

Image classification

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16 June 2025

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Introduction

Introduction

- ▶ Animals-10

- ▶ dataset of 26179 images of animals in 10 classes

- ▶ https:

- [//www.kaggle.com/datasets/alessiocorrado99/animals10/data](https://www.kaggle.com/datasets/alessiocorrado99/animals10/data)

Aims

Build image classification models for the 10 classes in the dataset

- 1) “manually” setting up convolutional neural networks from scratch
- 2) transfer learning from pre-trained models
- 3) compare performance metrics

Data challenges

- ▶ category names encoded by folder structure
- ▶ no predetermined train-validation-test sets
- ▶ unbalanced category sizes

Animal	Count
butterfly	2112
cat	1668
chicken	3098
cow	1866
dog	4863
elephant	1446
horse	2623
sheep	1820
spider	4821
squirrel	1862

Formats

- ▶ some variation in formats
- ▶ some images with 4 channels (+ 1 with 1 channel)

Format	Channels	Count
jpeg	3	24209
jpg	1	1
	3	1917
	4	1
png	3	2
	4	49

Sizes

- ▶ lots of variation

width

- ▶ 283 distinct values
- ▶ most common:
 - ▶ 300: 19942 times
 - ▶ 640: 1765 times
 - ▶ 225: 496 times

height

- ▶ 454 distinct values
- ▶ most common:
 - ▶ 300: 4870 times
 - ▶ 225: 4401 times
 - ▶ 200: 3295 times

Summary of challenges

- ▶ normalising image formats and sizes
- ▶ applying train-validation-test-split
- ▶ translating category titles and create labeling

Methodological considerations

General project structure

- ▶ 3 distinct notebooks
 1. preprocessing
 2. convolutional neural networks
 3. transfer learning
- ▶ `auxiliary.py`: helper functions for notebooks 2 and 3
- ▶ export of (some) models to separate folder
- ▶ (later) export of training graphics to assets folder

Preprocessing notebook

Function for cataloguing

- ▶ extract and save metainformation in a table about all images in a folder
 - ▶ filepath
 - ▶ category
 - ▶ extracted from folder name, translate to English when reading the raw dataset
 - ▶ if *not* working on raw data, apply `sklearn.preprocessing.LabelEncoder` to generate column with numerical labels
 - ▶ format
 - ▶ width, height, mode, channels
 - ▶ table saved as DataFrame and exported as csv
- ▶ catalogue raw dataset for inspection
- ▶ reformat and save processed images in different folder
- ▶ catalogue normalised/cleaned dataset

Image reformatting

- ▶ use Pillow library
- ▶ apply to all images:
 - ▶ reformat to RGB (3 channels)
 - ▶ rescale to 224x224 pixel size
 - ▶ save as jpg with 90% compression

Regarding train-val-test-split

- ▶ applied to dataframes
 - ▶ filepaths later used to load images
- ▶ `train_df, intermed_df = train_test_split(clean_df, stratify=clean_df['category'], test_size=0.3, random_state=5)`
- ▶ `val_df, test_df = train_test_split(intermed_df, stratify=intermed_df['category'], test_size=1/3, random_state=5)`

Dealing with unbalanced dataset

- ▶ tested 3 versions
 - ▶ downsampling: to size of smallest category (1012)
 - ▶ upsampling: to size of largest category (3404)
 - ▶ “mid”-sampling: to mean category size (1832)
- ▶ eventually used mid-sampled training set for all remaining model training, best balance of size and doubling
- ▶ aside: tried running best performing model with upsampled dataset \Rightarrow first ever kernel crash

Relevant auxiliary function

`sample_to_n(df,n)`

- ▶ use `sklearn.utils.resample` to sample a dataframe to desired size
- ▶ only applied to training dataframe, val and test remain unmodified (and unbalanced)

Feeding data to the model

- ▶ data are fed to models as `tensorflow.Datasets`
 - ▶ shuffling and augmentation for training dataset(s), but not for validation or training
- ▶ augmentation helps ensuring upsampling does not lead to plain duplicates

Relevant auxiliary function

`mk_tf_dataset(df, shuffle=True, augment=False, preprocess_fn=None)`

- ▶ make a `tf.Dataset` from a dataframe
 - ▶ loads images based on the filepath
 - ▶ applies preprocessing, augmentation, shuffling as desired
- ▶ augmentations using `tf.image`, e.g. zooming, shifting, flipping, brightness, saturation etc.

