

# Image classification using Network in Network(NiN) architecture

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## Abstract

Convolution neural network (CNN, or ConvNet) are a special kind of neural networks specially designed for recognizing patterns from pixels of images. In this case study we implement convolution neural network using **Network in Network(NiN)** architecture. The architecture used is inspired by the **inception module of GoogLeNet** where we use collaborative pooling of parallel convolution networks .

## Keywords

Network in Network(NiN) — Inception architecture — Convolution Network — Pooling Layers — Deep Learning — ReLU Activation — SGD — Dropout — Softmax — Batch Normalization — Weight Normalization — l2 Regularisation

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## 1. Introduction

Image classification is an important application of ConvNets. There are various architectures to design a ConvNet. The purpose of this case study is to experiment and establish an understanding of various techniques. Convolution layers and pooling layers are basic building blocks of a ConvNet. And its is crucial to understand the reason behind choosing the shape and sequence of these layers.

We have used NiN architecture where we have built parallel ConvNets and used a concatenation layer to collaborate the learning of different layers. These small NiNs are further stacked vertically further with layers of NiNs. With this study

we wish to demonstrate that parallel networks learn different features of the images and collaborating these networks outperform the traditional approach of vertically stacking convolution and pooling layers.

ConvNets can face issues with training. Training on the whole data simultaneously creates a large computational overhead for little performance gain. Training on a single observation can produce unpredictable results that do not generalise. Additionally, neural networks are prone to exploding coefficients and can suffer from the zero-gradient trap with the chosen ReLU activation. In order to address these challenges, the following features will be deployed within the neural network:

- Dropout
- Batch normalization
- Weight Normalization
- Adam optimiser
- l2 Regularisation

Since this is a multiclass problem with 62 unique classes, a Softmax activation has been chosen for the output layer, allowing for the calculation and comparison of class probabilities.

### 1.1 Data

There are 62 classes in this dataset. The dataset has been split into training set and validation set, where the training set has 37,882 images of alphabets and numbers; while the validation set has 6,262 images. The images are of size 128\*128 pixels with 3 channels.

## 2. Techniques

### 2.1 Convolution Layer

Convolution neural networks are special networks which take advantage of the fact the input consists of images. In contrast

to regular neural networks ConvNets have neurons arranged in three dimensions(i.e. height,width and depth of the image). Here depths is also referred as the number of colour channels in the image.

Figure 1 gives shows that convolution layers can be seen as hidden layer in neural networks while the output layer is a vector of size Number\_Of\_Classes arranged along depth dimension.

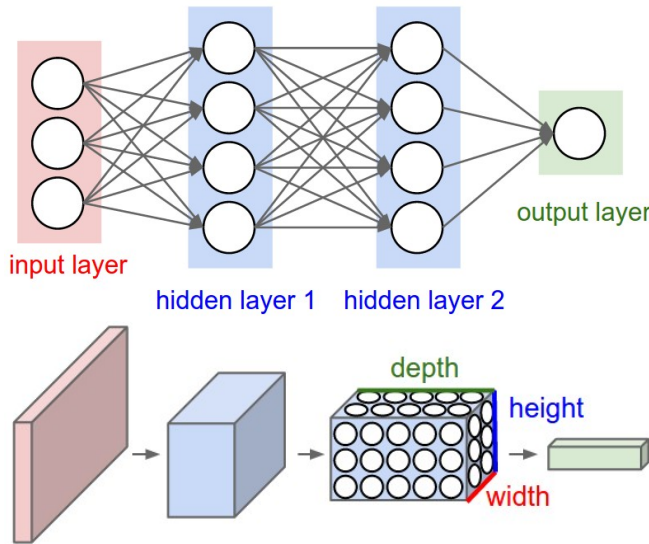


Figure 1. Visualisation of ConvNet

### 2.1.1 Building blocks of ConvNet

As mentioned earlier we have build ConvNet using NiN architecture inspired by GoogLeNet . The three building blocks of the network are: **Convolutional Layer**, **Pooling Layer**, and **Fully-Connected Layer**(similar to regular neural networks). Details about the layers:

- **Convolutional Layer:** Computes the output of filter applied to the local regions of the image. The filter as shown in figure 2 is used to extract spatial features of the image. The efficiency of feature extraction depends upon **depth**(depth of the input to the conv layer), **stride**(number of pixels by which we slide filter over the input matrix) and **zero padding**( zero padding is done along the border of the image to control the size of feature map). Since convolution is a linear operation, **ReLU activation** is often used to learn non-linearity in the data.
- **Pooling layer:** Spatial pooling(aka downsampling) reduces the dimension of each feature map while preserving the most important information. Various methods like max, average sum etc. can be used to perform spatial pooling. In ConvNets pooling layer is stacked over conv layer to reduce the length\*width of the output while preserving the features learnt by different filters. Pooling layer makes the input representation smaller and manageable. Another most important feature of

pooling layer is that it makes the network invariant of the the small distortions and variations in the input image.

