Anomaly Detection in Machine State Using Machine Learning Algorithm (A Deep Learning Approach)

Thesis Presentation, 13-02-2018

Master of Engineering in Information Technology

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Presentation Outline

- **Problem description**
  - Rovema Gmbh Packaging
- **Proposed method**
  - Motivation
  - Background Information
- **Model architecture**
- **Data collection and Results analysis**
- **Future Work**

Rovema Gmbh

- Leading packaging machines manufacturer
- More than 29,000 packaging machines delivered
- 30 countries

Packaging machines

Auger dosing scratching problem

Manual technique

- Experienced worker
- Specialized headphones
- Occasional checks

Ploblems with manual technique ☹

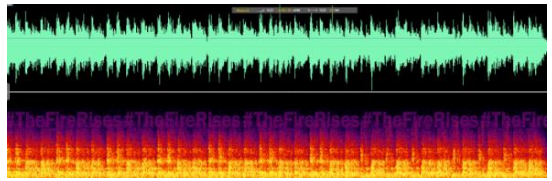
- An experienced worker is needed all the time.
- Scratching sounds are very subtle.
- Scratching occurs for different products at different operation speeds.
- Lots of human error.
- Scratching can contaminate food.

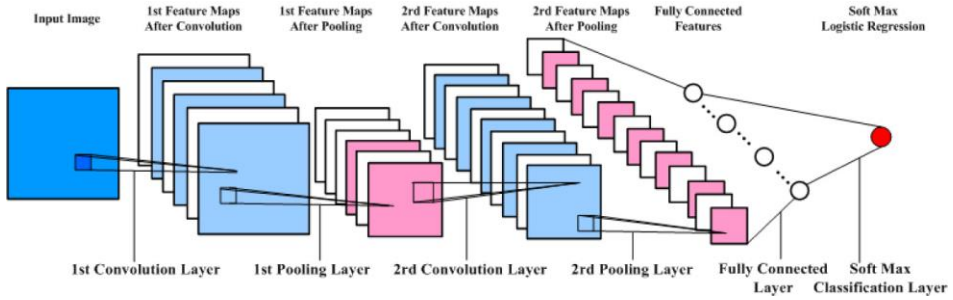
How to?

- **Find out safe limit of rotating speed (0 -1500 rpm) for each product.**
- **Automate this task using some machine learning technique.**

Proposed technique

- Data collection
- Audio spectrum analysis
- Deep learning model
  - Convolutional Neural Networks CNNs
  - Audio-visual image recognition
  - Transfer learning
- Overall structure for automation





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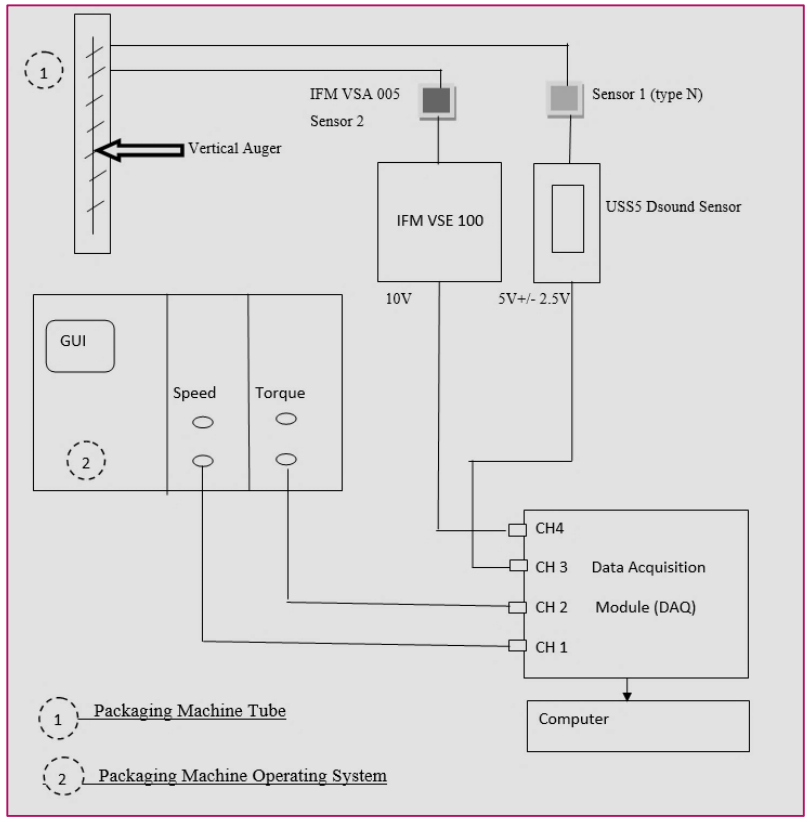
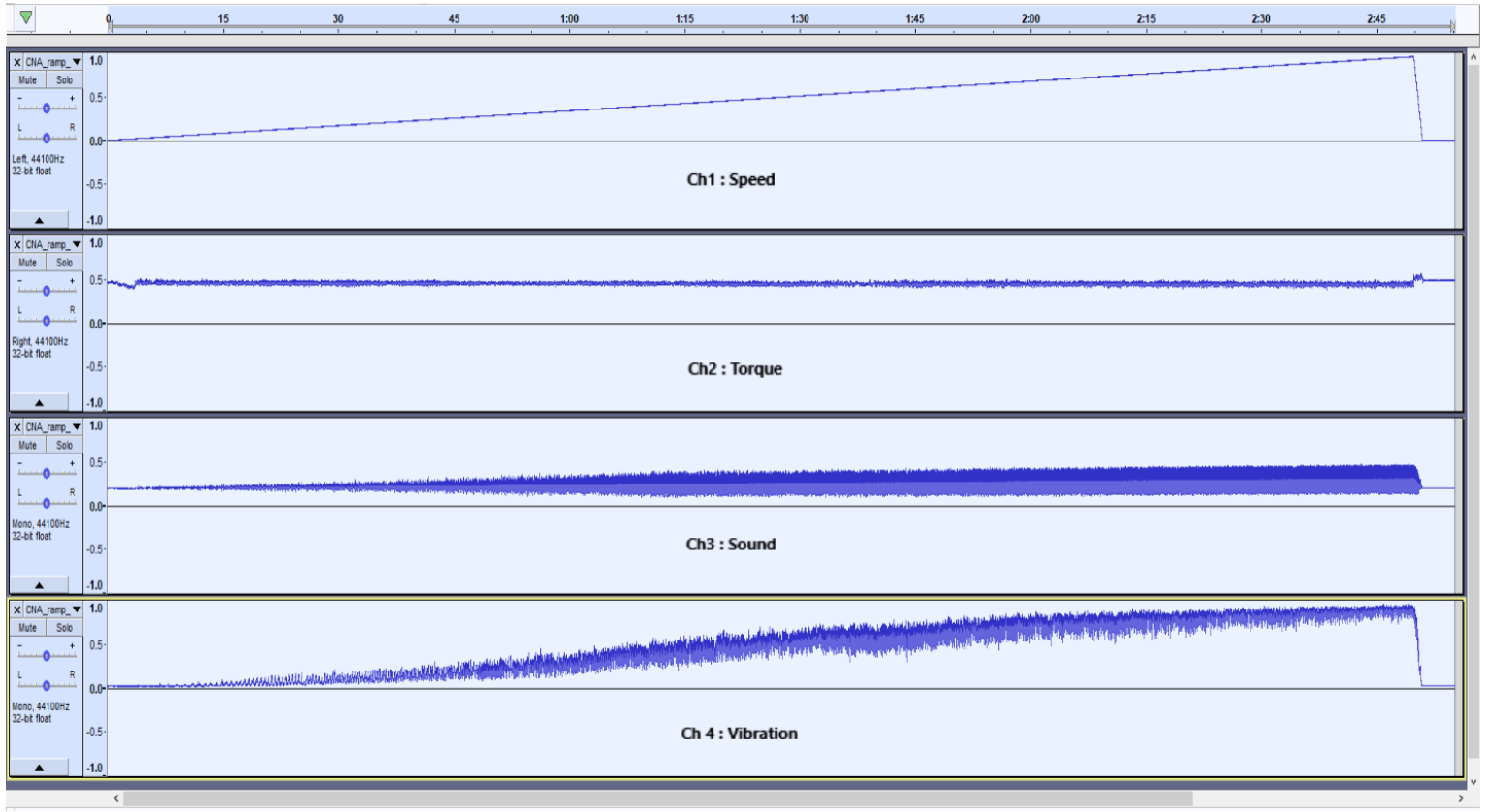
Data collection **Old** & **New** Auger

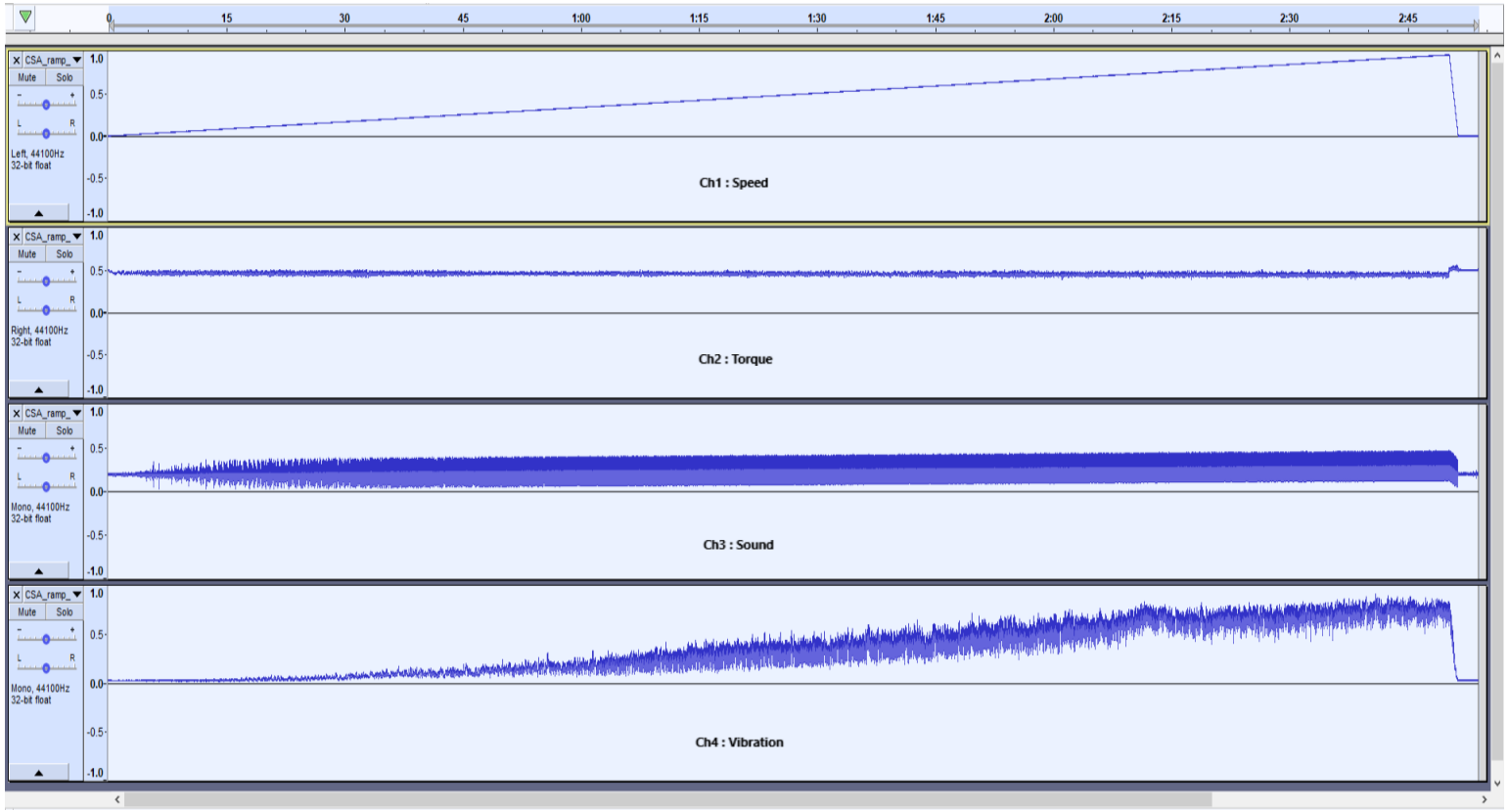
- Channel1: Speed
- Channel 2: Torque
- Channel 3: Sound
- Channel 4: Vibration