Some more auxiliary functions

- ▶ function for model evaluation
 - ▶ print results
 - ▶ logging core data to csv
- ▶ function for training and evaluating
 - ▶ more robust reuse
 - ▶ simpler internal changes
 - ▶ but: painful to deploy midway (and changes to interface also difficult)
- ▶ plot accuracy/loss over training epochs
 - ▶ implemented rather late
 - ▶ useful for identifying where training stops yielding results

CNNs from scratch

- ▶ variation in
 - ▶ 3-5 convolutional layers
 - ▶ pool: one pooling layer at (3,3) instead of (2,2)
 - ▶ decreasing size of convolutional layers
 - ▶ increasing size of convolutional layers (inv)
 - ▶ more than one ReLU dense layer
- ▶ mostly trained with mid-sampled training set (exceptions: up)

Insights

- ▶ 4 and 5 convolutional layers performed best
- ▶ “inverted” order (i.e. increasing size of conv layers) performed best
- ▶ slightly larger dense layer led to improvement in some cases

Excerpt of results

model_id	lrate	epochs	acc_train	accuracy
conv4invto128-dense256-up	0.00050	80	0.87568	0.71963
conv5invto128-dense1	0.00050	80	0.82495	0.71390
conv4invto128-dense1	0.00050	80	0.82991	0.71085
conv4invto128-dense256	0.00050	80	0.83657	0.70283
conv5invto128-dense256-up	0.00020	80	0.86639	0.70092
conv4invto128-pool-dense256-up	0.00050	80	0.83117	0.68373
conv4lesspoll-dense1	0.00050	35	0.74039	0.66883
conv3-dense1	0.00050	35	0.70912	0.66348
conv3invert-dense1	0.00050	35	0.71676	0.65050
conv4small-dense1	0.00070	30	0.68788	0.64629
conv4lesspoll-dense1	0.00050	80	0.67980	0.64591
conv4inv8to128-dense96	0.00010	80	0.72860	0.64553
conv5small-dense1	0.00070	30	0.67757	0.64286
conv4inv128-pool-dense256	0.00010	80	0.75704	0.63904
base-upsamp-augment+	0.00070	15	0.59175	0.56684
base-meansamp-augment+	0.00070	15	0.58133	0.54240
base-downsamp-augment+	0.00070	15	0.51018	0.52597

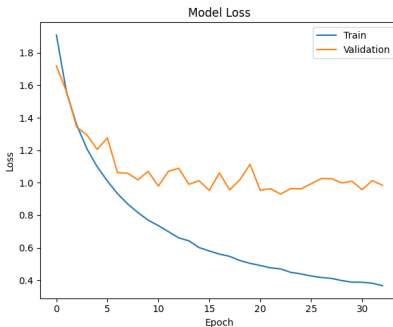
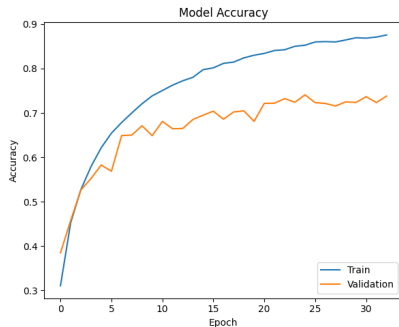
Strongest CNN

