigmoid',␣
 ↪input_shape=train_images[0].shape),
    tf.keras.layers.Conv2D(20, 3, padding='same', activation='sigmoid'),
```

```
    tf.keras.layers.MaxPool2D(pool_size=(8,8), padding='valid'),
    tf.keras.layers.Flatten(),
    tf.keras.layers.Dense(units=10, activation='softmax')
])
```

[ ]:
```
minmodel2.summary()
```

```
Model: "sequential_1"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_2 (Conv2D)           (None, 32, 32, 20)        560

 conv2d_3 (Conv2D)           (None, 32, 32, 20)        3620

 max_pooling2d_1 (MaxPooling  (None, 4, 4, 20)         0
 2D)

 flatten_1 (Flatten)         (None, 320)               0

 dense_1 (Dense)             (None, 10)                3210

=================================================================
Total params: 7,390
Trainable params: 7,390
Non-trainable params: 0
_________________________________________________________________
```

Tym razem mamy 7,390 parametrów, czyli mniej wiecej 7 razy więcej niż poprzednim razem.

[ ]:
```
minmodel2.compile(
    optimizer=tf.keras.optimizers.SGD(learning_rate=0.001, momentum=0.9),
    loss=tf.keras.losses.CategoricalCrossentropy(),
    metrics=['accuracy']
)
```

[ ]:
```
start_time = time.time()
history = minmodel2.fit(
    x=train_images,
    y=train_labels,
    batch_size=64,
    epochs=150,
    verbose=1,
    validation_data=(val_images, val_labels)
)
print(f"time: {time.time()-start_time}")
```

```
Epoch 1/150
```

```
2022-10-27 12:41:41.915278: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114]
Plugin optimizer for device_type GPU is enabled.

782/782 [==============================] - ETA: 0s - loss: 2.3068 - accuracy:
0.1018

2022-10-27 12:41:54.545722: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114]
Plugin optimizer for device_type GPU is enabled.

782/782 [==============================] - 14s 17ms/step - loss: 2.3068 -
accuracy: 0.1018 - val_loss: 2.3013 - val_accuracy: 0.1490
Epoch 2/150
782/782 [==============================] - 13s 16ms/step - loss: 2.3016 -
accuracy: 0.1101 - val_loss: 2.2999 - val_accuracy: 0.1167
Epoch 3/150
782/782 [==============================] - 13s 16ms/step - loss: 2.2967 -
accuracy: 0.1194 - val_loss: 2.2991 - val_accuracy: 0.1000
Epoch 4/150
782/782 [==============================] - 13s 16ms/step - loss: 2.2886 -
accuracy: 0.1386 - val_loss: 2.2833 - val_accuracy: 0.1334
Epoch 5/150
782/782 [==============================] - 13s 16ms/step - loss: 2.2717 -
accuracy: 0.1657 - val_loss: 2.2554 - val_accuracy: 0.2324
Epoch 6/150
782/782 [==============================] - 13s 16ms/step - loss: 2.2398 -
accuracy: 0.1991 - val_loss: 2.2133 - val_accuracy: 0.2430
Epoch 7/150
782/782 [==============================] - 13s 16ms/step - loss: 2.1872 -
accuracy: 0.2312 - val_loss: 2.1525 - val_accuracy: 0.2518
Epoch 8/150
782/782 [==============================] - 13s 16ms/step - loss: 2.1253 -
accuracy: 0.2524 - val_loss: 2.0901 - val_accuracy: 0.2585
Epoch 9/150
782/782 [==============================] - 13s 16ms/step - loss: 2.0687 -
accuracy: 0.2763 - val_loss: 2.0337 - val_accuracy: 0.2911
Epoch 10/150
782/782 [==============================] - 13s 17ms/step - loss: 2.0236 -
accuracy: 0.2894 - val_loss: 1.9916 - val_accuracy: 0.3034
Epoch 11/150
782/782 [==============================] - 13s 16ms/step - loss: 1.9854 -
accuracy: 0.3038 - val_loss: 1.9599 - val_accuracy: 0.3199
Epoch 12/150
782/782 [==============================] - 13s 16ms/step - loss: 1.9551 -
accuracy: 0.3136 - val_loss: 1.9291 - val_accuracy: 0.3252
Epoch 13/150
782/782 [==============================] - 13s 16ms/step - loss: 1.9285 -
accuracy: 0.3221 - val_loss: 1.9061 - val_accuracy: 0.3350
```

```
Epoch 14/150
782/782 [==============================] - 13s 16ms/step - loss: 1.9058 -
accuracy: 0.3285 - val_loss: 1.8836 - val_accuracy: 0.3395
Epoch 15/150
782/782 [==============================] - 13s 16ms/step - loss: 1.8854 -
accuracy: 0.3364 - val_loss: 1.8644 - val_accuracy: 0.3460
Epoch 16/150
782/782 [==============================] - 13s 17ms/step - loss: 1.8667 -
accuracy: 0.3413 - val_loss: 1.8464 - val_accuracy: 0.3529
Epoch 17/150
782/782 [==============================] - 13s 16ms/step - loss: 1.8502 -
accuracy: 0.3468 - val_loss: 1.8279 - val_accuracy: 0.3571
Epoch 18/150
782/782 [==============================] - 13s 17ms/step - loss: 1.8346 -
accuracy: 0.3521 - val_loss: 1.8153 - val_accuracy: 0.3610
Epoch 19/150
782/782 [==============================] - 13s 17ms/step - loss: 1.8191 -
accuracy: 0.3576 - val_loss: 1.8016 - val_accuracy: 0.3597
Epoch 20/150
782/782 [==============================] - 13s 16ms/step - loss: 1.8054 -
accuracy: 0.3616 - val_loss: 1.7890 - val_accuracy: 0.3717
Epoch 21/150
782/782 [==============================] - 13s 16ms/step - loss: 1.7915 -
accuracy: 0.3670 - val_loss: 1.7780 - val_accuracy: 0.3713
Epoch 22/150
782/782 [==============================] - 13s 16ms/step - loss: 1.7785 -
accuracy: 0.3719 - val_loss: 1.7637 - val_accuracy: 0.3766
Epoch 23/150
782/782 [==============================] - 13s 17ms/step - loss: 1.7659 -
accuracy: 0.3759 - val_loss: 1.7492 - val_accuracy: 0.3855
Epoch 24/150
782/782 [==============================] - 13s 17ms/step - loss: 1.7529 -
accuracy: 0.3793 - val_loss: 1.7429 - val_accuracy: 0.3838
Epoch 25/150
782/782 [==============================] - 13s 17ms/step - loss: 1.7408 -
accuracy: 0.3846 - val_loss: 1.7330 - val_accuracy: 0.3899
Epoch 26/150
782/782 [==============================] - 13s 17ms/step - loss: 1.7296 -
accuracy: 0.3892 - val_loss: 1.7152 - val_accuracy: 0.3953
Epoch 27/150
782/782 [==============================] - 13s 16ms/step - loss: 1.7185 -
accuracy: 0.3943 - val_loss: 1.7065 - val_accuracy: 0.4009
Epoch 28/150
782/782 [==============================] - 13s 16ms/step - loss: 1.7074 -
accuracy: 0.3974 - val_loss: 1.6950 - val_accuracy: 0.4015
Epoch 29/150
782/782 [==============================] - 13s 16ms/step - loss: 1.6967 -
accuracy: 0.4024 - val_loss: 1.6842 - val_accuracy: 0.4109
```

```
Epoch 30/150
782/782 [==============================] - 13s 16ms/step - loss: 1.6877 -
accuracy: 0.4064 - val_loss: 1.6761 - val_accuracy: 0.4149
Epoch 31/150
782/782 [==============================] - 13s 16ms/step - loss: 1.6779 -
accuracy: 0.4095 - val_loss: 1.6672 - val_accuracy: 0.4190
Epoch 32/150
782/782 [==============================] - 13s 16ms/step - loss: 1.6682 -
accuracy: 0.4135 - val_loss: 1.6573 - val_accuracy: 0.4227
Epoch 33/150
782/782 [==============================] - 13s 16ms/step - loss: 1.6599 -
accuracy: 0.4166 - val_loss: 1.6501 - val_accuracy: 0.4220
Epoch 34/150
782/782 [==============================] - 13s 16ms/step - loss: 1.6517 -
accuracy: 0.4190 - val_loss: 1.6411 - val_accuracy: 0.4256
Epoch 35/150
782/782 [==============================] - 13s 17ms/step - loss: 1.6438 -
accuracy: 0.4209 - val_loss: 1.6353 - val_accuracy: 0.4279
Epoch 36/150
782/782 [==============================] - 13s 16ms/step - loss: 1.6356 -
accuracy: 0.4259 - val_loss: 1.6258 - val_accuracy: 0.4313
Epoch 37/150
782/782 [==============================] - 13s 16ms/step - loss: 1.6280 -
accuracy: 0.4285 - val_loss: 1.6189 - val_accuracy: 0.4331
Epoch 38/150
782/782 [==============================] - 13s 16ms/step - loss: 1.6213 -
accuracy: 0.4316 - val_loss: 1.6109 - val_accuracy: 0.4364
Epoch 39/150
782/782 [==============================] - 13s 16ms/step - loss: 1.6132 -
accuracy: 0.4346 - val_loss: 1.6064 - val_accuracy: 0.4376
Epoch 40/150
782/782 [==============================] - 13s 16ms/step - loss: 1.6065 -
accuracy: 0.4364 - val_loss: 1.5961 - val_accuracy: 0.4429
Epoch 41/150
782/782 [==============================] - 13s 16ms/step - loss: 1.5988 -
accuracy: 0.4387 - val_loss: 1.5919 - val_accuracy: 0.4402
Epoch 42/150
782/782 [==============================] - 13s 16ms/step - loss: 1.5920 -
accuracy: 0.4417 - val_loss: 1.5831 - val_accuracy: 0.4439
Epoch 43/150
782/782 [==============================] - 13s 16ms/step - loss: 1.5854 -
accuracy: 0.4451 - val_loss: 1.5801 - val_accuracy: 0.4419
Epoch 44/150
782/782 [==============================] - 13s 16ms/step - loss: 1.5788 -
accuracy: 0.4458 - val_loss: 1.5701 - val_accuracy: 0.4465
Epoch 45/150
782/782 [==============================] - 13s 16ms/step - loss: 1.5725 -
accuracy: 0.4477 - val_loss: 1.5636 - val_accuracy: 0.4482
```

```
Epoch 46/150
782/782 [==============================] - 13s 16ms/step - loss: 1.5659 -
accuracy: 0.4495 - val_loss: 1.5564 - val_accuracy: 0.4541
Epoch 47/150
782/782 [==============================] - 13s 16ms/step - loss: 1.5599 -
accuracy: 0.4517 - val_loss: 1.5533 - val_accuracy: 0.4549
Epoch 48/150
782/782 [==============================] - 13s 16ms/step - loss: 1.5540 -
accuracy: 0.4528 - val_loss: 1.5483 - val_accuracy: 0.4550
Epoch 49/150
782/782 [==============================] - 13s 17ms/step - loss: 1.5481 -
accuracy: 0.4550 - val_loss: 1.5396 - val_accuracy: 0.4556
Epoch 50/150
782/782 [==============================] - 13s 16ms/step - loss: 1.5422 -
accuracy: 0.4574 - val_loss: 1.5334 - val_accuracy: 0.4595
Epoch 51/150
782/782 [==============================] - 13s 16ms/step - loss: 1.5368 -
accuracy: 0.4584 - val_loss: 1.5263 - val_accuracy: 0.4627
Epoch 52/150
782/782 [==============================] - 13s 16ms/step - loss: 1.5315 -
accuracy: 0.4598 - val_loss: 1.5259 - val_accuracy: 0.4636
Epoch 53/150
782/782 [==============================] - 13s 17ms/step - loss: 1.5263 -
accuracy: 0.4626 - val_loss: 1.5186 - val_accuracy: 0.4663
Epoch 54/150
782/782 [==============================] - 13s 16ms/step - loss: 1.5206 -
accuracy: 0.4640 - val_loss: 1.5112 - val_accuracy: 0.4676
Epoch 55/150
782/782 [==============================] - 13s 16ms/step - loss: 1.5154 -
accuracy: 0.4653 - val_loss: 1.5103 - val_accuracy: 0.4678
Epoch 56/150
782/782 [==============================] - 13s 16ms/step - loss: 1.5107 -
accuracy: 0.4669 - val_loss: 1.5034 - val_accuracy: 0.4714
Epoch 57/150
782/782 [==============================] - 13s 17ms/step - loss: 1.5059 -
accuracy: 0.4680 - val_loss: 1.5007 - val_accuracy: 0.4711
Epoch 58/150
782/782 [==============================] - 13s 17ms/step - loss: 1.5005 -
accuracy: 0.4707 - val_loss: 1.4930 - val_accuracy: 0.4749
Epoch 59/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4959 -
accuracy: 0.4712 - val_loss: 1.4922 - val_accuracy: 0.4725
Epoch 60/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4917 -
accuracy: 0.4723 - val_loss: 1.4834 - val_accuracy: 0.4777
Epoch 61/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4867 -
accuracy: 0.4738 - val_loss: 1.4805 - val_accuracy: 0.4740
```

```
Epoch 62/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4823 -
accuracy: 0.4754 - val_loss: 1.4736 - val_accuracy: 0.4809
Epoch 63/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4780 -
accuracy: 0.4778 - val_loss: 1.4717 - val_accuracy: 0.4820
Epoch 64/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4727 -
accuracy: 0.4796 - val_loss: 1.4659 - val_accuracy: 0.4828
Epoch 65/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4679 -
accuracy: 0.4812 - val_loss: 1.4613 - val_accuracy: 0.4831
Epoch 66/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4637 -
accuracy: 0.4822 - val_loss: 1.4549 - val_accuracy: 0.4880
Epoch 67/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4593 -
accuracy: 0.4843 - val_loss: 1.4527 - val_accuracy: 0.4870
Epoch 68/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4545 -
accuracy: 0.4864 - val_loss: 1.4479 - val_accuracy: 0.4899
Epoch 69/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4502 -
accuracy: 0.4884 - val_loss: 1.4435 - val_accuracy: 0.4929
Epoch 70/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4459 -
accuracy: 0.4884 - val_loss: 1.4398 - val_accuracy: 0.4951
Epoch 71/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4411 -
accuracy: 0.4900 - val_loss: 1.4373 - val_accuracy: 0.4939
Epoch 72/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4365 -
accuracy: 0.4928 - val_loss: 1.4329 - val_accuracy: 0.4945
Epoch 73/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4321 -
accuracy: 0.4934 - val_loss: 1.4290 - val_accuracy: 0.4996
Epoch 74/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4277 -
accuracy: 0.4952 - val_loss: 1.4297 - val_accuracy: 0.4940
Epoch 75/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4235 -
accuracy: 0.4964 - val_loss: 1.4194 - val_accuracy: 0.5005
Epoch 76/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4190 -
accuracy: 0.4980 - val_loss: 1.4185 - val_accuracy: 0.5000
Epoch 77/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4149 -
accuracy: 0.5000 - val_loss: 1.4126 - val_accuracy: 0.5021
```

```
Epoch 78/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4111 -
accuracy: 0.5023 - val_loss: 1.4084 - val_accuracy: 0.5036
Epoch 79/150
782/782 [==============================] - 13s 17ms/step - loss: 1.4064 -
accuracy: 0.5030 - val_loss: 1.4047 - val_accuracy: 0.5065
Epoch 80/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4017 -
accuracy: 0.5047 - val_loss: 1.3982 - val_accuracy: 0.5075
Epoch 81/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3973 -
accuracy: 0.5066 - val_loss: 1.3970 - val_accuracy: 0.5074
Epoch 82/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3933 -
accuracy: 0.5091 - val_loss: 1.3928 - val_accuracy: 0.5076
Epoch 83/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3892 -
accuracy: 0.5091 - val_loss: 1.3877 - val_accuracy: 0.5112
Epoch 84/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3841 -
accuracy: 0.5120 - val_loss: 1.3825 - val_accuracy: 0.5131
Epoch 85/150
782/782 [==============================] - 13s 17ms/step - loss: 1.3799 -
accuracy: 0.5127 - val_loss: 1.3815 - val_accuracy: 0.5137
Epoch 86/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3760 -
accuracy: 0.5141 - val_loss: 1.3761 - val_accuracy: 0.5136
Epoch 87/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3718 -
accuracy: 0.5152 - val_loss: 1.3722 - val_accuracy: 0.5167
Epoch 88/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3677 -
accuracy: 0.5192 - val_loss: 1.3702 - val_accuracy: 0.5169
Epoch 89/150
782/782 [==============================] - 13s 17ms/step - loss: 1.3641 -
accuracy: 0.5191 - val_loss: 1.3649 - val_accuracy: 0.5192
Epoch 90/150
782/782 [==============================] - 13s 17ms/step - loss: 1.3598 -
accuracy: 0.5206 - val_loss: 1.3653 - val_accuracy: 0.5188
Epoch 91/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3560 -
accuracy: 0.5223 - val_loss: 1.3556 - val_accuracy: 0.5231
Epoch 92/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3521 -
accuracy: 0.5237 - val_loss: 1.3521 - val_accuracy: 0.5226
Epoch 93/150
782/782 [==============================] - 13s 17ms/step - loss: 1.3483 -
accuracy: 0.5239 - val_loss: 1.3495 - val_accuracy: 0.5254
```

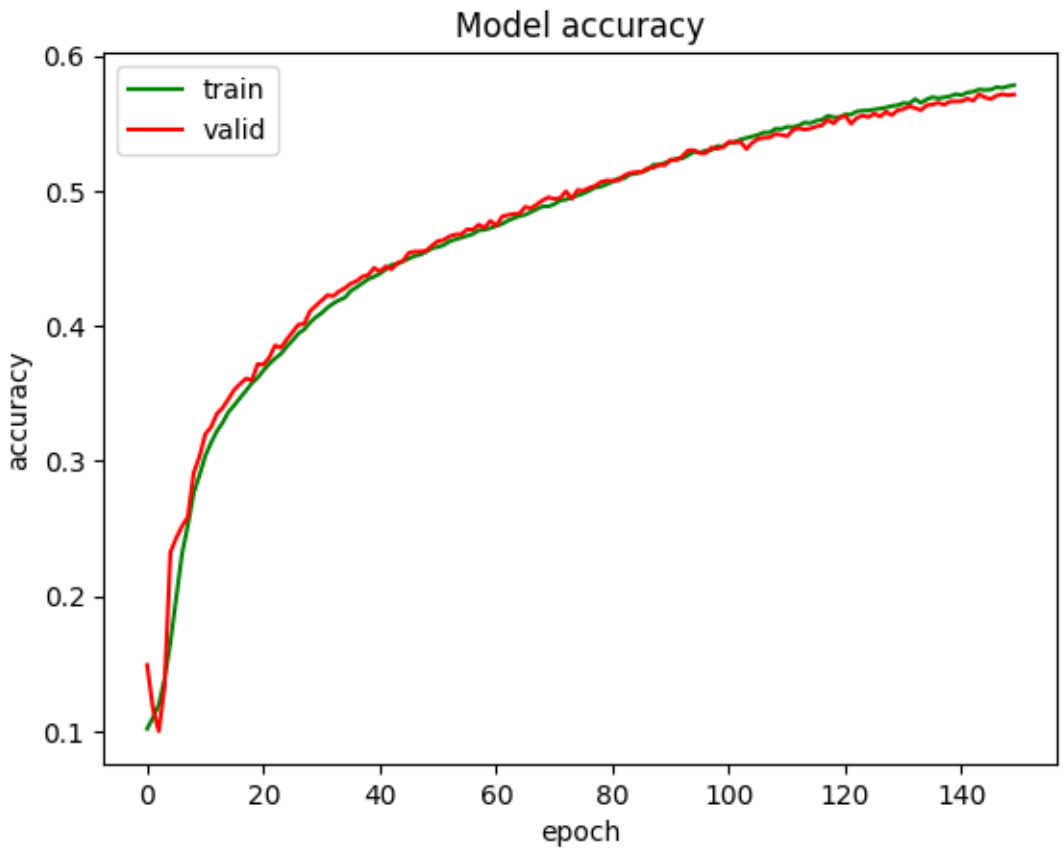
```
Epoch 94/150
782/782 [==============================] - 13s 17ms/step - loss: 1.3443 -
accuracy: 0.5262 - val_loss: 1.3448 - val_accuracy: 0.5299
Epoch 95/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3402 -
accuracy: 0.5290 - val_loss: 1.3423 - val_accuracy: 0.5299
Epoch 96/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3370 -
accuracy: 0.5282 - val_loss: 1.3425 - val_accuracy: 0.5277
Epoch 97/150
782/782 [==============================] - 13s 17ms/step - loss: 1.3335 -
accuracy: 0.5297 - val_loss: 1.3376 - val_accuracy: 0.5277
Epoch 98/150
782/782 [==============================] - 13s 17ms/step - loss: 1.3298 -
accuracy: 0.5300 - val_loss: 1.3313 - val_accuracy: 0.5319
Epoch 99/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3261 -
accuracy: 0.5330 - val_loss: 1.3287 - val_accuracy: 0.5311
Epoch 100/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3226 -
accuracy: 0.5327 - val_loss: 1.3286 - val_accuracy: 0.5322
Epoch 101/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3195 -
accuracy: 0.5352 - val_loss: 1.3223 - val_accuracy: 0.5362
Epoch 102/150
782/782 [==============================] - 13s 17ms/step - loss: 1.3160 -
accuracy: 0.5361 - val_loss: 1.3196 - val_accuracy: 0.5356
Epoch 103/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3130 -
accuracy: 0.5379 - val_loss: 1.3158 - val_accuracy: 0.5361
Epoch 104/150
782/782 [==============================] - 13s 17ms/step - loss: 1.3097 -
accuracy: 0.5391 - val_loss: 1.3220 - val_accuracy: 0.5309
Epoch 105/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3064 -
accuracy: 0.5403 - val_loss: 1.3109 - val_accuracy: 0.5354
Epoch 106/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3034 -
accuracy: 0.5413 - val_loss: 1.3098 - val_accuracy: 0.5384
Epoch 107/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3002 -
accuracy: 0.5431 - val_loss: 1.3065 - val_accuracy: 0.5391
Epoch 108/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2974 -
accuracy: 0.5431 - val_loss: 1.3052 - val_accuracy: 0.5394
Epoch 109/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2942 -
accuracy: 0.5459 - val_loss: 1.3003 - val_accuracy: 0.5421
```

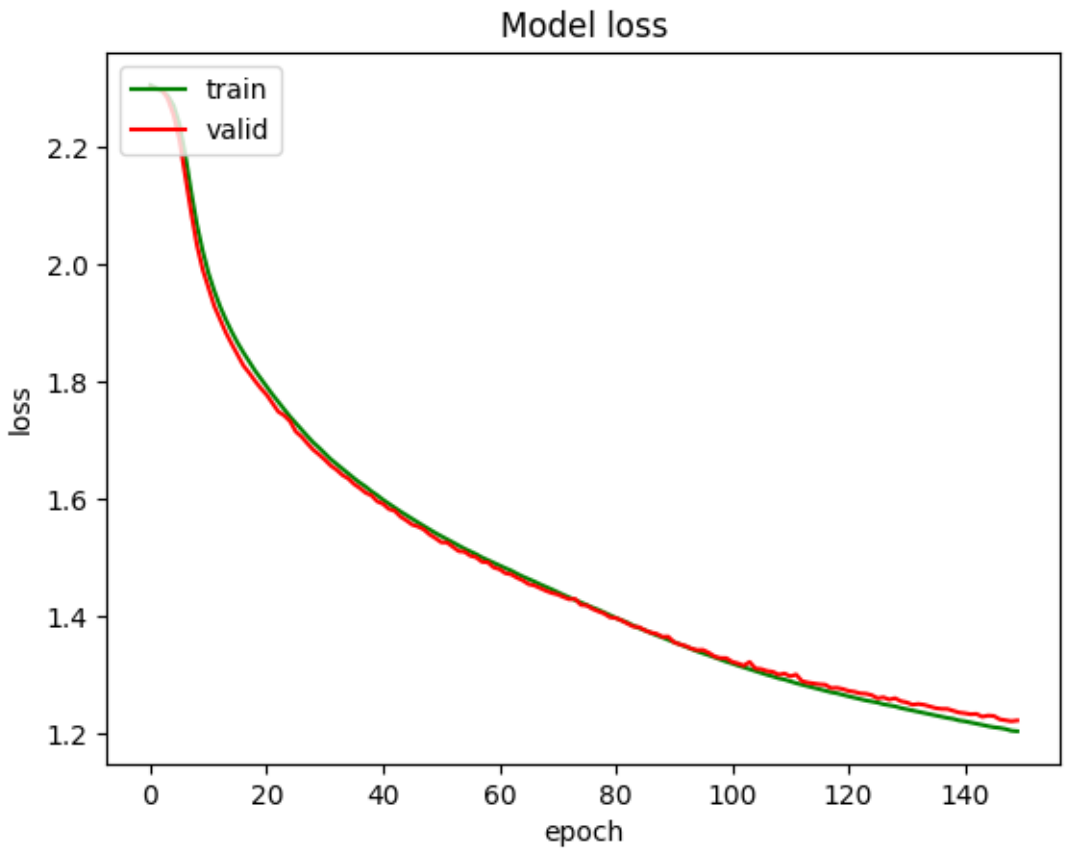
```
Epoch 110/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2920 -
accuracy: 0.5456 - val_loss: 1.3023 - val_accuracy: 0.5414
Epoch 111/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2890 -
accuracy: 0.5473 - val_loss: 1.2975 - val_accuracy: 0.5403
Epoch 112/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2859 -
accuracy: 0.5471 - val_loss: 1.3005 - val_accuracy: 0.5448
Epoch 113/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2833 -
accuracy: 0.5482 - val_loss: 1.2893 - val_accuracy: 0.5464
Epoch 114/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2810 -
accuracy: 0.5505 - val_loss: 1.2868 - val_accuracy: 0.5452
Epoch 115/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2781 -
accuracy: 0.5500 - val_loss: 1.2853 - val_accuracy: 0.5460
Epoch 116/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2759 -
accuracy: 0.5518 - val_loss: 1.2839 - val_accuracy: 0.5475
Epoch 117/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2733 -
accuracy: 0.5525 - val_loss: 1.2832 - val_accuracy: 0.5484
Epoch 118/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2704 -
accuracy: 0.5554 - val_loss: 1.2774 - val_accuracy: 0.5525
Epoch 119/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2686 -
accuracy: 0.5543 - val_loss: 1.2779 - val_accuracy: 0.5498
Epoch 120/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2660 -
accuracy: 0.5544 - val_loss: 1.2758 - val_accuracy: 0.5540
Epoch 121/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2635 -
accuracy: 0.5564 - val_loss: 1.2727 - val_accuracy: 0.5555
Epoch 122/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2612 -
accuracy: 0.5564 - val_loss: 1.2711 - val_accuracy: 0.5496
Epoch 123/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2586 -
accuracy: 0.5587 - val_loss: 1.2684 - val_accuracy: 0.5539
Epoch 124/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2563 -
accuracy: 0.5592 - val_loss: 1.2678 - val_accuracy: 0.5556
Epoch 125/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2546 -
accuracy: 0.5594 - val_loss: 1.2653 - val_accuracy: 0.5545
```

