Transfer Learning

Tutorial at SIBGRAPI 2019

Hands-On with Python and Keras

https://github.com/rribani/sibgrapi2019

Experiment 1

Flowers Dataset with a simple CNN

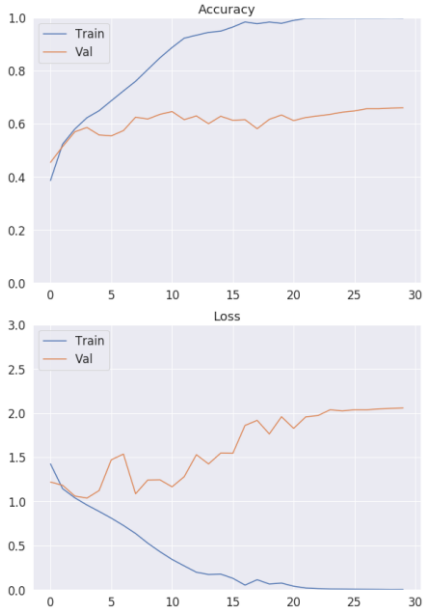
Experiment 1 - Flowers Dataset with a simple CNN

Simple Convolutional Neural Network

```
262/262 [==============================] - 14s 53ms/step - loss: 0.0102 - acc: 0.9985 - val_loss: 2.0835 - val_acc: 0.6494
Epoch 25/30
262/262 [==============================] - 14s 53ms/step - loss: 0.0071 - acc: 0.9985 - val_loss: 2.1554 - val_acc: 0.6529
Epoch 26/30
262/262 [==============================] - 14s 54ms/step - loss: 0.0057 - acc: 0.9985 - val_loss: 2.2204 - val_acc: 0.6471
Epoch 27/30
262/262 [==============================] - 14s 53ms/step - loss: 0.0055 - acc: 0.9985 - val_loss: 2.2234 - val_acc: 0.6518
Epoch 28/30
262/262 [==============================] - 14s 53ms/step - loss: 0.0037 - acc: 0.9989 - val_loss: 2.3232 - val_acc: 0.6447
Epoch 29/30
262/262 [==============================] - 14s 53ms/step - loss: 0.0041 - acc: 0.9985 - val_loss: 2.3449 - val_acc: 0.6471
Epoch 30/30
262/262 [==============================] - 14s 53ms/step - loss: 0.0038 - acc: 0.9985 - val_loss: 2.3623 - val_acc: 0.6459
Model trained.
```

```
Evaluating trained model...
Finished model.evaluate_generator
['loss', 'acc']
[2.400257244530846, 0.631764713455649]
```

Epochs	Train	Val	Test	Time
30	99.85%	64.59%	63.18%	7 min



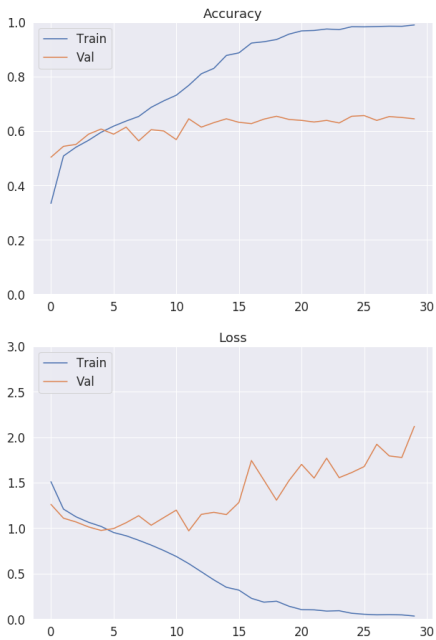
Experiment 1 - Flowers Dataset with a simple CNN

Simple CNN + Regularization

```
262/262 [==============================] - 14s 54ms/step - loss: 0.0053 - acc: 0.9985 - val_loss: 2.4158 - val_acc: 0.6388
Epoch 25/30
262/262 [==============================] - 14s 55ms/step - loss: 0.0049 - acc: 0.9985 - val_loss: 2.4076 - val_acc: 0.6435
Epoch 26/30
262/262 [==============================] - 14s 53ms/step - loss: 0.0042 - acc: 0.9985 - val_loss: 2.4459 - val_acc: 0.6424
Epoch 27/30
262/262 [==============================] - 14s 54ms/step - loss: 0.0040 - acc: 0.9985 - val_loss: 2.4307 - val_acc: 0.6388
Epoch 28/30
262/262 [==============================] - 14s 53ms/step - loss: 0.0036 - acc: 0.9985 - val_loss: 2.4398 - val_acc: 0.6376
Epoch 29/30
262/262 [==============================] - 14s 54ms/step - loss: 0.0034 - acc: 0.9985 - val_loss: 2.4630 - val_acc: 0.6376
Epoch 30/30
262/262 [==============================] - 14s 54ms/step - loss: 0.0033 - acc: 0.9985 - val_loss: 2.4666 - val_acc: 0.6376
Model trained.
```

```
Evaluating trained model...
Finished model.evaluate_generator
['loss', 'acc']
[2.3546724952319087, 0.6470588305417229]
```

Epochs	Train	Val	Test	Time
30	99.85%	63.76%	64.70%	7 min

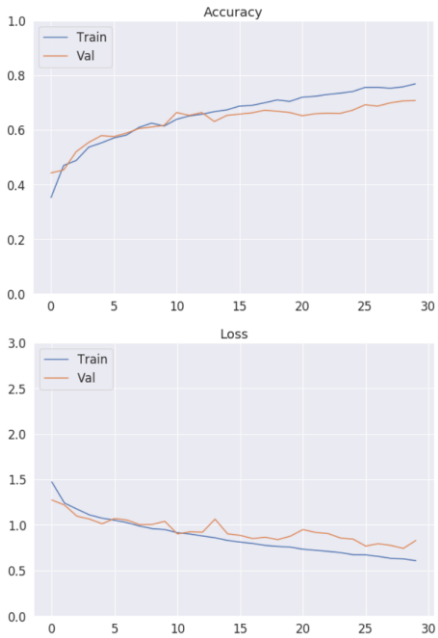


Experiment 1 - Flowers Dataset with a simple CNN

Simple CNN + Regularization + Augmentation

```
262/262 [==============================] - 58s 223ms/step - loss: 0.6952 - acc: 0.7342 - val_loss: 0.8563 - val_acc: 0.6600
Epoch 25/30
262/262 [==============================] - 60s 229ms/step - loss: 0.6723 - acc: 0.7408 - val_loss: 0.8442 - val_acc: 0.6718
Epoch 26/30
262/262 [==============================] - 60s 229ms/step - loss: 0.6711 - acc: 0.7552 - val_loss: 0.7680 - val_acc: 0.6918
Epoch 27/30
262/262 [==============================] - 59s 227ms/step - loss: 0.6541 - acc: 0.7556 - val_loss: 0.7942 - val_acc: 0.6871
Epoch 28/30
262/262 [==============================] - 60s 228ms/step - loss: 0.6320 - acc: 0.7531 - val_loss: 0.7755 - val_acc: 0.6988
Epoch 29/30
262/262 [==============================] - 60s 229ms/step - loss: 0.6273 - acc: 0.7571 - val_loss: 0.7424 - val_acc: 0.7059
Epoch 30/30
262/262 [==============================] - 58s 222ms/step - loss: 0.6090 - acc: 0.7682 - val_loss: 0.8297 - val_acc: 0.7071
Model trained.
Model saved.
```

```
Evaluating trained model...
Finished model.evaluate_generator
['loss', 'acc']
[0.8578244763262132, 0.7035294140086454]
```