Ramp measurement (0-1500 rpm)
Coscus - New Auger



Ramp measurement (0-1500 rpm)
Coscus - Old Aguer



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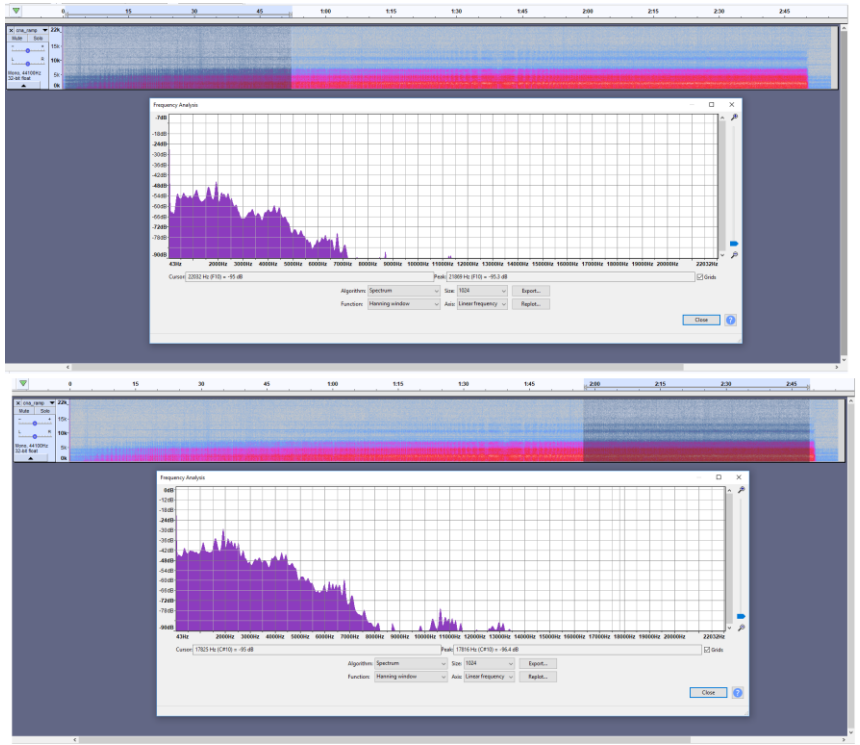
Obesrvations

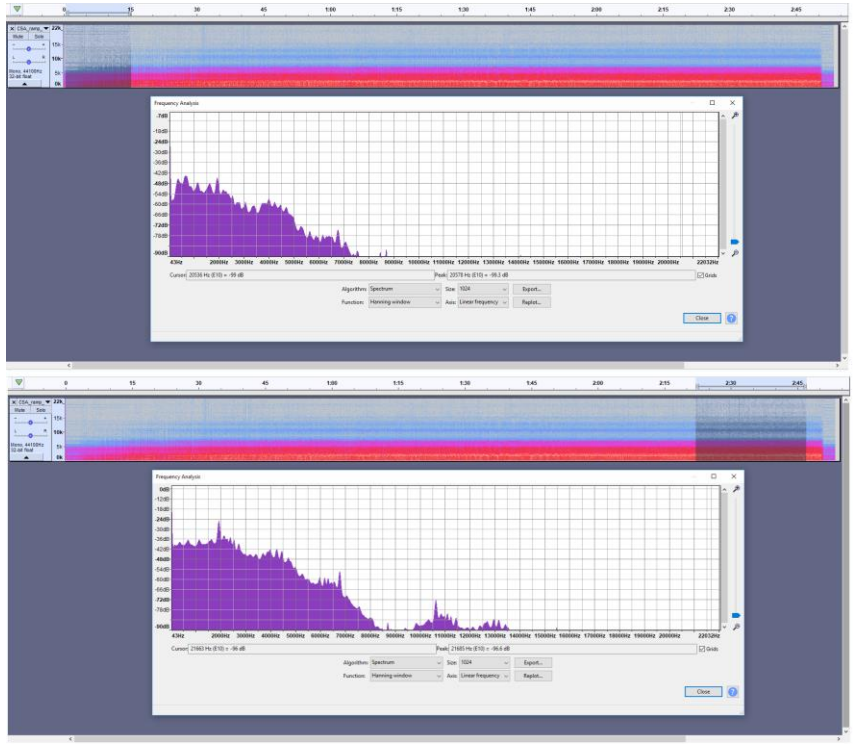
- Old auger start scrathing earlier at low rpm.
- New auger starts scratching at higher rpm.
- For each product scratching occurs at different speed.
- Scratching adds extra (high) frequencies.
- Scratching frequencies ~ (9.5k - 13.5k Hz).

Frequency Domain Analysis
Coscos

New

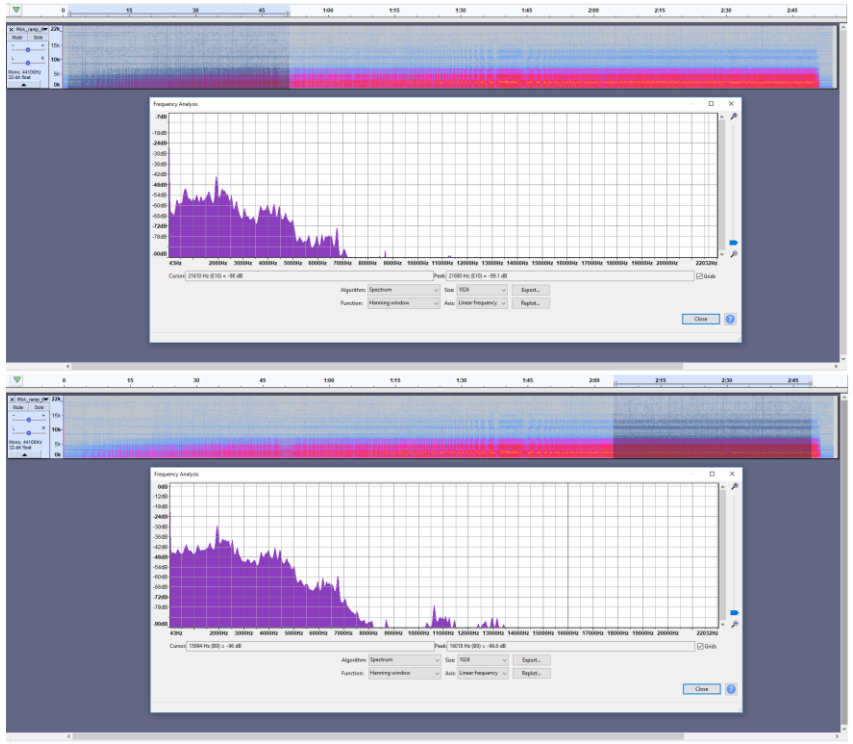


Old

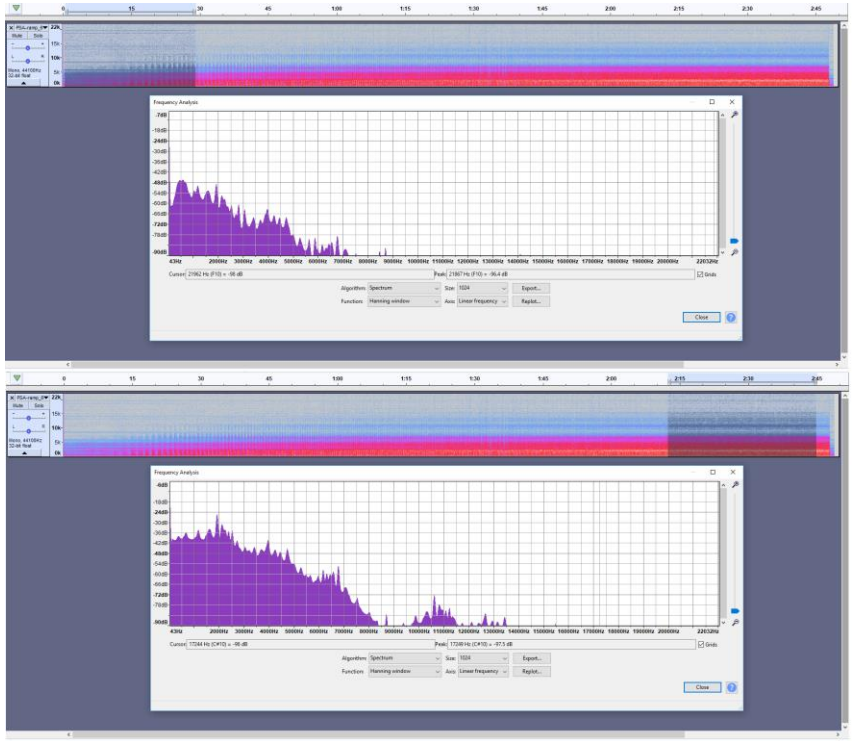


Frequency Domain Analysis
Powder

New



Old



Conclusion

- Scratching frequencies (9.5k -13.5k Hz)
- New auger (scratching)
  - Coscus ~ 574 rpm
  - Powder ~ 662 rpm
- Old Auger (scratching)
  - Coscus ~ 221 rpm
  - Powder ~ 165 rpm