```
Epoch 126/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2528 -
accuracy: 0.5602 - val_loss: 1.2600 - val_accuracy: 0.5570
Epoch 127/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2498 -
accuracy: 0.5610 - val_loss: 1.2617 - val_accuracy: 0.5549
Epoch 128/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2479 -
accuracy: 0.5615 - val_loss: 1.2578 - val_accuracy: 0.5584
Epoch 129/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2463 -
accuracy: 0.5627 - val_loss: 1.2602 - val_accuracy: 0.5559
Epoch 130/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2434 -
accuracy: 0.5631 - val_loss: 1.2550 - val_accuracy: 0.5595
Epoch 131/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2413 -
accuracy: 0.5649 - val_loss: 1.2530 - val_accuracy: 0.5604
Epoch 132/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2390 -
accuracy: 0.5644 - val_loss: 1.2490 - val_accuracy: 0.5625
Epoch 133/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2369 -
accuracy: 0.5677 - val_loss: 1.2503 - val_accuracy: 0.5612
Epoch 134/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2347 -
accuracy: 0.5650 - val_loss: 1.2489 - val_accuracy: 0.5596
Epoch 135/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2328 -
accuracy: 0.5675 - val_loss: 1.2462 - val_accuracy: 0.5632
Epoch 136/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2301 -
accuracy: 0.5692 - val_loss: 1.2432 - val_accuracy: 0.5638
Epoch 137/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2285 -
accuracy: 0.5683 - val_loss: 1.2419 - val_accuracy: 0.5651
Epoch 138/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2265 -
accuracy: 0.5691 - val_loss: 1.2418 - val_accuracy: 0.5636
Epoch 139/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2249 -
accuracy: 0.5699 - val_loss: 1.2386 - val_accuracy: 0.5660
Epoch 140/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2221 -
accuracy: 0.5715 - val_loss: 1.2357 - val_accuracy: 0.5661
Epoch 141/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2207 -
accuracy: 0.5707 - val_loss: 1.2345 - val_accuracy: 0.5662
```

```
Epoch 142/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2188 -
accuracy: 0.5727 - val_loss: 1.2328 - val_accuracy: 0.5681
Epoch 143/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2168 -
accuracy: 0.5733 - val_loss: 1.2333 - val_accuracy: 0.5666
Epoch 144/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2146 -
accuracy: 0.5750 - val_loss: 1.2285 - val_accuracy: 0.5713
Epoch 145/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2124 -
accuracy: 0.5745 - val_loss: 1.2305 - val_accuracy: 0.5691
Epoch 146/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2106 -
accuracy: 0.5748 - val_loss: 1.2297 - val_accuracy: 0.5678
Epoch 147/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2094 -
accuracy: 0.5766 - val_loss: 1.2241 - val_accuracy: 0.5703
Epoch 148/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2075 -
accuracy: 0.5761 - val_loss: 1.2224 - val_accuracy: 0.5714
Epoch 149/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2046 -
accuracy: 0.5773 - val_loss: 1.2209 - val_accuracy: 0.5707
Epoch 150/150
782/782 [==============================] - 13s 16ms/step - loss: 1.2038 -
accuracy: 0.5782 - val_loss: 1.2221 - val_accuracy: 0.5712
time: 1935.4221241474152
```

[ ]:
```
print_history(history.history)
```


Model accuracy
train
valid
accuracy
epoch
0.6
0.5
0.4
0.3
0.2
0.1
0
20
40
60
80
100
120
140



Czas trenowania wzrósł nieznacznie, jedynie mniej więcej 3 sekundy na każdej epoce, w sumie ok. 400 sekund.
Rezultaty wzrosły o prawie 10 punktów procentowych.
Jestem zdziwony że tak drastyczna zmiana liczby parametrów (ok 7 razy więcej), tak nieznacznie wpłynęła na czas trwania epoki.

[ ]:
```
def block(channels, activation='relu', input_shape=None,␣
↪batch_normalisation=False, dropout=None, gap=False):
    if input_shape:
        conv1 = tf.keras.layers.Conv2D(channels, 3, padding='same',␣
↪activation=activation, input_shape=input_shape)
    else:
        conv1 = tf.keras.layers.Conv2D(channels, 3, padding='same',␣
↪activation=activation)
    conv2 = tf.keras.layers.Conv2D(channels, 3, padding='same',␣
↪activation=activation)
    if batch_normalisation:
        batch_norm1 = tf.keras.layers.BatchNormalization()
        batch_norm2 = tf.keras.layers.BatchNormalization()
    if dropout:
```

```
        drops = tf.keras.layers.Dropout(dropout)
    if gap:
        pool = tf.keras.layers.
 ↪GlobalAveragePooling2D(data_format='channels_last', keepdims=False)
    else:
        pool = tf.keras.layers.MaxPool2D(pool_size=(2,2), padding='valid')

    if dropout:
        return [conv1, batch_norm1, conv2, batch_norm2, pool, drops]
    elif batch_normalisation:
        return [conv1, batch_norm1, conv2, batch_norm2, pool]
    else:
        return [conv1, conv2, pool]
```

Przygotowałem funkcję która przygotowuje nam taki blok, zwraca go jako listę, więc mogę go dodać do innego bloku, bądź listy innych warst i tf.keras.Sequential nie będzie mieć problemów z formatem

[ ]:
```
model1 = tf.keras.Sequential(
    block(channels=20, activation='sigmoid', input_shape=train_images[0].shape)␣
 ↪+
    block(channels=40, activation='sigmoid') + [
    tf.keras.layers.Flatten(),
    tf.keras.layers.Dense(units=10,activation='softmax')
])
```

[ ]:
```
model1.summary()
```

```
Model: "sequential_8"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_31 (Conv2D)          (None, 32, 32, 20)        560

 conv2d_32 (Conv2D)          (None, 32, 32, 20)        3620

 max_pooling2d_15 (MaxPoolin  (None, 16, 16, 20)       0
 g2D)

 conv2d_33 (Conv2D)          (None, 16, 16, 40)        7240

 conv2d_34 (Conv2D)          (None, 16, 16, 40)        14440

 max_pooling2d_16 (MaxPoolin  (None, 8, 8, 40)         0
 g2D)

 flatten_8 (Flatten)         (None, 2560)              0

 dense_8 (Dense)             (None, 10)                25610
```

```
=================================================================
Total params: 51,470
Trainable params: 51,470
Non-trainable params: 0
_________________________________________________________________
```

[ ]:
```
model1.compile(
    optimizer=tf.keras.optimizers.SGD(learning_rate=0.001, momentum=0.9),
    loss=tf.keras.losses.CategoricalCrossentropy(),
    metrics=['accuracy']
)
```

[ ]:
```
history1 = model1.fit(
    x=train_images,
    y=train_labels,
    batch_size=64,
    epochs=15,
    verbose=1,
    validation_data=(val_images, val_labels)
)
```

```
Epoch 1/15

2022-10-27 17:02:56.479463: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114]
Plugin optimizer for device_type GPU is enabled.

782/782 [==============================] - ETA: 0s - loss: 2.3263 - accuracy:
0.0988

2022-10-27 17:03:06.321068: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114]
Plugin optimizer for device_type GPU is enabled.

782/782 [==============================] - 11s 13ms/step - loss: 2.3263 -
accuracy: 0.0988 - val_loss: 2.3235 - val_accuracy: 0.1000
Epoch 2/15
782/782 [==============================] - 9s 12ms/step - loss: 2.3207 -
accuracy: 0.1001 - val_loss: 2.3315 - val_accuracy: 0.1000
Epoch 3/15
782/782 [==============================] - 10s 13ms/step - loss: 2.3157 -
accuracy: 0.1010 - val_loss: 2.3152 - val_accuracy: 0.1000
Epoch 4/15
782/782 [==============================] - 10s 12ms/step - loss: 2.3130 -
accuracy: 0.0996 - val_loss: 2.3067 - val_accuracy: 0.1000
Epoch 5/15
782/782 [==============================] - 10s 12ms/step - loss: 2.3097 -
accuracy: 0.1021 - val_loss: 2.3042 - val_accuracy: 0.1000
Epoch 6/15
```

```
782/782 [==============================] - 9s 12ms/step - loss: 2.3084 -
accuracy: 0.1012 - val_loss: 2.3053 - val_accuracy: 0.1000
Epoch 7/15
782/782 [==============================] - 9s 12ms/step - loss: 2.3074 -
accuracy: 0.1002 - val_loss: 2.3120 - val_accuracy: 0.1000
Epoch 8/15
782/782 [==============================] - 10s 12ms/step - loss: 2.3075 -
accuracy: 0.0980 - val_loss: 2.3070 - val_accuracy: 0.1000
Epoch 9/15
782/782 [==============================] - 10s 12ms/step - loss: 2.3071 -
accuracy: 0.0985 - val_loss: 2.3076 - val_accuracy: 0.1000
Epoch 10/15
782/782 [==============================] - 10s 12ms/step - loss: 2.3057 -
accuracy: 0.1003 - val_loss: 2.3071 - val_accuracy: 0.1000
Epoch 11/15
782/782 [==============================] - 10s 12ms/step - loss: 2.3058 -
accuracy: 0.0996 - val_loss: 2.3039 - val_accuracy: 0.1000
Epoch 12/15
782/782 [==============================] - 10s 13ms/step - loss: 2.3052 -
accuracy: 0.1000 - val_loss: 2.3041 - val_accuracy: 0.1000
Epoch 13/15
782/782 [==============================] - 10s 12ms/step - loss: 2.3048 -
accuracy: 0.1012 - val_loss: 2.3045 - val_accuracy: 0.1012
Epoch 14/15
782/782 [==============================] - 10s 13ms/step - loss: 2.3047 -
accuracy: 0.1013 - val_loss: 2.3053 - val_accuracy: 0.1000
Epoch 15/15
782/782 [==============================] - 10s 13ms/step - loss: 2.3046 -
accuracy: 0.1014 - val_loss: 2.3035 - val_accuracy: 0.1000
```

Wygląda to bardzo nieobiecująco, loss i accuracy praktycznie pozostały takie same...

[ ]:
```
model2 = tf.keras.Sequential(
    block(channels=20, activation='relu', input_shape=train_images[0].shape) +
    block(channels=40, activation='relu') + [
    tf.keras.layers.Flatten(),
    tf.keras.layers.Dense(units=10,activation='softmax')
])
```

[ ]:
```
model2.summary()
```

```
Model: "sequential_10"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_39 (Conv2D)          (None, 32, 32, 20)        560

 conv2d_40 (Conv2D)          (None, 32, 32, 20)        3620
```

```
 max_pooling2d_19 (MaxPoolin  (None, 16, 16, 20)       0
 g2D)

 conv2d_41 (Conv2D)          (None, 16, 16, 40)        7240

 conv2d_42 (Conv2D)          (None, 16, 16, 40)        14440

 max_pooling2d_20 (MaxPoolin  (None, 8, 8, 40)         0
 g2D)

 flatten_10 (Flatten)        (None, 2560)              0

 dense_10 (Dense)            (None, 10)                25610

=================================================================
Total params: 51,470
Trainable params: 51,470
Non-trainable params: 0
_________________________________________________________________
```

[ ]:
```
model2.compile(
    optimizer=tf.keras.optimizers.SGD(learning_rate=0.001, momentum=0.9),
    loss=tf.keras.losses.CategoricalCrossentropy(),
    metrics=['accuracy']
)
```

[ ]:
```
start_time = time.time()
hisotry2 = model2.fit(
    x=train_images,
    y=train_labels,
    batch_size=64,
    epochs=150,
    verbose=1,
    validation_data=(val_images, val_labels)
)
print(f"time: {time.time()-start_time}")
```

```
Epoch 1/150

2022-10-27 17:13:46.260185: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114]
Plugin optimizer for device_type GPU is enabled.

782/782 [==============================] - ETA: 0s - loss: 2.1764 - accuracy:
0.1938

2022-10-27 17:13:55.343189: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114]
Plugin optimizer for device_type GPU is enabled.
```

```
782/782 [==============================] - 10s 13ms/step - loss: 2.1764 -
accuracy: 0.1938 - val_loss: 1.9325 - val_accuracy: 0.3098
Epoch 2/150
782/782 [==============================] - 10s 13ms/step - loss: 1.7968 -
accuracy: 0.3655 - val_loss: 1.6535 - val_accuracy: 0.4148
Epoch 3/150
782/782 [==============================] - 10s 12ms/step - loss: 1.5625 -
accuracy: 0.4446 - val_loss: 1.4597 - val_accuracy: 0.4846
Epoch 4/150
782/782 [==============================] - 10s 12ms/step - loss: 1.4455 -
accuracy: 0.4854 - val_loss: 1.4012 - val_accuracy: 0.5023
Epoch 5/150
782/782 [==============================] - 9s 12ms/step - loss: 1.3731 -
accuracy: 0.5122 - val_loss: 1.3722 - val_accuracy: 0.5125
Epoch 6/150
782/782 [==============================] - 9s 12ms/step - loss: 1.3032 -
accuracy: 0.5382 - val_loss: 1.2813 - val_accuracy: 0.5449
Epoch 7/150
782/782 [==============================] - 10s 12ms/step - loss: 1.2455 -
accuracy: 0.5638 - val_loss: 1.2332 - val_accuracy: 0.5619
Epoch 8/150
782/782 [==============================] - 9s 12ms/step - loss: 1.1921 -
accuracy: 0.5786 - val_loss: 1.2683 - val_accuracy: 0.5587
Epoch 9/150
782/782 [==============================] - 10s 12ms/step - loss: 1.1488 -
accuracy: 0.5985 - val_loss: 1.1512 - val_accuracy: 0.5962
Epoch 10/150
782/782 [==============================] - 10s 12ms/step - loss: 1.1064 -
accuracy: 0.6111 - val_loss: 1.1262 - val_accuracy: 0.6082
Epoch 11/150
782/782 [==============================] - 10s 12ms/step - loss: 1.0716 -
accuracy: 0.6248 - val_loss: 1.1510 - val_accuracy: 0.5892
Epoch 12/150
782/782 [==============================] - 10s 12ms/step - loss: 1.0385 -
accuracy: 0.6370 - val_loss: 1.0850 - val_accuracy: 0.6189
Epoch 13/150
782/782 [==============================] - 10s 12ms/step - loss: 1.0063 -
accuracy: 0.6488 - val_loss: 1.0686 - val_accuracy: 0.6244
Epoch 14/150
782/782 [==============================] - 10s 12ms/step - loss: 0.9788 -
accuracy: 0.6585 - val_loss: 1.0482 - val_accuracy: 0.6316
Epoch 15/150
782/782 [==============================] - 10s 12ms/step - loss: 0.9537 -
accuracy: 0.6678 - val_loss: 1.0364 - val_accuracy: 0.6413
Epoch 16/150
782/782 [==============================] - 9s 12ms/step - loss: 0.9288 -
accuracy: 0.6770 - val_loss: 1.0184 - val_accuracy: 0.6470
Epoch 17/150
```

```
782/782 [==============================] - 10s 12ms/step - loss: 0.9060 -
accuracy: 0.6853 - val_loss: 1.0047 - val_accuracy: 0.6495
Epoch 18/150
782/782 [==============================] - 10s 12ms/step - loss: 0.8855 -
accuracy: 0.6929 - val_loss: 0.9988 - val_accuracy: 0.6589
Epoch 19/150
782/782 [==============================] - 10s 12ms/step - loss: 0.8636 -
accuracy: 0.7002 - val_loss: 1.0003 - val_accuracy: 0.6566
Epoch 20/150
782/782 [==============================] - 10s 12ms/step - loss: 0.8451 -
accuracy: 0.7076 - val_loss: 0.9741 - val_accuracy: 0.6643
Epoch 21/150
782/782 [==============================] - 10s 12ms/step - loss: 0.8313 -
accuracy: 0.7126 - val_loss: 0.9621 - val_accuracy: 0.6729
Epoch 22/150
782/782 [==============================] - 10s 12ms/step - loss: 0.8128 -
accuracy: 0.7192 - val_loss: 0.9445 - val_accuracy: 0.6762
Epoch 23/150
782/782 [==============================] - 10s 12ms/step - loss: 0.7955 -
accuracy: 0.7265 - val_loss: 0.9531 - val_accuracy: 0.6747
Epoch 24/150
782/782 [==============================] - 10s 12ms/step - loss: 0.7841 -
accuracy: 0.7277 - val_loss: 0.9334 - val_accuracy: 0.6811
Epoch 25/150
782/782 [==============================] - 10s 12ms/step - loss: 0.7691 -
accuracy: 0.7345 - val_loss: 0.9512 - val_accuracy: 0.6756
Epoch 26/150
782/782 [==============================] - 10s 12ms/step - loss: 0.7510 -
accuracy: 0.7413 - val_loss: 0.9635 - val_accuracy: 0.6761
Epoch 27/150
782/782 [==============================] - 10s 12ms/step - loss: 0.7396 -
accuracy: 0.7452 - val_loss: 0.9370 - val_accuracy: 0.6861
Epoch 28/150
782/782 [==============================] - 10s 12ms/step - loss: 0.7218 -
accuracy: 0.7495 - val_loss: 0.9486 - val_accuracy: 0.6801
Epoch 29/150
782/782 [==============================] - 10s 12ms/step - loss: 0.7153 -
accuracy: 0.7534 - val_loss: 0.9369 - val_accuracy: 0.6869
Epoch 30/150
782/782 [==============================] - 10s 12ms/step - loss: 0.7011 -
accuracy: 0.7576 - val_loss: 0.9384 - val_accuracy: 0.6906
Epoch 31/150
782/782 [==============================] - 10s 12ms/step - loss: 0.6892 -
accuracy: 0.7620 - val_loss: 0.9391 - val_accuracy: 0.6857
Epoch 32/150
782/782 [==============================] - 10s 12ms/step - loss: 0.6764 -
accuracy: 0.7668 - val_loss: 0.9538 - val_accuracy: 0.6800
Epoch 33/150
```

```
782/782 [==============================] - 10s 12ms/step - loss: 0.6639 -
accuracy: 0.7726 - val_loss: 0.9433 - val_accuracy: 0.6840
Epoch 34/150
782/782 [==============================] - 10s 12ms/step - loss: 0.6527 -
accuracy: 0.7746 - val_loss: 0.9399 - val_accuracy: 0.6898
Epoch 35/150
782/782 [==============================] - 9s 12ms/step - loss: 0.6407 -
accuracy: 0.7788 - val_loss: 0.9632 - val_accuracy: 0.6848
Epoch 36/150
782/782 [==============================] - 10s 12ms/step - loss: 0.6333 -
accuracy: 0.7812 - val_loss: 0.9992 - val_accuracy: 0.6737
Epoch 37/150
782/782 [==============================] - 10s 12ms/step - loss: 0.6201 -
accuracy: 0.7868 - val_loss: 0.9371 - val_accuracy: 0.6916
Epoch 38/150
782/782 [==============================] - 9s 12ms/step - loss: 0.6112 -
accuracy: 0.7881 - val_loss: 0.9672 - val_accuracy: 0.6895
Epoch 39/150
782/782 [==============================] - 10s 12ms/step - loss: 0.6048 -
accuracy: 0.7897 - val_loss: 0.9757 - val_accuracy: 0.6864
Epoch 40/150
782/782 [==============================] - 10s 12ms/step - loss: 0.5957 -
accuracy: 0.7932 - val_loss: 0.9826 - val_accuracy: 0.6825
Epoch 41/150
782/782 [==============================] - 10s 12ms/step - loss: 0.5833 -
accuracy: 0.7987 - val_loss: 0.9721 - val_accuracy: 0.6924
Epoch 42/150
782/782 [==============================] - 10s 12ms/step - loss: 0.5716 -
accuracy: 0.8036 - val_loss: 0.9630 - val_accuracy: 0.6880
Epoch 43/150
782/782 [==============================] - 10s 12ms/step - loss: 0.5658 -
accuracy: 0.8036 - val_loss: 0.9894 - val_accuracy: 0.6881
Epoch 44/150
782/782 [==============================] - 10s 12ms/step - loss: 0.5566 -
accuracy: 0.8071 - val_loss: 0.9798 - val_accuracy: 0.6850
Epoch 45/150
782/782 [==============================] - 10s 12ms/step - loss: 0.5504 -
accuracy: 0.8085 - val_loss: 0.9742 - val_accuracy: 0.6910
Epoch 46/150
782/782 [==============================] - 10s 12ms/step - loss: 0.5433 -
accuracy: 0.8106 - val_loss: 0.9940 - val_accuracy: 0.6882
Epoch 47/150
782/782 [==============================] - 10s 12ms/step - loss: 0.5310 -
accuracy: 0.8146 - val_loss: 0.9870 - val_accuracy: 0.6944
Epoch 48/150
782/782 [==============================] - 10s 12ms/step - loss: 0.5266 -
accuracy: 0.8162 - val_loss: 1.0158 - val_accuracy: 0.6895
Epoch 49/150
```

```
782/782 [==============================] - 10s 12ms/step - loss: 0.5158 -
accuracy: 0.8206 - val_loss: 1.0042 - val_accuracy: 0.6898
Epoch 50/150
782/782 [==============================] - 10s 12ms/step - loss: 0.5108 -
accuracy: 0.8222 - val_loss: 1.0017 - val_accuracy: 0.6887
Epoch 51/150
782/782 [==============================] - 9s 12ms/step - loss: 0.5006 -
accuracy: 0.8250 - val_loss: 1.0551 - val_accuracy: 0.6870
Epoch 52/150
782/782 [==============================] - 9s 12ms/step - loss: 0.4942 -
accuracy: 0.8276 - val_loss: 1.0436 - val_accuracy: 0.6843
Epoch 53/150
782/782 [==============================] - 9s 12ms/step - loss: 0.4864 -
accuracy: 0.8302 - val_loss: 1.0286 - val_accuracy: 0.6918
Epoch 54/150
782/782 [==============================] - 9s 12ms/step - loss: 0.4809 -
accuracy: 0.8316 - val_loss: 1.0505 - val_accuracy: 0.6904
Epoch 55/150
782/782 [==============================] - 10s 12ms/step - loss: 0.4708 -
accuracy: 0.8369 - val_loss: 1.0623 - val_accuracy: 0.6878
Epoch 56/150
782/782 [==============================] - 10s 12ms/step - loss: 0.4604 -
accuracy: 0.8404 - val_loss: 1.0736 - val_accuracy: 0.6832
Epoch 57/150
782/782 [==============================] - 9s 12ms/step - loss: 0.4544 -
accuracy: 0.8403 - val_loss: 1.1103 - val_accuracy: 0.6791
Epoch 58/150
782/782 [==============================] - 10s 12ms/step - loss: 0.4500 -
accuracy: 0.8428 - val_loss: 1.1045 - val_accuracy: 0.6860
Epoch 59/150
782/782 [==============================] - 10s 12ms/step - loss: 0.4458 -
accuracy: 0.8448 - val_loss: 1.0834 - val_accuracy: 0.6929
Epoch 60/150
782/782 [==============================] - 10s 12ms/step - loss: 0.4376 -
accuracy: 0.8465 - val_loss: 1.1157 - val_accuracy: 0.6878
Epoch 61/150
782/782 [==============================] - 10s 12ms/step - loss: 0.4300 -
accuracy: 0.8495 - val_loss: 1.1512 - val_accuracy: 0.6812
Epoch 62/150
782/782 [==============================] - 10s 12ms/step - loss: 0.4247 -
accuracy: 0.8524 - val_loss: 1.1393 - val_accuracy: 0.6874
Epoch 63/150
782/782 [==============================] - 10s 12ms/step - loss: 0.4198 -
accuracy: 0.8530 - val_loss: 1.1576 - val_accuracy: 0.6819
Epoch 64/150
782/782 [==============================] - 10s 12ms/step - loss: 0.4122 -
accuracy: 0.8545 - val_loss: 1.1698 - val_accuracy: 0.6803
Epoch 65/150
```

```
782/782 [==============================] - 10s 12ms/step - loss: 0.4047 -
accuracy: 0.8587 - val_loss: 1.1707 - val_accuracy: 0.6874
Epoch 66/150
782/782 [==============================] - 10s 12ms/step - loss: 0.3996 -
accuracy: 0.8597 - val_loss: 1.1836 - val_accuracy: 0.6845
Epoch 67/150
782/782 [==============================] - 10s 12ms/step - loss: 0.3985 -
accuracy: 0.8603 - val_loss: 1.1773 - val_accuracy: 0.6837
Epoch 68/150
782/782 [==============================] - 9s 12ms/step - loss: 0.3886 -
accuracy: 0.8632 - val_loss: 1.2086 - val_accuracy: 0.6817
Epoch 69/150
782/782 [==============================] - 10s 12ms/step - loss: 0.3824 -
accuracy: 0.8644 - val_loss: 1.2417 - val_accuracy: 0.6820
Epoch 70/150
782/782 [==============================] - 9s 12ms/step - loss: 0.3733 -
accuracy: 0.8687 - val_loss: 1.2322 - val_accuracy: 0.6818
Epoch 71/150
782/782 [==============================] - 10s 12ms/step - loss: 0.3715 -
accuracy: 0.8676 - val_loss: 1.2627 - val_accuracy: 0.6793
Epoch 72/150
782/782 [==============================] - 9s 12ms/step - loss: 0.3619 -
accuracy: 0.8726 - val_loss: 1.2703 - val_accuracy: 0.6812
Epoch 73/150
782/782 [==============================] - 9s 12ms/step - loss: 0.3561 -
accuracy: 0.8743 - val_loss: 1.2887 - val_accuracy: 0.6712
Epoch 74/150
782/782 [==============================] - 9s 12ms/step - loss: 0.3532 -
accuracy: 0.8752 - val_loss: 1.3037 - val_accuracy: 0.6816
Epoch 75/150
782/782 [==============================] - 9s 12ms/step - loss: 0.3472 -
accuracy: 0.8783 - val_loss: 1.3359 - val_accuracy: 0.6774
Epoch 76/150
782/782 [==============================] - 9s 12ms/step - loss: 0.3441 -
accuracy: 0.8777 - val_loss: 1.3303 - val_accuracy: 0.6792
Epoch 77/150
782/782 [==============================] - 9s 12ms/step - loss: 0.3349 -
accuracy: 0.8833 - val_loss: 1.3360 - val_accuracy: 0.6819
Epoch 78/150
782/782 [==============================] - 9s 12ms/step - loss: 0.3274 -
accuracy: 0.8852 - val_loss: 1.3708 - val_accuracy: 0.6785
Epoch 79/150
782/782 [==============================] - 9s 12ms/step - loss: 0.3272 -
accuracy: 0.8845 - val_loss: 1.3963 - val_accuracy: 0.6803
Epoch 80/150
782/782 [==============================] - 9s 12ms/step - loss: 0.3242 -
accuracy: 0.8840 - val_loss: 1.3869 - val_accuracy: 0.6743
Epoch 81/150
```