Epochs	Train	Val	Test	Time
30	76.82%	70.71%	70.35%	30 min

Experiment 1

Flowers Dataset with a simple CNN

Description	Epochs	Train	Val	Test	Time
Simple CNN	30	99.85%	64.59%	63.18%	7 min
Simple CNN + Regularization	30	99.85%	63.76%	64.70%	7 min
Simple CNN + Regularization + Augmentation	30	76.82%	70.71%	**70.35%**	30 min

Experiment 2

Flowers Dataset with a VGG16 trained from zero

Experiment 2 - Flowers Dataset with a VGG16

Base VGG16 + FC layers

```
262/262 [==============================] - 107s 408ms/step - loss: 0.3249 - acc: 0.8985 - val_loss: 2.1897 - val_acc: 0.5047
Epoch 25/30
262/262 [==============================] - 107s 408ms/step - loss: 0.2632 - acc: 0.9294 - val_loss: 2.2419 - val_acc: 0.5106
Epoch 26/30
262/262 [==============================] - 107s 408ms/step - loss: 0.2623 - acc: 0.9195 - val_loss: 2.4815 - val_acc: 0.4800
Epoch 27/30
262/262 [==============================] - 107s 407ms/step - loss: 0.2347 - acc: 0.9286 - val_loss: 2.4669 - val_acc: 0.5094
Epoch 28/30
262/262 [==============================] - 107s 407ms/step - loss: 0.1989 - acc: 0.9439 - val_loss: 2.4612 - val_acc: 0.5259
Epoch 29/30
262/262 [==============================] - 107s 407ms/step - loss: 0.1658 - acc: 0.9515 - val_loss: 2.9775 - val_acc: 0.4882
Epoch 30/30
262/262 [==============================] - 107s 407ms/step - loss: 0.1798 - acc: 0.9546 - val_loss: 2.6393 - val_acc: 0.5424
Model trained.
Model saved.
```

```
Evaluating trained model...
Finished model.evaluate_generator
['loss', 'acc']
[2.837037226382424, 0.5200000053819488]
```

Epochs	Train	Val	Test	Time
30	95.46%	54.24%	52.00%	53min

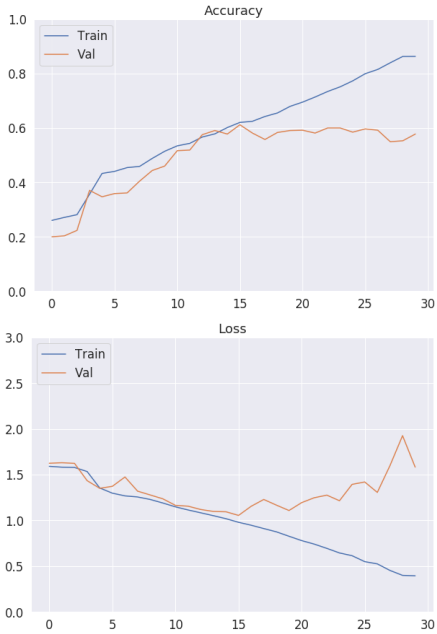
Experiment 2 - Flowers Dataset with a VGG16

Base VGG16 + FC layers + Regularization

```
262/262 [==============================] - 106s 406ms/step - loss: 0.6434 - acc: 0.7519 - val_loss: 1.2150 - val_acc: 0.6000
Epoch 25/30
262/262 [==============================] - 106s 405ms/step - loss: 0.6130 - acc: 0.7737 - val_loss: 1.3936 - val_acc: 0.5847
Epoch 26/30
262/262 [==============================] - 106s 406ms/step - loss: 0.5484 - acc: 0.8000 - val_loss: 1.4199 - val_acc: 0.5965
Epoch 27/30
262/262 [==============================] - 106s 406ms/step - loss: 0.5238 - acc: 0.8156 - val_loss: 1.3061 - val_acc: 0.5918
Epoch 28/30
262/262 [==============================] - 106s 405ms/step - loss: 0.4547 - acc: 0.8392 - val_loss: 1.5978 - val_acc: 0.5494
Epoch 29/30
262/262 [==============================] - 106s 406ms/step - loss: 0.3989 - acc: 0.8634 - val_loss: 1.9258 - val_acc: 0.5529
Epoch 30/30
262/262 [==============================] - 106s 405ms/step - loss: 0.3940 - acc: 0.8637 - val_loss: 1.5822 - val_acc: 0.5776
Model trained.
Model saved.
```

```
Evaluating trained model...
Finished model.evaluate_generator
['loss', 'acc']
[1.669417932804893, 0.5552941253080087]
```

Epochs	Train	Val	Test	Time
30	86.37%	57.76%	55.52%	53min



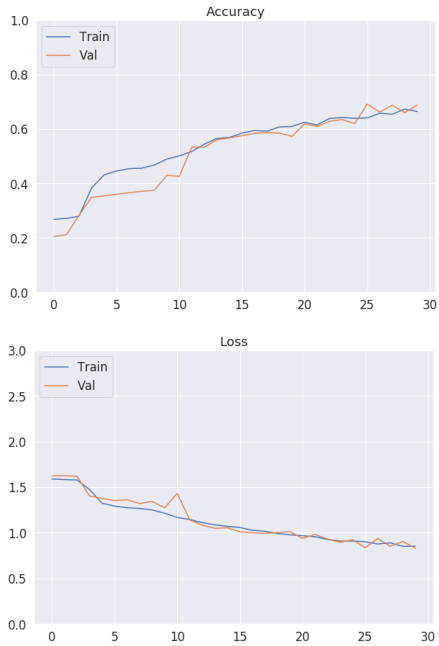
Experiment 2 - Flowers Dataset with a VGG16

Base VGG16 + FC layers + Regularization + Augmentation

```
262/262 [==============================] - 110s 418ms/step - loss: 0.9090 - acc: 0.6422 - val_loss: 0.8959 - val_acc: 0.6341
Epoch 25/30
262/262 [==============================] - 110s 418ms/step - loss: 0.9097 - acc: 0.6392 - val_loss: 0.9236 - val_acc: 0.6200
Epoch 26/30
262/262 [==============================] - 109s 415ms/step - loss: 0.9018 - acc: 0.6407 - val_loss: 0.8359 - val_acc: 0.6918
Epoch 27/30
262/262 [==============================] - 109s 417ms/step - loss: 0.8769 - acc: 0.6575 - val_loss: 0.9380 - val_acc: 0.6624
Epoch 28/30
262/262 [==============================] - 108s 414ms/step - loss: 0.8894 - acc: 0.6545 - val_loss: 0.8511 - val_acc: 0.6871
Epoch 29/30
262/262 [==============================] - 109s 414ms/step - loss: 0.8513 - acc: 0.6732 - val_loss: 0.9048 - val_acc: 0.6600
Epoch 30/30
262/262 [==============================] - 109s 417ms/step - loss: 0.8536 - acc: 0.6631 - val_loss: 0.8318 - val_acc: 0.6882
Model trained.
Model saved.
```

```
Evaluating trained model...
Finished model.evaluate_generator
['loss', 'acc']
[0.8119822400457719, 0.6658823563772089]
```

Epochs	Train	Val	Test	Time
30	66.31%	68.82%	66.58%	54min



Experiment 2

Flowers Dataset with a VGG16 trained from zero

Description	Epochs	Train	Val	Test	Time
Base VGG16 + FC layers	30	95.46%	54.24%	52.00%	53min
Base VGG16 + FC layers + Regularization	30	86.37%	57.76%	55.52%	53min
Base VGG16 + FC layers + Regularization + Augmentation	30	66.31%	68.82%	**66.58%**	54min