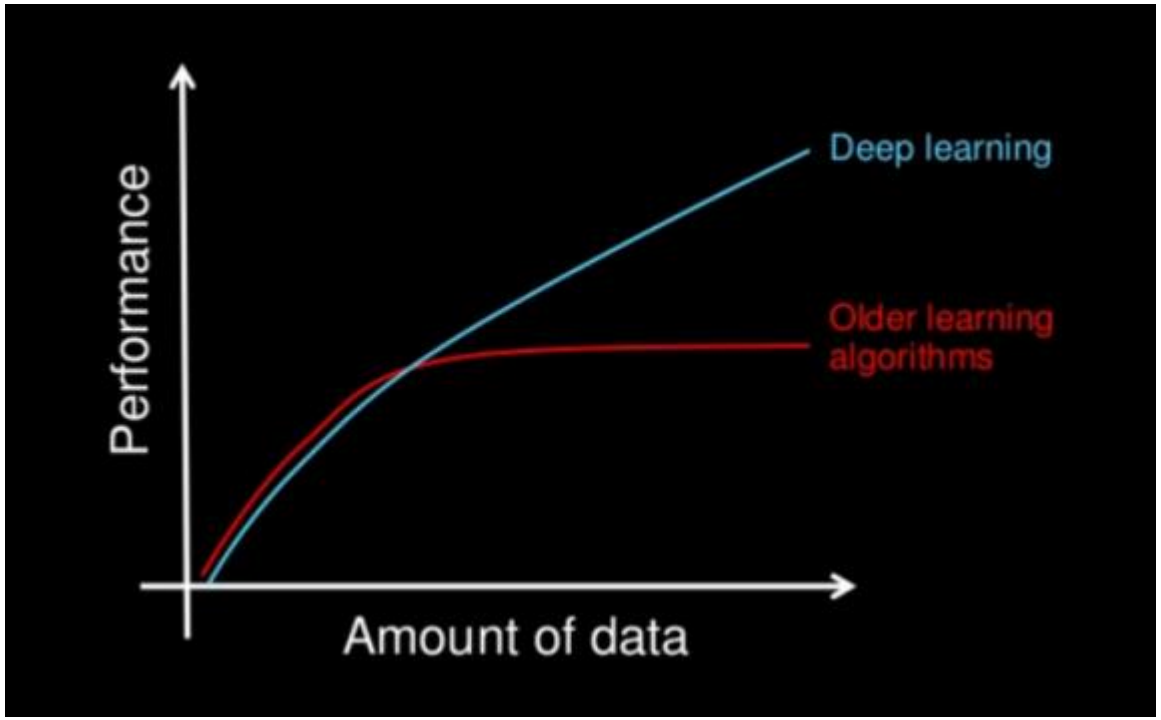
How to **automate** it?

-- AUTOMATION --

„Deep Learning!“

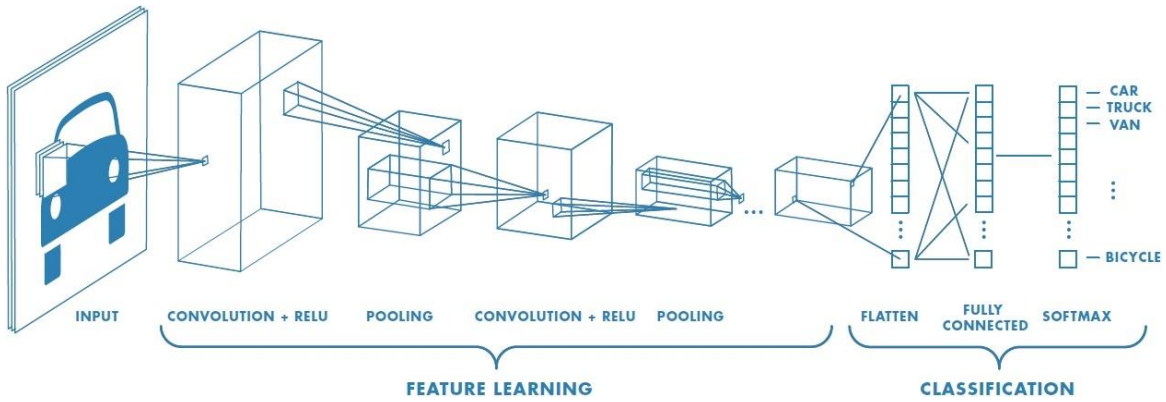
Motivation

Andrew Ng at ExtractConf 2015



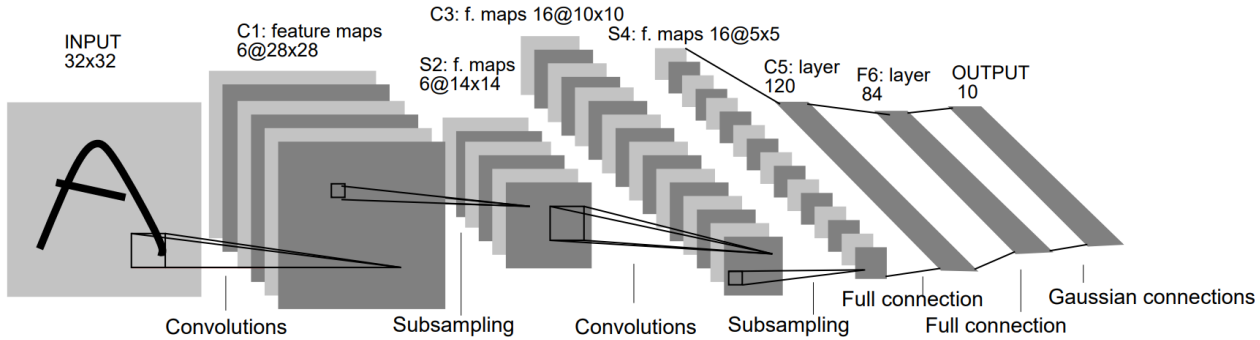
Convolutional Neural Networks
CNNs

- **Famous for visual recognition tasks**
  - Object detection
  - Object recognition
  - Handwritten digits recognition
- **Key facts**
  - Covolutional layers
  - Feed forward
  - Training via back-propagation algorithm



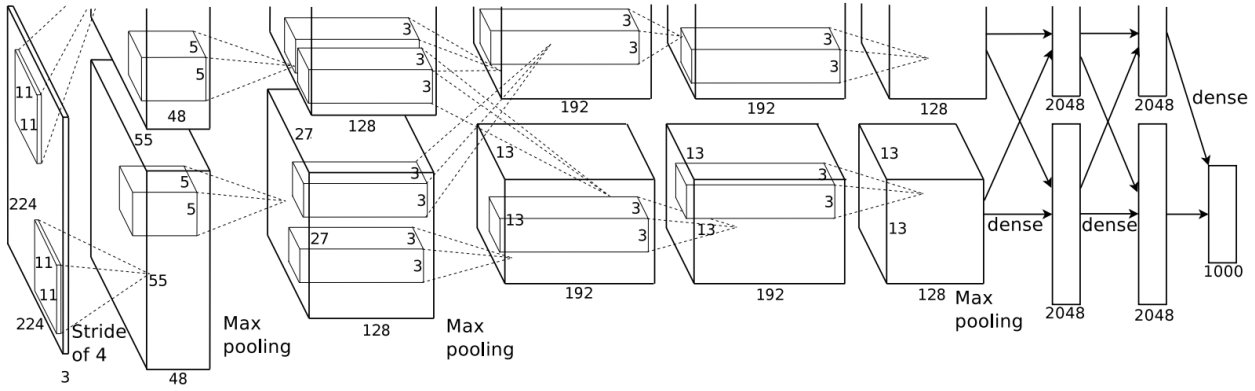
Evolution of **CNNs** **1998**

- **Le-Net**
  - By Yann LeCun
  - 7-layer model
  - Handwritten digits recognition
  - Training: MNIST dataset
    - 60,000 Training
    - 10,000 Test



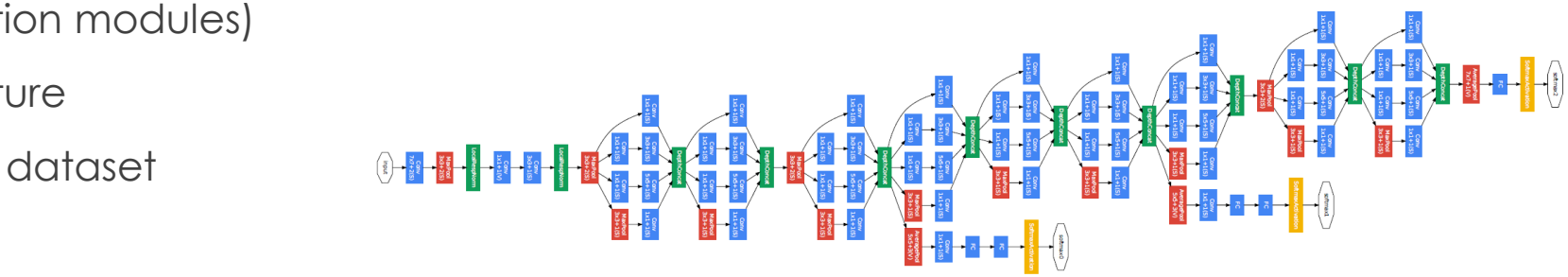
Evolution of **CNNs** **2012**

- **AlexNet**
  - By Alex Krizhevsky, Ilya Sutskever and Geoffrey Hinton.
  - 8-layer model
  - Object recognition
  - Training: ImageNet
    - 15 million images
- ILSVRC-2012 winner
  - Top-5 error rate 15.4%



Evolution of **CNNs** **2014**

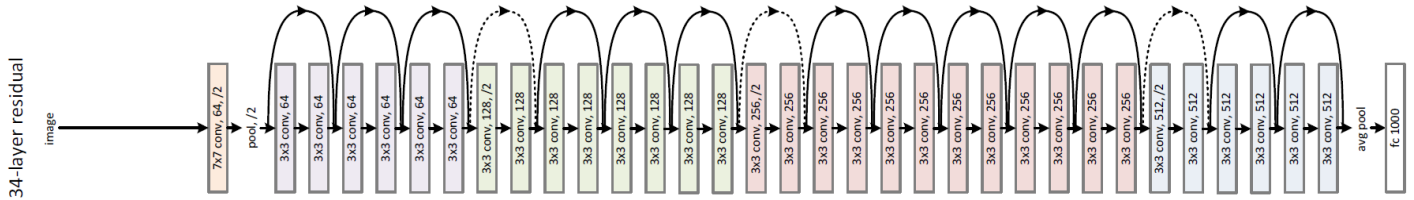
- **GoogleNet**
  - By GoogleBrain team
  - 22 layers (9- inception modules)
  - Complex architecture
  - Taining: ImageNet dataset
- ILSVRC-2014 winner
  - Top-5 error rate 6.7%