Layer Type	Output Shape	Param #
Conv2D	(None, 222, 222, 16)	448
MaxPooling2D	(None, 111, 111, 16)	0
Conv2D	(None, 109, 109, 32)	4,640
MaxPooling2D	(None, 54, 54, 32)	0
Conv2D	(None, 52, 52, 64)	18,496
MaxPooling2D	(None, 26, 26, 64)	0
Conv2D	(None, 24, 24, 128)	73,856
MaxPooling2D	(None, 12, 12, 128)	0
Flatten	(None, 18432)	0
Dense	(None, 256)	4,718,848
Dropout	(None, 256)	0
Dense	(None, 10)	2,570
Total params		14,456,580 (55.15 MB)
Trainable params		4,818,858 (18.38 MB)
Non-trainable params		0 (0.00 B)

Table 3: Model summary for ‘conv4invto128_dense256_upsamp’

- upsampled training set

Training progression for conv4invto128-dense256-upsamp



Second-best performing CNN

Layer Type	Output Shape	Param #
Conv2D	(None, 222, 222, 8)	224
MaxPooling2D	(None, 111, 111, 8)	0
Conv2D	(None, 109, 109, 16)	1,168
MaxPooling2D	(None, 54, 54, 16)	0
Conv2D	(None, 52, 52, 32)	4,640
MaxPooling2D	(None, 26, 26, 32)	0
Conv2D	(None, 24, 24, 64)	18,496
MaxPooling2D	(None, 12, 12, 64)	0
Conv2D	(None, 10, 10, 128)	73,856
MaxPooling2D	(None, 5, 5, 128)	0
Flatten	(None, 3200)	0
Dense	(None, 128)	409,728
Dropout	(None, 128)	0
Dense	(None, 10)	1,290
Total params		1,528,212 (5.83 MB)
Trainable params		509,402 (1.94 MB)
Non-trainable params		0 (0.00 B)

Table 4: Model summary for ‘conv5invto128_dense1’

Transfer learning

- ▶ all training on mid-sampled training set

Pre-trained models used

- ▶ MobileNet-V2
- ▶ ResNet-V2
- ▶ EfficientNetV2S

Insights

- ▶ adding dense layers provided no noticable benefit
- ▶ increasing dense layer neurons to 256 slightly improved results(?)
- ▶ slight benefits from fine-tuning, but diminishing returns (or different strategy)

Results overview

model_id	lr	epochs	acc_train	accuracy
effnet2S-small-finetune	0.00001	35	0.98826	0.97670
effnet2S-small	0.00050	12	0.97413	0.97479
mobnet2-dense256-finetune	0.00001	30	0.96692	0.96562
mobnet2-dense256	0.00050	13	0.95770	0.96142
mobnet2-small-tune20	0.00010	15	0.96588	0.96028
resnet2-small-finetune	0.00001	30	0.99383	0.95913
mobnet2-small-tune20	0.00010	5	0.96043	0.95760
mobnet2-small-tune20	0.00001	5	0.95360	0.95684
mobnet2-dense256	0.00050	13	0.96141	0.95607
mobnet2-2dense	0.00050	15	0.94110	0.95493
mobnet2-small	0.00070	15	0.95628	0.95302
mobnet2-3dense	0.00050	15	0.91332	0.95187
resnet2-small-finetune	0.00010	30	0.98957	0.94958
resnet2-small	0.00070	15	0.95448	0.94576

Best performing transfer learning (and overall)

Layer (type)	Output Shape	Param #
mobilenetv2_1.00_224	(None, 7, 7, 1280)	2,257,984
global_average_pooling2d	(None, 1280)	0
dense (Dense)	(None, 256)	327,936
dense_1 (Dense)	(None, 10)	2,570
Total params		3,249,508 (12.40 MB)
Trainable params		330,506 (1.26 MB)
Non-trainable params		2,257,984 (8.61 MB)