Comparison

Simple CNN vs VGG16 trained from scratch

Flowers Dataset

Description	Epochs	Train	Val	Test	Time
Simple CNN	30	99.85%	64.59%	63.18%	7 min
Simple CNN + Regularization	30	99.85%	63.76%	64.70%	7 min
Simple CNN + Regularization + Augmentation	30	76.82%	70.71%	**70.35%**	30 min

Description	Epochs	Train	Val	Test	Time
Base VGG16 + FC layers	30	95.46%	54.24%	52.00%	53min
Base VGG16 + FC layers + Regularization	30	86.37%	57.76%	55.52%	53min
Base VGG16 + FC layers + Regularization + Augmentation	30	66.31%	68.82%	**66.58%**	54min

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Description	Epochs	Train	Val	Test	Time
Simple CNN + Regularization + Augmentation	90	93.59%	73.65%	**74.58%**	1h30min
Base VGG16 + FC layers + Regularization + Augmentation	90	85.04%	72.24%	**75.41%**	1h50min

Experiment 3

Flowers Dataset with a VGG16 as feature extractor

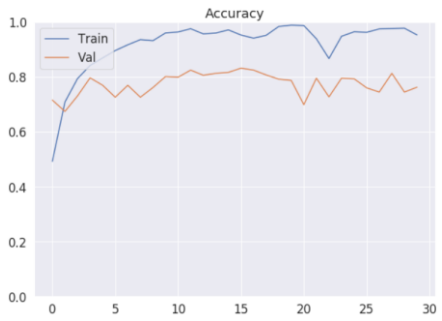
Experiment 3 - Flowers Dataset with a VGG16 as feature extractor

Base VGG16 + FC layers

```
262/262 [==============================] - 30s 113ms/step - loss: 0.1791 - acc: 0.9481 - val_loss: 0.6642 - val_acc: 0.7953
Epoch 25/30
262/262 [==============================] - 30s 113ms/step - loss: 0.1380 - acc: 0.9645 - val_loss: 0.6512 - val_acc: 0.7929
Epoch 26/30
262/262 [==============================] - 30s 113ms/step - loss: 0.1592 - acc: 0.9626 - val_loss: 0.6637 - val_acc: 0.7600
Epoch 27/30
262/262 [==============================] - 30s 113ms/step - loss: 0.0948 - acc: 0.9748 - val_loss: 1.0037 - val_acc: 0.7447
Epoch 28/30
262/262 [==============================] - 30s 113ms/step - loss: 0.1243 - acc: 0.9763 - val_loss: 0.6398 - val_acc: 0.8129
Epoch 29/30
262/262 [==============================] - 30s 113ms/step - loss: 0.1107 - acc: 0.9775 - val_loss: 0.6953 - val_acc: 0.7447
Epoch 30/30
262/262 [==============================] - 30s 113ms/step - loss: 0.1576 - acc: 0.9531 - val_loss: 0.7819 - val_acc: 0.7624
Model trained.
```

```
Evaluating trained model...
Finished model.evaluate_generator
['loss', 'acc']
[0.778138186760685, 0.7552941168055815]
```

Epochs	Train	Val	Test	Time
30	95.31%	76.24%	75.52%	15 min



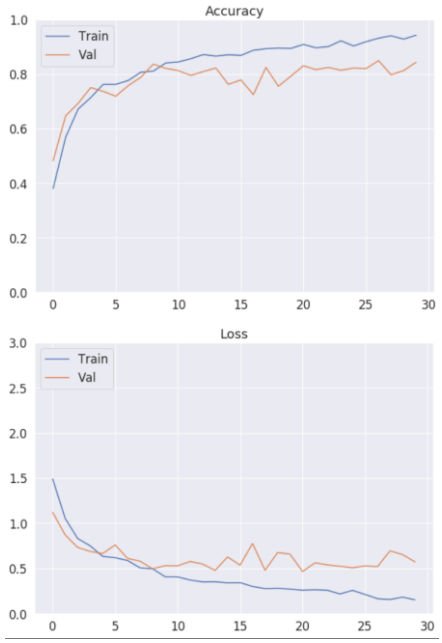
Experiment 3 - Flowers Dataset with a VGG16 as feature extractor

Base VGG16 + FC layers + Regularization

```
262/262 [==============================] - 30s 114ms/step - loss: 0.2189 - acc: 0.9216 - val_loss: 0.5256 - val_acc: 0.8141
Epoch 25/30
262/262 [==============================] - 30s 114ms/step - loss: 0.2575 - acc: 0.9034 - val_loss: 0.5075 - val_acc: 0.8224
Epoch 26/30
262/262 [==============================] - 30s 114ms/step - loss: 0.2139 - acc: 0.9182 - val_loss: 0.5289 - val_acc: 0.8200
Epoch 27/30
262/262 [==============================] - 30s 114ms/step - loss: 0.1658 - acc: 0.9321 - val_loss: 0.5209 - val_acc: 0.8494
Epoch 28/30
262/262 [==============================] - 30s 114ms/step - loss: 0.1566 - acc: 0.9408 - val_loss: 0.6951 - val_acc: 0.7976
Epoch 29/30
262/262 [==============================] - 30s 114ms/step - loss: 0.1839 - acc: 0.9286 - val_loss: 0.6543 - val_acc: 0.8129
Epoch 30/30
262/262 [==============================] - 30s 114ms/step - loss: 0.1535 - acc: 0.9427 - val_loss: 0.5738 - val_acc: 0.8435
Model trained.
```

```
Evaluating trained model...
Finished model.evaluate_generator
['loss', 'acc']
[0.6733438312678652, 0.8152941149823806]
```

Epochs	Train	Val	Test	Time
30	94.27%	84.35%	81.52%	15min



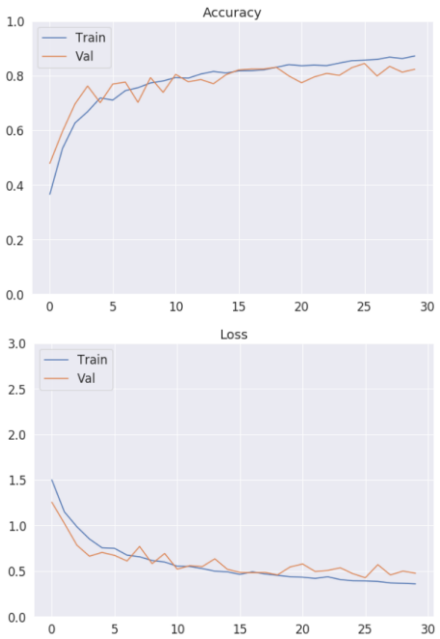
Experiment 3 - Flowers Dataset with a VGG16 as feature extractor

Base VGG16 + FC layers + Regularization + Augmentation

```
262/262 [==============================] - 62s 235ms/step - loss: 0.4069 - acc: 0.8457 - val_loss: 0.5360 - val_acc: 0.8012
Epoch 25/30
262/262 [==============================] - 61s 235ms/step - loss: 0.3949 - acc: 0.8536 - val_loss: 0.4714 - val_acc: 0.8294
Epoch 26/30
262/262 [==============================] - 61s 235ms/step - loss: 0.3917 - acc: 0.8564 - val_loss: 0.4265 - val_acc: 0.8447
Epoch 27/30
262/262 [==============================] - 61s 235ms/step - loss: 0.3855 - acc: 0.8599 - val_loss: 0.5701 - val_acc: 0.7988
Epoch 28/30
262/262 [==============================] - 61s 234ms/step - loss: 0.3703 - acc: 0.8665 - val_loss: 0.4569 - val_acc: 0.8341
Epoch 29/30
262/262 [==============================] - 61s 234ms/step - loss: 0.3661 - acc: 0.8621 - val_loss: 0.4995 - val_acc: 0.8129
Epoch 30/30
262/262 [==============================] - 61s 234ms/step - loss: 0.3599 - acc: 0.8725 - val_loss: 0.4763 - val_acc: 0.8235
Model trained.
```

```
Evaluating trained model...
Finished model.evaluate_generator
['loss', 'acc']
[0.517448072069708, 0.8235294075573192]
```

