//

CNN Pipeline

maXbox Starter 96 - Evaluate a pre-trained CNN Model based on the Cifar10 dataset.

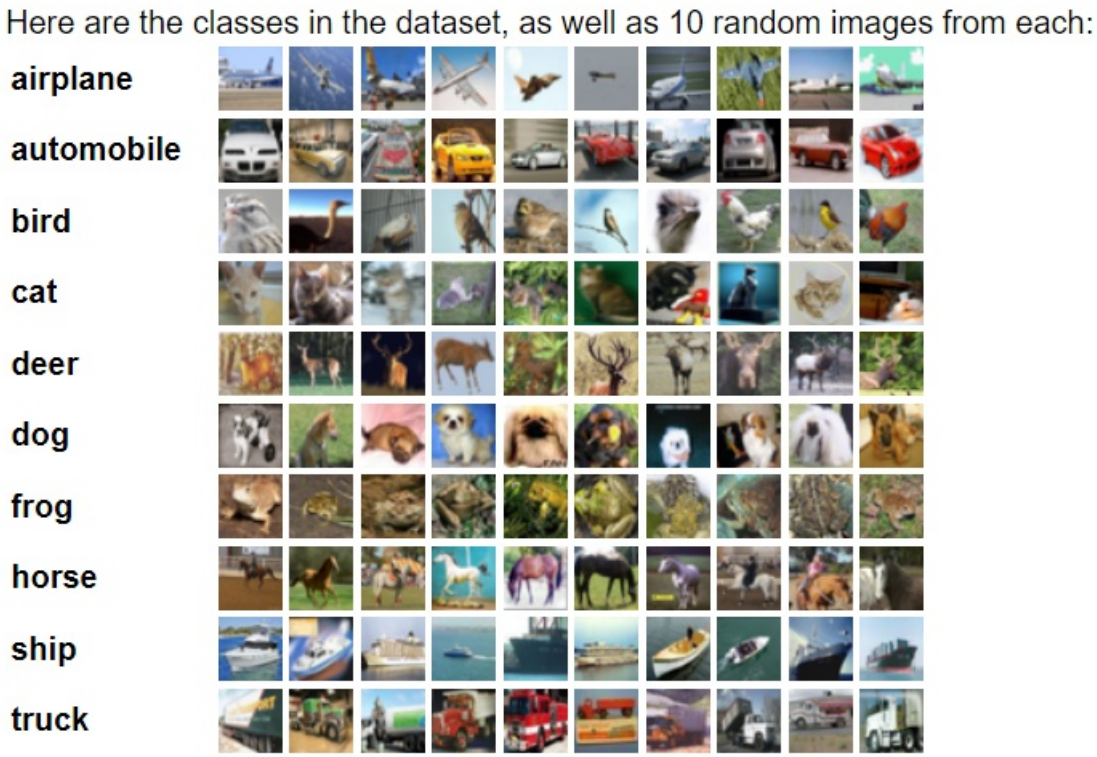
There are two kinds of data scientists:
1) Those who can extrapolate from incomplete data.

This machine learning tutor explains training the so called CIFAR-10 Image Classifier with loading and testing a pre-trained model.

The pre-trained model is: *SimpleSeparableImageClassifier124_50_2.nn*

This command line tool and script runs the CAI Network with CIFAR10 files; Utility to load cifar-10 image data into training and test data sets based on the script. Download the cifar-10 (python) version dataset from here, and extract the cifar-10-batches-1..5 folder into the same directory as the script (for validating use only *test_batch.bin*).

CIFAR-10 and CIFAR-100 datasets (toronto.edu)



Note about to build *SimpleSeparableImageClassifier*

The code contains example usage, and runs under Python3, JupyterNotebook, Lazarus and maXbox4. Note that the load_cifar_10_data() function has the option to load the images as negatives using negatives=True. There are 50000 training images and 10000 test images.
For the first script *1135_Cifar10SeparableConvolution_50.pas* you need the 50000 training images (cifar-10-batches-1..5).

For the second script *1135_uvisualcifar10test_mX4_1.pas* you need only the 10000 test images.