Evolution of **CNNs** **2015** (braekthrough)

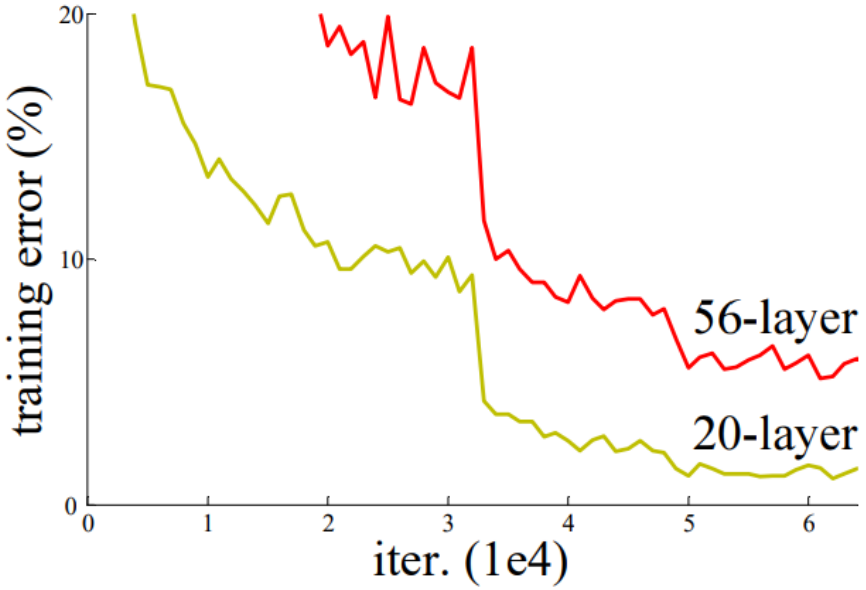
- **ResNet**
  - By Microsoft Research Asia team
  - Ultradeep152 layer model
  - Simple architecture
  - Residual blocks
  - Training: ImageNet dataset
- ILSVRC-2015 winner
  - Top-5 error rate 3.6%
  - Better than humans

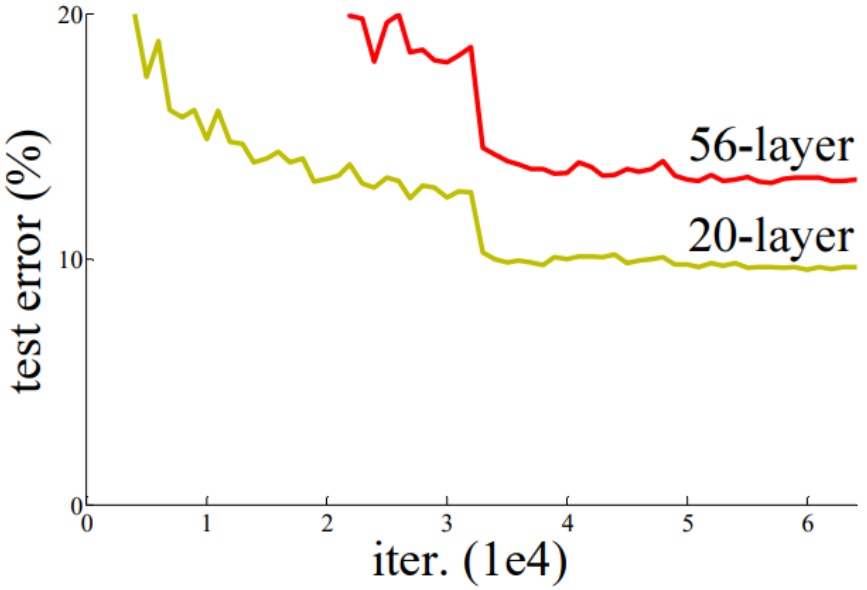
„Deeper the better“



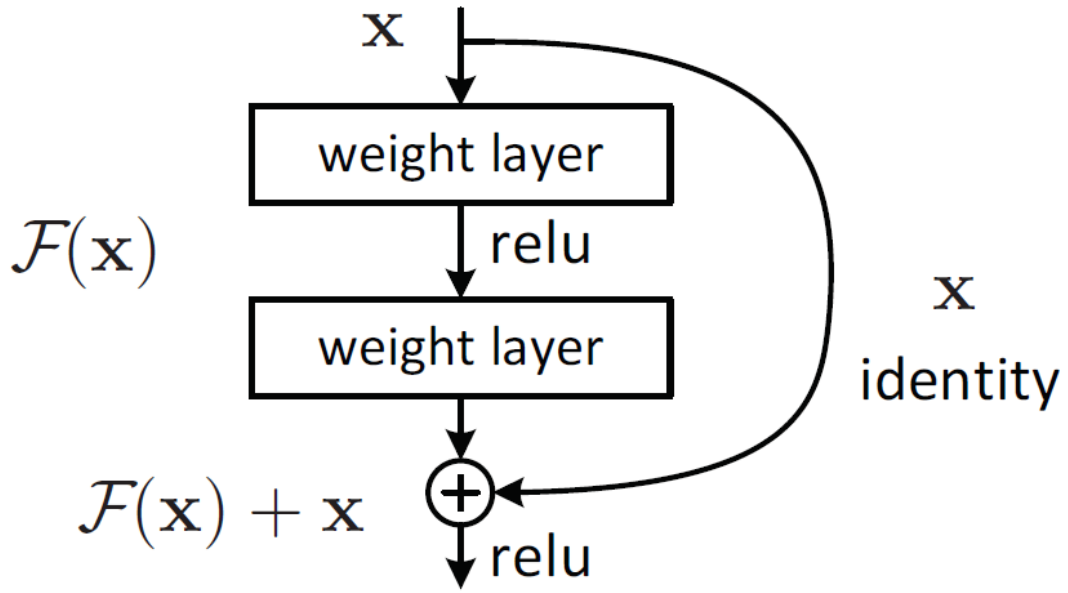
„Why **deeper** models were not successful in the past?“