Epochs	Train	Val	Test	Time
30	87.25%	82.35%	82.35%	30min



Experiment 3

Flowers Dataset with a VGG16 as feature extractor
(pre-trained on ImageNet)

Description	Epochs	Train	Val	Test	Time
VGG16 ImageNet Features + FC layers	30	95.31%	76.24%	75.52%	15 min
VGG16 ImageNet Features + FC layers + Regularization	30	94.27%	84.35%	81.52%	15min
VGG16 ImageNet Features + FC layers + Regularization + Augmentation	30	87.25%	82.35%	**82.35%**	30min

Comparison

Best without transfer learning vs VGG16 as feature extractor

Flowers Dataset

Description	Epochs	Train	Val	Test	Time
Simple CNN + Regularization + Augmentation	90	93.59%	73.65%	**74.58%**	1h30min
Base VGG16 + FC layers + Regularization + Augmentation	90	85.04%	72.24%	**75.41%**	1h50min

Description	Epochs	Train	Val	Test	Time
VGG16 ImageNet Features + FC layers	30	95.31%	76.24%	75.52%	15 min
VGG16 ImageNet Features + FC layers + Regularization	30	94.27%	84.35%	81.52%	15min
VGG16 ImageNet Features + FC layers + Regularization + Augmentation	30	87.25%	82.35%	**82.35%**	30min

Experiment 4

Flowers Dataset

Fine-tuning VGG16 layers

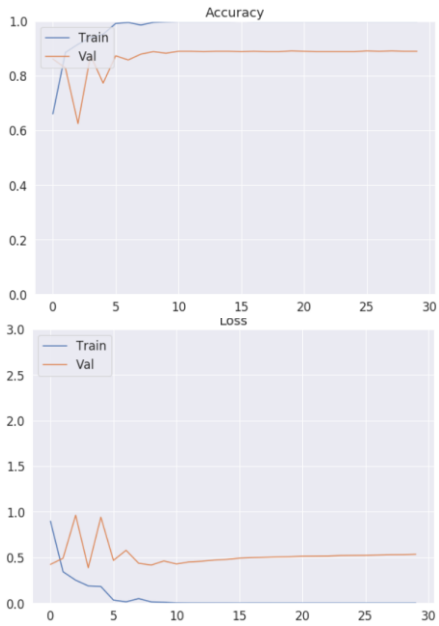
Experiment 4 - Flowers Dataset and fine-tuning

Fine-tuning VGG16 convolutional layers + FC layers

```
262/262 [==============================] - 42s 159ms/step - loss: 0.0016 - acc: 0.9985 - val_loss: 0.5280 - val_acc: 0.8941
Epoch 25/30
262/262 [==============================] - 42s 159ms/step - loss: 0.0015 - acc: 0.9985 - val_loss: 0.5298 - val_acc: 0.8965
Epoch 26/30
262/262 [==============================] - 42s 159ms/step - loss: 0.0015 - acc: 0.9985 - val_loss: 0.5327 - val_acc: 0.8953
Epoch 27/30
262/262 [==============================] - 42s 159ms/step - loss: 0.0015 - acc: 0.9985 - val_loss: 0.5331 - val_acc: 0.8976
Epoch 28/30
262/262 [==============================] - 42s 159ms/step - loss: 0.0015 - acc: 0.9985 - val_loss: 0.5355 - val_acc: 0.8965
Epoch 29/30
262/262 [==============================] - 42s 159ms/step - loss: 0.0015 - acc: 0.9985 - val_loss: 0.5374 - val_acc: 0.8953
Epoch 30/30
262/262 [==============================] - 42s 159ms/step - loss: 0.0015 - acc: 0.9985 - val_loss: 0.5372 - val_acc: 0.8953
Model trained.
```

```
Evaluating trained model...
Finished mobilenet.evaluate_generator
['loss', 'acc']
[0.5654662317217277, 0.8882352850016426]
```

Epochs	Train	Val	Test	Time
30	99.85%	89.53%	88.82%	21min



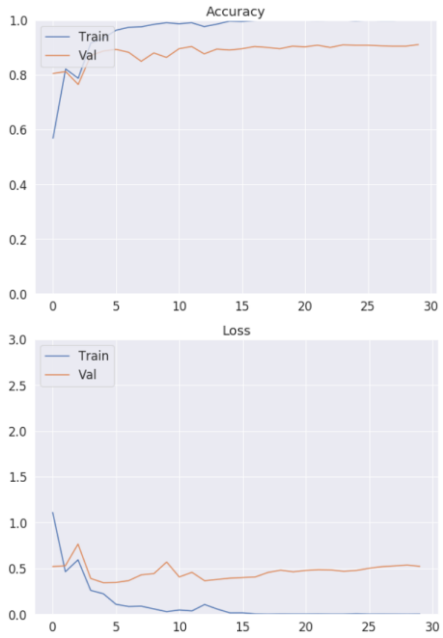
Experiment 4 - Flowers Dataset and fine-tuning

Fine-tuning VGG16 convolutional layers + FC layers + Regularization

```
262/262 [==============================] - 42s 159ms/step - loss: 0.0020 - acc: 0.9996 - val_loss: 0.4683 - val_acc: 0.9094
Epoch 25/30
262/262 [==============================] - 42s 159ms/step - loss: 0.0052 - acc: 0.9977 - val_loss: 0.4780 - val_acc: 0.9082
Epoch 26/30
262/262 [==============================] - 42s 159ms/step - loss: 0.0019 - acc: 0.9992 - val_loss: 0.5016 - val_acc: 0.9082
Epoch 27/30
262/262 [==============================] - 42s 159ms/step - loss: 0.0021 - acc: 0.9985 - val_loss: 0.5186 - val_acc: 0.9059
Epoch 28/30
262/262 [==============================] - 42s 159ms/step - loss: 0.0017 - acc: 0.9985 - val_loss: 0.5274 - val_acc: 0.9047
Epoch 29/30
262/262 [==============================] - 42s 159ms/step - loss: 0.0011 - acc: 0.9996 - val_loss: 0.5364 - val_acc: 0.9047
Epoch 30/30
262/262 [==============================] - 42s 159ms/step - loss: 0.0020 - acc: 0.9989 - val_loss: 0.5225 - val_acc: 0.9106
Model trained.
```

```
Evaluating trained model...
Finished mobilenet.evaluate_generator
['loss', 'acc']
[0.6183229378541161, 0.8988235228201922]
```

Epochs	Train	Val	Test	Time
30	99.89%	91.06%	89.88%	21min



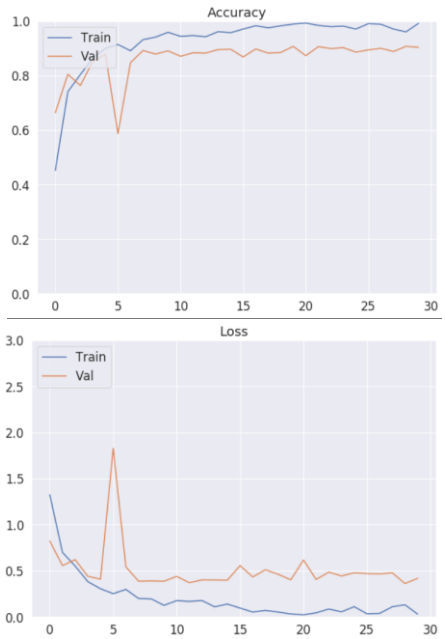
Experiment 4 - Flowers Dataset and fine-tuning