```
782/782 [==============================] - 9s 12ms/step - loss: 0.3166 -
accuracy: 0.8877 - val_loss: 1.4146 - val_accuracy: 0.6766
Epoch 82/150
782/782 [==============================] - 9s 12ms/step - loss: 0.3114 -
accuracy: 0.8894 - val_loss: 1.4435 - val_accuracy: 0.6740
Epoch 83/150
782/782 [==============================] - 9s 12ms/step - loss: 0.3048 -
accuracy: 0.8912 - val_loss: 1.4482 - val_accuracy: 0.6743
Epoch 84/150
782/782 [==============================] - 9s 12ms/step - loss: 0.3058 -
accuracy: 0.8915 - val_loss: 1.4765 - val_accuracy: 0.6692
Epoch 85/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2996 -
accuracy: 0.8938 - val_loss: 1.4991 - val_accuracy: 0.6730
Epoch 86/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2935 -
accuracy: 0.8957 - val_loss: 1.5373 - val_accuracy: 0.6742
Epoch 87/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2867 -
accuracy: 0.8986 - val_loss: 1.5678 - val_accuracy: 0.6674
Epoch 88/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2813 -
accuracy: 0.8999 - val_loss: 1.5570 - val_accuracy: 0.6769
Epoch 89/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2773 -
accuracy: 0.9019 - val_loss: 1.5878 - val_accuracy: 0.6675
Epoch 90/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2758 -
accuracy: 0.9016 - val_loss: 1.6030 - val_accuracy: 0.6732
Epoch 91/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2726 -
accuracy: 0.9027 - val_loss: 1.5743 - val_accuracy: 0.6740
Epoch 92/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2661 -
accuracy: 0.9040 - val_loss: 1.6248 - val_accuracy: 0.6733
Epoch 93/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2623 -
accuracy: 0.9060 - val_loss: 1.6553 - val_accuracy: 0.6669
Epoch 94/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2629 -
accuracy: 0.9040 - val_loss: 1.6822 - val_accuracy: 0.6721
Epoch 95/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2611 -
accuracy: 0.9065 - val_loss: 1.6824 - val_accuracy: 0.6715
Epoch 96/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2492 -
accuracy: 0.9100 - val_loss: 1.7615 - val_accuracy: 0.6631
Epoch 97/150
```

```
782/782 [==============================] - 9s 12ms/step - loss: 0.2520 -
accuracy: 0.9095 - val_loss: 1.7134 - val_accuracy: 0.6677
Epoch 98/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2416 -
accuracy: 0.9134 - val_loss: 1.8051 - val_accuracy: 0.6635
Epoch 99/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2431 -
accuracy: 0.9109 - val_loss: 1.8132 - val_accuracy: 0.6645
Epoch 100/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2367 -
accuracy: 0.9137 - val_loss: 1.7885 - val_accuracy: 0.6678
Epoch 101/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2330 -
accuracy: 0.9157 - val_loss: 1.8140 - val_accuracy: 0.6641
Epoch 102/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2258 -
accuracy: 0.9190 - val_loss: 1.8558 - val_accuracy: 0.6639
Epoch 103/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2255 -
accuracy: 0.9187 - val_loss: 1.8618 - val_accuracy: 0.6662
Epoch 104/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2281 -
accuracy: 0.9171 - val_loss: 1.9025 - val_accuracy: 0.6685
Epoch 105/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2236 -
accuracy: 0.9176 - val_loss: 1.9217 - val_accuracy: 0.6646
Epoch 106/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2184 -
accuracy: 0.9206 - val_loss: 1.9467 - val_accuracy: 0.6587
Epoch 107/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2142 -
accuracy: 0.9227 - val_loss: 1.9616 - val_accuracy: 0.6684
Epoch 108/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2064 -
accuracy: 0.9260 - val_loss: 1.9792 - val_accuracy: 0.6586
Epoch 109/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2012 -
accuracy: 0.9265 - val_loss: 2.0113 - val_accuracy: 0.6683
Epoch 110/150
782/782 [==============================] - 9s 12ms/step - loss: 0.2017 -
accuracy: 0.9265 - val_loss: 2.0679 - val_accuracy: 0.6605
Epoch 111/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1994 -
accuracy: 0.9265 - val_loss: 2.0906 - val_accuracy: 0.6599
Epoch 112/150
782/782 [==============================] - 10s 13ms/step - loss: 0.1954 -
accuracy: 0.9278 - val_loss: 2.1239 - val_accuracy: 0.6667
Epoch 113/150
```

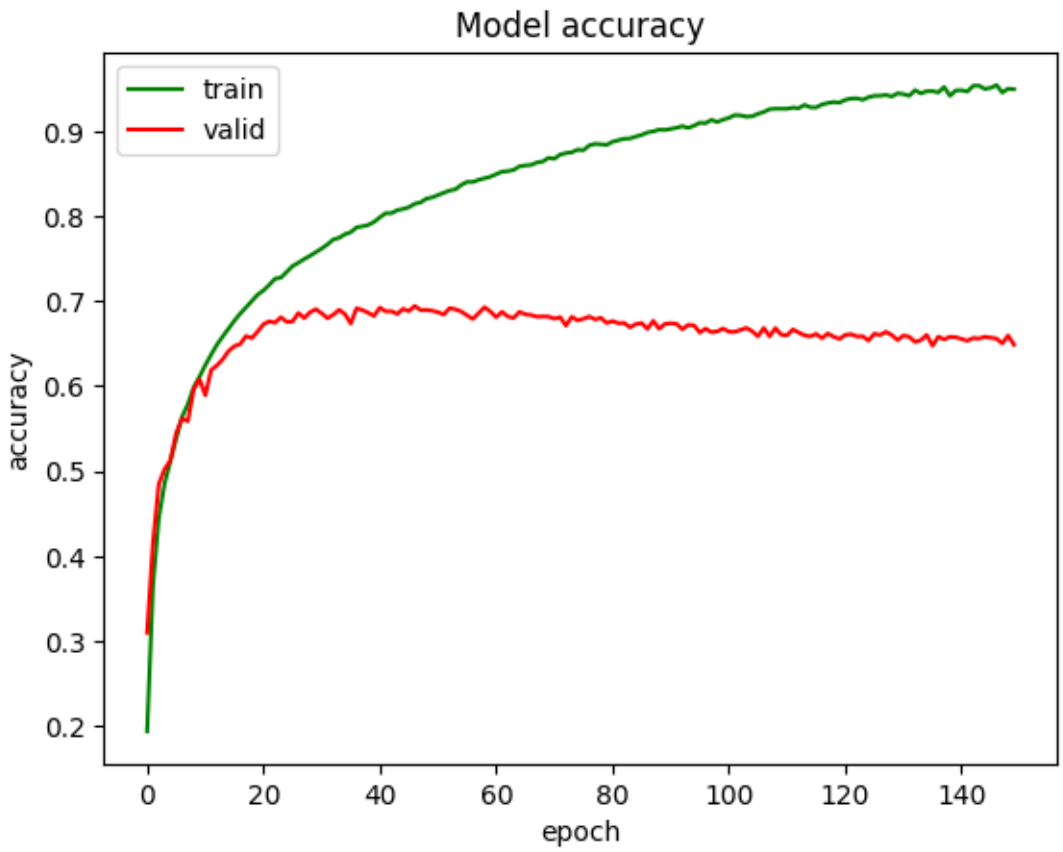
```
782/782 [==============================] - 10s 12ms/step - loss: 0.1971 -
accuracy: 0.9271 - val_loss: 2.1215 - val_accuracy: 0.6631
Epoch 114/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1878 -
accuracy: 0.9310 - val_loss: 2.1457 - val_accuracy: 0.6598
Epoch 115/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1938 -
accuracy: 0.9282 - val_loss: 2.1546 - val_accuracy: 0.6586
Epoch 116/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1942 -
accuracy: 0.9281 - val_loss: 2.1509 - val_accuracy: 0.6614
Epoch 117/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1838 -
accuracy: 0.9315 - val_loss: 2.1966 - val_accuracy: 0.6564
Epoch 118/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1811 -
accuracy: 0.9332 - val_loss: 2.2334 - val_accuracy: 0.6620
Epoch 119/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1776 -
accuracy: 0.9344 - val_loss: 2.2444 - val_accuracy: 0.6582
Epoch 120/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1771 -
accuracy: 0.9337 - val_loss: 2.3007 - val_accuracy: 0.6556
Epoch 121/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1702 -
accuracy: 0.9369 - val_loss: 2.3485 - val_accuracy: 0.6602
Epoch 122/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1685 -
accuracy: 0.9385 - val_loss: 2.3378 - val_accuracy: 0.6612
Epoch 123/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1634 -
accuracy: 0.9387 - val_loss: 2.4258 - val_accuracy: 0.6585
Epoch 124/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1700 -
accuracy: 0.9370 - val_loss: 2.3814 - val_accuracy: 0.6587
Epoch 125/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1587 -
accuracy: 0.9400 - val_loss: 2.4350 - val_accuracy: 0.6537
Epoch 126/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1583 -
accuracy: 0.9417 - val_loss: 2.4299 - val_accuracy: 0.6617
Epoch 127/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1552 -
accuracy: 0.9418 - val_loss: 2.5343 - val_accuracy: 0.6602
Epoch 128/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1554 -
accuracy: 0.9427 - val_loss: 2.4799 - val_accuracy: 0.6639
Epoch 129/150
```

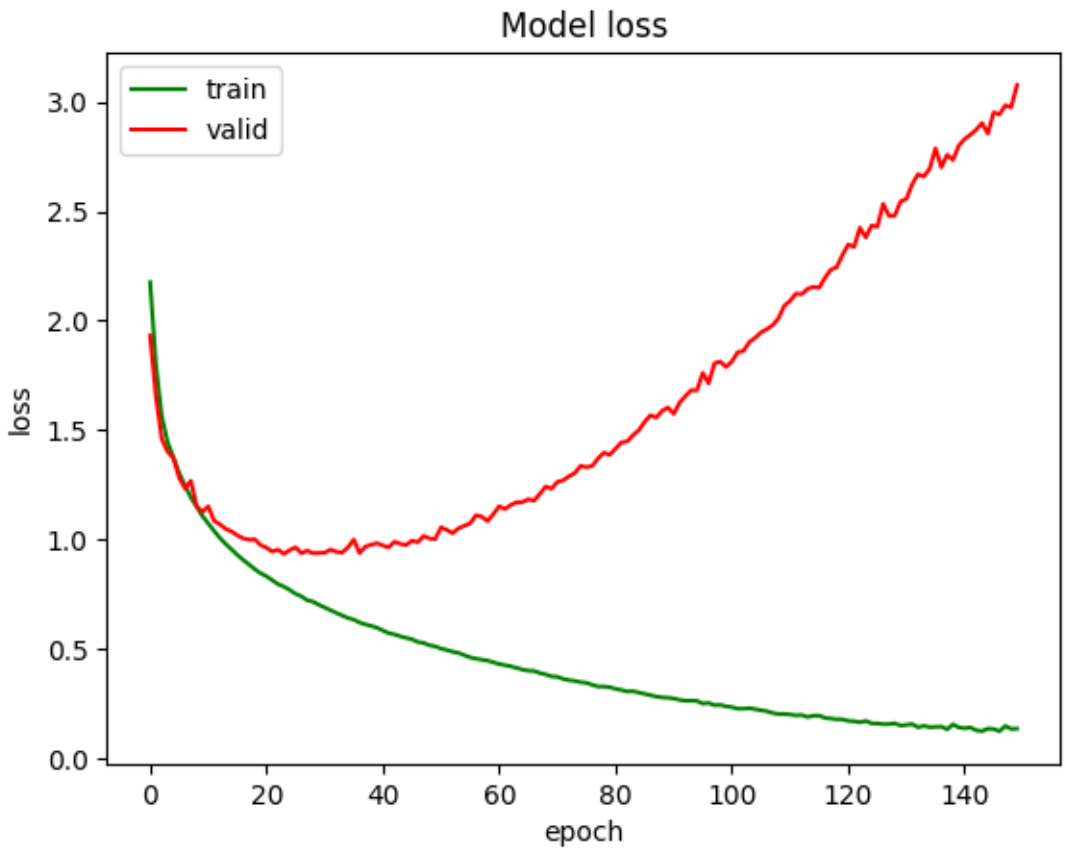
```
782/782 [==============================] - 10s 12ms/step - loss: 0.1588 -
accuracy: 0.9409 - val_loss: 2.4807 - val_accuracy: 0.6602
Epoch 130/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1487 -
accuracy: 0.9447 - val_loss: 2.5458 - val_accuracy: 0.6542
Epoch 131/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1516 -
accuracy: 0.9437 - val_loss: 2.5567 - val_accuracy: 0.6596
Epoch 132/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1550 -
accuracy: 0.9417 - val_loss: 2.6246 - val_accuracy: 0.6581
Epoch 133/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1410 -
accuracy: 0.9483 - val_loss: 2.6703 - val_accuracy: 0.6520
Epoch 134/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1472 -
accuracy: 0.9446 - val_loss: 2.6596 - val_accuracy: 0.6542
Epoch 135/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1413 -
accuracy: 0.9471 - val_loss: 2.6953 - val_accuracy: 0.6603
Epoch 136/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1421 -
accuracy: 0.9472 - val_loss: 2.7888 - val_accuracy: 0.6476
Epoch 137/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1438 -
accuracy: 0.9458 - val_loss: 2.7017 - val_accuracy: 0.6582
Epoch 138/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1313 -
accuracy: 0.9521 - val_loss: 2.7591 - val_accuracy: 0.6551
Epoch 139/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1543 -
accuracy: 0.9416 - val_loss: 2.7353 - val_accuracy: 0.6580
Epoch 140/150
782/782 [==============================] - 10s 13ms/step - loss: 0.1401 -
accuracy: 0.9481 - val_loss: 2.8006 - val_accuracy: 0.6576
Epoch 141/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1364 -
accuracy: 0.9482 - val_loss: 2.8311 - val_accuracy: 0.6556
Epoch 142/150
782/782 [==============================] - 10s 13ms/step - loss: 0.1398 -
accuracy: 0.9468 - val_loss: 2.8509 - val_accuracy: 0.6534
Epoch 143/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1270 -
accuracy: 0.9536 - val_loss: 2.8740 - val_accuracy: 0.6567
Epoch 144/150
782/782 [==============================] - 10s 13ms/step - loss: 0.1234 -
accuracy: 0.9536 - val_loss: 2.9041 - val_accuracy: 0.6560
Epoch 145/150
```

```
782/782 [==============================] - 10s 12ms/step - loss: 0.1347 -
accuracy: 0.9498 - val_loss: 2.8561 - val_accuracy: 0.6581
Epoch 146/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1330 -
accuracy: 0.9511 - val_loss: 2.9528 - val_accuracy: 0.6571
Epoch 147/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1228 -
accuracy: 0.9544 - val_loss: 2.9438 - val_accuracy: 0.6560
Epoch 148/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1467 -
accuracy: 0.9455 - val_loss: 2.9854 - val_accuracy: 0.6503
Epoch 149/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1333 -
accuracy: 0.9501 - val_loss: 2.9757 - val_accuracy: 0.6595
Epoch 150/150
782/782 [==============================] - 10s 12ms/step - loss: 0.1348 -
accuracy: 0.9494 - val_loss: 3.0778 - val_accuracy: 0.6488
time: 1426.2418642044067
```

Model liczył się bardzo szybko, szybciej nawet niż nasz pierwotny model, który jest dużo prostszy i ma o wiele mniej parametrów.
Możemy zauważyć, że accuracy jest bardzo wysokie, a loss bardzo niski, ale niestety tylko dla zbioru treningowego, zbiór walidacyjny ma lepsze wyniki niż poprzednie modele (jeśli chodzi o accuracy, jeśli chodzi o loss, to jest on dużo wyższy niż początkowy), ale bardzo mocno odstające od zbioru treningowego, co sugeruje overfitting.

[ ]:
```
print_history(hisotry2.history)
```


Model accuracy
train
valid
accuracy
epoch
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
20
40
60
80
100
120
140



[ ]:
```
model3 = tf.keras.Sequential(
    block(channels=20, activation='relu', input_shape=train_images[0].shape) +
    block(channels=40, activation='relu') +
    block(channels=80, activation='relu') +
    block(channels=160, activation='relu') + [
    tf.keras.layers.Flatten(),
    tf.keras.layers.Dense(units=10,activation='softmax')
])
```

[ ]:
```
model3.summary()
```

```
Model: "sequential_17"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_91 (Conv2D)          (None, 32, 32, 20)        560

 conv2d_92 (Conv2D)          (None, 32, 32, 20)        3620

 max_pooling2d_45 (MaxPoolin  (None, 16, 16, 20)       0
```

```
g2D)

conv2d_93 (Conv2D)          (None, 16, 16, 40)        7240

conv2d_94 (Conv2D)          (None, 16, 16, 40)        14440

max_pooling2d_46 (MaxPoolin  (None, 8, 8, 40)         0
g2D)

conv2d_95 (Conv2D)          (None, 8, 8, 80)          28880

conv2d_96 (Conv2D)          (None, 8, 8, 80)          57680

max_pooling2d_47 (MaxPoolin  (None, 4, 4, 80)         0
g2D)

conv2d_97 (Conv2D)          (None, 4, 4, 160)         115360

conv2d_98 (Conv2D)          (None, 4, 4, 160)         230560

max_pooling2d_48 (MaxPoolin  (None, 2, 2, 160)        0
g2D)

flatten_17 (Flatten)        (None, 640)               0

dense_17 (Dense)            (None, 10)                6410

=================================================================
Total params: 464,750
Trainable params: 464,750
Non-trainable params: 0
_________________________________________________________________
```

[ ]:
```
model3.compile(
    optimizer=tf.keras.optimizers.SGD(learning_rate=0.001, momentum=0.9),
    loss=tf.keras.losses.CategoricalCrossentropy(),
    metrics=['accuracy']
)
```

[ ]:
```
start_time = time.time()
hisotry3 = model3.fit(
    x=train_images,
    y=train_labels,
    batch_size=64,
    epochs=150,
    verbose=1,
    validation_data=(val_images, val_labels)
```

```
)
print(f"time: {time.time()-start_time}")
```

```
Epoch 1/150

2022-10-27 20:10:25.753797: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114]
Plugin optimizer for device_type GPU is enabled.

782/782 [==============================] - ETA: 0s - loss: 2.2530 - accuracy:
0.1568

2022-10-27 20:10:38.747768: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114]
Plugin optimizer for device_type GPU is enabled.

782/782 [==============================] - 14s 17ms/step - loss: 2.2530 -
accuracy: 0.1568 - val_loss: 2.0130 - val_accuracy: 0.2606
Epoch 2/150
782/782 [==============================] - 13s 17ms/step - loss: 1.9138 -
accuracy: 0.3023 - val_loss: 1.7708 - val_accuracy: 0.3632
Epoch 3/150
782/782 [==============================] - 13s 17ms/step - loss: 1.6901 -
accuracy: 0.3857 - val_loss: 1.7128 - val_accuracy: 0.3930
Epoch 4/150
782/782 [==============================] - 13s 17ms/step - loss: 1.5419 -
accuracy: 0.4435 - val_loss: 1.4859 - val_accuracy: 0.4646
Epoch 5/150
782/782 [==============================] - 13s 17ms/step - loss: 1.4403 -
accuracy: 0.4821 - val_loss: 1.4032 - val_accuracy: 0.4954
Epoch 6/150
782/782 [==============================] - 13s 16ms/step - loss: 1.3609 -
accuracy: 0.5137 - val_loss: 1.3121 - val_accuracy: 0.5320
Epoch 7/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2796 -
accuracy: 0.5440 - val_loss: 1.2709 - val_accuracy: 0.5454
Epoch 8/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2075 -
accuracy: 0.5712 - val_loss: 1.2667 - val_accuracy: 0.5463
Epoch 9/150
782/782 [==============================] - 13s 17ms/step - loss: 1.1437 -
accuracy: 0.5970 - val_loss: 1.1683 - val_accuracy: 0.5835
Epoch 10/150
782/782 [==============================] - 13s 17ms/step - loss: 1.0727 -
accuracy: 0.6245 - val_loss: 1.1763 - val_accuracy: 0.5854
Epoch 11/150
782/782 [==============================] - 13s 17ms/step - loss: 1.0061 -
accuracy: 0.6473 - val_loss: 1.1088 - val_accuracy: 0.6118
Epoch 12/150
782/782 [==============================] - 13s 17ms/step - loss: 0.9445 -
```

```
accuracy: 0.6704 - val_loss: 1.0566 - val_accuracy: 0.6300
Epoch 13/150
782/782 [==============================] - 13s 17ms/step - loss: 0.8851 -
accuracy: 0.6933 - val_loss: 1.0650 - val_accuracy: 0.6301
Epoch 14/150
782/782 [==============================] - 13s 17ms/step - loss: 0.8225 -
accuracy: 0.7134 - val_loss: 1.0454 - val_accuracy: 0.6408
Epoch 15/150
782/782 [==============================] - 13s 17ms/step - loss: 0.7657 -
accuracy: 0.7329 - val_loss: 1.0137 - val_accuracy: 0.6461
Epoch 16/150
782/782 [==============================] - 13s 17ms/step - loss: 0.7167 -
accuracy: 0.7502 - val_loss: 1.0779 - val_accuracy: 0.6494
Epoch 17/150
782/782 [==============================] - 13s 17ms/step - loss: 0.6591 -
accuracy: 0.7682 - val_loss: 1.0487 - val_accuracy: 0.6516
Epoch 18/150
782/782 [==============================] - 13s 16ms/step - loss: 0.6011 -
accuracy: 0.7902 - val_loss: 1.0893 - val_accuracy: 0.6440
Epoch 19/150
782/782 [==============================] - 13s 17ms/step - loss: 0.5422 -
accuracy: 0.8101 - val_loss: 1.0952 - val_accuracy: 0.6614
Epoch 20/150
782/782 [==============================] - 13s 17ms/step - loss: 0.4944 -
accuracy: 0.8279 - val_loss: 1.1397 - val_accuracy: 0.6529
Epoch 21/150
782/782 [==============================] - 13s 17ms/step - loss: 0.4365 -
accuracy: 0.8483 - val_loss: 1.2416 - val_accuracy: 0.6450
Epoch 22/150
782/782 [==============================] - 13s 17ms/step - loss: 0.3858 -
accuracy: 0.8643 - val_loss: 1.2674 - val_accuracy: 0.6555
Epoch 23/150
782/782 [==============================] - 13s 17ms/step - loss: 0.3461 -
accuracy: 0.8773 - val_loss: 1.3653 - val_accuracy: 0.6519
Epoch 24/150
782/782 [==============================] - 13s 17ms/step - loss: 0.3080 -
accuracy: 0.8897 - val_loss: 1.3998 - val_accuracy: 0.6534
Epoch 25/150
782/782 [==============================] - 13s 16ms/step - loss: 0.2656 -
accuracy: 0.9056 - val_loss: 1.5213 - val_accuracy: 0.6409
Epoch 26/150
782/782 [==============================] - 13s 17ms/step - loss: 0.2221 -
accuracy: 0.9216 - val_loss: 1.5691 - val_accuracy: 0.6581
Epoch 27/150
782/782 [==============================] - 13s 17ms/step - loss: 0.2103 -
accuracy: 0.9247 - val_loss: 1.6293 - val_accuracy: 0.6568
Epoch 28/150
782/782 [==============================] - 13s 17ms/step - loss: 0.1962 -
```

```
accuracy: 0.9290 - val_loss: 1.7684 - val_accuracy: 0.6442
Epoch 29/150
782/782 [==============================] - 14s 18ms/step - loss: 0.1770 -
accuracy: 0.9380 - val_loss: 1.7525 - val_accuracy: 0.6580
Epoch 30/150
782/782 [==============================] - 14s 17ms/step - loss: 0.1432 -
accuracy: 0.9489 - val_loss: 1.9447 - val_accuracy: 0.6453
Epoch 31/150
782/782 [==============================] - 13s 17ms/step - loss: 0.1410 -
accuracy: 0.9502 - val_loss: 1.8869 - val_accuracy: 0.6415
Epoch 32/150
782/782 [==============================] - 13s 16ms/step - loss: 0.1239 -
accuracy: 0.9560 - val_loss: 2.0502 - val_accuracy: 0.6475
Epoch 33/150
782/782 [==============================] - 13s 16ms/step - loss: 0.1256 -
accuracy: 0.9562 - val_loss: 1.9736 - val_accuracy: 0.6625
Epoch 34/150
782/782 [==============================] - 13s 17ms/step - loss: 0.1084 -
accuracy: 0.9611 - val_loss: 2.1262 - val_accuracy: 0.6449
Epoch 35/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0984 -
accuracy: 0.9638 - val_loss: 2.1979 - val_accuracy: 0.6535
Epoch 36/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0958 -
accuracy: 0.9662 - val_loss: 2.0748 - val_accuracy: 0.6578
Epoch 37/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0836 -
accuracy: 0.9702 - val_loss: 2.1868 - val_accuracy: 0.6554
Epoch 38/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0750 -
accuracy: 0.9740 - val_loss: 2.3209 - val_accuracy: 0.6593
Epoch 39/150
782/782 [==============================] - 14s 17ms/step - loss: 0.0869 -
accuracy: 0.9706 - val_loss: 2.2995 - val_accuracy: 0.6621
Epoch 40/150
782/782 [==============================] - 14s 18ms/step - loss: 0.0631 -
accuracy: 0.9783 - val_loss: 2.3279 - val_accuracy: 0.6546
Epoch 41/150
782/782 [==============================] - 14s 17ms/step - loss: 0.0596 -
accuracy: 0.9792 - val_loss: 2.3856 - val_accuracy: 0.6588
Epoch 42/150
782/782 [==============================] - 14s 17ms/step - loss: 0.0556 -
accuracy: 0.9808 - val_loss: 2.4468 - val_accuracy: 0.6540
Epoch 43/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0649 -
accuracy: 0.9771 - val_loss: 2.5763 - val_accuracy: 0.6555
Epoch 44/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0532 -
```

```
accuracy: 0.9816 - val_loss: 2.7291 - val_accuracy: 0.6496
Epoch 45/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0414 -
accuracy: 0.9854 - val_loss: 2.6668 - val_accuracy: 0.6513
Epoch 46/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0550 -
accuracy: 0.9807 - val_loss: 2.5888 - val_accuracy: 0.6540
Epoch 47/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0588 -
accuracy: 0.9804 - val_loss: 2.6018 - val_accuracy: 0.6511
Epoch 48/150
782/782 [==============================] - 14s 18ms/step - loss: 0.0539 -
accuracy: 0.9809 - val_loss: 2.5863 - val_accuracy: 0.6631
Epoch 49/150
782/782 [==============================] - 14s 17ms/step - loss: 0.0397 -
accuracy: 0.9864 - val_loss: 2.8490 - val_accuracy: 0.6607
Epoch 50/150
782/782 [==============================] - 14s 17ms/step - loss: 0.0487 -
accuracy: 0.9823 - val_loss: 2.6761 - val_accuracy: 0.6665
Epoch 51/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0456 -
accuracy: 0.9845 - val_loss: 2.5743 - val_accuracy: 0.6640
Epoch 52/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0326 -
accuracy: 0.9885 - val_loss: 2.9693 - val_accuracy: 0.6697
Epoch 53/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0269 -
accuracy: 0.9912 - val_loss: 2.8219 - val_accuracy: 0.6629
Epoch 54/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0351 -
accuracy: 0.9878 - val_loss: 2.7480 - val_accuracy: 0.6650
Epoch 55/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0315 -
accuracy: 0.9887 - val_loss: 2.9182 - val_accuracy: 0.6572
Epoch 56/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0297 -
accuracy: 0.9898 - val_loss: 2.8996 - val_accuracy: 0.6629
Epoch 57/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0341 -
accuracy: 0.9882 - val_loss: 2.9604 - val_accuracy: 0.6587
Epoch 58/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0305 -
accuracy: 0.9895 - val_loss: 3.0200 - val_accuracy: 0.6647
Epoch 59/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0302 -
accuracy: 0.9894 - val_loss: 3.0581 - val_accuracy: 0.6659
Epoch 60/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0273 -
```