10 years ago

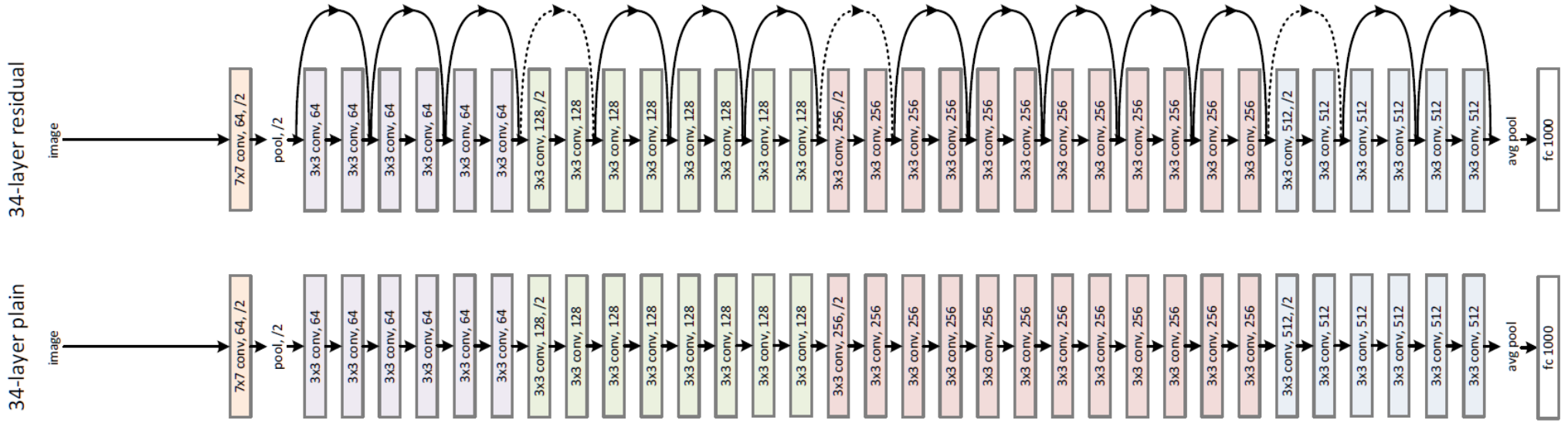

training error (%)
20
10
0
0
1
2
3
4
5
6
iter. (1e4)
56-layer
20-layer


test error (%)
20
10
0
0
1
2
3
4
5
6
iter. (1e4)
56-layer
20-layer

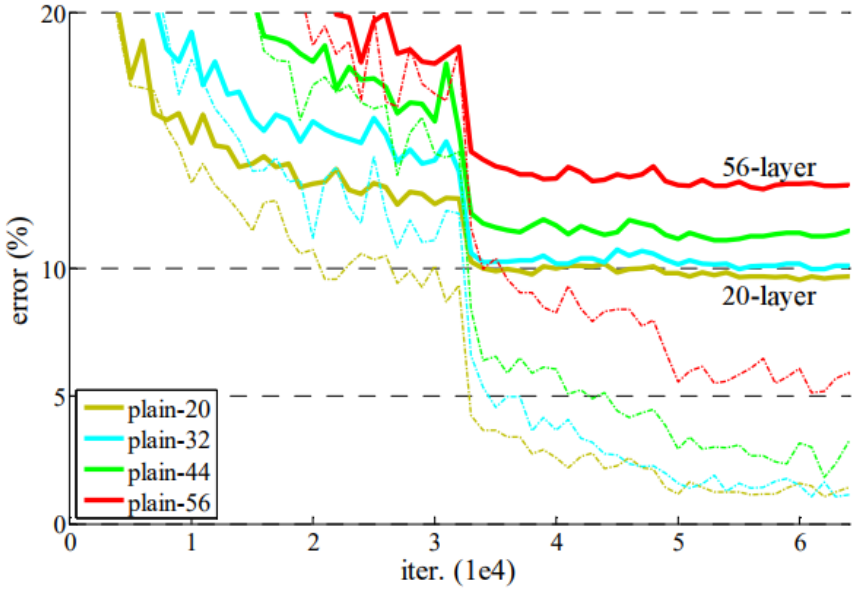
Identity Mappings
2015

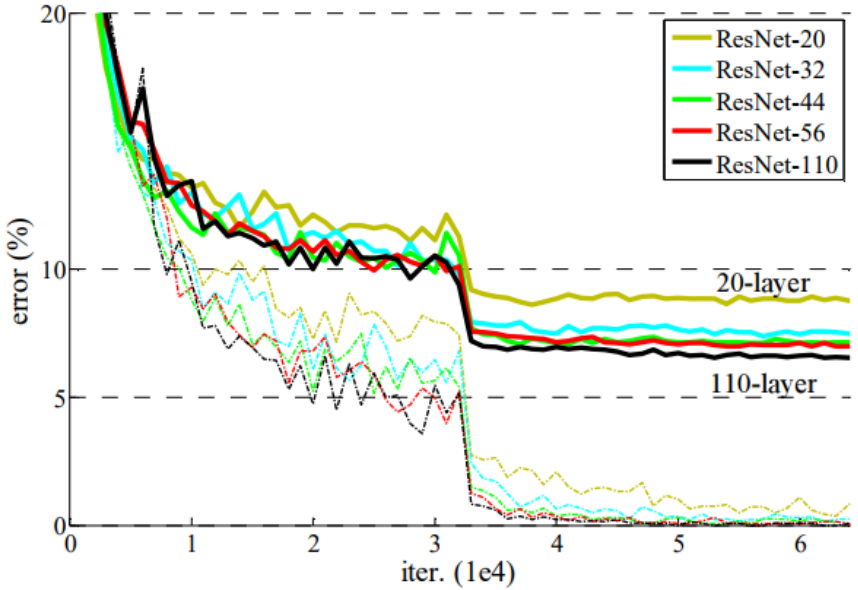


PlainNet vs ResNet



Comparison
Plain(left) vs **ResNet**(right)





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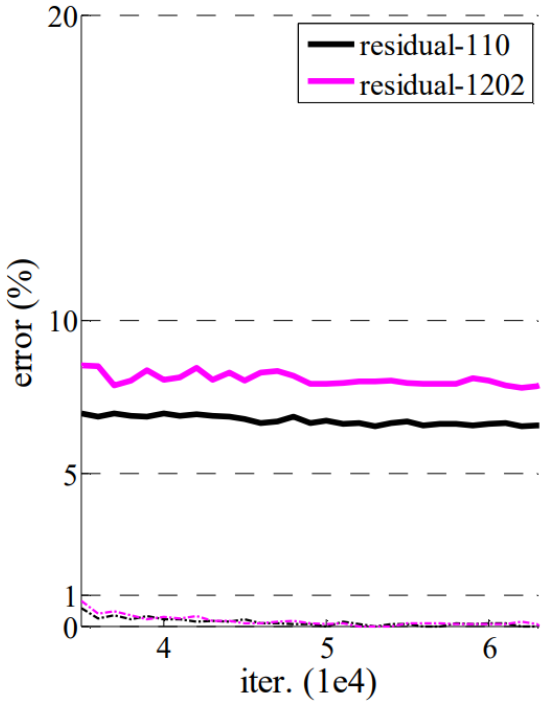
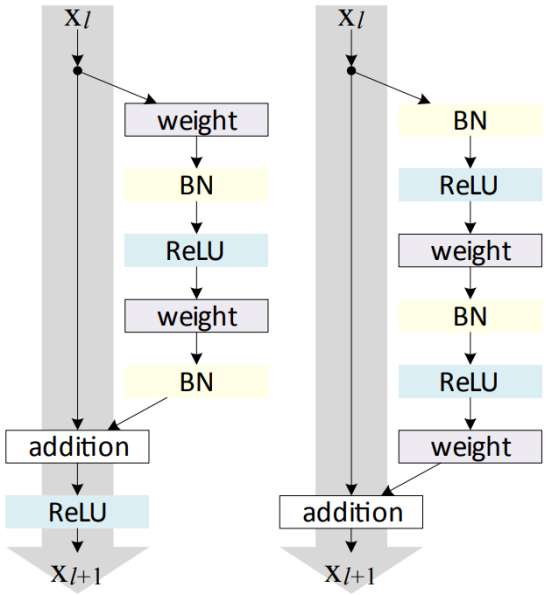
Ultra deep ResNets
1202-layers



Modification in architecture **2016**



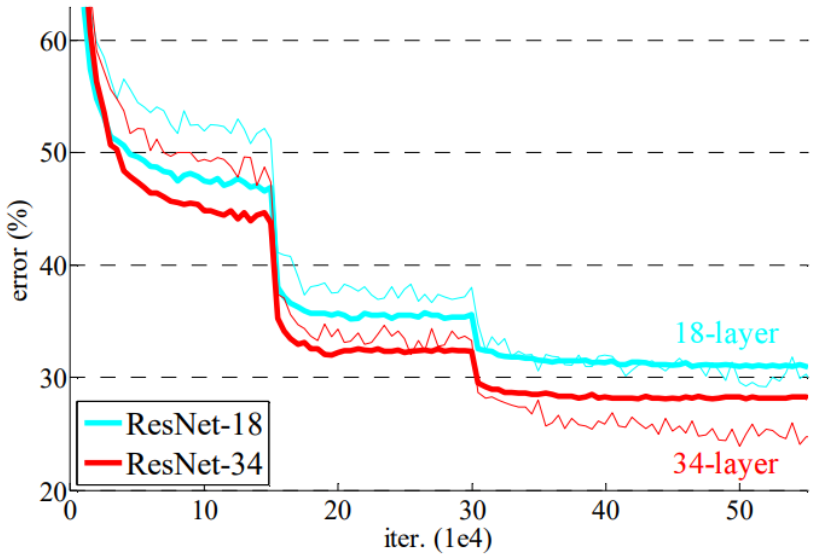
(a) original (b) proposed

Improved Results
2016

„Hence, deeper the better!“

Model Selection
ResNet-18,34

layer name	output size	18-layer	34-layer
conv1	112×112	7×7, 64, stride 2	
conv2_x	56×56	3×3 max pool, stride 2	
		$\begin{bmatrix} 3\times3, 64 \\ 3\times3, 64 \end{bmatrix}\times2$	$\begin{bmatrix} 3\times3, 64 \\ 3\times3, 64 \end{bmatrix}\times3$
conv3_x	28×28	$\begin{bmatrix} 3\times3, 128 \\ 3\times3, 128 \end{bmatrix}\times2$	$\begin{bmatrix} 3\times3, 128 \\ 3\times3, 128 \end{bmatrix}\times4$
conv4_x	14×14	$\begin{bmatrix} 3\times3, 256 \\ 3\times3, 256 \end{bmatrix}\times2$	$\begin{bmatrix} 3\times3, 256 \\ 3\times3, 256 \end{bmatrix}\times6$
conv5_x	7×7	$\begin{bmatrix} 3\times3, 512 \\ 3\times3, 512 \end{bmatrix}\times2$	$\begin{bmatrix} 3\times3, 512 \\ 3\times3, 512 \end{bmatrix}\times3$
	1×1	average pool, 1000-d fc, softmax	
FLOPs		1.8×10^9	3.6×10^9



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Transfer learning

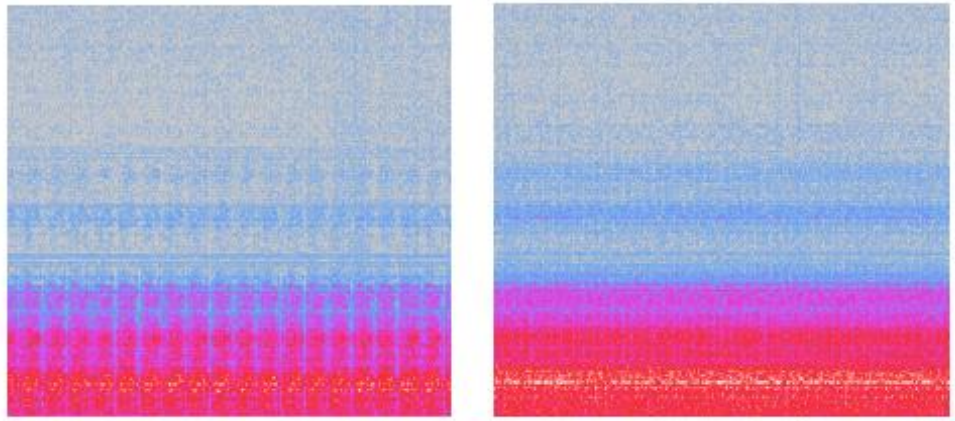
- Taking pre-trained models ResNet-18,34
- Removing the final layer with 1000 categories
- Adding new layer with custom categories (normal , scratching)
- Re-training and fine-tuning on new data
- Testing the results

"One **Picture** Worth Ten **Thousand Words**"

-- Chinese proverb

Audio to **Spectrogram** images

- **4 sec** audio – one image
- Image dimensions **256x256**
- Format **.png**
- **FFT** with Hanning window – **2048**
- Overlap **50%**



Labeling audio sample

New auger

- **cna_ramp.wav (Coscus)**
  - **Total** length 0 - 165s
  - **Scratching** 65 -165s
- **pna_ramp.wav (Powder)**
  - **Total** length 0 - 165s
  - **Scratching** 75 - 165s

Old auger

- **csa_ramp.wav (Coscus)**
  - **Total** length 0 -165s
  - **Scratching** 25 -165s
- **psa_ramp.wav (Powder)**
  - **Total** length 0 -165s
  - **Scratching** 55 -165s

Labeling images

- **Normal** Sound images – 0
- **Scratching** Sound images – 1

```
D:\Master-Thesis\Juypyter-Notebooks\Thesis_Project\images/img34.png     0
D:\Master-Thesis\Juypyter-Notebooks\Thesis_Project\images/img35.png     0
D:\Master-Thesis\Juypyter-Notebooks\Thesis_Project\images/img37.png     1
D:\Master-Thesis\Juypyter-Notebooks\Thesis_Project\images/img38.png     1
D:\Master-Thesis\Juypyter-Notebooks\Thesis_Project\images/img40.png     1
```