So we do have the following 10 files as our pipeline:

```
data_batch_1.bin (30,730,000 bytes)
data_batch_2.bin (30,730,000 bytes)
data_batch_3.bin (30,730,000 bytes)
data_batch_4.bin (30,730,000 bytes)
data_batch_5.bin (30,730,000 bytes)
1135_Cifar10SeparableConvolution_50.pas     to train model (~10 hours)
SimpleSeparableImageClassifier124_50_2.nn   output pre-trained model
SimpleSeparableImageClassifier124_50_2.csv  result report

test_batch.bin    (30,730,000 bytes)        input to script 1135_uvis..
SimpleSeparableImageClassifier124_50_2.nn   input to script
1135_uvisualcifar10test_mX4_1.pas           to test and evaluate model
```

We start with a short introduction to the CIFAR-10 Separable CNN Classification Example SimpleSeparable (comments in code). As I said you don't need to run the first script (about 9 hours and 2 GByte RAM) because you can experiment and explore direct with the second script and the pre-trained model *.nn and direct test with a TestBatch() procedure.

Adding neurons and neuronal layers is often a possible way to improve artificial neural networks when you have enough hardware and computing time. In the case that you can't afford time, parameters and hardware, you'll look for efficiency with Separable Convolutions (SCNN). This is what the first script does:

```
NN.DebugWeights();
NN.DebugStructure();
WriteLn('Layers: '+itoa( NN.CountLayers()));
WriteLn('Neurons: '+itoa( NN.CountNeurons()));
WriteLn('Weights: '+itoa( NN.CountWeights()));

CreateCifar10Volumes(ImgTrainingVolumes, ImgValidationVolumes,
                                         ImgTestVolumes, csEncodeRGB);

NeuralFit:= TNeuralImageFit.Create;
NeuralFit.FileNameBase:= 'SimpleSeparableImageClassifier124_50_2';
NeuralFit.InitialLearningRate:= 0.001;  //0.001
NeuralFit.LearningRateDecay:= 0.1 //0.01;
NeuralFit.StaircaseEpochs:= 10;
NeuralFit.Inertia:= 0.9;
NeuralFit.L2Decay:= 0.0001;  //0.00001;
NeuralFit.Fit(NN, ImgTrainingVolumes, ImgValidationVolumes,
              ImgTestVolumes, {NumClasses=}10, {batchsize=}128, {epochs=}50);
NeuralFit.Free;
```

As you can see the output is the NeuralFit.FileNameBase. As can be seen on above script, a separable convolution is a composition of 2 building blocks:

- A depth-wise convolution followed by
- a point-wise convolution.

And we can see the progress during learning rate:

```
Epochs: 40 Examples seen:1600000 Test Accuracy: 0.7010 Test Error: 0.8364 Test
Loss: 0.8692 Total time: 218.73min
Epochs: 40. Working time: 3.85 hours.
Epochs: 50 Examples seen:2000000 Test Accuracy: 0.7242 Test Error: 0.7753 Test
Loss: 0.8144 Total time: 292.09min
Epoch time: 3.2000 minutes. 50 epochs: 2.7000 hours.
Epochs: 50. Working time: 4.87 hours.
```

Now we jump to the second script as our main topic. The origin is based on a Lazarus Experiment.
https://sourceforge.net/p/cai/svncode/HEAD/tree/trunk/lazarus/experiments/visualCifar10test/uvisualcifar10test.pas

Pre-trained models means the models which have been already trained on some sort of data like cifar with different number of classes. Considering this fact, the model should have learned a robust hierarchy of features, which are spatial, rotation, and translation invariant, as we have seen before with regard to features learned by CNN models.
So the pipeline of the process goes like this:

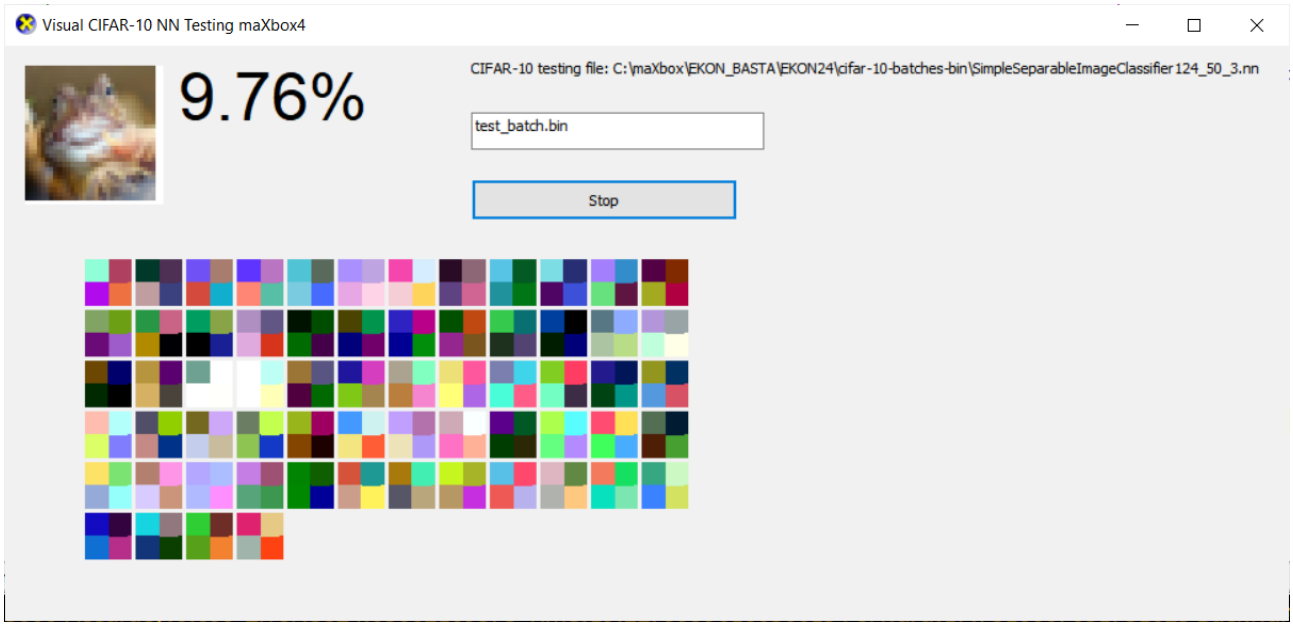
1. Train (or fit) a model to get the feature map with weights.
2. Test the classifier on unseen date with the pre-trained model.
3. Evaluate the classifier with different pre-trained models.

The last point means we can change in our second script the pre-trained model to compare the score or benchmark for better accuracy:
We can compare *ImageClassifierSELU_Tutor89_5.nn* with *SimpleSeparableImageClassifier124_50_2.nn*.

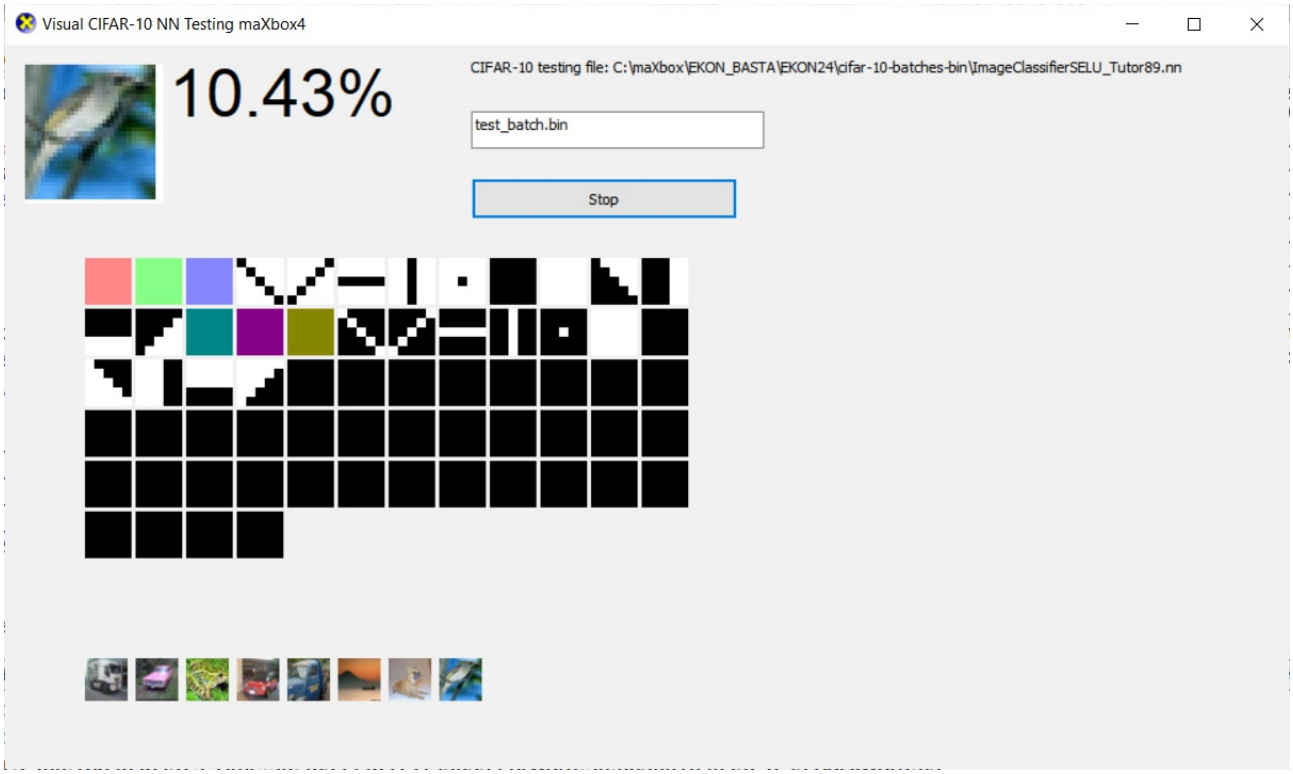
```
Const PReModel_NN = 'SimpleSeparableImageClassifier124_50_2.nn';
      //PReModel_NN = 'SimpleSeparableImageClassifier.nn';
      //PReModel_NN = 'SimpleSeparableImageClassifier124.nn';
      //PReModel_NN = 'SimpleSeparableImageClassifier124_50_3.nn';
      //PReModel_NN = 'ImageClassifierSELU_Tutor89.nn';

  NN := TNNet.Create();

  writeln('Creating CNeural Network...');
  ImgVolumes := TNNetVolumeList.Create(true);
  NumClasses := 10;

  fileName:= Exepath+PReModel_NN; //OpenDialogNN.FileName;

  writeln('Loading neural network from file: '+fileName);
  NN.LoadFromFile(fileName);
  NN.EnableDropouts(false);
  firstNeuronalLayer := NN.GetFirstNeuronalLayerIdx(0);

  pOutput := TNNetVolume.Create0(NumClasses,1,1,0);   //or 1
  vOutput := TNNetVolume.Create0(NumClasses,1,1,0);
  vDisplay:= TNNetVolume.Create0(NumClasses,1,1,0);

  SetLength(aImage, NN.Layers[firstNeuronalLayer].Neurons.Count);
  SetLength(sImage, NumClasses);
```