```
accuracy: 0.9912 - val_loss: 2.9402 - val_accuracy: 0.6660
Epoch 61/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0418 -
accuracy: 0.9862 - val_loss: 3.0426 - val_accuracy: 0.6476
Epoch 62/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0279 -
accuracy: 0.9911 - val_loss: 2.9498 - val_accuracy: 0.6658
Epoch 63/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0252 -
accuracy: 0.9918 - val_loss: 3.1412 - val_accuracy: 0.6596
Epoch 64/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0309 -
accuracy: 0.9898 - val_loss: 2.9614 - val_accuracy: 0.6682
Epoch 65/150
782/782 [==============================] - 13s 16ms/step - loss: 0.0092 -
accuracy: 0.9972 - val_loss: 3.3190 - val_accuracy: 0.6708
Epoch 66/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0054 -
accuracy: 0.9981 - val_loss: 3.3942 - val_accuracy: 0.6642
Epoch 67/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0222 -
accuracy: 0.9923 - val_loss: 3.2285 - val_accuracy: 0.6559
Epoch 68/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0251 -
accuracy: 0.9916 - val_loss: 3.0740 - val_accuracy: 0.6685
Epoch 69/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0234 -
accuracy: 0.9921 - val_loss: 3.1688 - val_accuracy: 0.6644
Epoch 70/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0242 -
accuracy: 0.9918 - val_loss: 3.2028 - val_accuracy: 0.6697
Epoch 71/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0152 -
accuracy: 0.9948 - val_loss: 3.2338 - val_accuracy: 0.6667
Epoch 72/150
782/782 [==============================] - 14s 17ms/step - loss: 0.0193 -
accuracy: 0.9936 - val_loss: 3.2737 - val_accuracy: 0.6682
Epoch 73/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0360 -
accuracy: 0.9881 - val_loss: 3.1430 - val_accuracy: 0.6564
Epoch 74/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0337 -
accuracy: 0.9881 - val_loss: 3.0751 - val_accuracy: 0.6639
Epoch 75/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0210 -
accuracy: 0.9930 - val_loss: 3.2226 - val_accuracy: 0.6556
Epoch 76/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0108 -
```

```
accuracy: 0.9962 - val_loss: 3.2641 - val_accuracy: 0.6664
Epoch 77/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0200 -
accuracy: 0.9935 - val_loss: 3.2389 - val_accuracy: 0.6679
Epoch 78/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0204 -
accuracy: 0.9930 - val_loss: 3.2275 - val_accuracy: 0.6717
Epoch 79/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0284 -
accuracy: 0.9903 - val_loss: 3.0991 - val_accuracy: 0.6698
Epoch 80/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0086 -
accuracy: 0.9974 - val_loss: 3.3241 - val_accuracy: 0.6674
Epoch 81/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0067 -
accuracy: 0.9978 - val_loss: 3.2919 - val_accuracy: 0.6676
Epoch 82/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0054 -
accuracy: 0.9982 - val_loss: 3.4064 - val_accuracy: 0.6650
Epoch 83/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0139 -
accuracy: 0.9956 - val_loss: 3.5175 - val_accuracy: 0.6558
Epoch 84/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0187 -
accuracy: 0.9935 - val_loss: 3.4662 - val_accuracy: 0.6655
Epoch 85/150
782/782 [==============================] - 13s 16ms/step - loss: 0.0181 -
accuracy: 0.9939 - val_loss: 3.3165 - val_accuracy: 0.6664
Epoch 86/150
782/782 [==============================] - 13s 16ms/step - loss: 0.0260 -
accuracy: 0.9919 - val_loss: 3.2668 - val_accuracy: 0.6645
Epoch 87/150
782/782 [==============================] - 13s 16ms/step - loss: 0.0194 -
accuracy: 0.9939 - val_loss: 3.3585 - val_accuracy: 0.6682
Epoch 88/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0178 -
accuracy: 0.9939 - val_loss: 3.3700 - val_accuracy: 0.6675
Epoch 89/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0211 -
accuracy: 0.9933 - val_loss: 3.3404 - val_accuracy: 0.6663
Epoch 90/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0294 -
accuracy: 0.9902 - val_loss: 3.3598 - val_accuracy: 0.6663
Epoch 91/150
782/782 [==============================] - 13s 16ms/step - loss: 0.0192 -
accuracy: 0.9937 - val_loss: 3.3081 - val_accuracy: 0.6642
Epoch 92/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0102 -
```

```
accuracy: 0.9964 - val_loss: 3.3996 - val_accuracy: 0.6679
Epoch 93/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0125 -
accuracy: 0.9958 - val_loss: 3.5905 - val_accuracy: 0.6556
Epoch 94/150
782/782 [==============================] - 13s 16ms/step - loss: 0.0188 -
accuracy: 0.9935 - val_loss: 3.5541 - val_accuracy: 0.6679
Epoch 95/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0082 -
accuracy: 0.9974 - val_loss: 3.4231 - val_accuracy: 0.6783
Epoch 96/150
782/782 [==============================] - 13s 17ms/step - loss: 0.0025 -
accuracy: 0.9994 - val_loss: 3.5242 - val_accuracy: 0.6783
Epoch 97/150
782/782 [==============================] - 13s 16ms/step - loss: 7.0897e-04 -
accuracy: 0.9998 - val_loss: 3.6393 - val_accuracy: 0.6761
Epoch 98/150
782/782 [==============================] - 13s 17ms/step - loss: 3.1175e-04 -
accuracy: 0.9999 - val_loss: 3.6098 - val_accuracy: 0.6845
Epoch 99/150
782/782 [==============================] - 13s 17ms/step - loss: 6.2531e-05 -
accuracy: 1.0000 - val_loss: 3.6367 - val_accuracy: 0.6851
Epoch 100/150
782/782 [==============================] - 14s 17ms/step - loss: 4.4727e-05 -
accuracy: 1.0000 - val_loss: 3.6590 - val_accuracy: 0.6852
Epoch 101/150
782/782 [==============================] - 13s 17ms/step - loss: 3.8122e-05 -
accuracy: 1.0000 - val_loss: 3.6794 - val_accuracy: 0.6854
Epoch 102/150
782/782 [==============================] - 13s 17ms/step - loss: 3.3713e-05 -
accuracy: 1.0000 - val_loss: 3.6958 - val_accuracy: 0.6856
Epoch 103/150
782/782 [==============================] - 13s 17ms/step - loss: 3.0533e-05 -
accuracy: 1.0000 - val_loss: 3.7122 - val_accuracy: 0.6851
Epoch 104/150
782/782 [==============================] - 13s 17ms/step - loss: 2.7980e-05 -
accuracy: 1.0000 - val_loss: 3.7270 - val_accuracy: 0.6851
Epoch 105/150
782/782 [==============================] - 13s 17ms/step - loss: 2.5887e-05 -
accuracy: 1.0000 - val_loss: 3.7397 - val_accuracy: 0.6854
Epoch 106/150
782/782 [==============================] - 13s 17ms/step - loss: 2.4168e-05 -
accuracy: 1.0000 - val_loss: 3.7517 - val_accuracy: 0.6855
Epoch 107/150
782/782 [==============================] - 13s 17ms/step - loss: 2.2679e-05 -
accuracy: 1.0000 - val_loss: 3.7631 - val_accuracy: 0.6852
Epoch 108/150
782/782 [==============================] - 13s 17ms/step - loss: 2.1392e-05 -
```

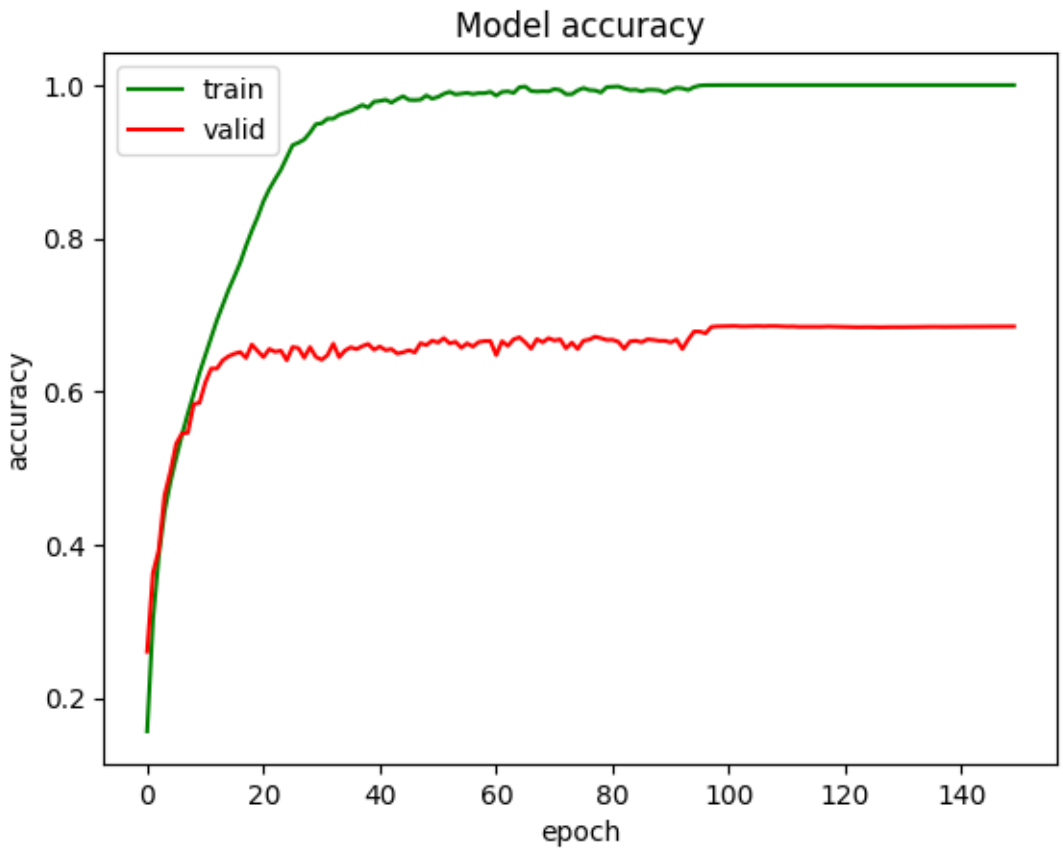
```
accuracy: 1.0000 - val_loss: 3.7741 - val_accuracy: 0.6855
Epoch 109/150
782/782 [==============================] - 13s 17ms/step - loss: 2.0255e-05 -
accuracy: 1.0000 - val_loss: 3.7844 - val_accuracy: 0.6855
Epoch 110/150
782/782 [==============================] - 13s 17ms/step - loss: 1.9265e-05 -
accuracy: 1.0000 - val_loss: 3.7942 - val_accuracy: 0.6852
Epoch 111/150
782/782 [==============================] - 13s 17ms/step - loss: 1.8371e-05 -
accuracy: 1.0000 - val_loss: 3.8040 - val_accuracy: 0.6849
Epoch 112/150
782/782 [==============================] - 13s 17ms/step - loss: 1.7574e-05 -
accuracy: 1.0000 - val_loss: 3.8132 - val_accuracy: 0.6850
Epoch 113/150
782/782 [==============================] - 13s 17ms/step - loss: 1.6845e-05 -
accuracy: 1.0000 - val_loss: 3.8214 - val_accuracy: 0.6846
Epoch 114/150
782/782 [==============================] - 13s 17ms/step - loss: 1.6183e-05 -
accuracy: 1.0000 - val_loss: 3.8295 - val_accuracy: 0.6846
Epoch 115/150
782/782 [==============================] - 13s 17ms/step - loss: 1.5580e-05 -
accuracy: 1.0000 - val_loss: 3.8377 - val_accuracy: 0.6845
Epoch 116/150
782/782 [==============================] - 13s 16ms/step - loss: 1.5017e-05 -
accuracy: 1.0000 - val_loss: 3.8451 - val_accuracy: 0.6845
Epoch 117/150
782/782 [==============================] - 13s 16ms/step - loss: 1.4502e-05 -
accuracy: 1.0000 - val_loss: 3.8524 - val_accuracy: 0.6846
Epoch 118/150
782/782 [==============================] - 13s 17ms/step - loss: 1.4022e-05 -
accuracy: 1.0000 - val_loss: 3.8594 - val_accuracy: 0.6849
Epoch 119/150
782/782 [==============================] - 13s 17ms/step - loss: 1.3579e-05 -
accuracy: 1.0000 - val_loss: 3.8664 - val_accuracy: 0.6847
Epoch 120/150
782/782 [==============================] - 13s 17ms/step - loss: 1.3167e-05 -
accuracy: 1.0000 - val_loss: 3.8731 - val_accuracy: 0.6843
Epoch 121/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2779e-05 -
accuracy: 1.0000 - val_loss: 3.8796 - val_accuracy: 0.6843
Epoch 122/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2418e-05 -
accuracy: 1.0000 - val_loss: 3.8859 - val_accuracy: 0.6842
Epoch 123/150
782/782 [==============================] - 13s 17ms/step - loss: 1.2077e-05 -
accuracy: 1.0000 - val_loss: 3.8921 - val_accuracy: 0.6841
Epoch 124/150
782/782 [==============================] - 13s 17ms/step - loss: 1.1757e-05 -
```

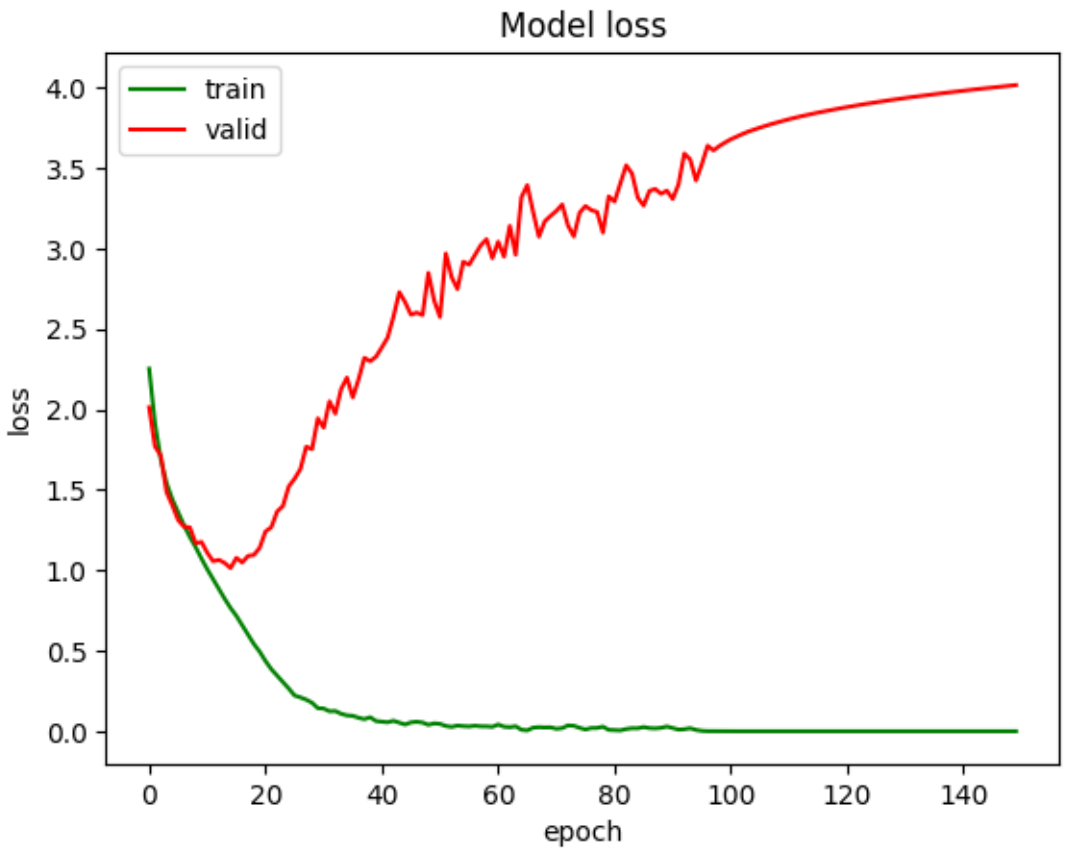
```
accuracy: 1.0000 - val_loss: 3.8980 - val_accuracy: 0.6842
Epoch 125/150
782/782 [==============================] - 13s 17ms/step - loss: 1.1455e-05 -
accuracy: 1.0000 - val_loss: 3.9039 - val_accuracy: 0.6842
Epoch 126/150
782/782 [==============================] - 13s 17ms/step - loss: 1.1168e-05 -
accuracy: 1.0000 - val_loss: 3.9094 - val_accuracy: 0.6841
Epoch 127/150
782/782 [==============================] - 13s 17ms/step - loss: 1.0894e-05 -
accuracy: 1.0000 - val_loss: 3.9151 - val_accuracy: 0.6840
Epoch 128/150
782/782 [==============================] - 13s 17ms/step - loss: 1.0636e-05 -
accuracy: 1.0000 - val_loss: 3.9205 - val_accuracy: 0.6842
Epoch 129/150
782/782 [==============================] - 13s 17ms/step - loss: 1.0393e-05 -
accuracy: 1.0000 - val_loss: 3.9259 - val_accuracy: 0.6842
Epoch 130/150
782/782 [==============================] - 13s 17ms/step - loss: 1.0160e-05 -
accuracy: 1.0000 - val_loss: 3.9310 - val_accuracy: 0.6841
Epoch 131/150
782/782 [==============================] - 13s 17ms/step - loss: 9.9389e-06 -
accuracy: 1.0000 - val_loss: 3.9361 - val_accuracy: 0.6842
Epoch 132/150
782/782 [==============================] - 13s 17ms/step - loss: 9.7254e-06 -
accuracy: 1.0000 - val_loss: 3.9409 - val_accuracy: 0.6842
Epoch 133/150
782/782 [==============================] - 13s 17ms/step - loss: 9.5227e-06 -
accuracy: 1.0000 - val_loss: 3.9457 - val_accuracy: 0.6843
Epoch 134/150
782/782 [==============================] - 13s 17ms/step - loss: 9.3284e-06 -
accuracy: 1.0000 - val_loss: 3.9504 - val_accuracy: 0.6844
Epoch 135/150
782/782 [==============================] - 13s 17ms/step - loss: 9.1424e-06 -
accuracy: 1.0000 - val_loss: 3.9551 - val_accuracy: 0.6846
Epoch 136/150
782/782 [==============================] - 13s 17ms/step - loss: 8.9649e-06 -
accuracy: 1.0000 - val_loss: 3.9595 - val_accuracy: 0.6846
Epoch 137/150
782/782 [==============================] - 13s 17ms/step - loss: 8.7935e-06 -
accuracy: 1.0000 - val_loss: 3.9641 - val_accuracy: 0.6845
Epoch 138/150
782/782 [==============================] - 13s 17ms/step - loss: 8.6290e-06 -
accuracy: 1.0000 - val_loss: 3.9684 - val_accuracy: 0.6845
Epoch 139/150
782/782 [==============================] - 13s 17ms/step - loss: 8.4730e-06 -
accuracy: 1.0000 - val_loss: 3.9729 - val_accuracy: 0.6846
Epoch 140/150
782/782 [==============================] - 13s 17ms/step - loss: 8.3204e-06 -
```

```
accuracy: 1.0000 - val_loss: 3.9771 - val_accuracy: 0.6846
Epoch 141/150
782/782 [==============================] - 13s 17ms/step - loss: 8.1746e-06 -
accuracy: 1.0000 - val_loss: 3.9812 - val_accuracy: 0.6847
Epoch 142/150
782/782 [==============================] - 13s 17ms/step - loss: 8.0346e-06 -
accuracy: 1.0000 - val_loss: 3.9853 - val_accuracy: 0.6847
Epoch 143/150
782/782 [==============================] - 13s 17ms/step - loss: 7.8985e-06 -
accuracy: 1.0000 - val_loss: 3.9895 - val_accuracy: 0.6847
Epoch 144/150
782/782 [==============================] - 13s 17ms/step - loss: 7.7677e-06 -
accuracy: 1.0000 - val_loss: 3.9934 - val_accuracy: 0.6847
Epoch 145/150
782/782 [==============================] - 13s 17ms/step - loss: 7.6416e-06 -
accuracy: 1.0000 - val_loss: 3.9973 - val_accuracy: 0.6848
Epoch 146/150
782/782 [==============================] - 13s 17ms/step - loss: 7.5192e-06 -
accuracy: 1.0000 - val_loss: 4.0011 - val_accuracy: 0.6849
Epoch 147/150
782/782 [==============================] - 13s 17ms/step - loss: 7.4024e-06 -
accuracy: 1.0000 - val_loss: 4.0050 - val_accuracy: 0.6849
Epoch 148/150
782/782 [==============================] - 13s 17ms/step - loss: 7.2875e-06 -
accuracy: 1.0000 - val_loss: 4.0085 - val_accuracy: 0.6850
Epoch 149/150
782/782 [==============================] - 13s 17ms/step - loss: 7.1777e-06 -
accuracy: 1.0000 - val_loss: 4.0124 - val_accuracy: 0.6850
Epoch 150/150
782/782 [==============================] - 13s 17ms/step - loss: 7.0706e-06 -
accuracy: 1.0000 - val_loss: 4.0160 - val_accuracy: 0.6850
time: 1967.3622839450836
```

Tym razem model liczył się odrobinę wolniej od poprzedniego modelu, dalej jestem zaskoczony, że tak duża różnica w rozmiarach modelu liczy się tak niewiele wolniej.
Mamy bardzo typowy przykład overfittingu, na danych treningowych model działa wyśmienicie, ale na walidacyjnych radzi sobie znacznie gorzej(choć wciąż lepiej od poprzednich modeli). Co ciekawe, wartość loss jest większa niż startowa, dla danych walidacyjnych. Nasz model nauczył się wszystkich zdjęć ze zbioru treningowego na pamięć.

[ ]:
```
print_history(hisotry3.history)
```


Model accuracy
train
valid
1.0
0.8
0.6
0.4
0.2
accuracy
0
20
40
60
80
100
120
140
epoch



1 Batch norm

Dodałem batch normalization dzięki funkcji batchnormalization, z kerasa.
Dodałem te warstwy normalizujące po każdej warstwie konwolucyjnej, zgodnie z poleceniem.

[ ]:
```
model = tf.keras.Sequential(
    block(channels=20, activation='relu', input_shape=train_images[0].shape,␣
 ↪batch_normalisation=True) +
    block(channels=40, activation='relu', batch_normalisation=True) +
    block(channels=80, activation='relu', batch_normalisation=True) +
    block(channels=160, activation='relu', batch_normalisation=True) + [
    tf.keras.layers.Flatten(),
    tf.keras.layers.Dense(units=10,activation='softmax')
])
```

[ ]:
```
model.summary()
```

```
Model: "sequential_18"
_________________________________________________________________
 Layer (type)                 Output Shape              Param #
```

```
=================================================================
conv2d_105 (Conv2D)          (None, 32, 32, 20)        560

batch_normalization_30 (Bat  (None, 32, 32, 20)       80
chNormalization)

conv2d_106 (Conv2D)          (None, 32, 32, 20)        3620

batch_normalization_31 (Bat  (None, 32, 32, 20)       80
chNormalization)

max_pooling2d_52 (MaxPoolin  (None, 16, 16, 20)       0
g2D)

conv2d_107 (Conv2D)          (None, 16, 16, 40)        7240

batch_normalization_32 (Bat  (None, 16, 16, 40)       160
chNormalization)

conv2d_108 (Conv2D)          (None, 16, 16, 40)        14440

batch_normalization_33 (Bat  (None, 16, 16, 40)       160
chNormalization)

max_pooling2d_53 (MaxPoolin  (None, 8, 8, 40)         0
g2D)

conv2d_109 (Conv2D)          (None, 8, 8, 80)          28880

batch_normalization_34 (Bat  (None, 8, 8, 80)         320
chNormalization)

conv2d_110 (Conv2D)          (None, 8, 8, 80)          57680

batch_normalization_35 (Bat  (None, 8, 8, 80)         320
chNormalization)

max_pooling2d_54 (MaxPoolin  (None, 4, 4, 80)         0
g2D)

conv2d_111 (Conv2D)          (None, 4, 4, 160)         115360

batch_normalization_36 (Bat  (None, 4, 4, 160)        640
chNormalization)

conv2d_112 (Conv2D)          (None, 4, 4, 160)         230560

batch_normalization_37 (Bat  (None, 4, 4, 160)        640
```

```
 chNormalization)

 max_pooling2d_55 (MaxPoolin  (None, 2, 2, 160)        0
 g2D)

 flatten_18 (Flatten)        (None, 640)               0

 dense_18 (Dense)            (None, 10)                6410

=================================================================
Total params: 467,150
Trainable params: 465,950
Non-trainable params: 1,200
_________________________________________________________________
```

[ ]:
```
model.compile(
    optimizer=tf.keras.optimizers.SGD(learning_rate=0.001, momentum=0.9),
    loss=tf.keras.losses.CategoricalCrossentropy(),
    metrics=['accuracy']
)
```

[ ]:
```
start_time = time.time()
hisotry = model.fit(
    x=train_images,
    y=train_labels,
    batch_size=64,
    epochs=150,
    verbose=1,
    validation_data=(val_images, val_labels)
)
print(f"time: {time.time()-start_time}")
```

```
Epoch 1/150

2022-10-27 22:04:04.992124: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114]
Plugin optimizer for device_type GPU is enabled.

782/782 [==============================] - ETA: 0s - loss: 1.5026 - accuracy:
0.4813

2022-10-27 22:04:20.253288: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114]
Plugin optimizer for device_type GPU is enabled.