Fine-tuning VGG16 convolutional layers + FC layers + Regularization + Augmentation

```
Epoch 25/30
262/262 [==============================] - 63s 240ms/step - loss: 0.1108 - acc: 0.9706 - val_loss: 0.4784 - val_acc: 0.8859
Epoch 26/30
262/262 [==============================] - 63s 240ms/step - loss: 0.0346 - acc: 0.9905 - val_loss: 0.4700 - val_acc: 0.8941
Epoch 27/30
262/262 [==============================] - 63s 241ms/step - loss: 0.0379 - acc: 0.9882 - val_loss: 0.4652 - val_acc: 0.9000
Epoch 28/30
262/262 [==============================] - 63s 240ms/step - loss: 0.1105 - acc: 0.9706 - val_loss: 0.4788 - val_acc: 0.8882
Epoch 29/30
262/262 [==============================] - 63s 240ms/step - loss: 0.1315 - acc: 0.9603 - val_loss: 0.3619 - val_acc: 0.9071
Epoch 30/30
262/262 [==============================] - 63s 241ms/step - loss: 0.0304 - acc: 0.9916 - val_loss: 0.4188 - val_acc: 0.9035
Model trained.
```

```
Evaluating trained model...
Finished mobilenet.evaluate_generator
['loss', 'acc']
[0.4179920466008779, 0.907058816797593]
```

Epochs	Train	Val	Test	Time
30	99.16%	90.35%	90.71%	31min



Experiment 4

Flowers Dataset and fine-tuning VGG16 layers
(pre-trained on ImageNet)

Description	Epochs	Train	Val	Test	Time
Fine-tuning VGG16 + FC layers	30	99.85%	89.53%	88.82%	21min
Fine-tuning VGG16 + FC layers + Regularization	30	99.89%	91.06%	89.88%	21min
Fine-tuning VGG16 + FC layers + Regularization + Augmentation	30	99.16%	90.35%	**90.71%**	31min

Comparison

No transfer learning vs VGG16 as feature extractor vs Fine-tuning

Flowers Dataset

Description	Epochs	Train	Val	Test	Time
Simple CNN + Regularization + Augmentation	90	93.59%	73.65%	**74.58%**	1h30min
Base VGG16 + FC layers + Regularization + Augmentation	90	85.04%	72.24%	**75.41%**	1h50min

Description	Epochs	Train	Val	Test	Time
VGG16 ImageNet Features + FC layers	30	95.31%	76.24%	75.52%	15 min
VGG16 ImageNet Features + FC layers + Regularization	30	94.27%	84.35%	81.52%	15min
VGG16 ImageNet Features + FC layers + Regularization + Augmentation	30	87.25%	82.35%	**82.35%**	30min

Description	Epochs	Train	Val	Test	Time
Fine-tuning VGG16 + FC layers	30	99.85%	89.53%	88.82%	21min
Fine-tuning VGG16 + FC layers + Regularization	30	99.89%	91.06%	89.88%	21min
Fine-tuning VGG16 + FC layers + Regularization + Augmentation	30	99.16%	90.35%	**90.71%**	31min

Experiment 5

Chest X-Ray Dataset with a VGG16 trained from zero

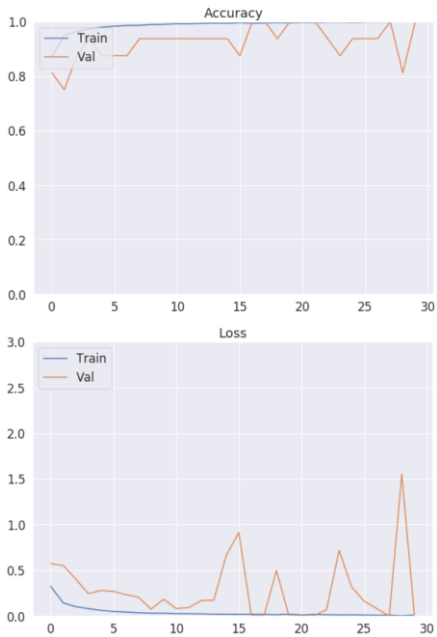
Experiment 5 - Chest X-Ray Dataset with a VGG16 trained from zero

Base VGG16 + FC layers

```
522/522 [==============================] - 122s 234ms/step - loss: 0.0151 - acc: 0.9973 - val_loss: 0.0053 - val_acc: 1.0000
Epoch 25/30
522/522 [==============================] - 122s 234ms/step - loss: 0.0161 - acc: 0.9967 - val_loss: 6.5812e-05 - val_acc: 1.0000
Epoch 26/30
522/522 [==============================] - 122s 234ms/step - loss: 0.0101 - acc: 0.9977 - val_loss: 0.0252 - val_acc: 1.0000
Epoch 27/30
522/522 [==============================] - 122s 234ms/step - loss: 0.0141 - acc: 0.9975 - val_loss: 0.0766 - val_acc: 0.9375
Epoch 28/30
522/522 [==============================] - 122s 234ms/step - loss: 0.0085 - acc: 0.9983 - val_loss: 0.4211 - val_acc: 0.9375
Epoch 29/30
522/522 [==============================] - 122s 234ms/step - loss: 0.0085 - acc: 0.9985 - val_loss: 0.0285 - val_acc: 1.0000
Epoch 30/30
522/522 [==============================] - 122s 234ms/step - loss: 0.0104 - acc: 0.9981 - val_loss: 0.2132 - val_acc: 0.9375
Model trained.
```

```
Evaluating trained model...
Finished model.evaluate_generator
['loss', 'acc']
[3.7262536037352776, 0.7419354814675546]
```

Epochs	Train	Val	Test	Time
30	99.81%	93.75%	74.19%	1h



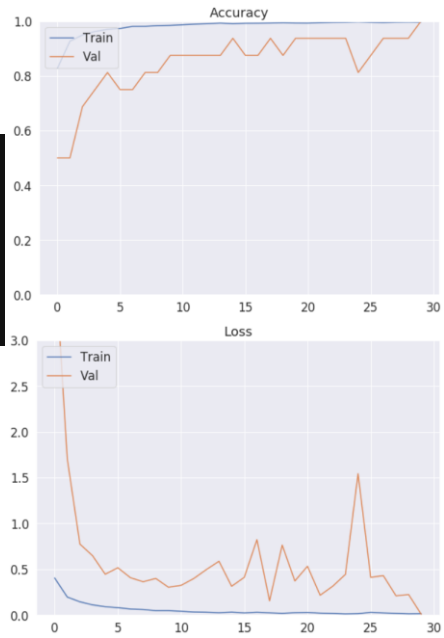
Experiment 5 - Chest X-Ray Dataset with a VGG16 trained from zero

Base VGG16 + FC layers + Regularization

```
Epoch 25/30
522/522 [==============================] - 123s 235ms/step - loss: 0.0153 - acc: 0.9975 - val_loss: 1.5435 - val_acc: 0.8125
Epoch 26/30
522/522 [==============================] - 123s 235ms/step - loss: 0.0295 - acc: 0.9960 - val_loss: 0.4121 - val_acc: 0.8750
Epoch 27/30
522/522 [==============================] - 123s 236ms/step - loss: 0.0231 - acc: 0.9952 - val_loss: 0.4305 - val_acc: 0.9375
Epoch 28/30
522/522 [==============================] - 123s 235ms/step - loss: 0.0184 - acc: 0.9964 - val_loss: 0.2103 - val_acc: 0.9375
Epoch 29/30
522/522 [==============================] - 123s 235ms/step - loss: 0.0136 - acc: 0.9969 - val_loss: 0.2238 - val_acc: 0.9375
Epoch 30/30
522/522 [==============================] - 123s 235ms/step - loss: 0.0149 - acc: 0.9964 - val_loss: 0.0076 - val_acc: 1.0000
Model trained.
```

```
Evaluating trained model...
Finished model.evaluate_generator
['loss', 'acc']
[3.350984032067562, 0.7564516105959492]
```