Training Device

- Device Build Info:
  - NVIDIA GPU GTX 950 M
  - 4 GB Dedicated RAM
  - CUDA Toolkit v.8
  - CNTK v.2

```
Selected GPU[0] GeForce GTX 950M as the process wide default device.
-------------------------------------------------------------------
Build info:

                Built time: Jul 31 2017 03:29:10
                Last modified date: Wed Jul 26 04:19:54 2017
                Build type: Release
                Build target: GPU
                With 1bit-SGD: no
                With ASGD: yes
                Math lib: mkl
                CUDA_PATH: C:\Program Files\NVIDIA GPU Computing Toolkit\CUDA\v8.0
                CUB_PATH: c:\local\cub-1.4.1
                CUDNN_PATH: C:\local\cudnn-8.0-windows10-x64-v6.0.21\cuda
                Build Branch: HEAD
                Build SHA1: 5643a5619097b125f49e629f5bdbbc5a6ceedcf0
                Built by svcphil on DPHAIM-25
                Build Path: C:\jenkins\workspace\CNTK-Build-Windows\Source\CNTKv2LibraryDll\
                MPI distribution: Microsoft MPI
                MPI version: 7.0.12437.6
-------------------------------------------------------------------
[I 15:17:11.308 NotebookApp] Saving file at /Thesis_Project/Audio_Anomaly_Detector.ipynb
[I 15:17:16.753 NotebookApp] 302 GET /notebooks/audio/cna_ramp.wav (::1) 2.01ms
-------------------------------------------------------------------
```

Training

18 – layer

- **auger_18_new**
  - 18 layer model for new auger trained on (Coscus) **can_ramp.wav**
- **auger_18_old**
  - 18 layer model for old auger trained on (Coscus) **csa_ramp.wav**

34 – layer

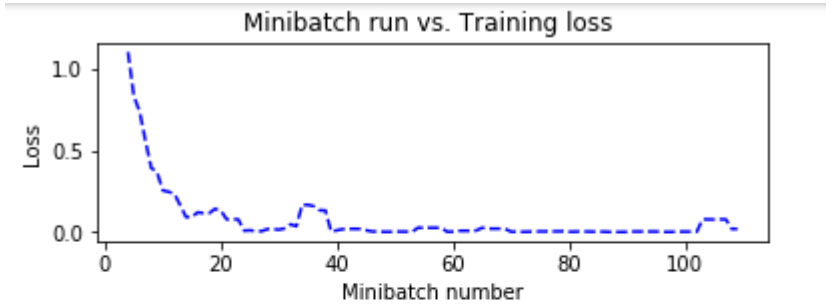
- **auger_34_new**
  - 34 layer model for new auger trained on (Coscus) **can_ramp.wav**
- **auger_34_old**
  - 34 layer model for old auger trained on (Coscus) **csa_ramp.wav**

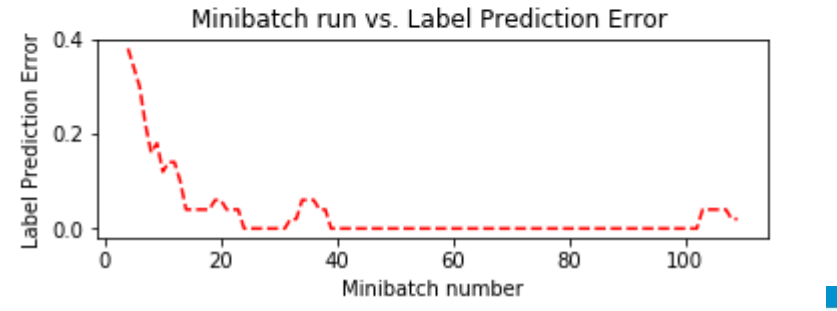
Training parameters 18 – layer models

- **Parameters:**
  - Total number of epochs = 10
  - Minibatch size = 10
  - Learning rate = 0.01
  - Momentum = 0.9
  - L2 Regularization = 0.0005
- **Size of dataset**
  - Training Set = 110 images
  - Test Set = 55 images
- **Model Input dimension**
  - 224x224x3
- **Model output dimension**
  - 2 (Normal , Scratching)

Training
18 – layer model for **new auger**

```
Training transfer learning model for 10 epochs (epochSize = 110).
Training 15898178 parameters in 68 parameter tensors.
Finished Epoch[1 of 10]: [Training] loss = 0.675340 * 110, metric = 25.45% * 110 7.290s ( 15.1 samples/s);
Finished Epoch[2 of 10]: [Training] loss = 0.103662 * 110, metric = 4.55% * 110 2.084s ( 52.8 samples/s);
Finished Epoch[3 of 10]: [Training] loss = 0.024449 * 110, metric = 0.91% * 110 2.072s ( 53.1 samples/s);
Finished Epoch[4 of 10]: [Training] loss = 0.069667 * 110, metric = 1.82% * 110 2.062s ( 53.4 samples/s);
Finished Epoch[5 of 10]: [Training] loss = 0.012901 * 110, metric = 0.00% * 110 2.085s ( 52.8 samples/s);
Finished Epoch[6 of 10]: [Training] loss = 0.013070 * 110, metric = 0.00% * 110 2.074s ( 53.0 samples/s);
Finished Epoch[7 of 10]: [Training] loss = 0.002669 * 110, metric = 0.00% * 110 2.078s ( 52.9 samples/s);
Finished Epoch[8 of 10]: [Training] loss = 0.001932 * 110, metric = 0.00% * 110 2.097s ( 52.5 samples/s);
Finished Epoch[9 of 10]: [Training] loss = 0.001962 * 110, metric = 0.00% * 110 2.095s ( 52.5 samples/s);
Finished Epoch[10 of 10]: [Training] loss = 0.044288 * 110, metric = 2.73% * 110 2.064s ( 53.3 samples/s);
```





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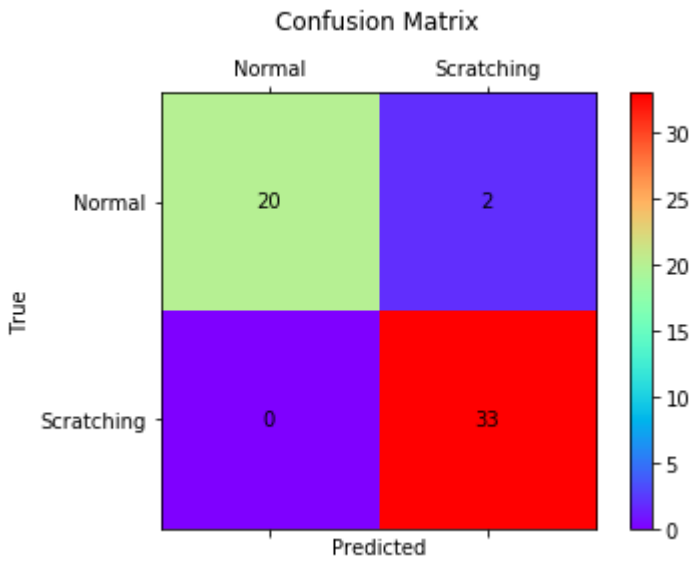
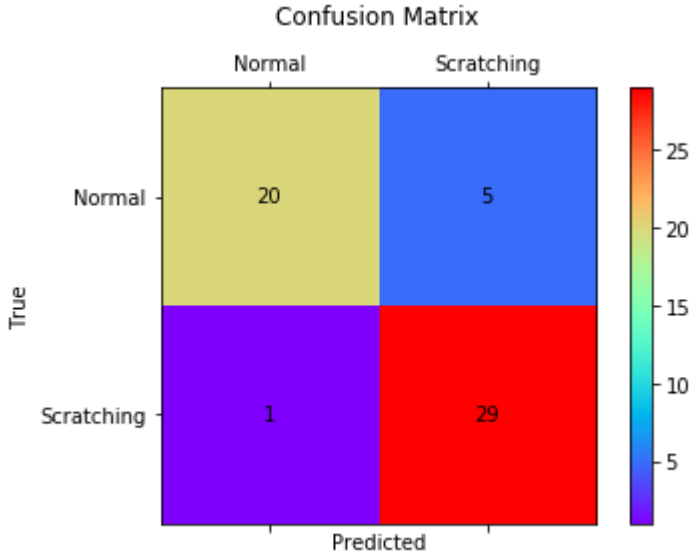
Testing
18 – layer model for **new auger**

- **Coscus :** 53/55 (correct)

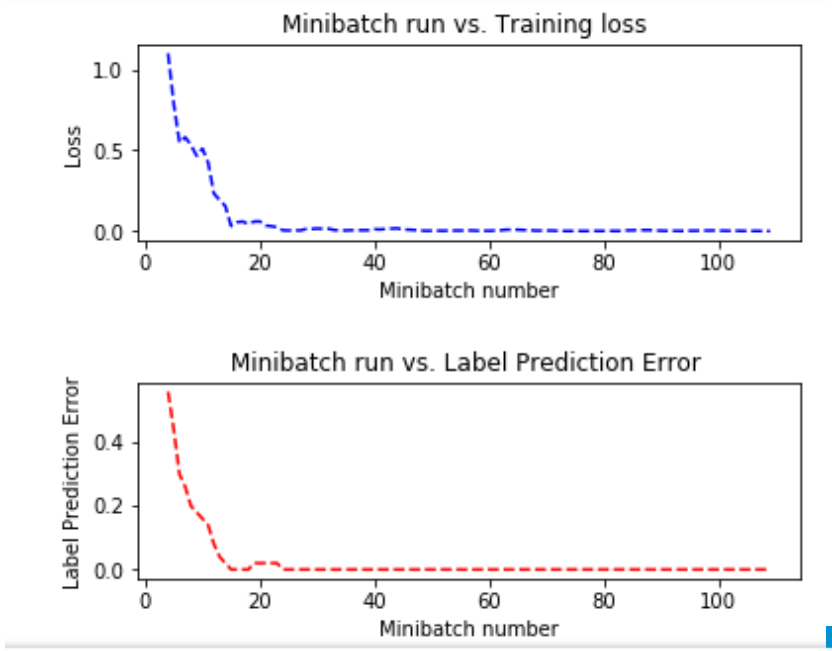


- **Powder :** 49/55 (correct)



Training
18 – layer model for **old auger**

```
Training transfer learning model for 10 epochs (epochSize = 110).
Training 15898178 parameters in 68 parameter tensors.
Finished Epoch[1 of 10]: [Training] loss = 0.767972 * 110, metric = 34.55% * 110 7.319s ( 15.0 samples/s);
Finished Epoch[2 of 10]: [Training] loss = 0.042112 * 110, metric = 0.91% * 110 2.075s ( 53.0 samples/s);
Finished Epoch[3 of 10]: [Training] loss = 0.009754 * 110, metric = 0.00% * 110 2.049s ( 53.7 samples/s);
Finished Epoch[4 of 10]: [Training] loss = 0.010068 * 110, metric = 0.00% * 110 2.077s ( 53.0 samples/s);
Finished Epoch[5 of 10]: [Training] loss = 0.003641 * 110, metric = 0.00% * 110 2.084s ( 52.8 samples/s);
Finished Epoch[6 of 10]: [Training] loss = 0.005322 * 110, metric = 0.00% * 110 2.075s ( 53.0 samples/s);
Finished Epoch[7 of 10]: [Training] loss = 0.002149 * 110, metric = 0.00% * 110 2.083s ( 52.8 samples/s);
Finished Epoch[8 of 10]: [Training] loss = 0.003658 * 110, metric = 0.00% * 110 2.074s ( 53.0 samples/s);
Finished Epoch[9 of 10]: [Training] loss = 0.002528 * 110, metric = 0.00% * 110 2.081s ( 52.9 samples/s);
Finished Epoch[10 of 10]: [Training] loss = 0.001378 * 110, metric = 0.00% * 110 2.080s ( 52.9 samples/s);
```