782/782 [==============================] - 17s 21ms/step - loss: 1.5026 -
accuracy: 0.4813 - val_loss: 1.4780 - val_accuracy: 0.4960
Epoch 2/150
782/782 [==============================] - 16s 20ms/step - loss: 1.0254 -
accuracy: 0.6400 - val_loss: 1.2252 - val_accuracy: 0.5861
```

```
Epoch 3/150
782/782 [==============================] - 16s 20ms/step - loss: 0.8234 -
accuracy: 0.7124 - val_loss: 0.9440 - val_accuracy: 0.6751
Epoch 4/150
782/782 [==============================] - 17s 22ms/step - loss: 0.6751 -
accuracy: 0.7665 - val_loss: 0.8876 - val_accuracy: 0.6969
Epoch 5/150
782/782 [==============================] - 16s 20ms/step - loss: 0.5589 -
accuracy: 0.8056 - val_loss: 0.9135 - val_accuracy: 0.6931
Epoch 6/150
782/782 [==============================] - 16s 20ms/step - loss: 0.4569 -
accuracy: 0.8430 - val_loss: 0.8722 - val_accuracy: 0.7106
Epoch 7/150
782/782 [==============================] - 15s 20ms/step - loss: 0.3600 -
accuracy: 0.8783 - val_loss: 0.9563 - val_accuracy: 0.6991
Epoch 8/150
782/782 [==============================] - 15s 20ms/step - loss: 0.2790 -
accuracy: 0.9098 - val_loss: 0.9088 - val_accuracy: 0.7189
Epoch 9/150
782/782 [==============================] - 16s 20ms/step - loss: 0.2035 -
accuracy: 0.9390 - val_loss: 0.9961 - val_accuracy: 0.7136
Epoch 10/150
782/782 [==============================] - 15s 20ms/step - loss: 0.1463 -
accuracy: 0.9586 - val_loss: 0.9580 - val_accuracy: 0.7262
Epoch 11/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0986 -
accuracy: 0.9767 - val_loss: 1.0420 - val_accuracy: 0.7195
Epoch 12/150
782/782 [==============================] - 15s 20ms/step - loss: 0.0623 -
accuracy: 0.9891 - val_loss: 1.0272 - val_accuracy: 0.7322
Epoch 13/150
782/782 [==============================] - 15s 20ms/step - loss: 0.0414 -
accuracy: 0.9949 - val_loss: 1.0408 - val_accuracy: 0.7322
Epoch 14/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0266 -
accuracy: 0.9980 - val_loss: 1.0706 - val_accuracy: 0.7361
Epoch 15/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0176 -
accuracy: 0.9994 - val_loss: 1.0947 - val_accuracy: 0.7333
Epoch 16/150
782/782 [==============================] - 15s 20ms/step - loss: 0.0135 -
accuracy: 0.9995 - val_loss: 1.1058 - val_accuracy: 0.7368
Epoch 17/150
782/782 [==============================] - 15s 20ms/step - loss: 0.0104 -
accuracy: 0.9997 - val_loss: 1.1203 - val_accuracy: 0.7388
Epoch 18/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0086 -
accuracy: 0.9998 - val_loss: 1.1328 - val_accuracy: 0.7382
```

```
Epoch 19/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0080 -
accuracy: 0.9998 - val_loss: 1.1325 - val_accuracy: 0.7377
Epoch 20/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0064 -
accuracy: 0.9999 - val_loss: 1.1496 - val_accuracy: 0.7387
Epoch 21/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0056 -
accuracy: 0.9999 - val_loss: 1.1673 - val_accuracy: 0.7393
Epoch 22/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0066 -
accuracy: 0.9998 - val_loss: 1.1798 - val_accuracy: 0.7352
Epoch 23/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0048 -
accuracy: 1.0000 - val_loss: 1.1765 - val_accuracy: 0.7397
Epoch 24/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0043 -
accuracy: 0.9999 - val_loss: 1.1921 - val_accuracy: 0.7393
Epoch 25/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0039 -
accuracy: 0.9999 - val_loss: 1.2036 - val_accuracy: 0.7399
Epoch 26/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0036 -
accuracy: 1.0000 - val_loss: 1.2080 - val_accuracy: 0.7400
Epoch 27/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0031 -
accuracy: 1.0000 - val_loss: 1.2164 - val_accuracy: 0.7386
Epoch 28/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0028 -
accuracy: 1.0000 - val_loss: 1.2198 - val_accuracy: 0.7421
Epoch 29/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0029 -
accuracy: 0.9999 - val_loss: 1.2251 - val_accuracy: 0.7389
Epoch 30/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0033 -
accuracy: 0.9999 - val_loss: 1.2458 - val_accuracy: 0.7409
Epoch 31/150
782/782 [==============================] - 15s 20ms/step - loss: 0.0025 -
accuracy: 1.0000 - val_loss: 1.2428 - val_accuracy: 0.7422
Epoch 32/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0023 -
accuracy: 1.0000 - val_loss: 1.2516 - val_accuracy: 0.7388
Epoch 33/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0024 -
accuracy: 1.0000 - val_loss: 1.2559 - val_accuracy: 0.7410
Epoch 34/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0022 -
accuracy: 1.0000 - val_loss: 1.2627 - val_accuracy: 0.7395
```

```
Epoch 35/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0020 -
accuracy: 1.0000 - val_loss: 1.2664 - val_accuracy: 0.7386
Epoch 36/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0018 -
accuracy: 1.0000 - val_loss: 1.2705 - val_accuracy: 0.7396
Epoch 37/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0018 -
accuracy: 1.0000 - val_loss: 1.2727 - val_accuracy: 0.7396
Epoch 38/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0018 -
accuracy: 1.0000 - val_loss: 1.2797 - val_accuracy: 0.7397
Epoch 39/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0018 -
accuracy: 1.0000 - val_loss: 1.2919 - val_accuracy: 0.7375
Epoch 40/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0016 -
accuracy: 1.0000 - val_loss: 1.2872 - val_accuracy: 0.7412
Epoch 41/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0017 -
accuracy: 0.9999 - val_loss: 1.2951 - val_accuracy: 0.7393
Epoch 42/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0016 -
accuracy: 1.0000 - val_loss: 1.2991 - val_accuracy: 0.7405
Epoch 43/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0014 -
accuracy: 1.0000 - val_loss: 1.2975 - val_accuracy: 0.7415
Epoch 44/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0013 -
accuracy: 1.0000 - val_loss: 1.3045 - val_accuracy: 0.7415
Epoch 45/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0013 -
accuracy: 1.0000 - val_loss: 1.3044 - val_accuracy: 0.7413
Epoch 46/150
782/782 [==============================] - 16s 20ms/step - loss: 0.0013 -
accuracy: 1.0000 - val_loss: 1.3104 - val_accuracy: 0.7412
Epoch 47/150
782/782 [==============================] - 15s 20ms/step - loss: 0.0013 -
accuracy: 1.0000 - val_loss: 1.3126 - val_accuracy: 0.7405
Epoch 48/150
782/782 [==============================] - 15s 20ms/step - loss: 0.0011 -
accuracy: 1.0000 - val_loss: 1.3180 - val_accuracy: 0.7415
Epoch 49/150
782/782 [==============================] - 15s 20ms/step - loss: 0.0012 -
accuracy: 1.0000 - val_loss: 1.3224 - val_accuracy: 0.7416
Epoch 50/150
782/782 [==============================] - 15s 19ms/step - loss: 0.0012 -
accuracy: 1.0000 - val_loss: 1.3262 - val_accuracy: 0.7419
```

```
Epoch 51/150
782/782 [==============================] - 15s 20ms/step - loss: 0.0011 -
accuracy: 1.0000 - val_loss: 1.3350 - val_accuracy: 0.7413
Epoch 52/150
782/782 [==============================] - 15s 19ms/step - loss: 0.0011 -
accuracy: 1.0000 - val_loss: 1.3319 - val_accuracy: 0.7412
Epoch 53/150
782/782 [==============================] - 15s 20ms/step - loss: 0.0011 -
accuracy: 1.0000 - val_loss: 1.3381 - val_accuracy: 0.7414
Epoch 54/150
782/782 [==============================] - 15s 19ms/step - loss: 0.0010 -
accuracy: 1.0000 - val_loss: 1.3363 - val_accuracy: 0.7397
Epoch 55/150
782/782 [==============================] - 15s 19ms/step - loss: 9.3960e-04 -
accuracy: 1.0000 - val_loss: 1.3433 - val_accuracy: 0.7410
Epoch 56/150
782/782 [==============================] - 15s 19ms/step - loss: 0.0010 -
accuracy: 1.0000 - val_loss: 1.3478 - val_accuracy: 0.7394
Epoch 57/150
782/782 [==============================] - 15s 20ms/step - loss: 9.2894e-04 -
accuracy: 1.0000 - val_loss: 1.3498 - val_accuracy: 0.7406
Epoch 58/150
782/782 [==============================] - 16s 20ms/step - loss: 9.2239e-04 -
accuracy: 1.0000 - val_loss: 1.3553 - val_accuracy: 0.7418
Epoch 59/150
782/782 [==============================] - 15s 19ms/step - loss: 9.9525e-04 -
accuracy: 1.0000 - val_loss: 1.3763 - val_accuracy: 0.7359
Epoch 60/150
782/782 [==============================] - 15s 19ms/step - loss: 0.0055 -
accuracy: 0.9992 - val_loss: 1.3676 - val_accuracy: 0.7329
Epoch 61/150
782/782 [==============================] - 15s 20ms/step - loss: 0.0021 -
accuracy: 0.9999 - val_loss: 1.3699 - val_accuracy: 0.7389
Epoch 62/150
782/782 [==============================] - 15s 19ms/step - loss: 0.0014 -
accuracy: 1.0000 - val_loss: 1.3694 - val_accuracy: 0.7400
Epoch 63/150
782/782 [==============================] - 15s 19ms/step - loss: 0.0011 -
accuracy: 1.0000 - val_loss: 1.3760 - val_accuracy: 0.7403
Epoch 64/150
782/782 [==============================] - 15s 19ms/step - loss: 0.0010 -
accuracy: 1.0000 - val_loss: 1.3762 - val_accuracy: 0.7409
Epoch 65/150
782/782 [==============================] - 15s 19ms/step - loss: 9.8151e-04 -
accuracy: 1.0000 - val_loss: 1.3760 - val_accuracy: 0.7416
Epoch 66/150
782/782 [==============================] - 15s 19ms/step - loss: 8.8301e-04 -
accuracy: 1.0000 - val_loss: 1.3747 - val_accuracy: 0.7413
```

```
Epoch 67/150
782/782 [==============================] - 15s 19ms/step - loss: 7.9803e-04 -
accuracy: 1.0000 - val_loss: 1.3815 - val_accuracy: 0.7421
Epoch 68/150
782/782 [==============================] - 15s 19ms/step - loss: 0.0012 -
accuracy: 1.0000 - val_loss: 1.3820 - val_accuracy: 0.7399
Epoch 69/150
782/782 [==============================] - 15s 19ms/step - loss: 9.2804e-04 -
accuracy: 1.0000 - val_loss: 1.3838 - val_accuracy: 0.7387
Epoch 70/150
782/782 [==============================] - 15s 19ms/step - loss: 8.6036e-04 -
accuracy: 1.0000 - val_loss: 1.3897 - val_accuracy: 0.7403
Epoch 71/150
782/782 [==============================] - 15s 20ms/step - loss: 7.9090e-04 -
accuracy: 1.0000 - val_loss: 1.3910 - val_accuracy: 0.7390
Epoch 72/150
782/782 [==============================] - 15s 19ms/step - loss: 8.7235e-04 -
accuracy: 1.0000 - val_loss: 1.3934 - val_accuracy: 0.7397
Epoch 73/150
782/782 [==============================] - 15s 19ms/step - loss: 7.2716e-04 -
accuracy: 1.0000 - val_loss: 1.3927 - val_accuracy: 0.7412
Epoch 74/150
782/782 [==============================] - 15s 19ms/step - loss: 7.4694e-04 -
accuracy: 1.0000 - val_loss: 1.4010 - val_accuracy: 0.7401
Epoch 75/150
782/782 [==============================] - 15s 19ms/step - loss: 7.8145e-04 -
accuracy: 1.0000 - val_loss: 1.3993 - val_accuracy: 0.7433
Epoch 76/150
782/782 [==============================] - 15s 19ms/step - loss: 7.2696e-04 -
accuracy: 1.0000 - val_loss: 1.4020 - val_accuracy: 0.7410
Epoch 77/150
782/782 [==============================] - 15s 19ms/step - loss: 7.1300e-04 -
accuracy: 1.0000 - val_loss: 1.4082 - val_accuracy: 0.7414
Epoch 78/150
782/782 [==============================] - 15s 20ms/step - loss: 6.6163e-04 -
accuracy: 1.0000 - val_loss: 1.4103 - val_accuracy: 0.7411
Epoch 79/150
782/782 [==============================] - 15s 19ms/step - loss: 0.0012 -
accuracy: 0.9999 - val_loss: 1.4296 - val_accuracy: 0.7351
Epoch 80/150
782/782 [==============================] - 15s 19ms/step - loss: 0.0047 -
accuracy: 0.9993 - val_loss: 1.4034 - val_accuracy: 0.7374
Epoch 81/150
782/782 [==============================] - 15s 19ms/step - loss: 0.0012 -
accuracy: 1.0000 - val_loss: 1.4067 - val_accuracy: 0.7371
Epoch 82/150
782/782 [==============================] - 15s 19ms/step - loss: 0.0011 -
accuracy: 1.0000 - val_loss: 1.4094 - val_accuracy: 0.7364
```

```
Epoch 83/150
782/782 [==============================] - 15s 19ms/step - loss: 8.5697e-04 -
accuracy: 1.0000 - val_loss: 1.4144 - val_accuracy: 0.7382
Epoch 84/150
782/782 [==============================] - 15s 19ms/step - loss: 9.9288e-04 -
accuracy: 1.0000 - val_loss: 1.4189 - val_accuracy: 0.7375
Epoch 85/150
782/782 [==============================] - 15s 19ms/step - loss: 7.7958e-04 -
accuracy: 1.0000 - val_loss: 1.4198 - val_accuracy: 0.7373
Epoch 86/150
782/782 [==============================] - 15s 19ms/step - loss: 6.7466e-04 -
accuracy: 1.0000 - val_loss: 1.4224 - val_accuracy: 0.7402
Epoch 87/150
782/782 [==============================] - 15s 20ms/step - loss: 6.9757e-04 -
accuracy: 1.0000 - val_loss: 1.4319 - val_accuracy: 0.7392
Epoch 88/150
782/782 [==============================] - 15s 20ms/step - loss: 0.0013 -
accuracy: 0.9999 - val_loss: 1.4306 - val_accuracy: 0.7377
Epoch 89/150
782/782 [==============================] - 15s 19ms/step - loss: 7.6174e-04 -
accuracy: 1.0000 - val_loss: 1.4311 - val_accuracy: 0.7367
Epoch 90/150
782/782 [==============================] - 15s 20ms/step - loss: 7.2263e-04 -
accuracy: 1.0000 - val_loss: 1.4318 - val_accuracy: 0.7383
Epoch 91/150
782/782 [==============================] - 15s 19ms/step - loss: 5.8430e-04 -
accuracy: 1.0000 - val_loss: 1.4385 - val_accuracy: 0.7379
Epoch 92/150
782/782 [==============================] - 15s 20ms/step - loss: 5.9802e-04 -
accuracy: 1.0000 - val_loss: 1.4374 - val_accuracy: 0.7389
Epoch 93/150
782/782 [==============================] - 15s 20ms/step - loss: 5.7406e-04 -
accuracy: 1.0000 - val_loss: 1.4393 - val_accuracy: 0.7386
Epoch 94/150
782/782 [==============================] - 15s 19ms/step - loss: 6.2019e-04 -
accuracy: 1.0000 - val_loss: 1.4409 - val_accuracy: 0.7392
Epoch 95/150
782/782 [==============================] - 15s 20ms/step - loss: 5.5834e-04 -
accuracy: 1.0000 - val_loss: 1.4433 - val_accuracy: 0.7387
Epoch 96/150
782/782 [==============================] - 15s 20ms/step - loss: 5.0662e-04 -
accuracy: 1.0000 - val_loss: 1.4465 - val_accuracy: 0.7397
Epoch 97/150
782/782 [==============================] - 15s 20ms/step - loss: 4.8730e-04 -
accuracy: 1.0000 - val_loss: 1.4487 - val_accuracy: 0.7379
Epoch 98/150
782/782 [==============================] - 15s 20ms/step - loss: 4.9862e-04 -
accuracy: 1.0000 - val_loss: 1.4514 - val_accuracy: 0.7398
```

```
Epoch 99/150
782/782 [==============================] - 15s 20ms/step - loss: 6.0171e-04 -
accuracy: 1.0000 - val_loss: 1.4560 - val_accuracy: 0.7380
Epoch 100/150
782/782 [==============================] - 15s 20ms/step - loss: 4.8082e-04 -
accuracy: 1.0000 - val_loss: 1.4536 - val_accuracy: 0.7386
Epoch 101/150
782/782 [==============================] - 15s 20ms/step - loss: 4.4656e-04 -
accuracy: 1.0000 - val_loss: 1.4556 - val_accuracy: 0.7393
Epoch 102/150
782/782 [==============================] - 15s 20ms/step - loss: 5.7542e-04 -
accuracy: 1.0000 - val_loss: 1.4556 - val_accuracy: 0.7385
Epoch 103/150
782/782 [==============================] - 15s 20ms/step - loss: 5.0106e-04 -
accuracy: 1.0000 - val_loss: 1.4539 - val_accuracy: 0.7397
Epoch 104/150
782/782 [==============================] - 15s 20ms/step - loss: 4.6609e-04 -
accuracy: 1.0000 - val_loss: 1.4595 - val_accuracy: 0.7394
Epoch 105/150
782/782 [==============================] - 15s 19ms/step - loss: 4.2501e-04 -
accuracy: 1.0000 - val_loss: 1.4639 - val_accuracy: 0.7386
Epoch 106/150
782/782 [==============================] - 15s 19ms/step - loss: 3.9558e-04 -
accuracy: 1.0000 - val_loss: 1.4626 - val_accuracy: 0.7387
Epoch 107/150
782/782 [==============================] - 15s 20ms/step - loss: 5.1860e-04 -
accuracy: 1.0000 - val_loss: 1.4726 - val_accuracy: 0.7389
Epoch 108/150
782/782 [==============================] - 15s 20ms/step - loss: 4.2724e-04 -
accuracy: 1.0000 - val_loss: 1.4674 - val_accuracy: 0.7385
Epoch 109/150
782/782 [==============================] - 15s 19ms/step - loss: 4.4954e-04 -
accuracy: 1.0000 - val_loss: 1.4712 - val_accuracy: 0.7391
Epoch 110/150
782/782 [==============================] - 15s 20ms/step - loss: 4.6241e-04 -
accuracy: 1.0000 - val_loss: 1.4730 - val_accuracy: 0.7380
Epoch 111/150
782/782 [==============================] - 15s 19ms/step - loss: 4.3391e-04 -
accuracy: 1.0000 - val_loss: 1.4717 - val_accuracy: 0.7387
Epoch 112/150
782/782 [==============================] - 15s 19ms/step - loss: 4.2202e-04 -
accuracy: 1.0000 - val_loss: 1.4781 - val_accuracy: 0.7388
Epoch 113/150
782/782 [==============================] - 15s 20ms/step - loss: 4.2225e-04 -
accuracy: 1.0000 - val_loss: 1.4740 - val_accuracy: 0.7401
Epoch 114/150
782/782 [==============================] - 15s 20ms/step - loss: 3.8804e-04 -
accuracy: 1.0000 - val_loss: 1.4771 - val_accuracy: 0.7389
```

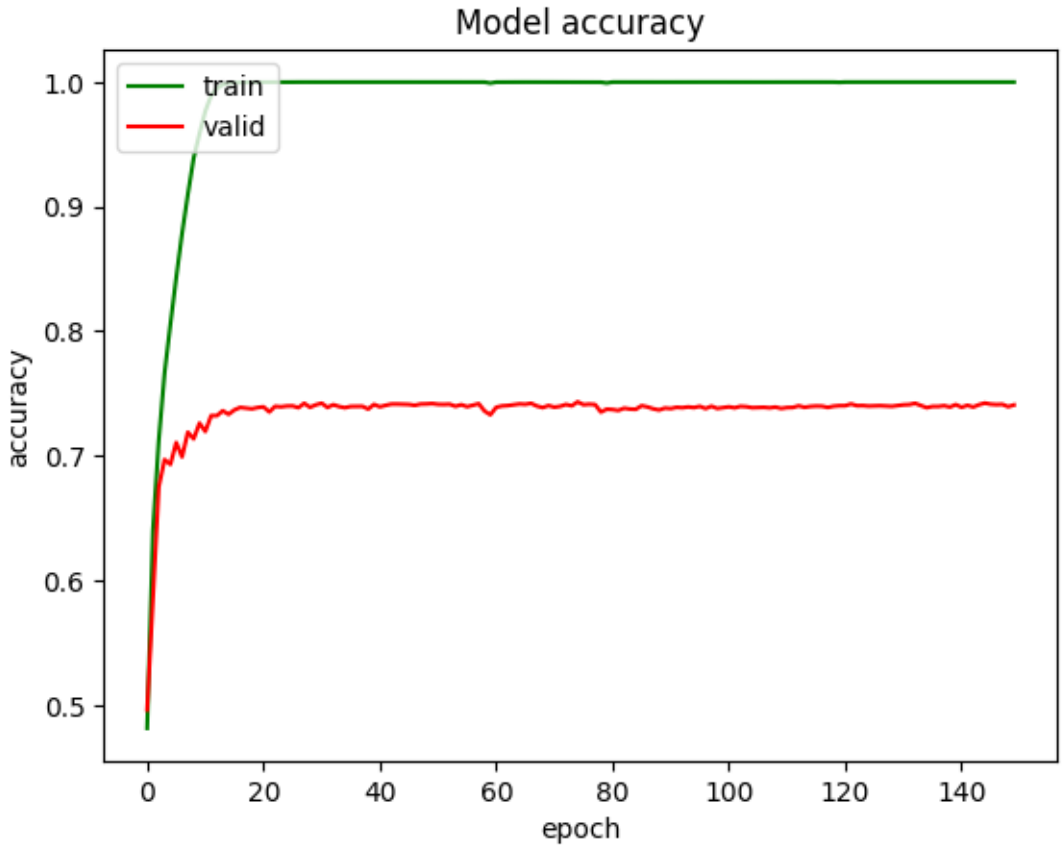
```
Epoch 115/150
782/782 [==============================] - 15s 20ms/step - loss: 3.5012e-04 -
accuracy: 1.0000 - val_loss: 1.4797 - val_accuracy: 0.7396
Epoch 116/150
782/782 [==============================] - 15s 20ms/step - loss: 4.0253e-04 -
accuracy: 1.0000 - val_loss: 1.4809 - val_accuracy: 0.7399
Epoch 117/150
782/782 [==============================] - 15s 19ms/step - loss: 3.6453e-04 -
accuracy: 1.0000 - val_loss: 1.4813 - val_accuracy: 0.7398
Epoch 118/150
782/782 [==============================] - 15s 20ms/step - loss: 3.6232e-04 -
accuracy: 1.0000 - val_loss: 1.4843 - val_accuracy: 0.7388
Epoch 119/150
782/782 [==============================] - 15s 20ms/step - loss: 3.9150e-04 -
accuracy: 1.0000 - val_loss: 1.4883 - val_accuracy: 0.7398
Epoch 120/150
782/782 [==============================] - 15s 20ms/step - loss: 0.0015 -
accuracy: 0.9998 - val_loss: 1.4933 - val_accuracy: 0.7402
Epoch 121/150
782/782 [==============================] - 15s 19ms/step - loss: 5.6292e-04 -
accuracy: 1.0000 - val_loss: 1.4905 - val_accuracy: 0.7402
Epoch 122/150
782/782 [==============================] - 15s 20ms/step - loss: 5.1645e-04 -
accuracy: 1.0000 - val_loss: 1.4874 - val_accuracy: 0.7416
Epoch 123/150
782/782 [==============================] - 15s 20ms/step - loss: 4.7962e-04 -
accuracy: 1.0000 - val_loss: 1.4884 - val_accuracy: 0.7402
Epoch 124/150
782/782 [==============================] - 15s 20ms/step - loss: 4.0013e-04 -
accuracy: 1.0000 - val_loss: 1.4905 - val_accuracy: 0.7403
Epoch 125/150
782/782 [==============================] - 15s 20ms/step - loss: 3.6702e-04 -
accuracy: 1.0000 - val_loss: 1.4899 - val_accuracy: 0.7399
Epoch 126/150
782/782 [==============================] - 15s 20ms/step - loss: 3.9806e-04 -
accuracy: 1.0000 - val_loss: 1.4897 - val_accuracy: 0.7400
Epoch 127/150
782/782 [==============================] - 15s 20ms/step - loss: 3.6187e-04 -
accuracy: 1.0000 - val_loss: 1.4916 - val_accuracy: 0.7402
Epoch 128/150
782/782 [==============================] - 15s 19ms/step - loss: 3.8183e-04 -
accuracy: 1.0000 - val_loss: 1.4917 - val_accuracy: 0.7400
Epoch 129/150
782/782 [==============================] - 16s 20ms/step - loss: 3.2445e-04 -
accuracy: 1.0000 - val_loss: 1.4926 - val_accuracy: 0.7397
Epoch 130/150
782/782 [==============================] - 16s 21ms/step - loss: 3.3378e-04 -
accuracy: 1.0000 - val_loss: 1.4962 - val_accuracy: 0.7403
```

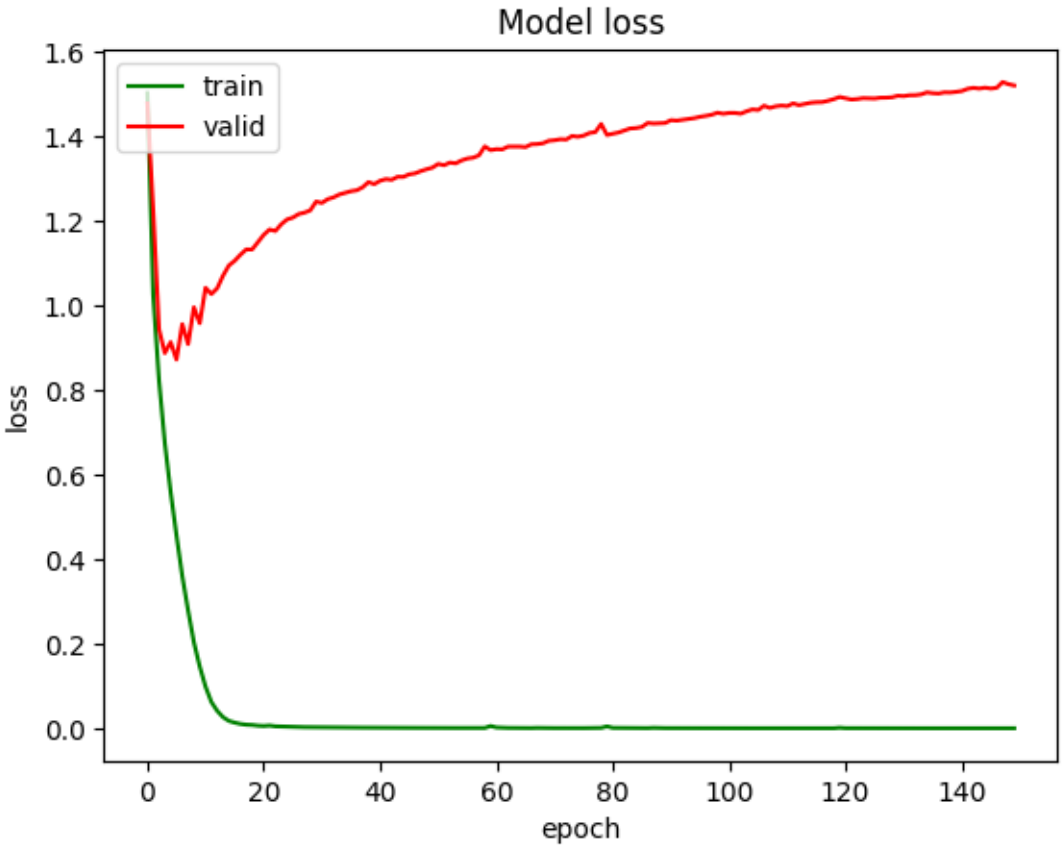
```
Epoch 131/150
782/782 [==============================] - 16s 20ms/step - loss: 3.2361e-04 -
accuracy: 1.0000 - val_loss: 1.4954 - val_accuracy: 0.7409
Epoch 132/150
782/782 [==============================] - 16s 20ms/step - loss: 3.3827e-04 -
accuracy: 1.0000 - val_loss: 1.4975 - val_accuracy: 0.7411
Epoch 133/150
782/782 [==============================] - 16s 20ms/step - loss: 3.2768e-04 -
accuracy: 1.0000 - val_loss: 1.4976 - val_accuracy: 0.7421
Epoch 134/150
782/782 [==============================] - 16s 20ms/step - loss: 3.4196e-04 -
accuracy: 1.0000 - val_loss: 1.4994 - val_accuracy: 0.7403
Epoch 135/150
782/782 [==============================] - 16s 20ms/step - loss: 4.0048e-04 -
accuracy: 1.0000 - val_loss: 1.5041 - val_accuracy: 0.7386
Epoch 136/150
782/782 [==============================] - 16s 20ms/step - loss: 3.2058e-04 -
accuracy: 1.0000 - val_loss: 1.5023 - val_accuracy: 0.7396
Epoch 137/150
782/782 [==============================] - 16s 20ms/step - loss: 3.3128e-04 -
accuracy: 1.0000 - val_loss: 1.5015 - val_accuracy: 0.7396
Epoch 138/150
782/782 [==============================] - 16s 20ms/step - loss: 2.8696e-04 -
accuracy: 1.0000 - val_loss: 1.5042 - val_accuracy: 0.7402
Epoch 139/150
782/782 [==============================] - 16s 20ms/step - loss: 2.8008e-04 -
accuracy: 1.0000 - val_loss: 1.5039 - val_accuracy: 0.7391
Epoch 140/150
782/782 [==============================] - 16s 20ms/step - loss: 2.8299e-04 -
accuracy: 1.0000 - val_loss: 1.5054 - val_accuracy: 0.7411
Epoch 141/150
782/782 [==============================] - 16s 20ms/step - loss: 3.2932e-04 -
accuracy: 1.0000 - val_loss: 1.5074 - val_accuracy: 0.7389
Epoch 142/150
782/782 [==============================] - 16s 20ms/step - loss: 4.5912e-04 -
accuracy: 1.0000 - val_loss: 1.5127 - val_accuracy: 0.7405
Epoch 143/150
782/782 [==============================] - 16s 20ms/step - loss: 3.5665e-04 -
accuracy: 1.0000 - val_loss: 1.5149 - val_accuracy: 0.7391
Epoch 144/150
782/782 [==============================] - 16s 20ms/step - loss: 9.0228e-04 -
accuracy: 0.9999 - val_loss: 1.5133 - val_accuracy: 0.7410
Epoch 145/150
782/782 [==============================] - 16s 20ms/step - loss: 4.2301e-04 -
accuracy: 1.0000 - val_loss: 1.5154 - val_accuracy: 0.7423
Epoch 146/150
782/782 [==============================] - 15s 20ms/step - loss: 3.5230e-04 -
accuracy: 1.0000 - val_loss: 1.5133 - val_accuracy: 0.7414
```