Epochs	Train	Val	Test	Time
30	99.64%	1.00%	75.64%	1h



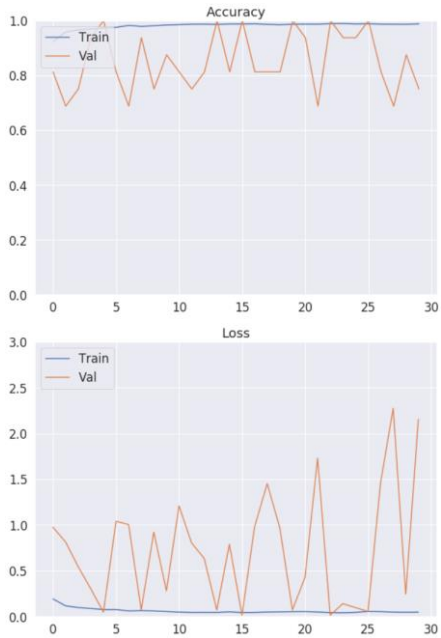
Experiment 5 - Chest X-Ray Dataset with a VGG16 trained from zero

Base VGG16 + FC layers + Regularization + Augmentation

```
Epoch 25/30
522/522 [==============================] - 158s 303ms/step - loss: 0.0454 - acc: 0.9874 - val_loss: 0.0979 - val_acc: 0.9375
Epoch 26/30
522/522 [==============================] - 160s 306ms/step - loss: 0.0550 - acc: 0.9881 - val_loss: 0.0558 - val_acc: 1.0000
Epoch 27/30
522/522 [==============================] - 156s 298ms/step - loss: 0.0536 - acc: 0.9868 - val_loss: 1.4588 - val_acc: 0.8125
Epoch 28/30
522/522 [==============================] - 158s 302ms/step - loss: 0.0479 - acc: 0.9866 - val_loss: 2.2739 - val_acc: 0.6875
Epoch 29/30
522/522 [==============================] - 156s 300ms/step - loss: 0.0464 - acc: 0.9864 - val_loss: 0.2443 - val_acc: 0.8750
Epoch 30/30
522/522 [==============================] - 159s 305ms/step - loss: 0.0478 - acc: 0.9877 - val_loss: 2.1545 - val_acc: 0.7500
Model trained.
```

```
Evaluating trained model...
Finished mobilenet.evaluate_generator
['loss', 'acc']
[1.157482362570208, 0.8790322522963246]
```

Epochs	Train	Val	Test	Time
30	98.77%	75.00%	87.90%	1h20min



Experiment 5

Chest X-Ray Dataset with a VGG16 trained from zero

Description	Epochs	Train	Val	Test	Time
Base VGG16 + FC layers	30	99.81%	93.75%	74.19%	1h
Base VGG16 + FC layers + Regularization	30	99.64%	1.00%	75.64%	1h
Base VGG16 + FC layers + Regularization + Augmentation	30	98.77%	75.00%	**87.90%**	1h20min

Experiment 6

Chest X-Ray Dataset with a VGG16 as feature extractor

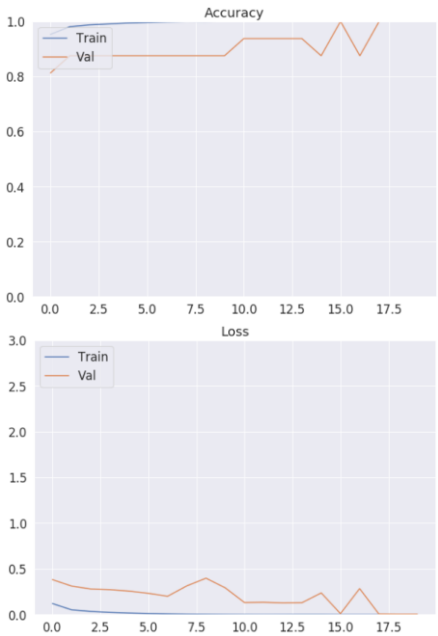
Experiment 6 - Chest X-Ray Dataset with a VGG16 as feature extractor

VGG16 ImageNet Features + FC layers

```
522/522 [==============================] - 105s 201ms/step - loss: 0.0014 - acc: 0.9998 - val_loss: 0.1297 - val_acc: 0.9375
Epoch 15/20
522/522 [==============================] - 105s 201ms/step - loss: 0.0014 - acc: 0.9998 - val_loss: 0.2364 - val_acc: 0.8750
Epoch 16/20
522/522 [==============================] - 105s 202ms/step - loss: 4.2857e-04 - acc: 0.9998 - val_loss: 0.0102 - val_acc: 1.0000
Epoch 17/20
522/522 [==============================] - 104s 200ms/step - loss: 5.9853e-04 - acc: 0.9998 - val_loss: 0.2837 - val_acc: 0.8750
Epoch 18/20
522/522 [==============================] - 104s 200ms/step - loss: 5.8310e-04 - acc: 0.9998 - val_loss: 0.0062 - val_acc: 1.0000
Epoch 19/20
522/522 [==============================] - 105s 202ms/step - loss: 1.3484e-04 - acc: 1.0000 - val_loss: 0.0047 - val_acc: 1.0000
Epoch 20/20
522/522 [==============================] - 106s 203ms/step - loss: 5.0902e-04 - acc: 0.9998 - val_loss: 0.0047 - val_acc: 1.0000
Model trained.
```

```
Evaluating trained model...
Finished mobilenet.evaluate_generator
['loss', 'acc']
[2.7395112536276782, 0.7661290303353341]
```

Epochs	Train	Val	Test	Time
20	99.98%	1.00%	76.61%	35min



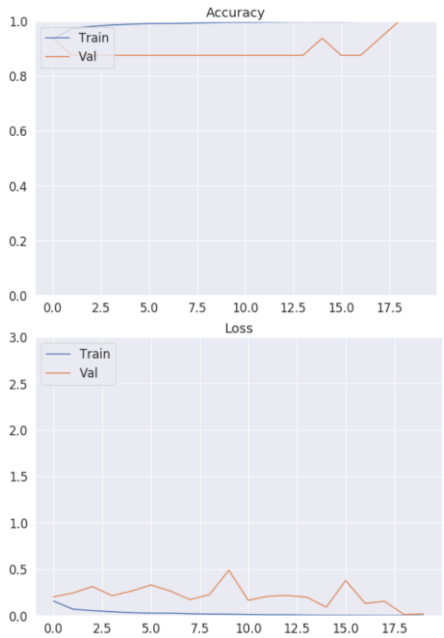
Experiment 6 - Chest X-Ray Dataset with a VGG16 as feature extractor