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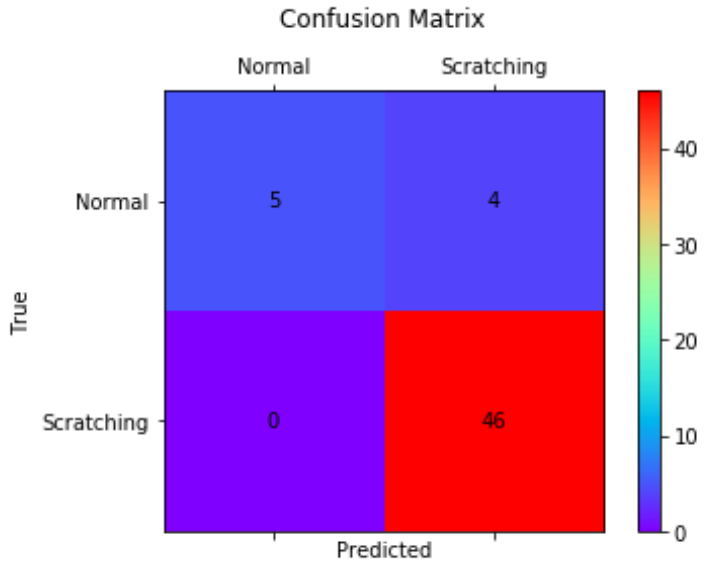
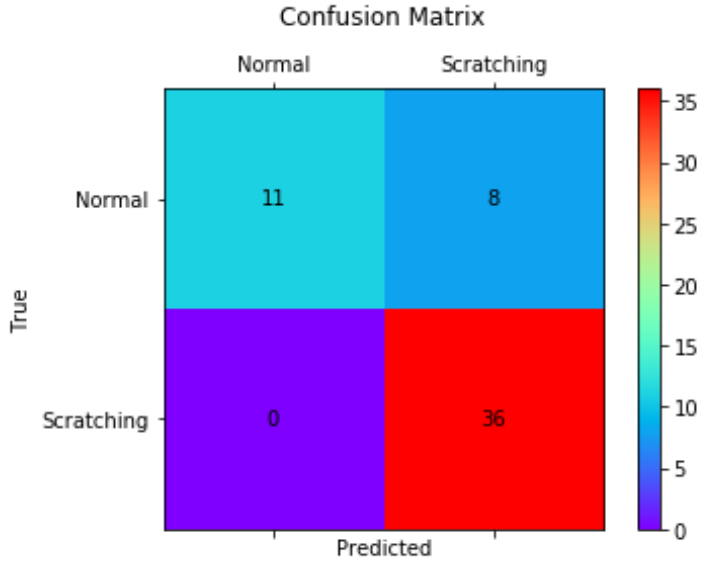
Testing
18 – layer model for **old auger**

- **Coscus :** 51/55 (correct)



- **Powder :** 47/55 (correct)

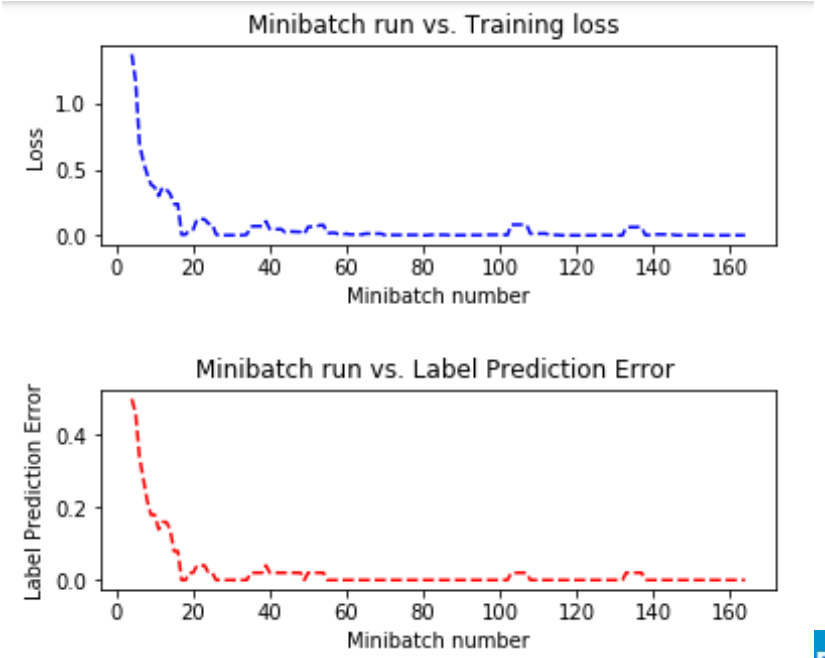


Training parameters 34 – layer models

- **Parameters:**
  - Total number of epochs = 15
  - Minibatch size = 10
  - Learning rate = 0.01
  - Momentum = 0.9
  - L2 Regularization = 0.0005
- **Size of dataset**
  - Training Set = 110 images
  - Test Set = 55 images
- **Model Input dimension**
  - 224x224x3
- **Model output dimension**
  - 2 (Normal , Scratching)

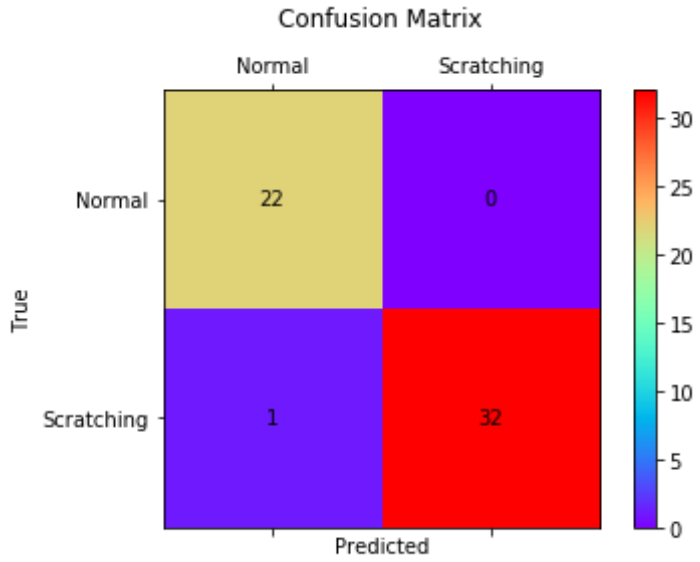
Training
34 – layer model for **new auger**

```
Training transfer learning model for 15 epochs (epochSize = 110).
Training 21285698 parameters in 110 parameter tensors.
Finished Epoch[1 of 15]: [Training] loss = 0.835481 * 110, metric = 33.64% * 110 11.090s (  9.9 samples/s);
Finished Epoch[2 of 15]: [Training] loss = 0.163774 * 110, metric = 5.45% * 110 3.167s ( 34.7 samples/s);
Finished Epoch[3 of 15]: [Training] loss = 0.003764 * 110, metric = 0.00% * 110 3.127s ( 35.2 samples/s);
Finished Epoch[4 of 15]: [Training] loss = 0.053829 * 110, metric = 1.82% * 110 3.157s ( 34.8 samples/s);
Finished Epoch[5 of 15]: [Training] loss = 0.047927 * 110, metric = 1.82% * 110 3.139s ( 35.0 samples/s);
Finished Epoch[6 of 15]: [Training] loss = 0.011860 * 110, metric = 0.00% * 110 3.139s ( 35.0 samples/s);
Finished Epoch[7 of 15]: [Training] loss = 0.003214 * 110, metric = 0.00% * 110 3.140s ( 35.0 samples/s);
Finished Epoch[8 of 15]: [Training] loss = 0.002601 * 110, metric = 0.00% * 110 3.129s ( 35.2 samples/s);
Finished Epoch[9 of 15]: [Training] loss = 0.003899 * 110, metric = 0.00% * 110 3.118s ( 35.3 samples/s);
Finished Epoch[10 of 15]: [Training] loss = 0.042980 * 110, metric = 0.91% * 110 3.143s ( 35.0 samples/s);
Finished Epoch[11 of 15]: [Training] loss = 0.002166 * 110, metric = 0.00% * 110 3.139s ( 35.0 samples/s);
Finished Epoch[12 of 15]: [Training] loss = 0.000994 * 110, metric = 0.00% * 110 3.129s ( 35.2 samples/s);
Finished Epoch[13 of 15]: [Training] loss = 0.032731 * 110, metric = 0.91% * 110 3.150s ( 34.9 samples/s);
Finished Epoch[14 of 15]: [Training] loss = 0.001513 * 110, metric = 0.00% * 110 3.141s ( 35.0 samples/s);
Finished Epoch[15 of 15]: [Training] loss = 0.000996 * 110, metric = 0.00% * 110 3.141s ( 35.0 samples/s);
```

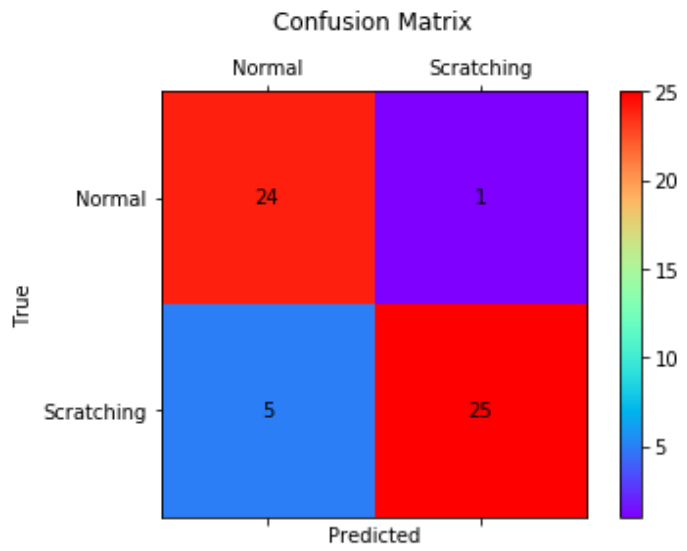


Testing
34 – layer model for **new auger**

- **Coscus :** 54/55 (correct)