```
Epoch 147/150
782/782 [==============================] - 16s 20ms/step - loss: 3.7816e-04 -
accuracy: 1.0000 - val_loss: 1.5151 - val_accuracy: 0.7411
Epoch 148/150
782/782 [==============================] - 16s 20ms/step - loss: 6.1537e-04 -
accuracy: 0.9999 - val_loss: 1.5286 - val_accuracy: 0.7413
Epoch 149/150
782/782 [==============================] - 16s 20ms/step - loss: 3.9483e-04 -
accuracy: 1.0000 - val_loss: 1.5237 - val_accuracy: 0.7394
Epoch 150/150
782/782 [==============================] - 15s 20ms/step - loss: 3.2838e-04 -
accuracy: 1.0000 - val_loss: 1.5205 - val_accuracy: 0.7408
time: 2317.193153142929
```

Tym razem niewiele zwiększyliśmy rozmiar modelu (szczególnie pod względem liczby parametrów, szczególnie pod względem liczby parametrów do uczenia), tymczasem czas trawania uczenia wzrósł około o tyle samo co poprzednim razem.
Dalej napotykamy ten sam problem - overfitting. Nasz model praktycznie doskonale zapamiętał zbiór treningowy, lecz nie daje aż takiej dobrej rady ze zbiorem walidacyjnym.
Model daje sobie radę nieznacznie lepiej niż poprzednia wersja bez normalizacji batchy.

[ ]:
```
print_history(hisotry.history)
```





2 DROPOUT

[ ]:
```
model = tf.keras.Sequential(
    block(channels=20, activation='relu', input_shape=train_images[0].shape,␣
 ↪batch_normalisation=True, dropout=0.1) +
    block(channels=40, activation='relu', batch_normalisation=True, dropout=0.
 ↪2) +
    block(channels=80, activation='relu', batch_normalisation=True, dropout=0.
 ↪3) +
    block(channels=160, activation='relu', batch_normalisation=True, dropout=0.
 ↪4) + [
    tf.keras.layers.Flatten(),
    tf.keras.layers.Dense(units=10,activation='softmax')
])
```

[ ]:
```
model.summary()
```

```
Model: "sequential_19"
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_113 (Conv2D)          (None, 32, 32, 20)        560

batch_normalization_38 (Bat  (None, 32, 32, 20)       80
chNormalization)

conv2d_114 (Conv2D)          (None, 32, 32, 20)        3620

batch_normalization_39 (Bat  (None, 32, 32, 20)       80
chNormalization)

max_pooling2d_56 (MaxPoolin  (None, 16, 16, 20)       0
g2D)

dropout_4 (Dropout)          (None, 16, 16, 20)        0

conv2d_115 (Conv2D)          (None, 16, 16, 40)        7240

batch_normalization_40 (Bat  (None, 16, 16, 40)       160
chNormalization)

conv2d_116 (Conv2D)          (None, 16, 16, 40)        14440

batch_normalization_41 (Bat  (None, 16, 16, 40)       160
chNormalization)

max_pooling2d_57 (MaxPoolin  (None, 8, 8, 40)         0
g2D)

dropout_5 (Dropout)          (None, 8, 8, 40)          0

conv2d_117 (Conv2D)          (None, 8, 8, 80)          28880

batch_normalization_42 (Bat  (None, 8, 8, 80)         320
chNormalization)

conv2d_118 (Conv2D)          (None, 8, 8, 80)          57680

batch_normalization_43 (Bat  (None, 8, 8, 80)         320
chNormalization)

max_pooling2d_58 (MaxPoolin  (None, 4, 4, 80)         0
g2D)

dropout_6 (Dropout)          (None, 4, 4, 80)          0
```

```
conv2d_119 (Conv2D)          (None, 4, 4, 160)         115360

batch_normalization_44 (Bat  (None, 4, 4, 160)         640
chNormalization)

conv2d_120 (Conv2D)          (None, 4, 4, 160)         230560

batch_normalization_45 (Bat  (None, 4, 4, 160)         640
chNormalization)

max_pooling2d_59 (MaxPoolin  (None, 2, 2, 160)         0
g2D)

dropout_7 (Dropout)          (None, 2, 2, 160)         0

flatten_19 (Flatten)         (None, 640)               0

dense_19 (Dense)             (None, 10)                6410

=================================================================
Total params: 467,150
Trainable params: 465,950
Non-trainable params: 1,200
_________________________________________________________________
```

[ ]:
```python
model.compile(
    optimizer=tf.keras.optimizers.SGD(learning_rate=0.001, momentum=0.9),
    loss=tf.keras.losses.CategoricalCrossentropy(),
    metrics=['accuracy']
)
```

[ ]:
```python
start_time = time.time()
history = model.fit(
    x=train_images,
    y=train_labels,
    batch_size=64,
    epochs=150,
    verbose=1,
    validation_data=(val_images, val_labels)
)
print(f"time: {time.time()-start_time}")
```

```
Epoch 1/150

2022-10-27 22:44:48.449655: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114]
Plugin optimizer for device_type GPU is enabled.

782/782 [==============================] - ETA: 0s - loss: 1.8990 - accuracy:
```

```
0.3744

2022-10-27 22:45:04.592333: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114]
Plugin optimizer for device_type GPU is enabled.

782/782 [==============================] - 19s 22ms/step - loss: 1.8990 -
accuracy: 0.3744 - val_loss: 1.4651 - val_accuracy: 0.4627
Epoch 2/150
782/782 [==============================] - 16s 21ms/step - loss: 1.4158 -
accuracy: 0.4985 - val_loss: 1.3939 - val_accuracy: 0.5429
Epoch 3/150
782/782 [==============================] - 16s 21ms/step - loss: 1.2437 -
accuracy: 0.5579 - val_loss: 1.1554 - val_accuracy: 0.5926
Epoch 4/150
782/782 [==============================] - 16s 21ms/step - loss: 1.1185 -
accuracy: 0.6037 - val_loss: 0.9758 - val_accuracy: 0.6532
Epoch 5/150
782/782 [==============================] - 16s 21ms/step - loss: 1.0304 -
accuracy: 0.6367 - val_loss: 0.9476 - val_accuracy: 0.6678
Epoch 6/150
782/782 [==============================] - 16s 21ms/step - loss: 0.9492 -
accuracy: 0.6636 - val_loss: 0.8802 - val_accuracy: 0.6922
Epoch 7/150
782/782 [==============================] - 16s 21ms/step - loss: 0.8946 -
accuracy: 0.6835 - val_loss: 0.8773 - val_accuracy: 0.6903
Epoch 8/150
782/782 [==============================] - 16s 21ms/step - loss: 0.8413 -
accuracy: 0.7043 - val_loss: 0.8147 - val_accuracy: 0.7205
Epoch 9/150
782/782 [==============================] - 16s 21ms/step - loss: 0.7983 -
accuracy: 0.7185 - val_loss: 0.7859 - val_accuracy: 0.7239
Epoch 10/150
782/782 [==============================] - 16s 21ms/step - loss: 0.7600 -
accuracy: 0.7330 - val_loss: 0.7492 - val_accuracy: 0.7422
Epoch 11/150
782/782 [==============================] - 16s 21ms/step - loss: 0.7313 -
accuracy: 0.7431 - val_loss: 0.7449 - val_accuracy: 0.7389
Epoch 12/150
782/782 [==============================] - 16s 21ms/step - loss: 0.7017 -
accuracy: 0.7533 - val_loss: 0.6893 - val_accuracy: 0.7587
Epoch 13/150
782/782 [==============================] - 16s 21ms/step - loss: 0.6701 -
accuracy: 0.7643 - val_loss: 0.7089 - val_accuracy: 0.7530
Epoch 14/150
782/782 [==============================] - 16s 21ms/step - loss: 0.6522 -
accuracy: 0.7700 - val_loss: 0.6696 - val_accuracy: 0.7634
Epoch 15/150
782/782 [==============================] - 16s 21ms/step - loss: 0.6301 -
```

```
accuracy: 0.7817 - val_loss: 0.6656 - val_accuracy: 0.7686
Epoch 16/150
782/782 [==============================] - 16s 21ms/step - loss: 0.6112 -
accuracy: 0.7865 - val_loss: 0.6751 - val_accuracy: 0.7702
Epoch 17/150
782/782 [==============================] - 16s 21ms/step - loss: 0.5937 -
accuracy: 0.7915 - val_loss: 0.6802 - val_accuracy: 0.7691
Epoch 18/150
782/782 [==============================] - 16s 21ms/step - loss: 0.5798 -
accuracy: 0.7948 - val_loss: 0.6958 - val_accuracy: 0.7619
Epoch 19/150
782/782 [==============================] - 16s 21ms/step - loss: 0.5654 -
accuracy: 0.7999 - val_loss: 0.6216 - val_accuracy: 0.7871
Epoch 20/150
782/782 [==============================] - 17s 22ms/step - loss: 0.5503 -
accuracy: 0.8048 - val_loss: 0.6079 - val_accuracy: 0.7878
Epoch 21/150
782/782 [==============================] - 17s 21ms/step - loss: 0.5357 -
accuracy: 0.8121 - val_loss: 0.6279 - val_accuracy: 0.7867
Epoch 22/150
782/782 [==============================] - 16s 21ms/step - loss: 0.5220 -
accuracy: 0.8160 - val_loss: 0.6684 - val_accuracy: 0.7692
Epoch 23/150
782/782 [==============================] - 16s 21ms/step - loss: 0.5098 -
accuracy: 0.8205 - val_loss: 0.6143 - val_accuracy: 0.7863
Epoch 24/150
782/782 [==============================] - 16s 21ms/step - loss: 0.4974 -
accuracy: 0.8243 - val_loss: 0.7947 - val_accuracy: 0.7339
Epoch 25/150
782/782 [==============================] - 16s 21ms/step - loss: 0.4877 -
accuracy: 0.8272 - val_loss: 0.6189 - val_accuracy: 0.7846
Epoch 26/150
782/782 [==============================] - 16s 21ms/step - loss: 0.4775 -
accuracy: 0.8304 - val_loss: 0.6054 - val_accuracy: 0.7933
Epoch 27/150
782/782 [==============================] - 16s 21ms/step - loss: 0.4627 -
accuracy: 0.8359 - val_loss: 0.5788 - val_accuracy: 0.8009
Epoch 28/150
782/782 [==============================] - 16s 21ms/step - loss: 0.4491 -
accuracy: 0.8423 - val_loss: 0.5798 - val_accuracy: 0.8038
Epoch 29/150
782/782 [==============================] - 16s 21ms/step - loss: 0.4445 -
accuracy: 0.8417 - val_loss: 0.5763 - val_accuracy: 0.8054
Epoch 30/150
782/782 [==============================] - 16s 21ms/step - loss: 0.4350 -
accuracy: 0.8466 - val_loss: 0.6083 - val_accuracy: 0.7979
Epoch 31/150
782/782 [==============================] - 16s 21ms/step - loss: 0.4235 -
```

```
accuracy: 0.8503 - val_loss: 0.6137 - val_accuracy: 0.7935
Epoch 32/150
782/782 [==============================] - 16s 21ms/step - loss: 0.4133 -
accuracy: 0.8540 - val_loss: 0.5828 - val_accuracy: 0.8021
Epoch 33/150
782/782 [==============================] - 16s 21ms/step - loss: 0.4028 -
accuracy: 0.8558 - val_loss: 0.5622 - val_accuracy: 0.8127
Epoch 34/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3984 -
accuracy: 0.8578 - val_loss: 0.5812 - val_accuracy: 0.8096
Epoch 35/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3906 -
accuracy: 0.8604 - val_loss: 0.5554 - val_accuracy: 0.8127
Epoch 36/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3825 -
accuracy: 0.8647 - val_loss: 0.6068 - val_accuracy: 0.8013
Epoch 37/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3684 -
accuracy: 0.8685 - val_loss: 0.5846 - val_accuracy: 0.8096
Epoch 38/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3693 -
accuracy: 0.8690 - val_loss: 0.5911 - val_accuracy: 0.8055
Epoch 39/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3596 -
accuracy: 0.8723 - val_loss: 0.5603 - val_accuracy: 0.8161
Epoch 40/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3527 -
accuracy: 0.8748 - val_loss: 0.6650 - val_accuracy: 0.7881
Epoch 41/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3483 -
accuracy: 0.8764 - val_loss: 0.5559 - val_accuracy: 0.8189
Epoch 42/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3413 -
accuracy: 0.8773 - val_loss: 0.5676 - val_accuracy: 0.8158
Epoch 43/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3306 -
accuracy: 0.8810 - val_loss: 0.6433 - val_accuracy: 0.7963
Epoch 44/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3281 -
accuracy: 0.8821 - val_loss: 0.5580 - val_accuracy: 0.8201
Epoch 45/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3234 -
accuracy: 0.8854 - val_loss: 0.5735 - val_accuracy: 0.8143
Epoch 46/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3132 -
accuracy: 0.8883 - val_loss: 0.5818 - val_accuracy: 0.8123
Epoch 47/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3056 -
```

```
accuracy: 0.8930 - val_loss: 0.5786 - val_accuracy: 0.8158
Epoch 48/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3036 -
accuracy: 0.8911 - val_loss: 0.5877 - val_accuracy: 0.8143
Epoch 49/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3003 -
accuracy: 0.8917 - val_loss: 0.5655 - val_accuracy: 0.8198
Epoch 50/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2929 -
accuracy: 0.8936 - val_loss: 0.5762 - val_accuracy: 0.8207
Epoch 51/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2836 -
accuracy: 0.8989 - val_loss: 0.5850 - val_accuracy: 0.8171
Epoch 52/150
782/782 [==============================] - 17s 21ms/step - loss: 0.2851 -
accuracy: 0.8985 - val_loss: 0.5692 - val_accuracy: 0.8229
Epoch 53/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2750 -
accuracy: 0.9010 - val_loss: 0.5629 - val_accuracy: 0.8237
Epoch 54/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2677 -
accuracy: 0.9041 - val_loss: 0.5564 - val_accuracy: 0.8249
Epoch 55/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2640 -
accuracy: 0.9063 - val_loss: 0.5680 - val_accuracy: 0.8238
Epoch 56/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2577 -
accuracy: 0.9084 - val_loss: 0.5784 - val_accuracy: 0.8212
Epoch 57/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2577 -
accuracy: 0.9061 - val_loss: 0.6005 - val_accuracy: 0.8227
Epoch 58/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2536 -
accuracy: 0.9082 - val_loss: 0.5981 - val_accuracy: 0.8183
Epoch 59/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2458 -
accuracy: 0.9111 - val_loss: 0.5740 - val_accuracy: 0.8280
Epoch 60/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2474 -
accuracy: 0.9116 - val_loss: 0.5990 - val_accuracy: 0.8216
Epoch 61/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2409 -
accuracy: 0.9141 - val_loss: 0.5788 - val_accuracy: 0.8247
Epoch 62/150
782/782 [==============================] - 17s 21ms/step - loss: 0.2339 -
accuracy: 0.9158 - val_loss: 0.5881 - val_accuracy: 0.8240
Epoch 63/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2321 -
```

```
accuracy: 0.9173 - val_loss: 0.5932 - val_accuracy: 0.8217
Epoch 64/150
782/782 [==============================] - 17s 21ms/step - loss: 0.2226 -
accuracy: 0.9200 - val_loss: 0.5915 - val_accuracy: 0.8244
Epoch 65/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2222 -
accuracy: 0.9203 - val_loss: 0.6315 - val_accuracy: 0.8182
Epoch 66/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2216 -
accuracy: 0.9203 - val_loss: 0.5915 - val_accuracy: 0.8246
Epoch 67/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2155 -
accuracy: 0.9219 - val_loss: 0.5932 - val_accuracy: 0.8288
Epoch 68/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2131 -
accuracy: 0.9235 - val_loss: 0.6035 - val_accuracy: 0.8220
Epoch 69/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2082 -
accuracy: 0.9256 - val_loss: 0.6041 - val_accuracy: 0.8256
Epoch 70/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2047 -
accuracy: 0.9263 - val_loss: 0.5720 - val_accuracy: 0.8341
Epoch 71/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2012 -
accuracy: 0.9264 - val_loss: 0.5912 - val_accuracy: 0.8285
Epoch 72/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1988 -
accuracy: 0.9281 - val_loss: 0.5984 - val_accuracy: 0.8266
Epoch 73/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1962 -
accuracy: 0.9296 - val_loss: 0.6007 - val_accuracy: 0.8249
Epoch 74/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1904 -
accuracy: 0.9304 - val_loss: 0.6084 - val_accuracy: 0.8259
Epoch 75/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1877 -
accuracy: 0.9327 - val_loss: 0.5965 - val_accuracy: 0.8270
Epoch 76/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1907 -
accuracy: 0.9311 - val_loss: 0.5955 - val_accuracy: 0.8300
Epoch 77/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1914 -
accuracy: 0.9303 - val_loss: 0.5966 - val_accuracy: 0.8305
Epoch 78/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1823 -
accuracy: 0.9353 - val_loss: 0.5967 - val_accuracy: 0.8308
Epoch 79/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1816 -
```

```
accuracy: 0.9341 - val_loss: 0.6119 - val_accuracy: 0.8281
Epoch 80/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1724 -
accuracy: 0.9380 - val_loss: 0.5993 - val_accuracy: 0.8337
Epoch 81/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1734 -
accuracy: 0.9384 - val_loss: 0.5998 - val_accuracy: 0.8337
Epoch 82/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1714 -
accuracy: 0.9378 - val_loss: 0.6205 - val_accuracy: 0.8294
Epoch 83/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1691 -
accuracy: 0.9396 - val_loss: 0.6179 - val_accuracy: 0.8314
Epoch 84/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1663 -
accuracy: 0.9405 - val_loss: 0.6243 - val_accuracy: 0.8268
Epoch 85/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1657 -
accuracy: 0.9386 - val_loss: 0.6269 - val_accuracy: 0.8279
Epoch 86/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1656 -
accuracy: 0.9409 - val_loss: 0.6287 - val_accuracy: 0.8309
Epoch 87/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1595 -
accuracy: 0.9434 - val_loss: 0.6230 - val_accuracy: 0.8321
Epoch 88/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1606 -
accuracy: 0.9418 - val_loss: 0.6326 - val_accuracy: 0.8291
Epoch 89/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1570 -
accuracy: 0.9419 - val_loss: 0.6486 - val_accuracy: 0.8284
Epoch 90/150
782/782 [==============================] - 17s 22ms/step - loss: 0.1552 -
accuracy: 0.9444 - val_loss: 0.6262 - val_accuracy: 0.8346
Epoch 91/150
782/782 [==============================] - 18s 23ms/step - loss: 0.1495 -
accuracy: 0.9469 - val_loss: 0.6055 - val_accuracy: 0.8359
Epoch 92/150
782/782 [==============================] - 18s 22ms/step - loss: 0.1550 -
accuracy: 0.9442 - val_loss: 0.6244 - val_accuracy: 0.8331
Epoch 93/150
782/782 [==============================] - 18s 23ms/step - loss: 0.1500 -
accuracy: 0.9462 - val_loss: 0.6430 - val_accuracy: 0.8324
Epoch 94/150
782/782 [==============================] - 17s 22ms/step - loss: 0.1449 -
accuracy: 0.9477 - val_loss: 0.6439 - val_accuracy: 0.8305
Epoch 95/150
782/782 [==============================] - 17s 22ms/step - loss: 0.1446 -
```