VGG16 ImageNet Features + FC layers + Regularization

```
522/522 [==============================] - 106s 202ms/step - loss: 0.0057 - acc: 0.9981 - val_loss: 0.1984 - val_acc: 0.8750
Epoch 15/20
522/522 [==============================] - 105s 201ms/step - loss: 0.0046 - acc: 0.9979 - val_loss: 0.0911 - val_acc: 0.9375
Epoch 16/20
522/522 [==============================] - 106s 203ms/step - loss: 0.0038 - acc: 0.9979 - val_loss: 0.3775 - val_acc: 0.8750
Epoch 17/20
522/522 [==============================] - 104s 200ms/step - loss: 0.0031 - acc: 0.9989 - val_loss: 0.1315 - val_acc: 0.8750
Epoch 18/20
522/522 [==============================] - 105s 200ms/step - loss: 0.0021 - acc: 0.9992 - val_loss: 0.1540 - val_acc: 0.9375
Epoch 19/20
522/522 [==============================] - 106s 204ms/step - loss: 0.0034 - acc: 0.9990 - val_loss: 0.0116 - val_acc: 1.0000
Epoch 20/20
522/522 [==============================] - 106s 202ms/step - loss: 0.0017 - acc: 0.9990 - val_loss: 0.0182 - val_acc: 1.0000
Model trained.
```

```
Evaluating trained model...
Finished mobilenet.evaluate_generator
['loss', 'acc']
[2.237655122524067, 0.7822580640354464]
```

Epochs	Train	Val	Test	Time
20	99.90%	1.00%	78.22%	35min

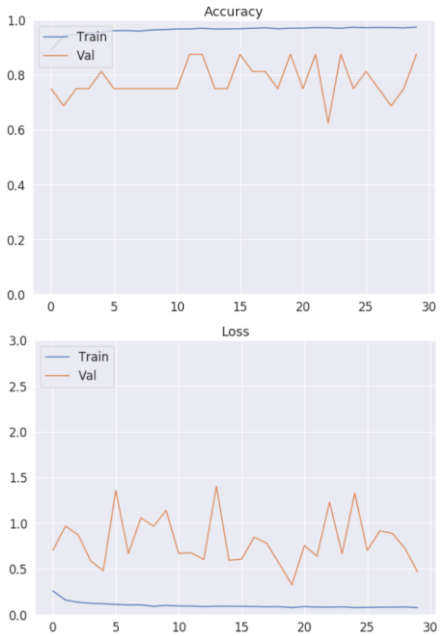


Experiment 6 - Chest X-Ray Dataset with a VGG16 as feature extractor

VGG16 ImageNet Features + FC layers + Regularization + Augmentation

```
522/522 [==============================] - 171s 328ms/step - loss: 0.0838 - acc: 0.9703 - val_loss: 0.6647 - val_acc: 0.8750
Epoch 25/30
522/522 [==============================] - 176s 338ms/step - loss: 0.0763 - acc: 0.9741 - val_loss: 1.3294 - val_acc: 0.7500
Epoch 26/30
522/522 [==============================] - 173s 332ms/step - loss: 0.0782 - acc: 0.9720 - val_loss: 0.7004 - val_acc: 0.8125
Epoch 27/30
522/522 [==============================] - 172s 329ms/step - loss: 0.0797 - acc: 0.9734 - val_loss: 0.9156 - val_acc: 0.7500
Epoch 28/30
522/522 [==============================] - 176s 338ms/step - loss: 0.0807 - acc: 0.9726 - val_loss: 0.8870 - val_acc: 0.6875
Epoch 29/30
522/522 [==============================] - 174s 333ms/step - loss: 0.0827 - acc: 0.9716 - val_loss: 0.7225 - val_acc: 0.7500
Epoch 30/30
522/522 [==============================] - 173s 331ms/step - loss: 0.0764 - acc: 0.9745 - val_loss: 0.4655 - val_acc: 0.8750
Model trained.
```

```
Evaluating trained model...
Finished mobilenet.evaluate_generator
['loss', 'acc']
[0.28273410563293333, 0.9290322497967751]
```



Epochs	Train	Val	Test	Time
30	97.45%	87.50%	92.90%	1h26min

Experiment 6

Chest X-Ray Dataset with a VGG16 as feature extractor (pre-trained on ImageNet)

Description	Epochs	Train	Val	Test	Time
VGG16 ImageNet Features + FC layers	20	99.98%	1.00%	76.61%	35min
VGG16 ImageNet Features + FC layers + Regularization	20	99.90%	1.00%	78.22%	35min
VGG16 ImageNet Features + FC layers + Regularization + Augmentation	30	97.45%	87.50%	**92.90%**	1h26min

Comparison

Without transfer learning vs VGG16 as feature extractor

Chest X-Ray Dataset

Description	Epochs	Train	Val	Test	Time
Base VGG16 + FC layers	30	99.83%	1.00%	79.35%	1h
Base VGG16 + FC layers + Regularization	30	99.73%	1.00%	74.99%	1h
Base VGG16 + FC layers + Regularization + Augmentation	30	98.77%	75.00%	87.90%	1h20min

Description	Epochs	Train	Val	Test	Time
VGG16 ImageNet Features + FC layers	20	99.98%	1.00%	**76.61%**	35min
VGG16 ImageNet Features + FC layers + Regularization	20	99.90%	1.00%	78.22%	35min
VGG16 ImageNet Features + FC layers + Regularization + Augmentation	30	97.45%	87.50%	**92.90%**	1h26min

Experiment 7

Chest X-Ray Dataset

Fine-tuning VGG16 layers

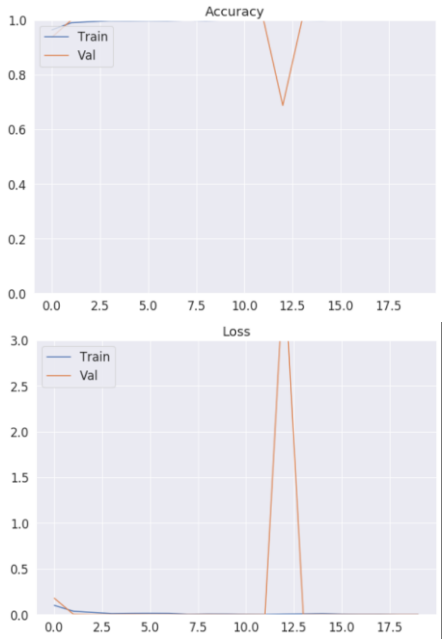
Experiment 7 – Chest X-Ray Dataset and fine-tuning

Fine-tuning VGG16 convolutional layers + FC layers

```
522/522 [==============================] - 103s 197ms/step - loss: 0.0068 - acc: 0.9989 - val_loss: 1.0960e-07 - val_acc: 1.0000
Epoch 15/20
522/522 [==============================] - 104s 200ms/step - loss: 0.0099 - acc: 0.9985 - val_loss: 1.0960e-07 - val_acc: 1.0000
Epoch 16/20
522/522 [==============================] - 105s 202ms/step - loss: 0.0049 - acc: 0.9994 - val_loss: 1.0960e-07 - val_acc: 1.0000
Epoch 17/20
522/522 [==============================] - 106s 203ms/step - loss: 0.0032 - acc: 0.9994 - val_loss: 1.0960e-07 - val_acc: 1.0000
Epoch 18/20
522/522 [==============================] - 103s 198ms/step - loss: 0.0035 - acc: 0.9996 - val_loss: 1.0960e-07 - val_acc: 1.0000
Epoch 19/20
522/522 [==============================] - 105s 200ms/step - loss: 1.1448e-07 - acc: 1.0000 - val_loss: 1.0960e-07 - val_acc: 1.0000
Epoch 20/20
522/522 [==============================] - 105s 200ms/step - loss: 1.1432e-07 - acc: 1.0000 - val_loss: 1.0960e-07 - val_acc: 1.0000
Model trained.
```

```
Evaluating trained model...
Finished mobilenet.evaluate_generator
['loss', 'acc']
[3.2722972354850643, 0.7774193483975625]
```