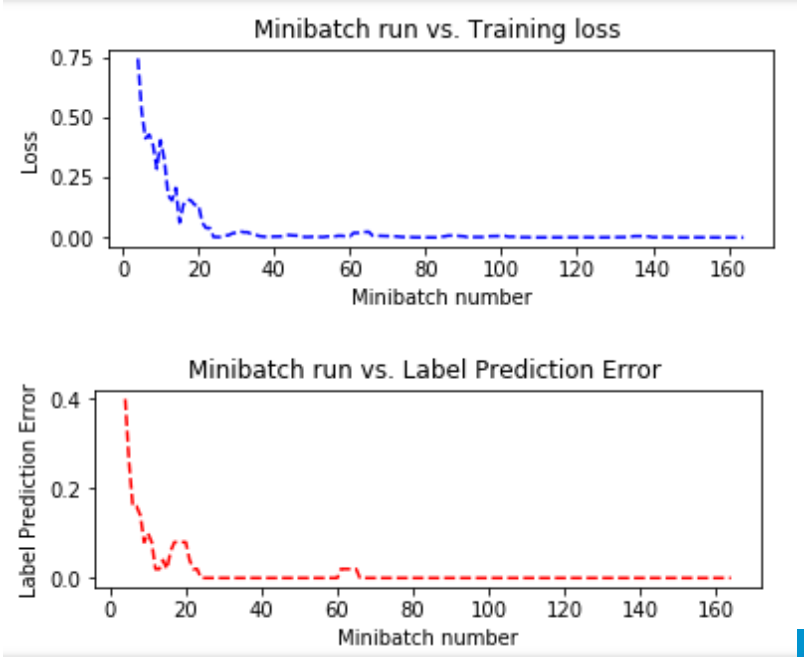


- **Powder :** 49/55 (correct)



Training
34 – layer model for **old auger**

```
Training transfer learning model for 15 epochs (epochSize = 110).
Training 21285698 parameters in 110 parameter tensors.
Finished Epoch[1 of 15]: [Training] loss = 0.533680 * 110, metric = 22.73% * 110 11.049s ( 10.0 samples/s);
Finished Epoch[2 of 15]: [Training] loss = 0.090602 * 110, metric = 4.55% * 110 3.130s ( 35.1 samples/s);
Finished Epoch[3 of 15]: [Training] loss = 0.014205 * 110, metric = 0.00% * 110 3.131s ( 35.1 samples/s);
Finished Epoch[4 of 15]: [Training] loss = 0.006953 * 110, metric = 0.00% * 110 3.166s ( 34.7 samples/s);
Finished Epoch[5 of 15]: [Training] loss = 0.003390 * 110, metric = 0.00% * 110 3.151s ( 34.9 samples/s);
Finished Epoch[6 of 15]: [Training] loss = 0.013089 * 110, metric = 0.91% * 110 3.147s ( 35.0 samples/s);
Finished Epoch[7 of 15]: [Training] loss = 0.003988 * 110, metric = 0.00% * 110 3.130s ( 35.1 samples/s);
Finished Epoch[8 of 15]: [Training] loss = 0.004020 * 110, metric = 0.00% * 110 3.123s ( 35.2 samples/s);
Finished Epoch[9 of 15]: [Training] loss = 0.003755 * 110, metric = 0.00% * 110 3.163s ( 34.8 samples/s);
Finished Epoch[10 of 15]: [Training] loss = 0.002074 * 110, metric = 0.00% * 110 3.158s ( 34.8 samples/s);
Finished Epoch[11 of 15]: [Training] loss = 0.001020 * 110, metric = 0.00% * 110 3.160s ( 34.8 samples/s);
Finished Epoch[12 of 15]: [Training] loss = 0.000564 * 110, metric = 0.00% * 110 3.146s ( 35.0 samples/s);
Finished Epoch[13 of 15]: [Training] loss = 0.003924 * 110, metric = 0.00% * 110 3.133s ( 35.1 samples/s);
Finished Epoch[14 of 15]: [Training] loss = 0.000684 * 110, metric = 0.00% * 110 3.131s ( 35.1 samples/s);
Finished Epoch[15 of 15]: [Training] loss = 0.000755 * 110, metric = 0.00% * 110 3.148s ( 34.9 samples/s);
```



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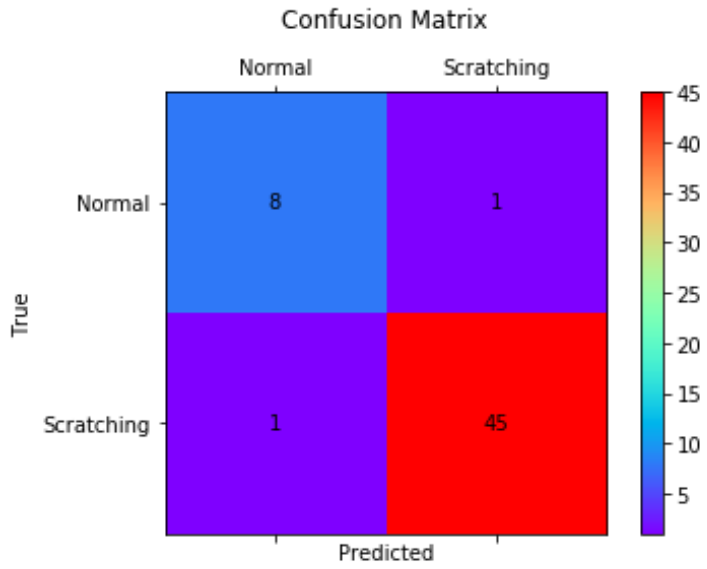
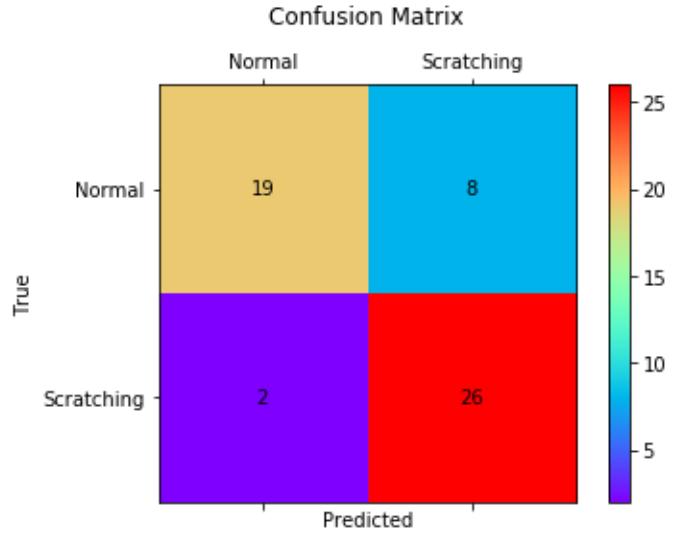
Fachhochschule
Frankfurt am Main
University of
Applied Sciences

Testing
34 – layer model for **old auger**

- **Coscus :** 53/55 (correct)



- **Powder :** 45/55 (correct)

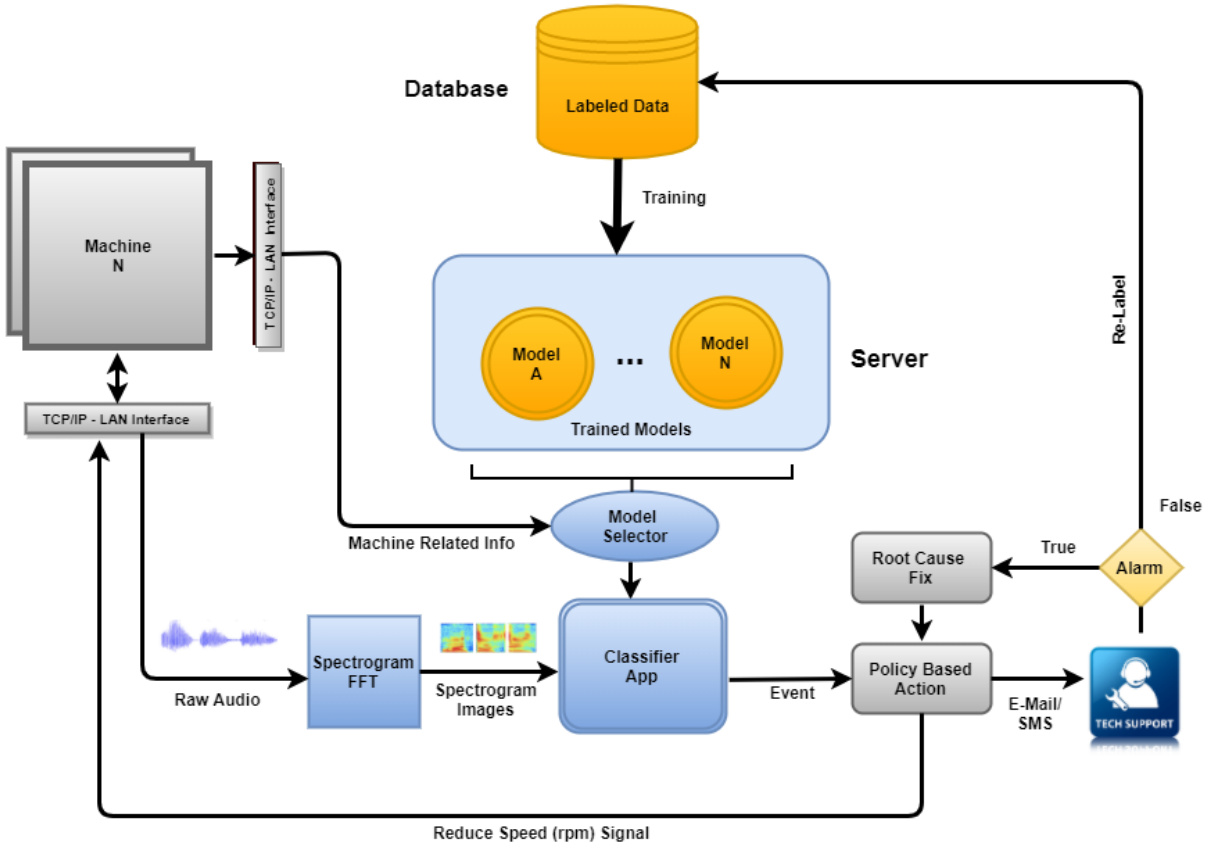


Summarizing Results

Test results of 18-layer model			
	Coscus	Powder	Overall accuracy
New	53/55	49/55	200/220
Old	51/55	47/55	= 90.9%

Test results of 34-layer model			
	Coscus	Powder	Overall accuracy
New	54/55	49/55	201/220
Old	53/55	45/55	= 91.3 %

Future Work



thank you!