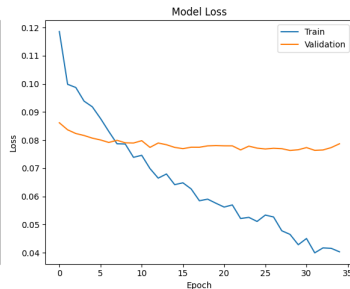
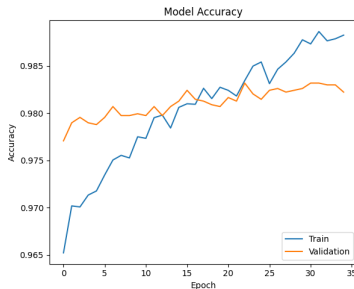
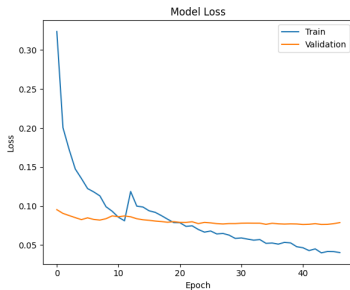
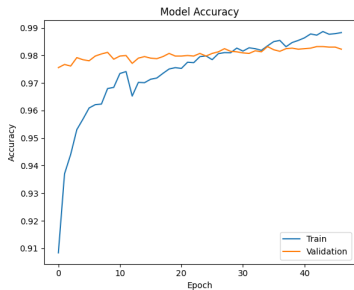
Table 5: Model summary for 'effnet2s_small'

Runner-up

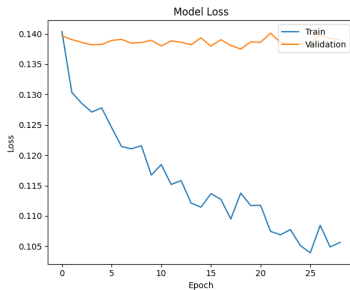
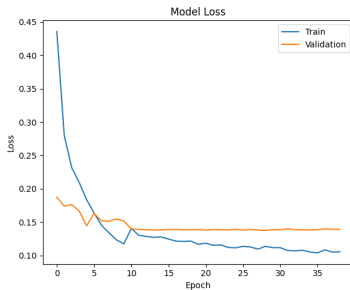
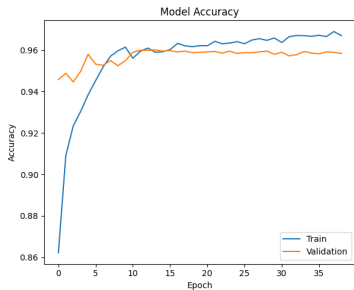
Layer Type	Output Shape	Param #
mobilenetv2_1.00_224	(None, 7, 7, 1280)	2,257,984
global_average_pooling2d	(None, 1280)	0
Dense	(None, 256)	327,936
Dense	(None, 10)	2,570
Total params		3,249,508 (12.40 MB)
Trainable params		330,506 (1.26 MB)
Non-trainable params		2,257,984 (8.61 MB)

Table 6: Model summary for ‘mobnet2_dense256’

Training plots effnet2S-small



Training plots mobnet2_dense256



Trade-offs

effnet2S-small (EfficientNetV2S)

- ▶ accuracy: 0.9767 (after finetuning)
- ▶ size: 20,661,866 parameters (78.82 MB)
- ▶ training time: ca. 6min + 14min

mobnet2-dense256 (MobileNet-V2)

- ▶ accuracy: 0.96692 (after finetuning)
- ▶ size: 3,249,508 (12.40 MB)
- ▶ training time: 2min 14s + 6min 9s

Conclusion

Manual CNNs

- ▶ 4 and 5 convolutional layers performed best
- ▶ “inverted” order (increasing size of conv layers) performed best
- ▶ slightly larger dense layer led to improvement in some cases

Transfer Learning

- ▶ adding dense layers provided no noticable benefit
- ▶ increasing dense layer neurons to 256 slightly improved results(?)
- ▶ slight benefits from fine-tuning, but diminishing returns (or different strategy)

- ▶ adding function definitions mid-project is time-consuming
 - ▶ same for modifications influencing the interfaces (changes to arguments or return values)
 - ▶ good to take decisions to outsource to functions (and separate file) early, otherwise it can be hard to get rid of dependencies/global variables etc.
- ▶ writing log to csv file is useful
 - ▶ clear plan of what exactly to log, too (see above)

Thanks for your attention!