```
accuracy: 0.9473 - val_loss: 0.6247 - val_accuracy: 0.8373
Epoch 96/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1398 -
accuracy: 0.9493 - val_loss: 0.6412 - val_accuracy: 0.8335
Epoch 97/150
782/782 [==============================] - 17s 22ms/step - loss: 0.1382 -
accuracy: 0.9497 - val_loss: 0.6383 - val_accuracy: 0.8340
Epoch 98/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1401 -
accuracy: 0.9498 - val_loss: 0.6261 - val_accuracy: 0.8355
Epoch 99/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1347 -
accuracy: 0.9511 - val_loss: 0.6511 - val_accuracy: 0.8323
Epoch 100/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1369 -
accuracy: 0.9504 - val_loss: 0.6400 - val_accuracy: 0.8361
Epoch 101/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1367 -
accuracy: 0.9500 - val_loss: 0.6255 - val_accuracy: 0.8355
Epoch 102/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1309 -
accuracy: 0.9528 - val_loss: 0.6410 - val_accuracy: 0.8322
Epoch 103/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1295 -
accuracy: 0.9531 - val_loss: 0.6709 - val_accuracy: 0.8290
Epoch 104/150
782/782 [==============================] - 17s 22ms/step - loss: 0.1309 -
accuracy: 0.9532 - val_loss: 0.6499 - val_accuracy: 0.8347
Epoch 105/150
782/782 [==============================] - 18s 23ms/step - loss: 0.1297 -
accuracy: 0.9523 - val_loss: 0.6432 - val_accuracy: 0.8347
Epoch 106/150
782/782 [==============================] - 17s 22ms/step - loss: 0.1243 -
accuracy: 0.9554 - val_loss: 0.6627 - val_accuracy: 0.8310
Epoch 107/150
782/782 [==============================] - 17s 22ms/step - loss: 0.1251 -
accuracy: 0.9554 - val_loss: 0.6698 - val_accuracy: 0.8321
Epoch 108/150
782/782 [==============================] - 18s 23ms/step - loss: 0.1251 -
accuracy: 0.9543 - val_loss: 0.6586 - val_accuracy: 0.8369
Epoch 109/150
782/782 [==============================] - 17s 22ms/step - loss: 0.1251 -
accuracy: 0.9549 - val_loss: 0.6619 - val_accuracy: 0.8355
Epoch 110/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1218 -
accuracy: 0.9565 - val_loss: 0.6598 - val_accuracy: 0.8362
Epoch 111/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1206 -
```

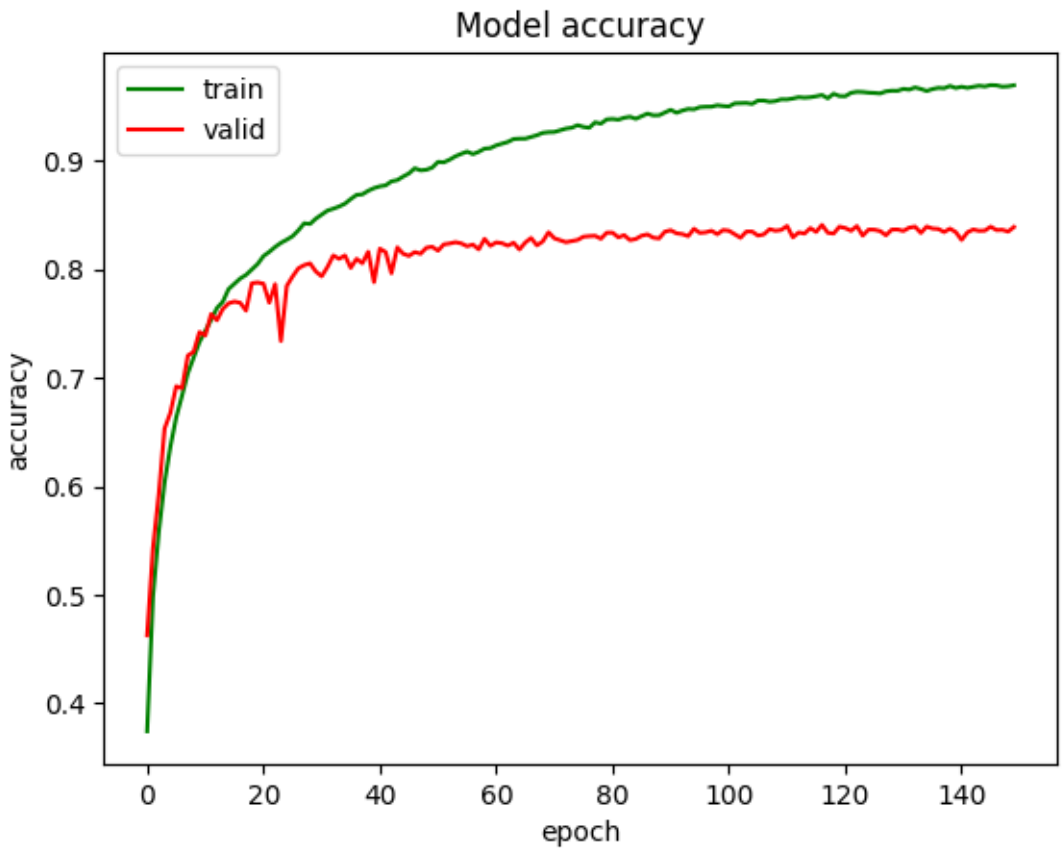
```
accuracy: 0.9564 - val_loss: 0.6526 - val_accuracy: 0.8399
Epoch 112/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1203 -
accuracy: 0.9573 - val_loss: 0.6737 - val_accuracy: 0.8294
Epoch 113/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1170 -
accuracy: 0.9585 - val_loss: 0.6630 - val_accuracy: 0.8339
Epoch 114/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1161 -
accuracy: 0.9580 - val_loss: 0.6645 - val_accuracy: 0.8329
Epoch 115/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1174 -
accuracy: 0.9585 - val_loss: 0.6449 - val_accuracy: 0.8379
Epoch 116/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1151 -
accuracy: 0.9593 - val_loss: 0.6810 - val_accuracy: 0.8344
Epoch 117/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1131 -
accuracy: 0.9605 - val_loss: 0.6488 - val_accuracy: 0.8409
Epoch 118/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1157 -
accuracy: 0.9575 - val_loss: 0.6716 - val_accuracy: 0.8336
Epoch 119/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1065 -
accuracy: 0.9617 - val_loss: 0.6900 - val_accuracy: 0.8329
Epoch 120/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1131 -
accuracy: 0.9596 - val_loss: 0.6579 - val_accuracy: 0.8392
Epoch 121/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1125 -
accuracy: 0.9594 - val_loss: 0.6431 - val_accuracy: 0.8380
Epoch 122/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1054 -
accuracy: 0.9625 - val_loss: 0.6719 - val_accuracy: 0.8354
Epoch 123/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1032 -
accuracy: 0.9635 - val_loss: 0.6594 - val_accuracy: 0.8398
Epoch 124/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1012 -
accuracy: 0.9633 - val_loss: 0.7021 - val_accuracy: 0.8309
Epoch 125/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1053 -
accuracy: 0.9627 - val_loss: 0.6799 - val_accuracy: 0.8365
Epoch 126/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1030 -
accuracy: 0.9624 - val_loss: 0.6852 - val_accuracy: 0.8364
Epoch 127/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1047 -
```

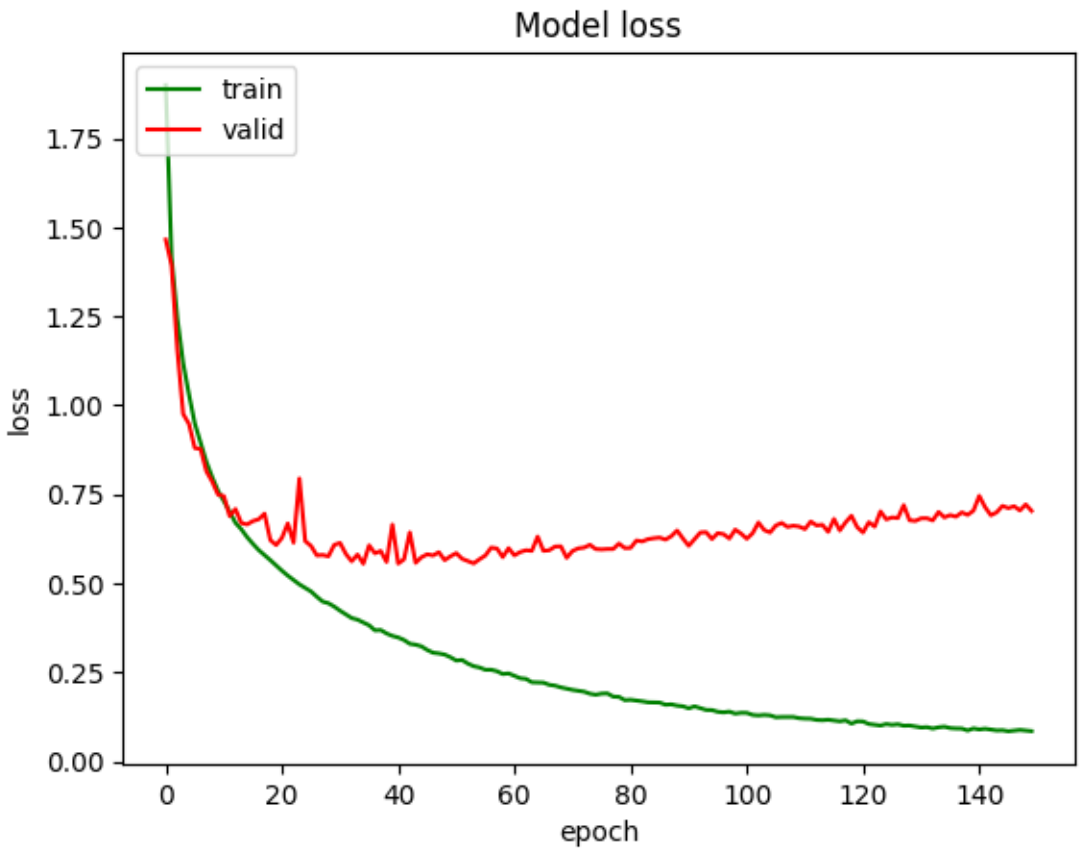
```
accuracy: 0.9620 - val_loss: 0.6837 - val_accuracy: 0.8352
Epoch 128/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1006 -
accuracy: 0.9639 - val_loss: 0.7198 - val_accuracy: 0.8313
Epoch 129/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1012 -
accuracy: 0.9645 - val_loss: 0.6773 - val_accuracy: 0.8365
Epoch 130/150
782/782 [==============================] - 17s 21ms/step - loss: 0.0986 -
accuracy: 0.9644 - val_loss: 0.6756 - val_accuracy: 0.8366
Epoch 131/150
782/782 [==============================] - 16s 21ms/step - loss: 0.0956 -
accuracy: 0.9662 - val_loss: 0.6828 - val_accuracy: 0.8353
Epoch 132/150
782/782 [==============================] - 17s 21ms/step - loss: 0.0966 -
accuracy: 0.9655 - val_loss: 0.6830 - val_accuracy: 0.8383
Epoch 133/150
782/782 [==============================] - 16s 21ms/step - loss: 0.0928 -
accuracy: 0.9675 - val_loss: 0.6769 - val_accuracy: 0.8392
Epoch 134/150
782/782 [==============================] - 16s 21ms/step - loss: 0.0962 -
accuracy: 0.9661 - val_loss: 0.7006 - val_accuracy: 0.8335
Epoch 135/150
782/782 [==============================] - 16s 21ms/step - loss: 0.0979 -
accuracy: 0.9642 - val_loss: 0.6854 - val_accuracy: 0.8393
Epoch 136/150
782/782 [==============================] - 16s 21ms/step - loss: 0.0940 -
accuracy: 0.9660 - val_loss: 0.6919 - val_accuracy: 0.8375
Epoch 137/150
782/782 [==============================] - 16s 21ms/step - loss: 0.0930 -
accuracy: 0.9671 - val_loss: 0.6875 - val_accuracy: 0.8371
Epoch 138/150
782/782 [==============================] - 16s 21ms/step - loss: 0.0927 -
accuracy: 0.9668 - val_loss: 0.6994 - val_accuracy: 0.8343
Epoch 139/150
782/782 [==============================] - 17s 21ms/step - loss: 0.0873 -
accuracy: 0.9689 - val_loss: 0.6925 - val_accuracy: 0.8374
Epoch 140/150
782/782 [==============================] - 16s 21ms/step - loss: 0.0931 -
accuracy: 0.9670 - val_loss: 0.7042 - val_accuracy: 0.8342
Epoch 141/150
782/782 [==============================] - 17s 21ms/step - loss: 0.0902 -
accuracy: 0.9681 - val_loss: 0.7459 - val_accuracy: 0.8270
Epoch 142/150
782/782 [==============================] - 16s 21ms/step - loss: 0.0921 -
accuracy: 0.9671 - val_loss: 0.7143 - val_accuracy: 0.8340
Epoch 143/150
782/782 [==============================] - 16s 21ms/step - loss: 0.0899 -
```

```
accuracy: 0.9680 - val_loss: 0.6914 - val_accuracy: 0.8366
Epoch 144/150
782/782 [==============================] - 17s 21ms/step - loss: 0.0875 -
accuracy: 0.9691 - val_loss: 0.6996 - val_accuracy: 0.8354
Epoch 145/150
782/782 [==============================] - 16s 21ms/step - loss: 0.0880 -
accuracy: 0.9684 - val_loss: 0.7176 - val_accuracy: 0.8356
Epoch 146/150
782/782 [==============================] - 16s 21ms/step - loss: 0.0852 -
accuracy: 0.9697 - val_loss: 0.7114 - val_accuracy: 0.8392
Epoch 147/150
782/782 [==============================] - 16s 21ms/step - loss: 0.0872 -
accuracy: 0.9694 - val_loss: 0.7167 - val_accuracy: 0.8361
Epoch 148/150
782/782 [==============================] - 16s 21ms/step - loss: 0.0888 -
accuracy: 0.9682 - val_loss: 0.7049 - val_accuracy: 0.8363
Epoch 149/150
782/782 [==============================] - 16s 21ms/step - loss: 0.0874 -
accuracy: 0.9685 - val_loss: 0.7218 - val_accuracy: 0.8347
Epoch 150/150
782/782 [==============================] - 16s 21ms/step - loss: 0.0855 -
accuracy: 0.9695 - val_loss: 0.7038 - val_accuracy: 0.8389
time: 2476.677229642868
```

Tym razem, liczyło się niewiele dłużej co poprzednim razem (batch normalization).
Model uczył się około 40 min.
Widzimy, że tym razem model nie jest zbytnio przeuczony i daje rozsądne wyniki.

[ ]:
```
print_history(history.history)
```


Model accuracy
train
valid
accuracy
epoch
0.4
0.5
0.6
0.7
0.8
0.9
0
20
40
60
80
100
120
140



3 Mind the gap

```
[ ]: model = tf.keras.Sequential(
        block(channels=20, activation='relu', input_shape=(None, None, 3),␣
     ↪batch_normalisation=True, dropout=0.1) +
        block(channels=40, activation='relu', batch_normalisation=True, dropout=0.
     ↪2) +
        block(channels=80, activation='relu', batch_normalisation=True, dropout=0.
     ↪3) +
        block(channels=160, activation='relu', batch_normalisation=True, dropout=0.
     ↪4, gap=True) + [
        tf.keras.layers.Dense(units=10,activation='softmax')
    ])
```

Ze względu na global average pooling, któremu ustawiłem keepdims na false, nie potrzebuję warstwy spłaszczającej, ponieważ warstwa GAP już to robi, zwłaszcza z parametrem keepdims=False. Dodatkowo ustawiłem input_shape na (None, None, 3), tak żeby sieć przyjmowała obrazy różnego rozmiaru na wejście.

[ ]:
```
model.summary()
```

```
Model: "sequential_29"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_193 (Conv2D)         (None, None, None, 20)    560

 batch_normalization_118 (Ba  (None, None, None, 20)   80
 tchNormalization)

 conv2d_194 (Conv2D)         (None, None, None, 20)    3620

 batch_normalization_119 (Ba  (None, None, None, 20)   80
 tchNormalization)

 max_pooling2d_87 (MaxPoolin  (None, None, None, 20)   0
 g2D)

 dropout_44 (Dropout)        (None, None, None, 20)    0

 conv2d_195 (Conv2D)         (None, None, None, 40)    7240

 batch_normalization_120 (Ba  (None, None, None, 40)   160
 tchNormalization)

 conv2d_196 (Conv2D)         (None, None, None, 40)    14440

 batch_normalization_121 (Ba  (None, None, None, 40)   160
 tchNormalization)

 max_pooling2d_88 (MaxPoolin  (None, None, None, 40)   0
 g2D)

 dropout_45 (Dropout)        (None, None, None, 40)    0

 conv2d_197 (Conv2D)         (None, None, None, 80)    28880

 batch_normalization_122 (Ba  (None, None, None, 80)   320
 tchNormalization)

 conv2d_198 (Conv2D)         (None, None, None, 80)    57680

 batch_normalization_123 (Ba  (None, None, None, 80)   320
 tchNormalization)

 max_pooling2d_89 (MaxPoolin  (None, None, None, 80)   0
 g2D)
```

```
 dropout_46 (Dropout)        (None, None, None, 80)    0

 conv2d_199 (Conv2D)         (None, None, None, 160)   115360

 batch_normalization_124 (Ba  (None, None, None, 160)  640
 tchNormalization)

 conv2d_200 (Conv2D)         (None, None, None, 160)   230560

 batch_normalization_125 (Ba  (None, None, None, 160)  640
 tchNormalization)

 global_average_pooling2d_9   (None, 160)              0
 (GlobalAveragePooling2D)

 dropout_47 (Dropout)        (None, 160)               0

 dense_29 (Dense)            (None, 10)                1610

=================================================================
Total params: 462,350
Trainable params: 461,150
Non-trainable params: 1,200
_________________________________________________________________
```

[ ]:
```
model.compile(
    optimizer=tf.keras.optimizers.SGD(learning_rate=0.001, momentum=0.9),
    loss=tf.keras.losses.CategoricalCrossentropy(),
    metrics=['accuracy']
)
```

[ ]:
```
start_time = time.time()
history = model.fit(
    x=train_images,
    y=train_labels,
    batch_size=64,
    epochs=150,
    verbose=1,
    validation_data=(val_images, val_labels)
)
print(f"time: {time.time()-start_time}")
```

```
Epoch 1/150

2022-10-28 01:01:37.073854: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114]
Plugin optimizer for device_type GPU is enabled.
```

```
782/782 [==============================] - ETA: 0s - loss: 1.6360 - accuracy:
0.3979

2022-10-28 01:01:53.844152: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114]
Plugin optimizer for device_type GPU is enabled.

782/782 [==============================] - 19s 23ms/step - loss: 1.6360 -
accuracy: 0.3979 - val_loss: 1.6287 - val_accuracy: 0.4209
Epoch 2/150
782/782 [==============================] - 17s 22ms/step - loss: 1.2431 -
accuracy: 0.5536 - val_loss: 1.1602 - val_accuracy: 0.5889
Epoch 3/150
782/782 [==============================] - 17s 22ms/step - loss: 1.1011 -
accuracy: 0.6058 - val_loss: 1.1346 - val_accuracy: 0.6009
Epoch 4/150
782/782 [==============================] - 17s 22ms/step - loss: 1.0060 -
accuracy: 0.6435 - val_loss: 0.9870 - val_accuracy: 0.6543
Epoch 5/150
782/782 [==============================] - 17s 22ms/step - loss: 0.9500 -
accuracy: 0.6629 - val_loss: 0.9658 - val_accuracy: 0.6568
Epoch 6/150
782/782 [==============================] - 17s 22ms/step - loss: 0.8977 -
accuracy: 0.6827 - val_loss: 0.8889 - val_accuracy: 0.6836
Epoch 7/150
782/782 [==============================] - 17s 22ms/step - loss: 0.8560 -
accuracy: 0.6965 - val_loss: 0.8075 - val_accuracy: 0.7161
Epoch 8/150
782/782 [==============================] - 17s 22ms/step - loss: 0.8168 -
accuracy: 0.7106 - val_loss: 0.8749 - val_accuracy: 0.6956
Epoch 9/150
782/782 [==============================] - 17s 21ms/step - loss: 0.7829 -
accuracy: 0.7256 - val_loss: 0.7739 - val_accuracy: 0.7298
Epoch 10/150
782/782 [==============================] - 17s 21ms/step - loss: 0.7465 -
accuracy: 0.7382 - val_loss: 0.7497 - val_accuracy: 0.7417
Epoch 11/150
782/782 [==============================] - 16s 21ms/step - loss: 0.7190 -
accuracy: 0.7479 - val_loss: 0.7074 - val_accuracy: 0.7540
Epoch 12/150
782/782 [==============================] - 17s 21ms/step - loss: 0.6890 -
accuracy: 0.7594 - val_loss: 0.6909 - val_accuracy: 0.7583
Epoch 13/150
782/782 [==============================] - 17s 22ms/step - loss: 0.6736 -
accuracy: 0.7625 - val_loss: 0.7068 - val_accuracy: 0.7590
Epoch 14/150
782/782 [==============================] - 17s 22ms/step - loss: 0.6486 -
accuracy: 0.7740 - val_loss: 0.6648 - val_accuracy: 0.7730
Epoch 15/150
```

```
782/782 [==============================] - 17s 22ms/step - loss: 0.6325 -
accuracy: 0.7786 - val_loss: 0.6496 - val_accuracy: 0.7748
Epoch 16/150
782/782 [==============================] - 17s 21ms/step - loss: 0.6167 -
accuracy: 0.7831 - val_loss: 0.6844 - val_accuracy: 0.7616
Epoch 17/150
782/782 [==============================] - 17s 21ms/step - loss: 0.5986 -
accuracy: 0.7907 - val_loss: 0.6528 - val_accuracy: 0.7745
Epoch 18/150
782/782 [==============================] - 16s 21ms/step - loss: 0.5853 -
accuracy: 0.7950 - val_loss: 0.6369 - val_accuracy: 0.7833
Epoch 19/150
782/782 [==============================] - 17s 21ms/step - loss: 0.5681 -
accuracy: 0.8018 - val_loss: 0.6644 - val_accuracy: 0.7740
Epoch 20/150
782/782 [==============================] - 17s 21ms/step - loss: 0.5523 -
accuracy: 0.8057 - val_loss: 0.6154 - val_accuracy: 0.7903
Epoch 21/150
782/782 [==============================] - 17s 21ms/step - loss: 0.5418 -
accuracy: 0.8105 - val_loss: 0.6065 - val_accuracy: 0.7931
Epoch 22/150
782/782 [==============================] - 16s 21ms/step - loss: 0.5378 -
accuracy: 0.8122 - val_loss: 0.6071 - val_accuracy: 0.7916
Epoch 23/150
782/782 [==============================] - 17s 21ms/step - loss: 0.5238 -
accuracy: 0.8171 - val_loss: 0.5964 - val_accuracy: 0.7957
Epoch 24/150
782/782 [==============================] - 17s 21ms/step - loss: 0.5111 -
accuracy: 0.8207 - val_loss: 0.5653 - val_accuracy: 0.8075
Epoch 25/150
782/782 [==============================] - 16s 21ms/step - loss: 0.4971 -
accuracy: 0.8277 - val_loss: 0.6111 - val_accuracy: 0.7894
Epoch 26/150
782/782 [==============================] - 16s 21ms/step - loss: 0.4917 -
accuracy: 0.8278 - val_loss: 0.6027 - val_accuracy: 0.7995
Epoch 27/150
782/782 [==============================] - 16s 21ms/step - loss: 0.4805 -
accuracy: 0.8302 - val_loss: 0.6175 - val_accuracy: 0.7908
Epoch 28/150
782/782 [==============================] - 17s 21ms/step - loss: 0.4712 -
accuracy: 0.8357 - val_loss: 0.5918 - val_accuracy: 0.8026
Epoch 29/150
782/782 [==============================] - 17s 21ms/step - loss: 0.4614 -
accuracy: 0.8378 - val_loss: 0.5339 - val_accuracy: 0.8182
Epoch 30/150
782/782 [==============================] - 17s 21ms/step - loss: 0.4546 -
accuracy: 0.8409 - val_loss: 0.5538 - val_accuracy: 0.8168
Epoch 31/150
```

```
782/782 [==============================] - 17s 21ms/step - loss: 0.4472 -
accuracy: 0.8439 - val_loss: 0.5470 - val_accuracy: 0.8165
Epoch 32/150
782/782 [==============================] - 17s 21ms/step - loss: 0.4373 -
accuracy: 0.8464 - val_loss: 0.5443 - val_accuracy: 0.8180
Epoch 33/150
782/782 [==============================] - 17s 21ms/step - loss: 0.4281 -
accuracy: 0.8502 - val_loss: 0.5620 - val_accuracy: 0.8153
Epoch 34/150
782/782 [==============================] - 17s 22ms/step - loss: 0.4207 -
accuracy: 0.8528 - val_loss: 0.5528 - val_accuracy: 0.8192
Epoch 35/150
782/782 [==============================] - 17s 22ms/step - loss: 0.4178 -
accuracy: 0.8519 - val_loss: 0.5850 - val_accuracy: 0.8092
Epoch 36/150
782/782 [==============================] - 16s 21ms/step - loss: 0.4095 -
accuracy: 0.8559 - val_loss: 0.5426 - val_accuracy: 0.8225
Epoch 37/150
782/782 [==============================] - 16s 21ms/step - loss: 0.4022 -
accuracy: 0.8591 - val_loss: 0.5453 - val_accuracy: 0.8206
Epoch 38/150
782/782 [==============================] - 17s 21ms/step - loss: 0.3957 -
accuracy: 0.8618 - val_loss: 0.5312 - val_accuracy: 0.8296
Epoch 39/150
782/782 [==============================] - 17s 21ms/step - loss: 0.3881 -
accuracy: 0.8653 - val_loss: 0.5315 - val_accuracy: 0.8240
Epoch 40/150
782/782 [==============================] - 17s 21ms/step - loss: 0.3801 -
accuracy: 0.8654 - val_loss: 0.5552 - val_accuracy: 0.8222
Epoch 41/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3758 -
accuracy: 0.8671 - val_loss: 0.5308 - val_accuracy: 0.8279
Epoch 42/150
782/782 [==============================] - 17s 21ms/step - loss: 0.3691 -
accuracy: 0.8699 - val_loss: 0.5285 - val_accuracy: 0.8314
Epoch 43/150
782/782 [==============================] - 17s 21ms/step - loss: 0.3617 -
accuracy: 0.8732 - val_loss: 0.5153 - val_accuracy: 0.8314
Epoch 44/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3554 -
accuracy: 0.8744 - val_loss: 0.5437 - val_accuracy: 0.8274
Epoch 45/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3583 -
accuracy: 0.8732 - val_loss: 0.5300 - val_accuracy: 0.8317
Epoch 46/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3497 -
accuracy: 0.8768 - val_loss: 0.5227 - val_accuracy: 0.8351
Epoch 47/150
```

```
782/782 [==============================] - 16s 21ms/step - loss: 0.3421 -
accuracy: 0.8798 - val_loss: 0.5574 - val_accuracy: 0.8200
Epoch 48/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3340 -
accuracy: 0.8828 - val_loss: 0.5308 - val_accuracy: 0.8339
Epoch 49/150
782/782 [==============================] - 17s 21ms/step - loss: 0.3285 -
accuracy: 0.8842 - val_loss: 0.5264 - val_accuracy: 0.8332
Epoch 50/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3266 -
accuracy: 0.8857 - val_loss: 0.5471 - val_accuracy: 0.8260
Epoch 51/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3197 -
accuracy: 0.8877 - val_loss: 0.5497 - val_accuracy: 0.8275
Epoch 52/150
782/782 [==============================] - 17s 21ms/step - loss: 0.3198 -
accuracy: 0.8889 - val_loss: 0.5288 - val_accuracy: 0.8349
Epoch 53/150
782/782 [==============================] - 17s 21ms/step - loss: 0.3128 -
accuracy: 0.8887 - val_loss: 0.5424 - val_accuracy: 0.8313
Epoch 54/150
782/782 [==============================] - 16s 21ms/step - loss: 0.3064 -
accuracy: 0.8919 - val_loss: 0.5307 - val_accuracy: 0.8343
Epoch 55/150
782/782 [==============================] - 17s 21ms/step - loss: 0.3040 -
accuracy: 0.8913 - val_loss: 0.5266 - val_accuracy: 0.8311
Epoch 56/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2965 -
accuracy: 0.8953 - val_loss: 0.5319 - val_accuracy: 0.8358
Epoch 57/150
782/782 [==============================] - 17s 21ms/step - loss: 0.2948 -
accuracy: 0.8969 - val_loss: 0.5658 - val_accuracy: 0.8247
Epoch 58/150
782/782 [==============================] - 17s 21ms/step - loss: 0.2932 -
accuracy: 0.8972 - val_loss: 0.5480 - val_accuracy: 0.8309
Epoch 59/150
782/782 [==============================] - 17s 21ms/step - loss: 0.2870 -
accuracy: 0.8990 - val_loss: 0.5303 - val_accuracy: 0.8370
Epoch 60/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2858 -
accuracy: 0.8985 - val_loss: 0.5403 - val_accuracy: 0.8353
Epoch 61/150
782/782 [==============================] - 17s 22ms/step - loss: 0.2789 -
accuracy: 0.9021 - val_loss: 0.5430 - val_accuracy: 0.8363
Epoch 62/150
782/782 [==============================] - 17s 21ms/step - loss: 0.2748 -
accuracy: 0.9037 - val_loss: 0.5333 - val_accuracy: 0.8357
Epoch 63/150
```