Also a view of the neurons is possible the get some insights of the power of segmentation and finally discrimination. So a pre-trained model is a

model that was trained on a large benchmark dataset to solve a problem similar to the one that we want to solve. Accordingly, due to the computational cost of training such models, it is common practice to import and use models from published platforms. We use a platform process pipeline ;-).
Lets start with a simple sample to compare (evaluate) this 2 models with our second script:



Pic: 1135_visualCNN4.png



Pic: 1135_visualCNN6.png

So it's obvious that the 2 models are underperformed. There is a list of models and their performance and parameter count here:

https://keras.io/api/applications/

LeNet for example is the most popular CNN architecture it is also the first CNN model which came in the year 1998. LeNet was originally developed to categorise handwritten digits from 0-9 of the MNIST Dataset. It is made up of seven layers, each with its own set of trainable parameters.

```
      Application.ProcessMessages();
      if pOutput.GetClass() = ImgVolumes[ImgIdx].Tag then begin
        Inc(Hit);
        //WriteLn(' Tag Label: '+ itoa(ImgVolumes[ImgIdx].Tag));
      end else begin
        Inc(Miss);
      end;
```

To get a better conclusion there's a simple representation of a neural net with some attributes and a TestBatch() procedure below:

```
  NN.DebugWeights();
  //WriteLn(' Layers: ',  NN.CountLayers()  );
  //WriteLn(' Neurons:',  NN.CountNeurons() );
  WriteLn('Neural CNN network has: ');
  WriteLn(' Layers: '+ itoa(NN.CountLayers()  ));
  WriteLn(' Neurons: '+ itoa(NN.CountNeurons() ));
  WriteLn(' Weights: '+ itoa(NN.CountWeights() ));
  WriteLn('Computing...');
```

```
Neural CNN network has:       Pre-Model:
 Layers: 13                   Layers: 11
 Neurons: 205                 Neurons: 124
 Weights: 20960               Weights: 14432
Computing...
```