- **Fully connected layer:** FC layers are used to compute the scores of classes. As the name suggests it is similar to normal neural networks have all neurons connected to output of previous layers. The output of FC layers is a vector of shape  $[1 \times \text{Number\_Of\_Classes}]$ .

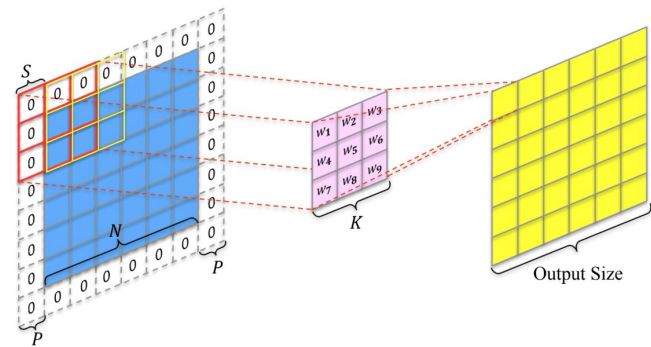


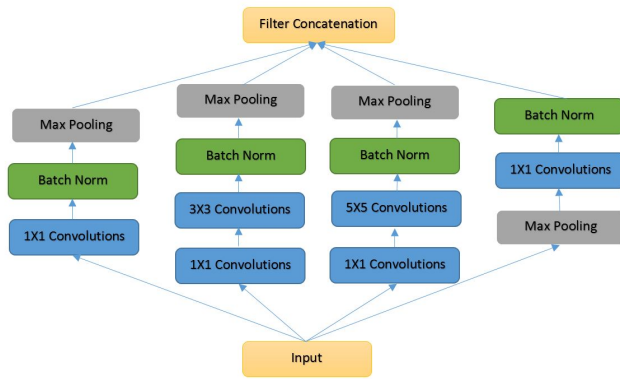
Figure 2. Convolutional Layer

## 2.2 Network Architecture

We have used **Inception architecture** to build the ConvNet in this experiment. Filter size plays a very important role in the performance in ConvNet. But how do we decide if we should use a filter of size 3x3 or 5x5 etc. Rather we create **parallel convolutions** and concatenate the feature maps before feeding it to the next layer. The use of competitive activation units in ConvNet utilises the fact that each smaller ConvNet is capable of doing simpler tasks. Using multiple layers divide the input feature space into a number of regions which is exponentially proportional to the number of layers. Since sub-networks are trained with the samples which fall into one of the regions and as a result it becomes specialised in one set of features. Using parallel layers avoid overfitting as we concatenate the filter outputs and utilise collaborative learning of all sub networks. If the next layer is again an inception module, the feature maps are passed through a mix of convolutions. This way the network is able to learn different features with the help of filters of different sizes and pick the best one. Having smaller convolutions help in learning local features while larger convolutions help in learning high abstracted features.

Figure 3 shows the inception module used for the first layer. We have used a variety of convolutions: 1x1, 3x3, 5x5 convolutions along with a 3x3 max pooling layer. Since larger convolutions use more computations, we have used **1x1 convolutions for dimensionality reduction** of the feature maps. After dimension reduction the feature map is passed to larger convolutions thus keeping the computations lower.

The output of the convolutions is passed to a batch normalisation layer which improves stability and performance of the network. Similar to the concept of normalizing the input to the network this method normalizes the input to every layer so



**Figure 3.** First Inception Layer

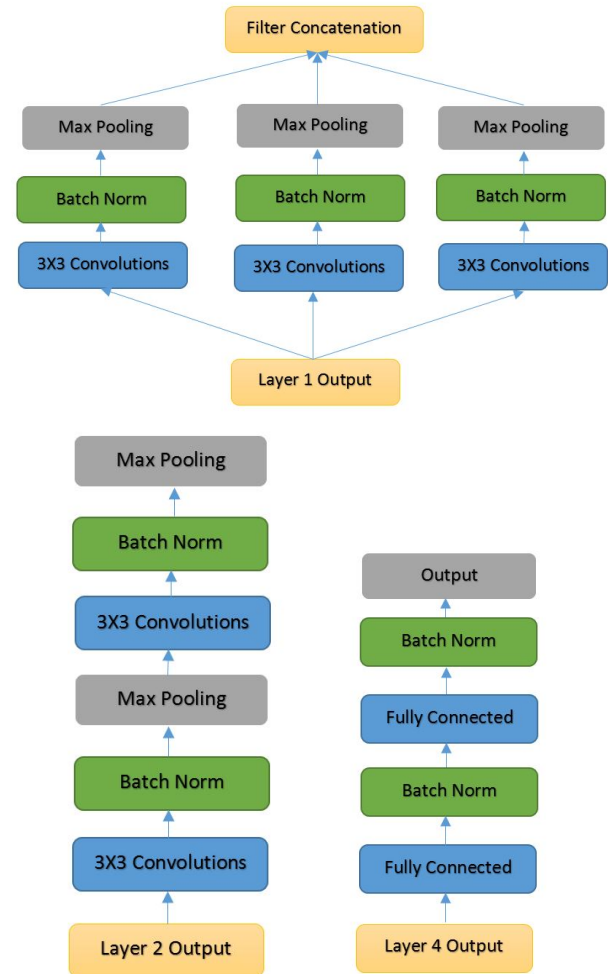
that they have a mean output of zero and standard deviation of one. By normalizing the input before applying the activations it reduces the amount by which the hidden units output shifts. It adds few more steps to the calculation of feed-forward and back-propagation, which slows down the network. But due to normalization of inputs the network converges faster which improves overall speed of the network each scale and also pre-conditions the model.

Finally multi scale filter outputs, weighted by batch normalization layer are combined in the **concatenation layer** before passing on to the next layer. We have used two inception layers to learn the low level features of the image. As shown in figure 4 further it was stacked with two convolutional layers to recognise higher level features in the image. As the input is passed via multiple conv-layers the network learns more complex features and increases the prediction accuracy.

Using conv-layers the network is able to learn both low level features and high level abstractions in the image. We use fully connected layers at the end of the network and outputs the N dimensional vector where N is the number of classes to be predicted. We have used **softmax** to find the class which is best suited to the input image. Fully connected layers connect to the out of the previous layer (which is activation map of the high level features) and find the features which are most suitable for a particular class. FC layer uses the most correlated features for a particular class and learns weights so that we get correct probability for the different classes when it performs product of weights and output of previous layer.

### 3. Experiments and results

An experiment was run to determine the optimal settings for a number of hyperparameters. These hyperparameters are network architecture, regularization, iteration and batch size. For the first hyperparameter, sophisticated architectures outperformed basic architectures. The introduction of multiple convolutional layers, as well as layer 'inception', raised out-of-sample performance considerably. The use of parallelized convolutions of different sizes meant that different streams could concentrate on extracting different features, and this capability was reflected in better performance.



**Figure 4.** Second Inception Layer, convolution layers and fully connected layers

The second hyperparameter, quickly became necessary as the network architecture exploded the count of trainable variables. In order to prevent these from overfitting, three regularization devices were used. Firstly, the model weights were penalized using L2 regularization. This suppressed extreme coefficient values in both the convolutional and fully-connected layers. L2 was eventually chosen as L1 produced sparsity, which reduced weights to zero. Secondly, batch normalization was employed in all convolutional and fully-connected layers. Batch-normalization was applied before activation functions, and was useful in preventing exploding or vanishing gradients. Lastly, a slight dropout probability was applied to the first fully-connected layer. All of these techniques improved out-of-sample performance when training accuracy approached the ceiling.

The third and fourth hyperparameters were set by trial and error. Iteration count was kept at 10,000 and batch size was 128. Lower values did not guarantee convergence and higher values resulted in overly-long training processes. Additionally, since the count of classes was so high, it was important to

ensure that there was sufficient chance of all classes appearing in any given training batch.

Once the hyperparameters were established, the final version of the network was trained. The results achieved are explored below.

### 3.1 Primary Metrics

Out of sample accuracy was 86.649%. This was a strong result but considerably lower than in-sample performance, which was 95%. Precision was 87.545%, Recall was 86.649% and F1 score was 96.64995%. All results were calculated on the test set and multiclass averaging was performed according to model weights. In multi-class problems it is always harder to interpret these metrics, since there is no clear null case. This is especially true given that all classes are of the same frequency, since weighting in this instance equates to a flat average. In reality results may differ, as some letters are more common than others.

### 3.2 Extensive analysis

#### 3.2.1 Confusion Matrix

The confusion matrix is an effective visualization of model performance. From the visualization provided in figure 5, some interesting observations emerge. Firstly, while the model is very accurate there are some classes where it is quite weak. For example, for the first class recall was 69% and precision was 79%, both far below average. The reason for this is that the first class is the number "0", and is very similar to the letters "O" and "o". Particularly with the diversity of fonts in the dataset, the model is having difficulty discriminating between similar-looking characters. This difficulty extends to cases - there is a striking correlation in the confusion matrix as classes are misclassified with a class exactly 26 steps away. The reason for this is confusion between upper case and lower case characters - this trend stops abruptly when classes cross over into numbers. Letters like "X": "x", and "Z": "z" in particular suffered from this problem.

Both these errors show the importance of context - a human reader would not make the mistake between capital "O" and zero largely due to whether it's in a context of numbers or letters. Unfortunately context is not something available to this model, so there is a performance ceiling. The confusion matrix (figure 5) of the network's performance on the validation data suggests that the model struggles to recognise classes 6 and 4 - there are more incorrect predictions of data in these classes than correct ones. Most other classes, however, are predicted well and this reflects the high accuracy scores explored in the previous section.

#### 3.2.2 ROC and ROC-AUC

The Response Operator Characteristics curve can be generalised to multiclass problems via a similar weighting method to the primary metrics discussed above. Weighting the AUC of individual ROCs gives an aggregated ROC AUC value of 98.15% This is much higher than the primary metrics given above, and reflects the relative uncertainty of some of the

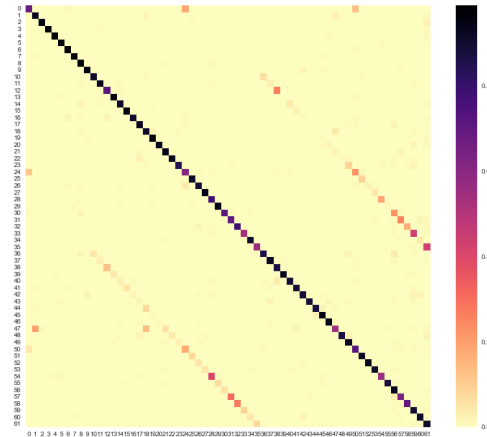


Figure 5. Confusion Matrix

model's predictions, where second and third place have been given a high probability too. This stems from the ambiguity in the label between similar cases and figures discussed above. The individual ROC curves are provided in figure 6.

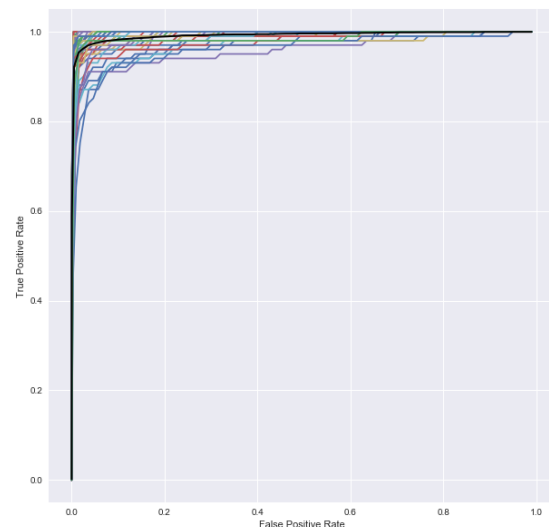


Figure 6. ROC-AUC

## 4. Discussion

In terms of design of the network we can see that the use of collaborative multi-scale convolution produces more accurate results as compared to conventional ConvNets. A better performance of Inception Style model can be attributed to the collaboration of multiple parallel networks. It is important

to note that the number of parameters is exponentially related to the number of features in training set. Inception style model has fewer parameters and it trains much faster using the collaborative approach.

## 5. Conclusions

This study has demonstrated a functioning ConvNet with some inception modules. It has performed well on an example dataset and meet expectations based on ConvNet's performance on held out data. Batch normalisation also helped in significant increase of network performance.

The performance of the ConvNet gives solid evidence that multiple networks are able to learn the sparsity in the data. The biggest advantage of using inception layer is significant decrease in the collaborative learning of different filters. As further study we would like to increase the depth of the networks and use filters to learn high level features to improve image classification of network.

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## 6. Appendix

### 6.1 Instructions on how to run code

Following python packages are used for creation of neural network:

- numpy
- pandas
- h5py
- matplotlib

- seaborn

We used windows machine to run this neural network. On following configuration it took around 90 minutes to execute the code:

- Operating system: Windows 10
- Processor: Intel Core i7-4600 CPU @ 2.10GHz
- RAM: 8.00 GB

Unzip the zip file submitted as part of assignment and follow following steps to execute the code.

#### 6.1.1 Data Setup

Copy following files from <https://canvas.sydney.edu.au/courses/2442/assignments/39353> to Input folder

- train\_128.h5
- train\_label.h5
- test\_128.h5

#### 6.1.2 Output

Output file with predicted labels for test file would be copied in Output folder. Name of the output file with predicted labels: Predicted\_labels.h5.