```
782/782 [==============================] - 17s 21ms/step - loss: 0.2664 -
accuracy: 0.9057 - val_loss: 0.5307 - val_accuracy: 0.8400
Epoch 64/150
782/782 [==============================] - 17s 21ms/step - loss: 0.2664 -
accuracy: 0.9041 - val_loss: 0.5251 - val_accuracy: 0.8377
Epoch 65/150
782/782 [==============================] - 17s 21ms/step - loss: 0.2638 -
accuracy: 0.9063 - val_loss: 0.5503 - val_accuracy: 0.8326
Epoch 66/150
782/782 [==============================] - 17s 22ms/step - loss: 0.2600 -
accuracy: 0.9086 - val_loss: 0.5404 - val_accuracy: 0.8372
Epoch 67/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2601 -
accuracy: 0.9077 - val_loss: 0.5377 - val_accuracy: 0.8375
Epoch 68/150
782/782 [==============================] - 17s 21ms/step - loss: 0.2549 -
accuracy: 0.9093 - val_loss: 0.5219 - val_accuracy: 0.8400
Epoch 69/150
782/782 [==============================] - 17s 22ms/step - loss: 0.2532 -
accuracy: 0.9094 - val_loss: 0.5393 - val_accuracy: 0.8405
Epoch 70/150
782/782 [==============================] - 17s 21ms/step - loss: 0.2489 -
accuracy: 0.9107 - val_loss: 0.5549 - val_accuracy: 0.8356
Epoch 71/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2432 -
accuracy: 0.9130 - val_loss: 0.5507 - val_accuracy: 0.8395
Epoch 72/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2429 -
accuracy: 0.9130 - val_loss: 0.5575 - val_accuracy: 0.8381
Epoch 73/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2397 -
accuracy: 0.9141 - val_loss: 0.5400 - val_accuracy: 0.8384
Epoch 74/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2316 -
accuracy: 0.9176 - val_loss: 0.5743 - val_accuracy: 0.8340
Epoch 75/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2285 -
accuracy: 0.9200 - val_loss: 0.5536 - val_accuracy: 0.8391
Epoch 76/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2266 -
accuracy: 0.9202 - val_loss: 0.5438 - val_accuracy: 0.8442
Epoch 77/150
782/782 [==============================] - 17s 21ms/step - loss: 0.2255 -
accuracy: 0.9192 - val_loss: 0.5518 - val_accuracy: 0.8391
Epoch 78/150
782/782 [==============================] - 17s 21ms/step - loss: 0.2204 -
accuracy: 0.9216 - val_loss: 0.5340 - val_accuracy: 0.8426
Epoch 79/150
```

```
782/782 [==============================] - 16s 21ms/step - loss: 0.2264 -
accuracy: 0.9188 - val_loss: 0.5561 - val_accuracy: 0.8404
Epoch 80/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2174 -
accuracy: 0.9230 - val_loss: 0.5911 - val_accuracy: 0.8333
Epoch 81/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2123 -
accuracy: 0.9248 - val_loss: 0.5444 - val_accuracy: 0.8424
Epoch 82/150
782/782 [==============================] - 17s 21ms/step - loss: 0.2118 -
accuracy: 0.9237 - val_loss: 0.5514 - val_accuracy: 0.8394
Epoch 83/150
782/782 [==============================] - 17s 21ms/step - loss: 0.2126 -
accuracy: 0.9238 - val_loss: 0.5496 - val_accuracy: 0.8457
Epoch 84/150
782/782 [==============================] - 17s 21ms/step - loss: 0.2098 -
accuracy: 0.9248 - val_loss: 0.5594 - val_accuracy: 0.8402
Epoch 85/150
782/782 [==============================] - 17s 21ms/step - loss: 0.2014 -
accuracy: 0.9283 - val_loss: 0.5717 - val_accuracy: 0.8324
Epoch 86/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2060 -
accuracy: 0.9261 - val_loss: 0.5608 - val_accuracy: 0.8439
Epoch 87/150
782/782 [==============================] - 16s 21ms/step - loss: 0.2024 -
accuracy: 0.9285 - val_loss: 0.6205 - val_accuracy: 0.8258
Epoch 88/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1998 -
accuracy: 0.9282 - val_loss: 0.5558 - val_accuracy: 0.8422
Epoch 89/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1955 -
accuracy: 0.9296 - val_loss: 0.5532 - val_accuracy: 0.8415
Epoch 90/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1963 -
accuracy: 0.9314 - val_loss: 0.5883 - val_accuracy: 0.8342
Epoch 91/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1924 -
accuracy: 0.9309 - val_loss: 0.5840 - val_accuracy: 0.8394
Epoch 92/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1913 -
accuracy: 0.9311 - val_loss: 0.5638 - val_accuracy: 0.8406
Epoch 93/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1891 -
accuracy: 0.9328 - val_loss: 0.5686 - val_accuracy: 0.8390
Epoch 94/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1850 -
accuracy: 0.9336 - val_loss: 0.5603 - val_accuracy: 0.8458
Epoch 95/150
```

```
782/782 [==============================] - 17s 21ms/step - loss: 0.1872 -
accuracy: 0.9334 - val_loss: 0.5665 - val_accuracy: 0.8382
Epoch 96/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1838 -
accuracy: 0.9342 - val_loss: 0.5941 - val_accuracy: 0.8374
Epoch 97/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1807 -
accuracy: 0.9370 - val_loss: 0.5703 - val_accuracy: 0.8369
Epoch 98/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1803 -
accuracy: 0.9357 - val_loss: 0.5803 - val_accuracy: 0.8391
Epoch 99/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1763 -
accuracy: 0.9384 - val_loss: 0.5730 - val_accuracy: 0.8400
Epoch 100/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1764 -
accuracy: 0.9362 - val_loss: 0.5759 - val_accuracy: 0.8445
Epoch 101/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1696 -
accuracy: 0.9393 - val_loss: 0.5872 - val_accuracy: 0.8429
Epoch 102/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1710 -
accuracy: 0.9397 - val_loss: 0.5714 - val_accuracy: 0.8453
Epoch 103/150
782/782 [==============================] - 17s 22ms/step - loss: 0.1696 -
accuracy: 0.9391 - val_loss: 0.5769 - val_accuracy: 0.8413
Epoch 104/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1681 -
accuracy: 0.9395 - val_loss: 0.5676 - val_accuracy: 0.8460
Epoch 105/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1701 -
accuracy: 0.9393 - val_loss: 0.5661 - val_accuracy: 0.8456
Epoch 106/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1672 -
accuracy: 0.9398 - val_loss: 0.5761 - val_accuracy: 0.8429
Epoch 107/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1641 -
accuracy: 0.9416 - val_loss: 0.5753 - val_accuracy: 0.8419
Epoch 108/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1606 -
accuracy: 0.9429 - val_loss: 0.5686 - val_accuracy: 0.8438
Epoch 109/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1638 -
accuracy: 0.9431 - val_loss: 0.5738 - val_accuracy: 0.8439
Epoch 110/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1624 -
accuracy: 0.9425 - val_loss: 0.5911 - val_accuracy: 0.8422
Epoch 111/150
```

```
782/782 [==============================] - 17s 21ms/step - loss: 0.1562 -
accuracy: 0.9442 - val_loss: 0.5879 - val_accuracy: 0.8417
Epoch 112/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1549 -
accuracy: 0.9453 - val_loss: 0.5779 - val_accuracy: 0.8461
Epoch 113/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1563 -
accuracy: 0.9439 - val_loss: 0.5853 - val_accuracy: 0.8421
Epoch 114/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1532 -
accuracy: 0.9439 - val_loss: 0.5874 - val_accuracy: 0.8445
Epoch 115/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1515 -
accuracy: 0.9465 - val_loss: 0.5855 - val_accuracy: 0.8420
Epoch 116/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1474 -
accuracy: 0.9468 - val_loss: 0.6026 - val_accuracy: 0.8430
Epoch 117/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1532 -
accuracy: 0.9459 - val_loss: 0.5878 - val_accuracy: 0.8459
Epoch 118/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1444 -
accuracy: 0.9486 - val_loss: 0.5816 - val_accuracy: 0.8453
Epoch 119/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1478 -
accuracy: 0.9466 - val_loss: 0.6020 - val_accuracy: 0.8421
Epoch 120/150
782/782 [==============================] - 17s 22ms/step - loss: 0.1460 -
accuracy: 0.9486 - val_loss: 0.6025 - val_accuracy: 0.8424
Epoch 121/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1412 -
accuracy: 0.9500 - val_loss: 0.5915 - val_accuracy: 0.8422
Epoch 122/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1428 -
accuracy: 0.9491 - val_loss: 0.5933 - val_accuracy: 0.8468
Epoch 123/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1471 -
accuracy: 0.9467 - val_loss: 0.5936 - val_accuracy: 0.8434
Epoch 124/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1404 -
accuracy: 0.9503 - val_loss: 0.6090 - val_accuracy: 0.8441
Epoch 125/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1414 -
accuracy: 0.9508 - val_loss: 0.6195 - val_accuracy: 0.8402
Epoch 126/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1371 -
accuracy: 0.9514 - val_loss: 0.6461 - val_accuracy: 0.8368
Epoch 127/150
```

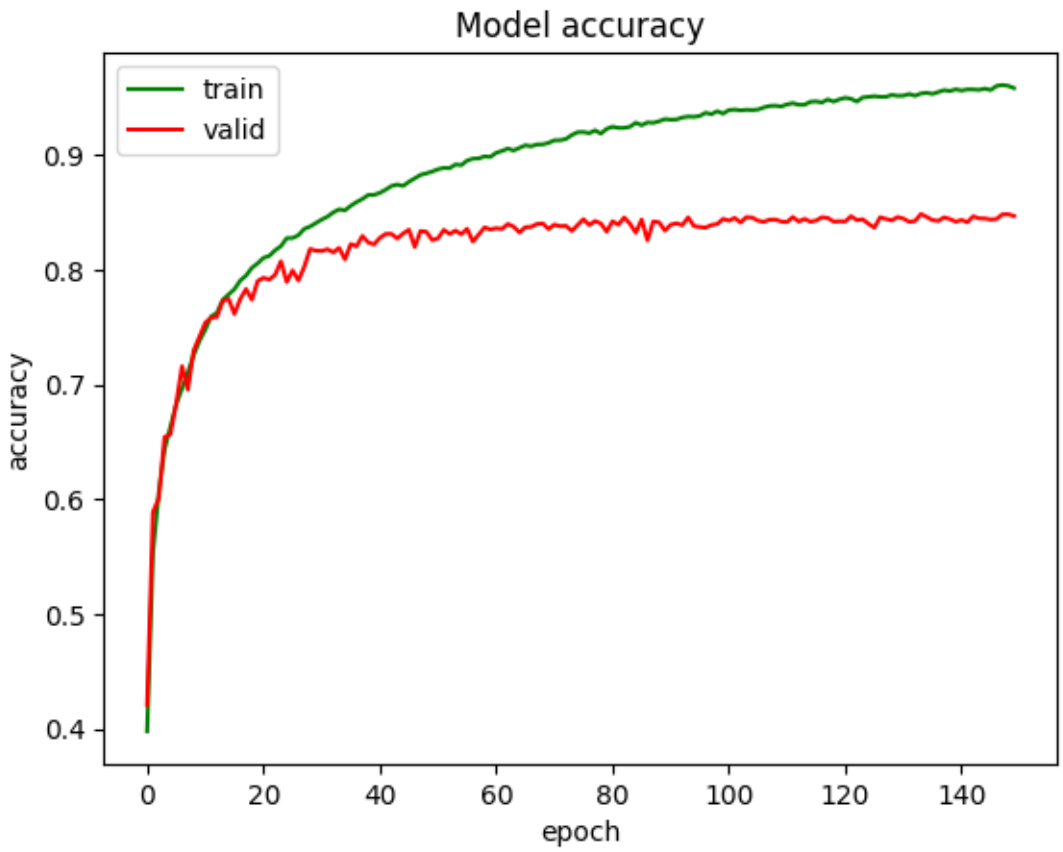
```
782/782 [==============================] - 17s 21ms/step - loss: 0.1393 -
accuracy: 0.9508 - val_loss: 0.6042 - val_accuracy: 0.8459
Epoch 128/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1385 -
accuracy: 0.9509 - val_loss: 0.6088 - val_accuracy: 0.8444
Epoch 129/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1331 -
accuracy: 0.9525 - val_loss: 0.5983 - val_accuracy: 0.8432
Epoch 130/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1356 -
accuracy: 0.9518 - val_loss: 0.6221 - val_accuracy: 0.8461
Epoch 131/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1357 -
accuracy: 0.9519 - val_loss: 0.6176 - val_accuracy: 0.8447
Epoch 132/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1314 -
accuracy: 0.9533 - val_loss: 0.6216 - val_accuracy: 0.8419
Epoch 133/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1325 -
accuracy: 0.9518 - val_loss: 0.6193 - val_accuracy: 0.8426
Epoch 134/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1302 -
accuracy: 0.9537 - val_loss: 0.6057 - val_accuracy: 0.8487
Epoch 135/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1296 -
accuracy: 0.9544 - val_loss: 0.6098 - val_accuracy: 0.8462
Epoch 136/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1322 -
accuracy: 0.9534 - val_loss: 0.6199 - val_accuracy: 0.8434
Epoch 137/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1244 -
accuracy: 0.9551 - val_loss: 0.6169 - val_accuracy: 0.8427
Epoch 138/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1239 -
accuracy: 0.9567 - val_loss: 0.6213 - val_accuracy: 0.8458
Epoch 139/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1244 -
accuracy: 0.9559 - val_loss: 0.6264 - val_accuracy: 0.8443
Epoch 140/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1220 -
accuracy: 0.9574 - val_loss: 0.6185 - val_accuracy: 0.8420
Epoch 141/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1211 -
accuracy: 0.9564 - val_loss: 0.6250 - val_accuracy: 0.8435
Epoch 142/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1231 -
accuracy: 0.9573 - val_loss: 0.6297 - val_accuracy: 0.8416
Epoch 143/150
```

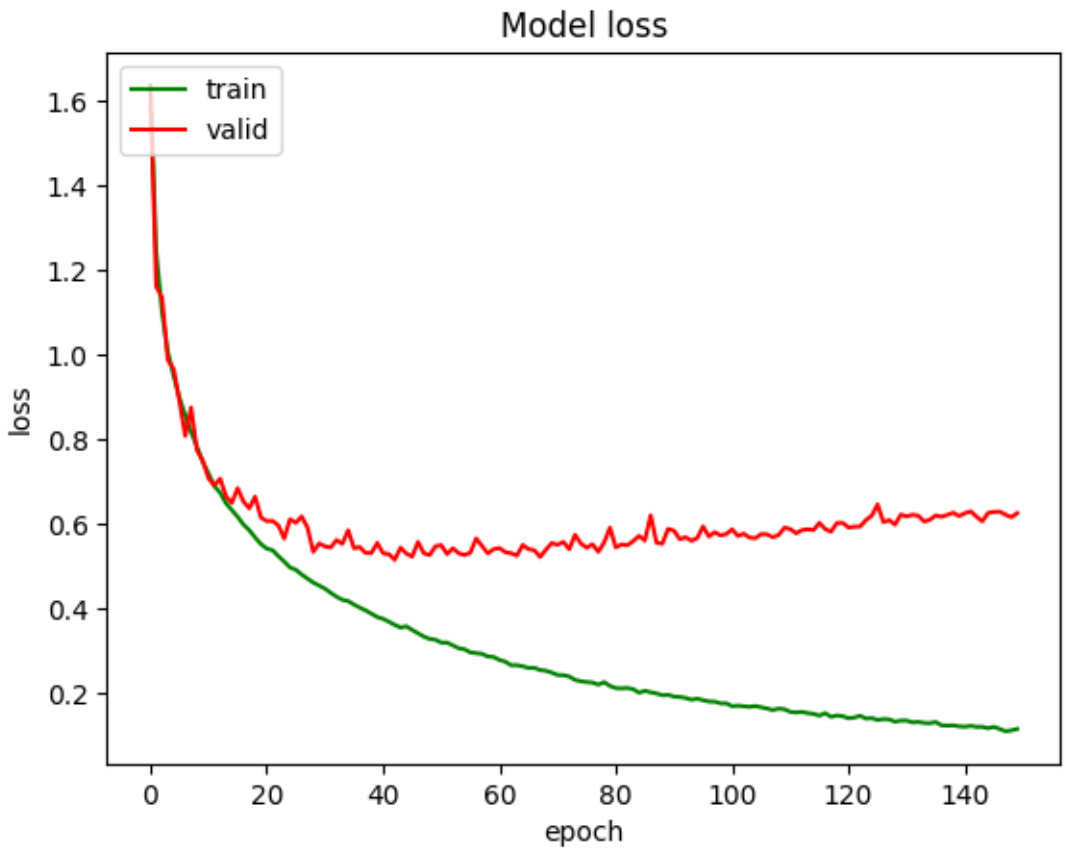
```
782/782 [==============================] - 16s 21ms/step - loss: 0.1208 -
accuracy: 0.9573 - val_loss: 0.6173 - val_accuracy: 0.8467
Epoch 144/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1209 -
accuracy: 0.9569 - val_loss: 0.6059 - val_accuracy: 0.8449
Epoch 145/150
782/782 [==============================] - 16s 21ms/step - loss: 0.1176 -
accuracy: 0.9580 - val_loss: 0.6260 - val_accuracy: 0.8448
Epoch 146/150
782/782 [==============================] - 17s 22ms/step - loss: 0.1208 -
accuracy: 0.9567 - val_loss: 0.6284 - val_accuracy: 0.8439
Epoch 147/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1157 -
accuracy: 0.9604 - val_loss: 0.6290 - val_accuracy: 0.8443
Epoch 148/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1105 -
accuracy: 0.9611 - val_loss: 0.6216 - val_accuracy: 0.8484
Epoch 149/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1126 -
accuracy: 0.9605 - val_loss: 0.6159 - val_accuracy: 0.8485
Epoch 150/150
782/782 [==============================] - 17s 21ms/step - loss: 0.1161 -
accuracy: 0.9584 - val_loss: 0.6253 - val_accuracy: 0.8470
time: 2493.4596331119537
```

Model znowu uczy się trochę dłużej, około 40 minut, ale nie aż tak dużo, biorąc pod uwagę zaawansowanie modelu.
Nie zachodzi zjawisko overfittingu, a wyniki są zadawalające.

[ ]:
```
model.save_weights('./checkpoints/CIFAR')
```

[ ]:
```
print_history(history.history)
```


Model accuracy
train
valid
accuracy
epoch
0.4
0.5
0.6
0.7
0.8
0.9
0
20
40
60
80
100
120
140



4 New Photo

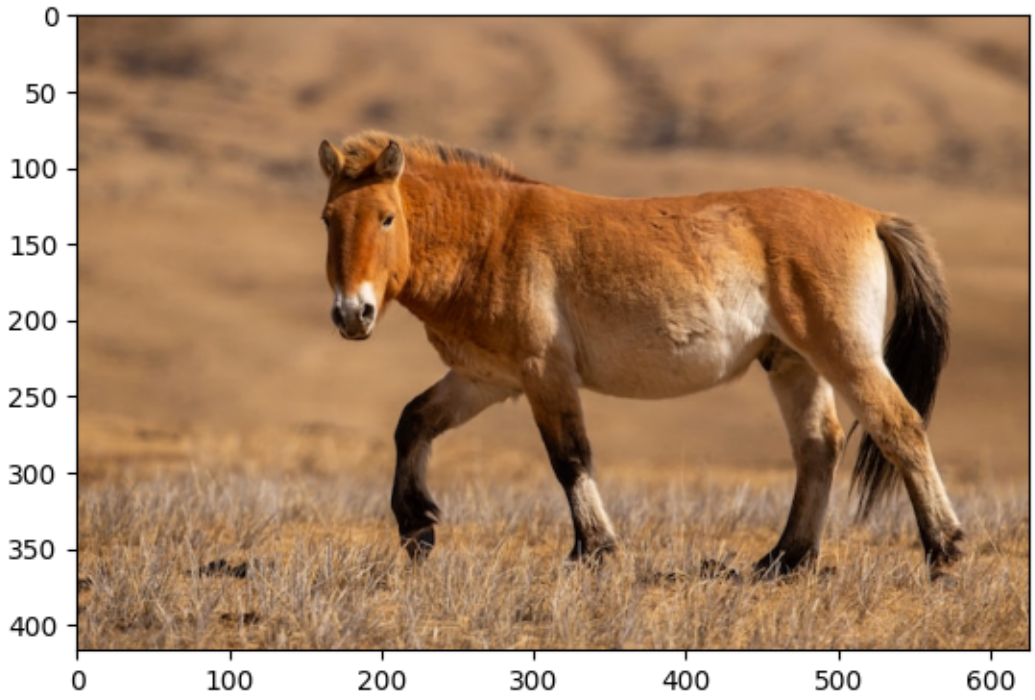
[ ]:
```
classes
```

[ ]:
```
['airplane',
 'automobile',
 'bird',
 'cat',
 'deer',
 'dog',
 'frog',
 'horse',
 'ship',
 'truck']
```

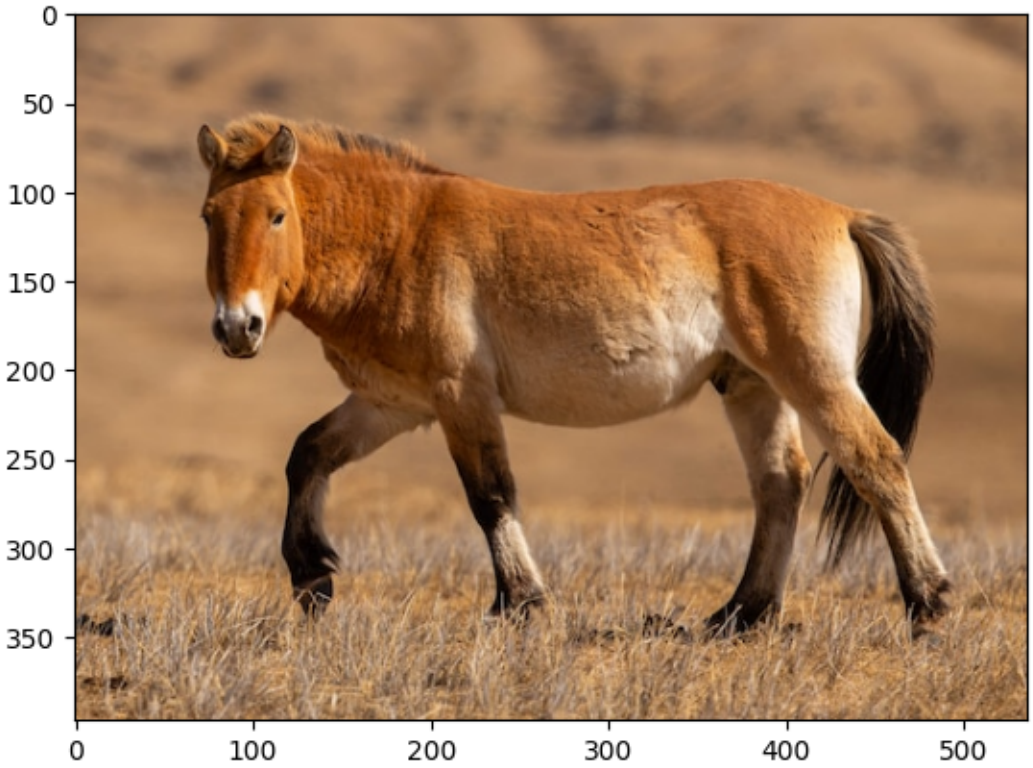
[ ]:
```
url = 'https://img.freepik.com/free-photo/
 ↪przewalskis-horse-portrait-magical-soft-light-during-winter-time-mongolia_475641-365.
 ↪jpg'
im = Image.open(requests.get(url, stream=True).raw)
```

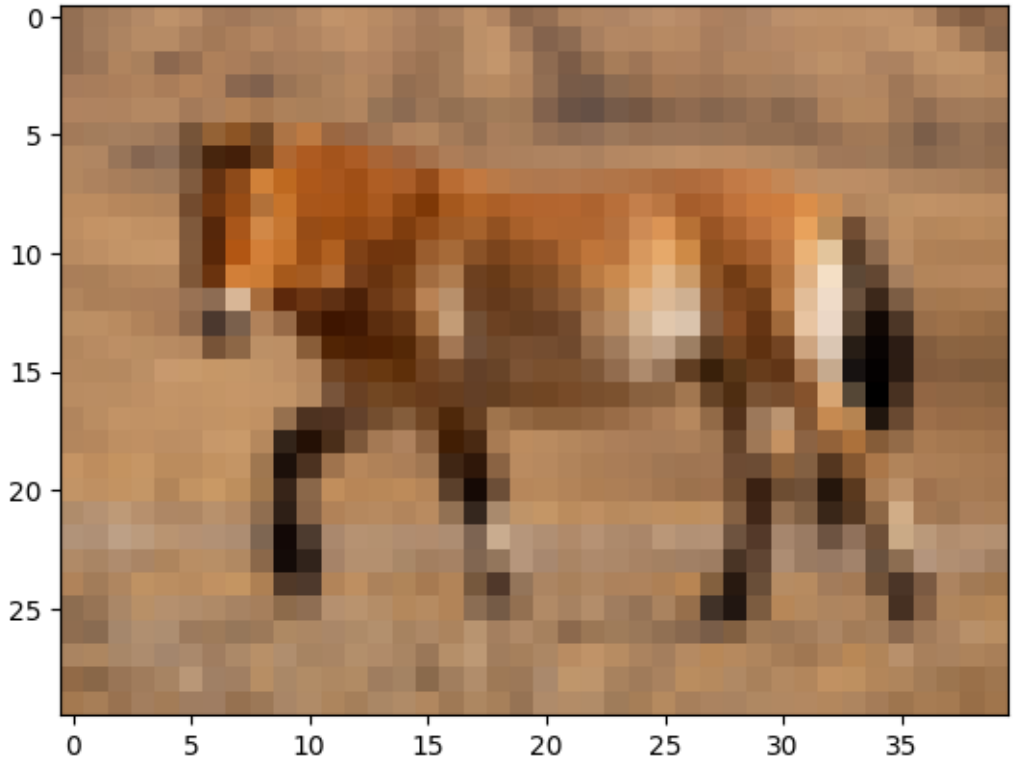
```
print(im.size)
plt.imshow(im)
plt.show()
img = im.crop((90,20,626,417))
print(img.size)
plt.imshow(img)
plt.show()
img.thumbnail((40,36))
plt.imshow(img)
plt.show()
print(img.size)
```

```
(626, 417)
```




```
(536, 397)
```


0
50
100
150
200
250
300
350
0
100
200
300
400
500


0
5
10
15
20
25
0
5
10
15
20
25
30
35

```
(40, 30)
```

Proporcja jest bardzo niesymetryczna, więc trochę ucinam zbędnych boków, ale dalej zachowując ciekawszy kształt niż kwadrat.

[ ]:
```
img = tf.expand_dims(tf.keras.utils.img_to_array(img),axis=0)
img.shape
```

[ ]:
```
TensorShape([1, 30, 40, 3])
```

[ ]:
```
pred = np.ndarray.flatten(model.predict(img))
pred
```

```
1/1 [==============================] - 0s 16ms/step
```

[ ]:
```
array([0., 0., 0., 0., 0., 0., 0., 0., 0., 1.], dtype=float32)
```

[ ]:
```
classes = tf.convert_to_tensor(classes)
classes
```

[ ]:
```
<tf.Tensor: shape=(10,), dtype=string, numpy=
array([b'airplane', b'automobile', b'bird', b'cat', b'deer', b'dog',
       b'frog', b'horse', b'ship', b'truck'], dtype=object)>
```

[ ]:
```
classes[pred==1]
```

[ ]:
```
<tf.Tensor: shape=(1,), dtype=string, numpy=array([b'truck'], dtype=object)>
```

Jak widać, niestety sieć nie poradziła sobie z niekwadratowym zdjęciem konia.

Na podstawie tego zadania, zrozumiałem jak łatwo przetrenować sieć i jak można poprawić działanie sieci.
Niestety mimo dosyć skomplikowanej architektury i sporego czasu liczenia, nie udało się uzyskać bardzo dobrego wyniku accuracy dla danych nietreningowych.