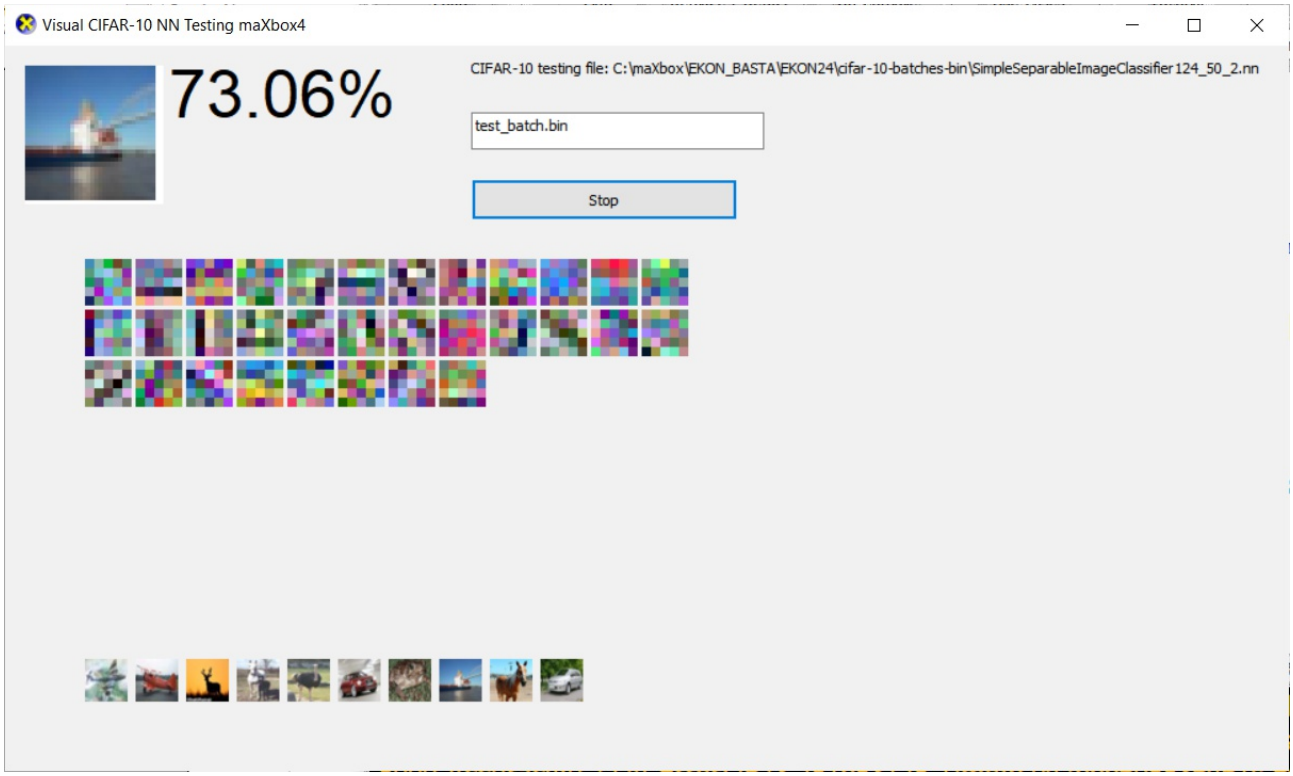
```
Directory of C:\maXbox\EKON_BASTA\EKON24\cifar-10-batches-bin\
This function tests a neural network on the passed ImgVolumes:
```

```
{procedure TestBatch
 (
  NN: TNNet; ImgVolumes: TNNetVolumeList; SampleSize: integer;
  out Rate, Loss, ErrorSum: TNeuralFloat
  ); }
    rate:= 0; loss:= 0;
    ErrorSum:= 0;
    TestBatch(NN, ImgVolumes, 1000, rate, loss, ErrorSum);
    writeln('Test batch score: '+Format(' Rate:%.4f, Loss:%.4f, ErrorSum:%.4f ',
                                        [rate, loss, ErrorSum]));
    LabClassRate.Caption:= format('Ø %.2f%% ',[rate*100]);
  end;
```

```
Ver: 4.7.6.10 (476). Workdir: C:\maXbox\EKON_BASTA\EKON24\cifar-10-batches-bin

Test batch score:  Rate:0.7130, Loss:0.1772, ErrorSum:905.7636
```

By following these ways you can make a CNN model that has a validation set accuracy of more than 95 % but the question is how specific is this validation.

```
Starting Testing.
Epochs: 50 Examples seen:2000000 Test Accuracy: 0.7386 Test Error: 0.7142 Test
Loss: 0.7534 Total time: 595.02min
Epoch time: 7.5000 minutes. 50 epochs: 6.3000 hours.
Epochs: 50. Working time: 9.92 hours.
CAI maXbox Neural Fit Finished.
terminate__
### mX4 executed: 06/07/2022 18:58:08  Runtime: 9:55:6.882  Memload: 48% use
```



Pic: 1135_visualCNN7.png

The learning rate is the crucial hyperparameter used during the training of deep convolution neural networks (DCNN) to improve model accuracy; this you can follow in the *SimpleSeparableImageClassifier124_50_2.csv*.

epoch	training accurac	training loss	training error	validation accura	validation loss	validation error	learning rate	time	test accuracy	test loss	test error
34	0.6847	0.8597	0.8348	0.7437	0.7539	0.7168	0.0000424	24224			
35	0.679	0.8116	0.8321	0.744	0.7518	0.7156	0.0000424	24898			
36	0.679	0.9	0.8579	0.7449	0.7506	0.7143	0.0000424	25566			
37	0.6824	0.8187	0.7777	0.7444	0.7493	0.7132	0.0000424	26237			
38	0.6803	0.8277	0.8318	0.7454	0.7488	0.7129	0.0000424	26905			
39	0.6797	0.7477	0.803	0.7458	0.748	0.7126	0.0000424	27575			
40	0.6802	0.9165	0.8089	0.746	0.7478	0.7118	0.0000424	28520	0.7374	0.7564	0.719
41	0.6814	1.0169	0.9353	0.7457	0.7476	0.7113	0.0000148	29189			
42	0.6833	1.1278	0.9435	0.7458	0.7468	0.7106	0.0000148	29858			
43	0.6813	0.9797	0.9069	0.7455	0.747	0.7103	0.0000148	30527			
44	0.6828	0.9151	0.8086	0.7458	0.7465	0.7102	0.0000148	31197			
45	0.6857	1.2414	1.0189	0.7464	0.7464	0.7094	0.0000148	31873			
46	0.6834	0.76	0.7693	0.7461	0.7462	0.7091	0.0000148	32552			
47	0.6851	0.9391	0.8937	0.7457	0.746	0.7086	0.0000148	33234			
48	0.6825	0.9652	0.8961	0.746	0.7455	0.7079	0.0000148	33906			
49	0.6893	0.931	0.8649	0.7465	0.7456	0.7074	0.0000148	34654			
50	0.6853	0.7832	0.7657	0.7462	0.7453	0.7074	0.0000148	35701	0.7386	0.7534	0.7142

Conclusion:

The proper way to use a CNN doesn't exists. The advice for ugly score is to use a smaller learning rate or larger batch size for the weights that

are being fine-tuned and a higher one for the randomly initialized weights (e.g. the ones in the softmax classifier) TNNetSoftMax. Pre-trained weights are already good, they need to be fine-tuned, not distorted.

The scripts can be found:

http://www.softwareschule.ch/examples/1135_Cifar10SeparableConvolution_50.pas

http://www.softwareschule.ch/examples/1135_uvisualcifar10test_mX4_1.pas

All scripts & data:

https://github.com/maxkleiner/neural-api/tree/master/examples/SeparableConvolution

Reference:

https://sourceforge.net/p/cai/svncode/HEAD/tree/trunk/lazarus/experiments/visualCifar10test/uvisualcifar10test.pas

Doc: https://maxbox4.wordpress.com

Script Ref: 1073__CAI_3_LearnerClassifier22_Tutor_89_2.txt

http://www.softwareschule.ch/examples/1073__CAI_3_LearnerClassifier22_Tutor_89_2.txt

https://entwickler-konferenz.de/blog/machine-learning-mit-cai/

https://www.freecodecamp.org/news/convolutional-neural-network-tutorial-for-beginners/

Appendix: show neurons from maXbox4 integration

```
{*-------------------------------------------------------------------------*)

 for NeuronCount:= 0 to NN.Layers[firstNeuronalLayer].Neurons.Count- 1 do begin
    aImage[NeuronCount]:= TImage.Create(FormVisualLearning);
    aImage[NeuronCount].Parent := FormVisualLearning;
    aImage[NeuronCount].Width  :=
              NN.Layers[firstNeuronalLayer].Neurons[NeuronCount].Weights.SizeX;
    aImage[NeuronCount].Height :=
              NN.Layers[firstNeuronalLayer].Neurons[NeuronCount].Weights.SizeY;
    aImage[NeuronCount].Top    := (NeuronCount div 12) * 38 + 160;   //120
    aImage[NeuronCount].Left   := (NeuronCount mod 12) * 38 + 60;
    aImage[NeuronCount].Stretch:=true;
 end;
```