Epochs	Train	Val	Test	Time
20	1.00%	1.00%	77.74%	35min



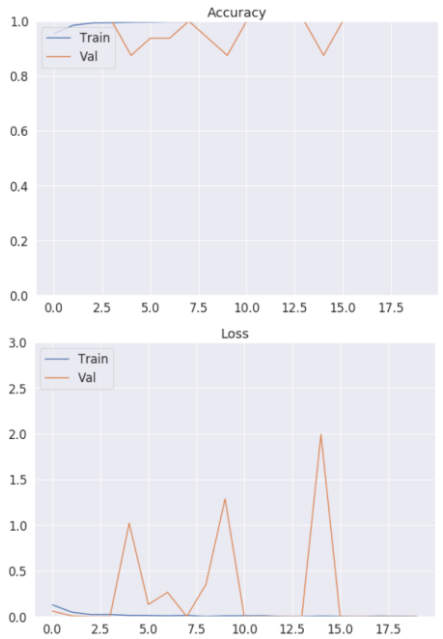
Experiment 7 – Chest X-Ray Dataset and fine-tuning

Fine-tuning VGG16 convolutional layers + FC layers + Regularization

```
522/522 [==============================] - 107s 205ms/step - loss: 6.6935e-04 - acc: 0.9998 - val_loss: 1.0960e-07 - val_acc: 1.0000
Epoch 15/20
522/522 [==============================] - 104s 200ms/step - loss: 0.0058 - acc: 0.9990 - val_loss: 1.9931 - val_acc: 0.8750
Epoch 16/20
522/522 [==============================] - 105s 202ms/step - loss: 0.0035 - acc: 0.9994 - val_loss: 1.0960e-07 - val_acc: 1.0000
Epoch 17/20
522/522 [==============================] - 106s 203ms/step - loss: 1.6439e-04 - acc: 0.9998 - val_loss: 3.0848e-05 - val_acc: 1.0000
Epoch 18/20
522/522 [==============================] - 107s 204ms/step - loss: 0.0057 - acc: 0.9992 - val_loss: 1.0960e-07 - val_acc: 1.0000
Epoch 19/20
522/522 [==============================] - 106s 203ms/step - loss: 0.0039 - acc: 0.9992 - val_loss: 1.0960e-07 - val_acc: 1.0000
Epoch 20/20
522/522 [==============================] - 106s 202ms/step - loss: 0.0017 - acc: 0.9994 - val_loss: 1.0960e-07 - val_acc: 1.0000
Model trained.
```

```
Evaluating trained model...
Finished model.evaluate_generator
['loss', 'acc']
[3.1561673658665805, 0.7903225767997003]
```

Epochs	Train	Val	Test	Time
20	99.97%	1.00%	79.03%	35min



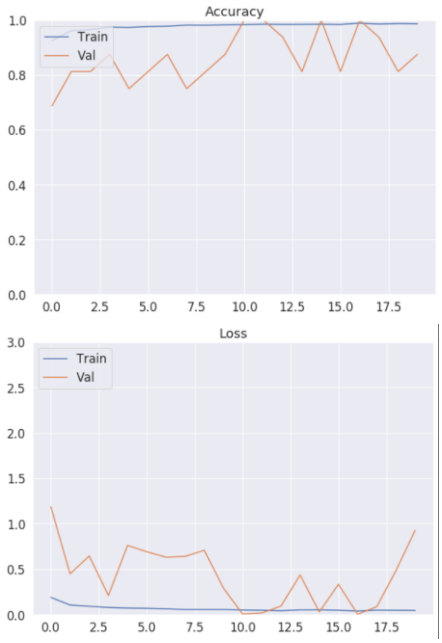
Experiment 7 – Chest X-Ray Dataset and fine-tuning

Fine-tuning VGG16 convolutional layers + FC layers + Regularization + Augmentation

```
522/522 [==============================] - 170s 326ms/step - loss: 0.0533 - acc: 0.9847 - val_loss: 0.4373 - val_acc: 0.8125
Epoch 15/20
522/522 [==============================] - 173s 331ms/step - loss: 0.0539 - acc: 0.9851 - val_loss: 0.0305 - val_acc: 1.0000
Epoch 16/20
522/522 [==============================] - 173s 332ms/step - loss: 0.0493 - acc: 0.9843 - val_loss: 0.3341 - val_acc: 0.8125
Epoch 17/20
522/522 [==============================] - 171s 327ms/step - loss: 0.0406 - acc: 0.9891 - val_loss: 0.0046 - val_acc: 1.0000
Epoch 18/20
522/522 [==============================] - 167s 319ms/step - loss: 0.0505 - acc: 0.9858 - val_loss: 0.0883 - val_acc: 0.9375
Epoch 19/20
522/522 [==============================] - 176s 337ms/step - loss: 0.0487 - acc: 0.9875 - val_loss: 0.4852 - val_acc: 0.8125
Epoch 20/20
522/522 [==============================] - 169s 324ms/step - loss: 0.0468 - acc: 0.9870 - val_loss: 0.9285 - val_acc: 0.8750
Model trained.
```

```
Evaluating trained model...
Finished model.evaluate_generator
['loss', 'acc']
[0.5643994614560979, 0.9274193471477877]
```

Epochs	Train	Val	Test	Time
20	98.70%	87.50%	92.74%	57min



Experiment 7

Chest X-Ray Dataset and fine-tuning VGG16 layers (pre-trained on ImageNet)

Description	Epochs	Train	Val	Test	Time
Fine-tuning VGG16 + FC layers	20	1.00%	1.00%	77.74%	35min
Fine-tuning VGG16 + FC layers + Regularization	20	99.97%	1.00%	79.03%	35min
Fine-tuning VGG16 + FC layers + Regularization + Augmentation	20	98.70%	87.50%	**92.74%**	57min

Comparison

VGG16 as feature extractor vs Fine-tuning

Chest X-Ray Dataset

Description	Epochs	Train	Val	Test	Time
Base VGG16 + FC layers	30	99.83%	1.00%	79.35%	1h
Base VGG16 + FC layers + Regularization	30	99.73%	1.00%	74.99%	1h
Base VGG16 + FC layers + Regularization + Augmentation	30	98.77%	75.00%	**87.90%**	1h20min

Description	Epochs	Train	Val	Test	Time
VGG16 ImageNet Features + FC layers	20	99.98%	1.00%	**76.61%**	35min
VGG16 ImageNet Features + FC layers + Regularization	20	99.90%	1.00%	78.22%	35min
VGG16 ImageNet Features + FC layers + Regularization + Augmentation	30	97.45%	87.50%	**92.90%**	1h26min

Description	Epochs	Train	Val	Test	Time
Fine-tuning VGG16 + FC layers	20	1.00%	1.00%	**77.74%**	35min
Fine-tuning VGG16 + FC layers + Regularization	20	99.97%	1.00%	79.03%	35min
Fine-tuning VGG16 + FC layers + Regularization + Augmentation	20	98.70%	87.50%	**92.74%**	57min

Experiment 8

MobileNet transfer learning from Dogs vs Cats Dataset to Chest X-Ray

Experiment 8

MobileNet transfer learning from Dogs vs Cats to Chest X-Ray

Description	Dataset	Epochs	Train	Val	Test	Time
MobileNet **trained from scratch** + GlobalAveragePooling + Conv2D 1x1 + Regularization + Augmentation	Dogs vs Cats	60	92.29%	90.78%	91.97%	5h32min
MobileNet trained from scratch + GlobalAveragePooling + Conv2D 1x1 + Regularization + Augmentation	Chest X-Ray	40	99.98%	81.25%	**76.94%**	1h
MobileNet **pre-trained on Dogs vs Cats** + GlobalAveragePooling + Conv2D 1x1 + Regularization + Augmentation	Chest X-Ray	40	80.38%	50.00%	**62.58%**	52min

Source Code

https://github.com/rribani/sibgrapi2019

Thank you!

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Sponsorship: