

Capstone Project

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Definition

Project Overview

In this project, I have trained a model that can decode sequences of digits from natural images used convolutional neural network. I have first tried MNIST dataset to train the models to see how well the model performs. I then train the model with Street View House Number (<http://ufldl.stanford.edu/housenumbers/>) data. And try to predict the digit from the images that contains numbers. The result is analyzed and some improvements are proposed.

Problem Statement

Detecting hand written or crafted multi digit numbers from real-world image or picture has number of applications such as Google street view housing number detection. However, it is usually hard for the computer to understand numbers from visual images. The problem is break down to 2 parts.

- How to detect number from visual data
- How to detect multiple digit numbers from visual data

Metrics

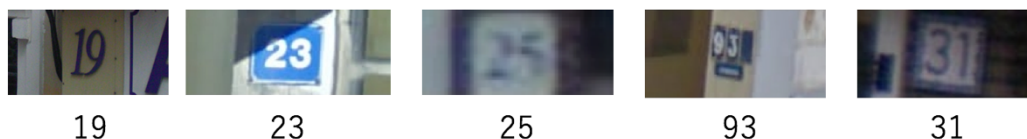
The metrics is fairly straight forward. I will prepare some pictures with hand written multi digit number and feed those to the model. I will measure how many of those numbers are predicted correctly. I think humans are very good at detecting multi digit numbers from visual image in general. So I will try to be as good as at least 90% of the detection.

Analysis

Data Exploration

The data used is downloaded from <http://ufldl.stanford.edu/housenumbers/>.

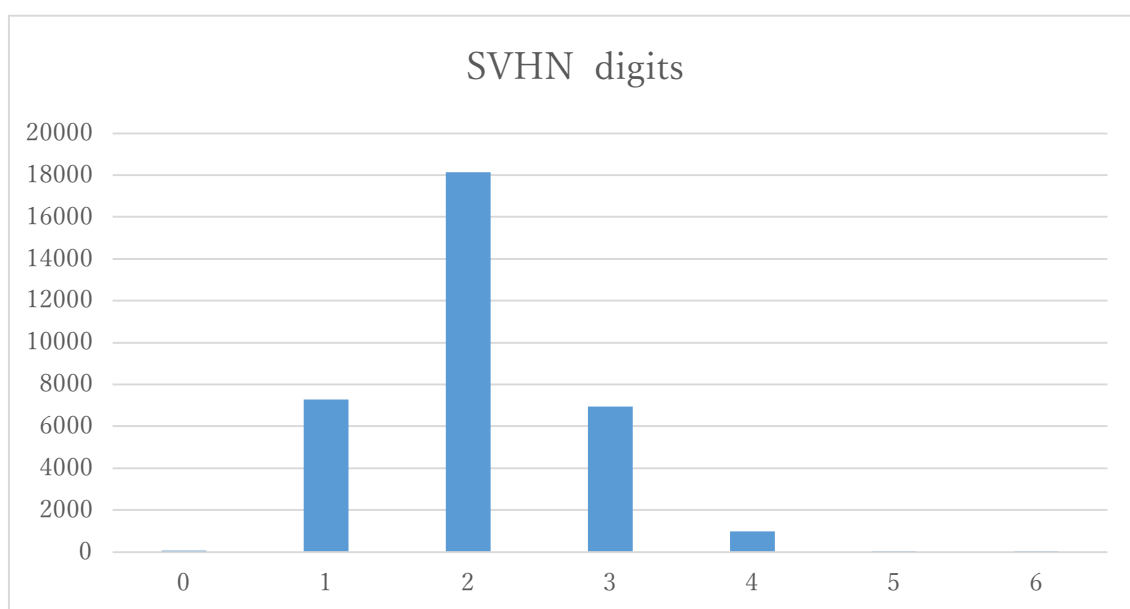
Below shows some of the data and labels downloaded.



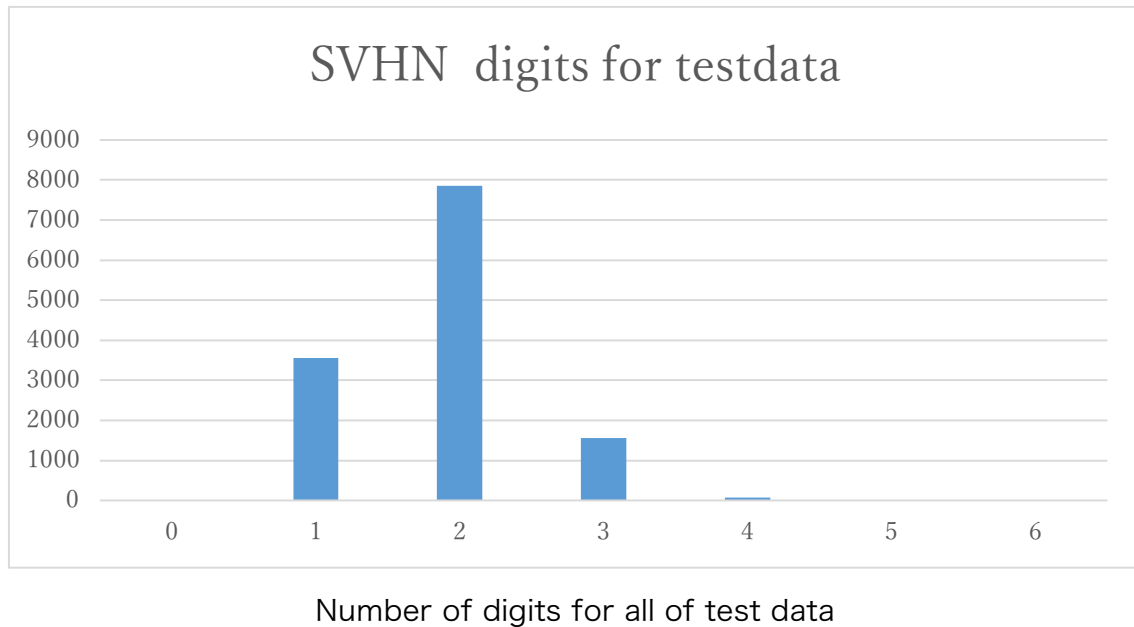
The picture has multi-digit numbers. The dimensions of picture are not organized and some of the numbers are fairly blur.

Below are the key statistical features of the data obtained.

	Training data	Test data
Number of data points	33402	13068



Number of digits for all of the training data

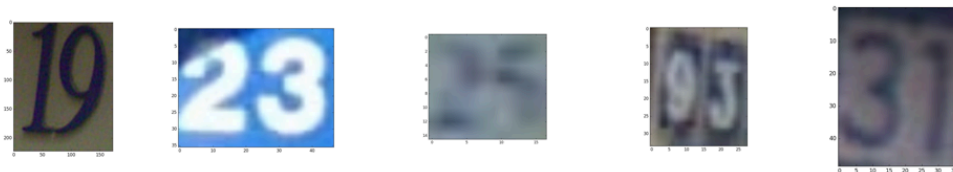


Exploratory visualization

The data comes with pre-defined information about how where all numbers reside inside of picture.

I have extract numbers from images based on the box to train the model.

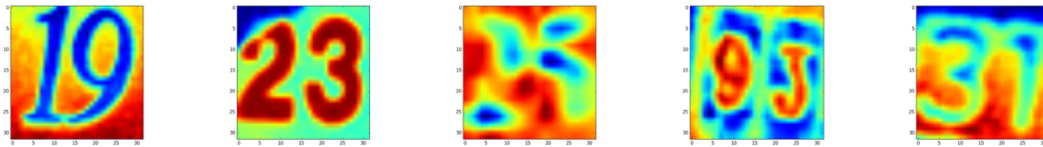
Below is the some of the extracted data.



For models to be trained easily and initialization of weights and biases, all pixels in images are then scaled such that means to be 0 by below formula.

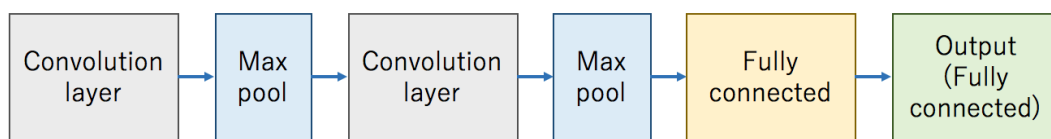
$$pixel = \frac{(pixel - 128)}{255}$$

Finally, image is resized to 32 * 32 pixels.
Some of the processed data looks like below.



Algorithms and Techniques

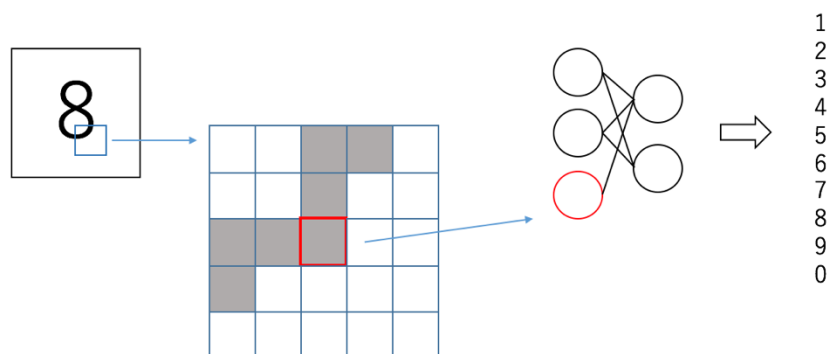
The algorithm I have used in this project is convolutional neural network which is suited for image recognition. Below is the overall architecture of the system.



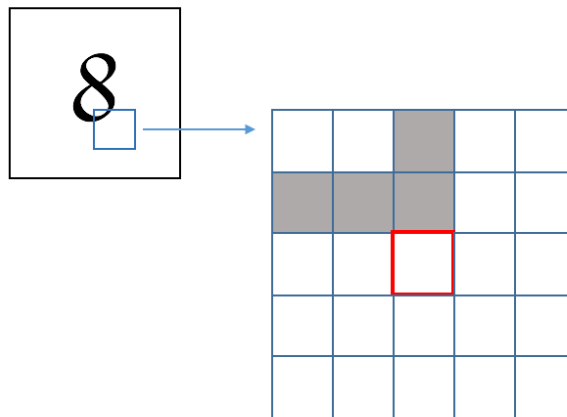
The explanation of each layer is outlined below.

Why convolution?

In traditional neural networks, all pixel of data is input. If 10 * 10 pixels image, there are 100 input to the network.



This may work just fine depending on the application, but there could be weak for the image which is distorted for example by using different fonts. This is illustrated by below picture.

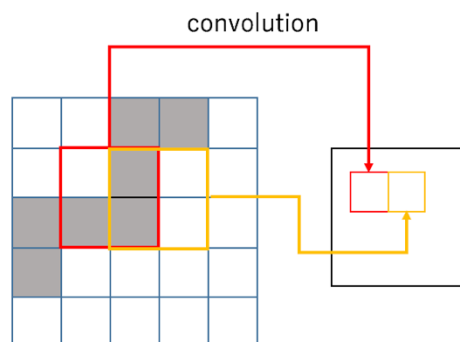


The same number 8 is the input, but same exact input pixel has different value.

Overall shape of input is resembling so maybe we can improve the neural network performance by treating some area of as input instead of 1 pixel. This data preprocessing idea is so called convolution.

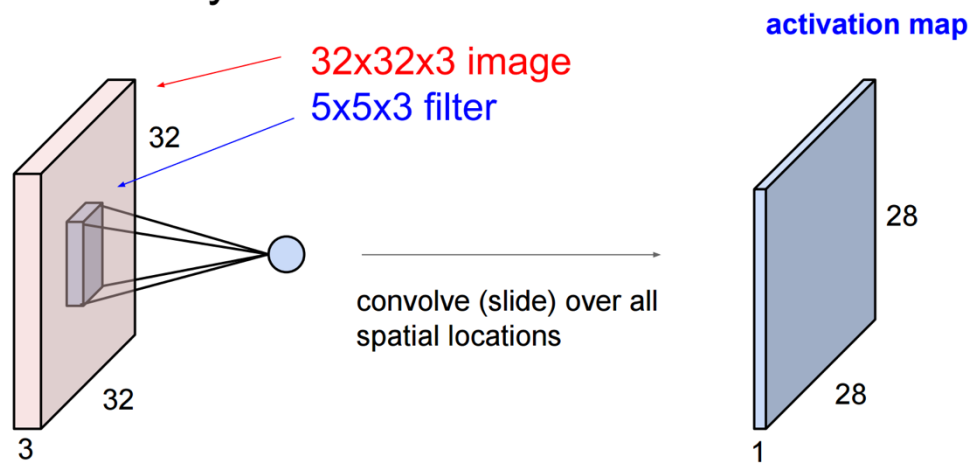
What is convolution?

With convolution, small area (pre-fixed width and height) are taken from original picture and this area of information is “convoluted” as new data point.



The process is iterated through all the pixels of the original data to create new data. Below picture shows how $5 \times 5 \times 3$ filter create new data of $28 \times 28 \times 1$ from $32 \times 32 \times 3$ original image.

Convolution Layer

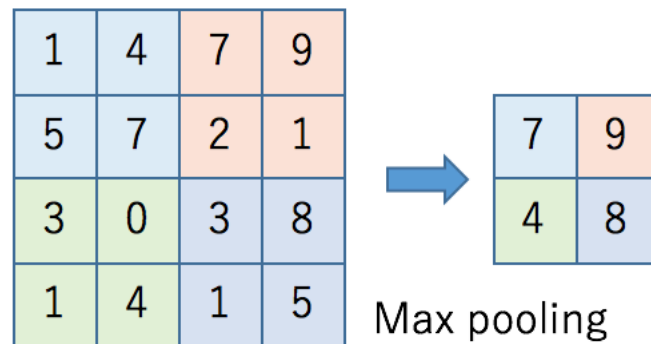


from http://cs231n.stanford.edu/slides/winter1516_lecture7.pdf

The created new data is then process through normal neural network for recognition of the image.

Pooling

Pooling is a function to reduce spatial size to reduce the amount of parameters and computation. Hence it is also to control overfitting. It is common to insert pooling layer in between convolutional layers. In this project, max pooling is used between convolutional layers which takes the maximum of all the data in given area. Example of 2×2 pooling is illustrated below.

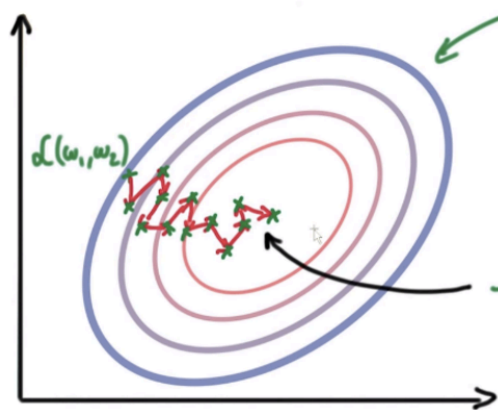


Fully connected layer

Fully connected layer is traditional neural network layer.

Stochastic gradient descent

When training model, parameters of each layer are adjusted through iteration to get optimal performance. For doing this, loss of the model is defined as sum of differentiable equation. Gradient descent algorithm works as to minimize this loss at each iteration by taking derivative of loss function and adjust parameter to reduce loss. For not to move parameter too aggressively, it is common that learning rate is defined and only some portion of learning at iteration is reflected. Stochastic gradient descent is the variant of gradient descent and it takes some portion of entire inputs and optimize parameters. This will hugely reduce the burden of computation.



from <https://deeplearning4j.org/updater>

There are many optimizing algorithm and AdaGrad is one of them. It scales alpha learning rate based on history gradients.

Benchmark

The benchmark of this project is Google's paper.

<http://static.googleusercontent.com/media/research.google.com/ja//pubs/archive/42241.pdf>. It states that the accuracy of their system for recognizing street view house number from images taken from real world is over 90%. So I hope my approach will get to somewhat close to that accuracy.

Methodology

Data Preprocessing

Data preprocessing has been done as below procedure.

1. Download data set from the internet
2. Slice the original image to the one containing multi digit numbers
 - 2-1. Slice is done by the outline that comes with the image
 - 2-2. If outline is unclear, the image is not included in the dataset
3. Image color is averaged so that image has only one layer of color
4. Image is resized to 32*32 pixels
5. Each pixel is scaled such that means to be 0

This processed data is used to train and test model accuracy.

Implementation

Tensorflow (<https://www.tensorflow.org/>) is used to implement convolutional neural network. In this project, I have used below as convolutional layers as well as fully connected layer and output layer.

- 5*5*16 convolutional layer
- max pooling
- 5*5*32 convolutional layer
- max pooling
- fully connected layer
- output layer

Output layer has 5 weights and biases for take into account multi-digits recognition.

```
def model(data):  
  
    conv = tf.nn.conv2d(data, layer1_weights, [1, 1, 1, 1], padding='SAME')  
  
    pool = tf.nn.max_pool(conv, ksize=[1, 2, 2, 1], strides=[1, 2, 2, 1], padding='SAME')
```

```

hidden = tf.nn.relu(pool + layer1_biases)

conv = tf.nn.conv2d(hidden, layer2_weights, [1, 1, 1, 1], padding='SAME')

pool = tf.nn.max_pool(conv, ksize=[1, 2, 2, 1], strides=[1, 2, 2, 1], padding='SAME')

hidden = tf.nn.relu(pool + layer2_biases)

shape = hidden.get_shape().as_list()

reshape = tf.reshape(hidden, [shape[0], shape[1] * shape[2] * shape[3]])

hidden = tf.nn.relu(tf.matmul(reshape, layer3_weights) + layer3_biases)


logits1 = tf.matmul(hidden, s1_weights) + s1_biases
logits2 = tf.matmul(hidden, s2_weights) + s2_biases
logits3 = tf.matmul(hidden, s3_weights) + s3_biases
logits4 = tf.matmul(hidden, s4_weights) + s4_biases
logits5 = tf.matmul(hidden, s5_weights) + s5_biases

return [logits1, logits2, logits3, logits4, logits5]

```

There are 5 logits output. Those are softmaxed and cross entropy is calculated and averaged. The loss function is defined as sum of those.

```

logits = model(tf_train_data_set)

loss = tf.reduce_mean(tf.nn.sparse_softmax_cross_entropy_with_logits(logits[0], tf_train_labels[:, 1])) +¥
    tf.reduce_mean(tf.nn.sparse_softmax_cross_entropy_with_logits(logits[1], tf_train_labels[:, 2])) +¥
    tf.reduce_mean(tf.nn.sparse_softmax_cross_entropy_with_logits(logits[2], tf_train_labels[:, 3])) +¥
    tf.reduce_mean(tf.nn.sparse_softmax_cross_entropy_with_logits(logits[3], tf_train_labels[:, 4])) +¥
    tf.reduce_mean(tf.nn.sparse_softmax_cross_entropy_with_logits(logits[4], tf_train_labels[:, 5]))

```

For optimizer, Adagrad optimizer is used. The learning rate is exponential decay.

```

global_step = tf.Variable(0)

learning_rate = tf.train.exponential_decay(0.05, global_step, 10000, 0.95)

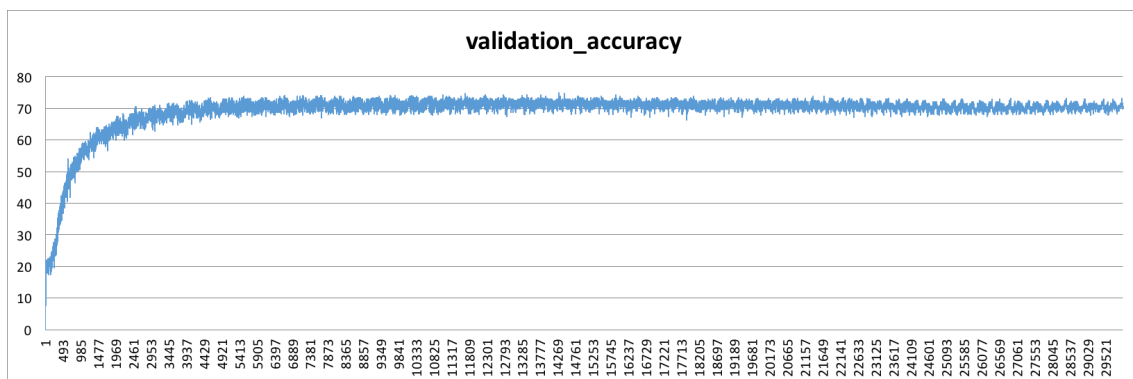
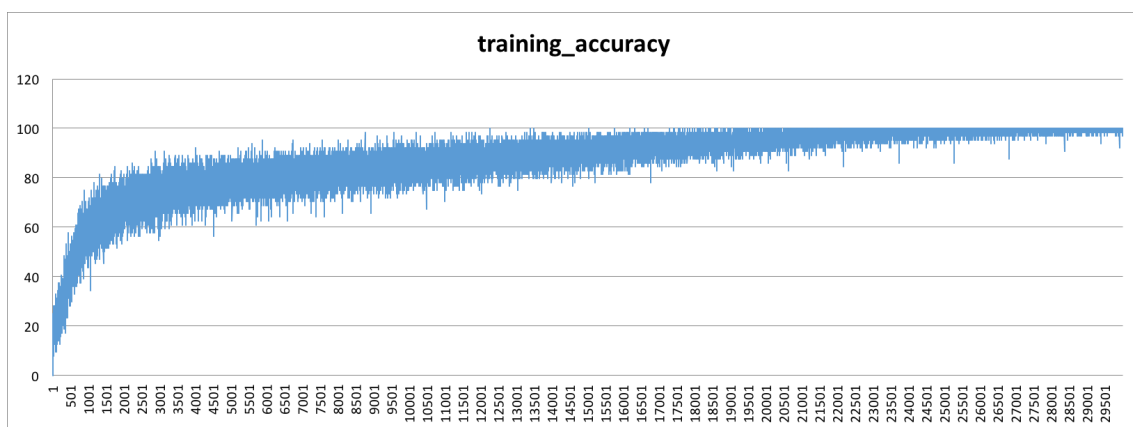
optimizer = tf.train.AdagradOptimizer(learning_rate).minimize(loss, global_step=global_step)

```

Result

Model evaluation

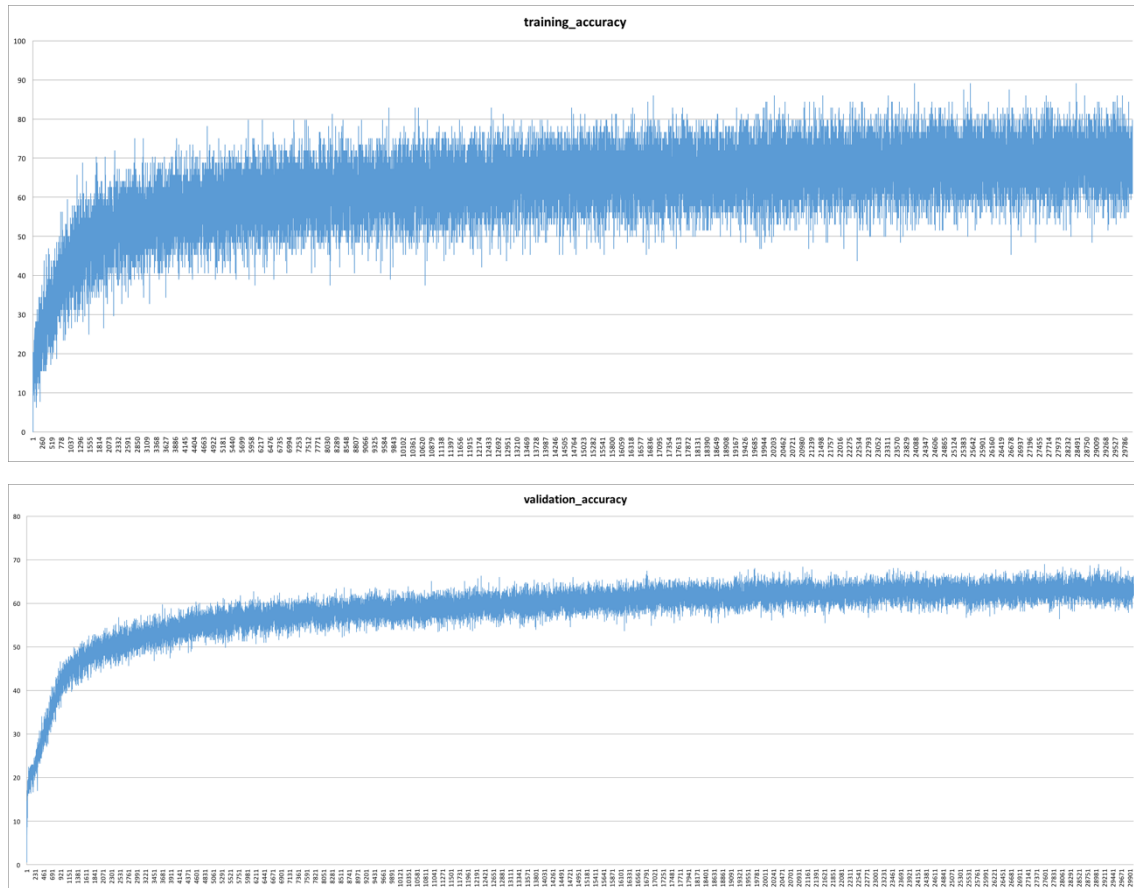
Below is the prediction accuracy for training data set and validation data set. The training is done 30,000 times. Accuracy is calculated as correct prediction divided by number of data times 100. Data is regarded as correctly predicted when all digit matches exactly.



As it can be seen, training accuracy almost get to 100% whereas validation set is saturated to be about 70%. I think this could be due to overfitting of the model.

For the model being overfit, I have added dropout to improve model performance. Dropout is added between 2nd convolutional layer and fully connected layer. The dropout factor is 0.5.

Below shows the accuracy of training and validation data.



The accuracy of both training and validation did not improve and both accuracy is around 60%. I think this could be because learning becomes slow and it requires more data and training steps to get to performance convergence.

Justification

Below pictures are some of the test data and predicted numbers.



Red number shows the content in the label which are provided with the original dataset. As it can be seen, model is making right predictions. However, the label itself is not representing correct number of the picture. I think the data labeling needs to be improved before training of the data.

Conclusion

The convolutional neural network model is trained for recognizing multi-digit numbers from pictures. While model shows reasonable accuracy for training data, it should be improved to be used in the real world applications.

Improvements may be achieved by

- Collect more data
- Train model more
- Adjust hyper parameters

Also deploying this application to mobile app would be next step to be addressed.