

CS486 Project: Comparison of Image Recognition Algorithms

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Abstract

Image recognition has been a popular field in Artificial Intelligence. Many real-world problems such as self-driving vehicles and medical diagnosis rely on image recognition. Researchers and programmers have come up with various neural network paradigms, such as Convolutional Neural Network(CNN), k-Nearest-Neighbours, and Recurrent Neural Network(RNN). Both CNN and RNN are popular algorithms in classification problems. The main reason that RNN is chosen is due to its recurrent feature. RNN is able to discover the internal sequential relation between images. CNN is chosen since it is one of the most widely-used algorithm in the field of image recognition. Therefore, this paper will use Fashion-MNIST data set to run image recognition using CNN and RNN algorithms and compare the time complexity, memory usage, and test set accuracy of the results.

Introduction

Catalyzed by the creation of ImageNet, the image recognition technology has advanced remarkably in recent years. The image recognition technology is the foundation of many emerging applications such as autonomous vehicles, augmented reality, medical diagnosis, etc. As the technology becomes more mature, the image recognition market is rapidly expanding. According to Markets and Markets (2017), the image recognition market is estimated to grow from 15.95 billion USD in 2016 to 38.92 billion USD in 2021. The fact that the market size would be more than doubled in five years shows the significance and potential of the image recognition technology.

Recent rapid development of the image recognition technology is largely thanks to the creation of an enormous image dataset named ImageNet. The idea was conceived by a university professor Fei-fei Li in 2006 after she realized the limitation of all the image datasets at the time: they were too limited in size and variety. She thought, to make advancements in image recognition, increasing the quality and quantity of training data might help more than improving on the algorithm alone. The ImageNet dataset was born in 2009, and an annual competition using the dataset as training data was started the next year. People quickly re-

alized that their algorithms performed better when trained on ImageNet compared to when trained on traditional image datasets. Since ImageNet contains a large sample of images of a variety of objects, it accurately reflects the performance of algorithms in the real world. The error rate on the test set has decreased year over year, demonstrating the steady improvements of image recognition algorithms each year.

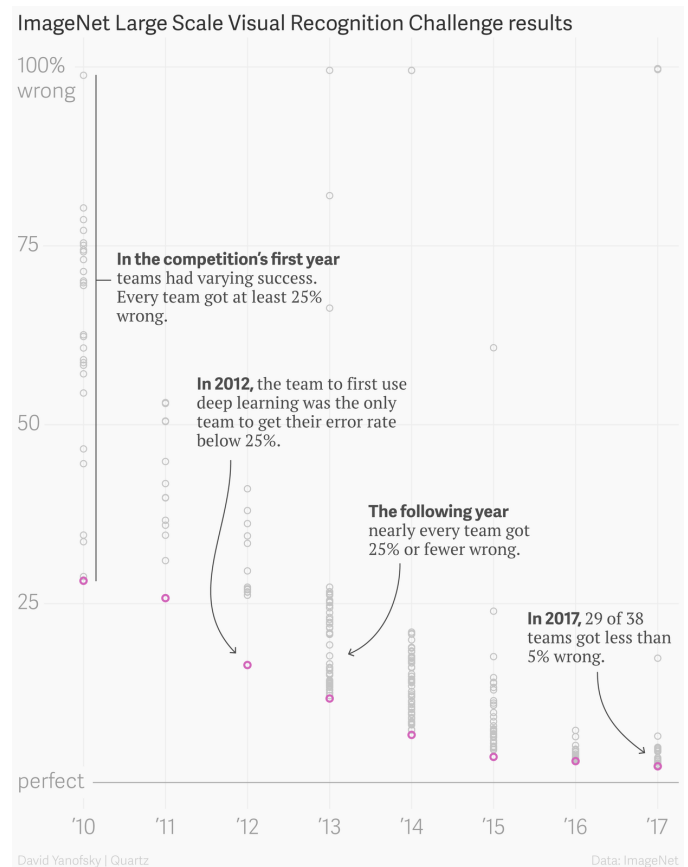


Figure 1: Error Rate of Image Recognition

In 2006, a university professor Fei-fei Li recognized the limitations of all the image databases at the time: they had limited number of classes of images and each class has very

limited number of images. She recognized that instead of trying to come up with a better algorithm, improving the quality of the training data might help more to make breakthroughs. The ImageNet database was born in 2008, and an annual competition using the database as training data with the same name was started in 2010. Quickly, people discovered that their algorithms performed better when trained with ImageNet compared to traditional image databases. Since ImageNet contains a large sample of images of a variety of objects, it accurately reflects the performance of image recognition algorithms in the real world. The test accuracy of the competition has increased year over year, showing how much image recognition technology advanced.

The most notable advancement in image recognition over recent years is Deep Convolutional Neural Network, an algorithm devised by used to enter the ImageNet competition in 2012. It performed marginally better than other algorithms...

Another field that has been gaining traction over recent years is augmented reality. Augmented reality superimposes information or visuals on the surroundings that users perceive. It has applications in medical visualization, maintenance and repair, annotation, robot path planning, entertainment, and military aircraft navigation and targeting. Augmented reality relies heavily on image recognition technology.

Related Work

(Cios, Shin 1995; Xiao, Rasul, Vollgraf 2017) These two papers are focusing on the general topic and the data set of image recognition using neural network. In the first paper, the proposed neural network algorithm, namely image recognition neural network, is designed to classify objects through the attributes of the images. This algorithm will take a grey-scaled image as an input and return an appropriate output to which the algorithm believes the given image matches. As an extension of the first paper, the second paper discusses the dataset that we will use in this project, named Fashion-MNIST. It contains 70,000 grey-scaled images with a size of 28×28 . This paper also states that Fashion-MNIST is considered as a better dataset for problem of image recognition using neural network compared to the old MNIST data set. (Simonyan, Zisserman 2015; Hijazi, Kumar, and Rowen 2015; Razavian, Azizpour, Sullivan, Carlsson 2014; Chen, Han, Wang, Jeng, and Fan 2018; Hou, Wu 2016; Lo, Chan, Lin, Li, Freedman, Mun 1995) All of these paper discuss image classification and they all manage to train the model using CNN. CNN is widely used in pattern- and image-recognition problems because they have significant benefits over other neural network techniques. In general, CNN is a good choice for image recognition because of the following properties. First, it avoids the influence of image distortion on prediction result. Second, it uses less amount of memory compared to other Neural Network algorithm. Third, CNN reduces the number of parameters dramatically; thus, training time is significantly reduced. These papers describes the basic CNN algorithm and the hidden layers to be used for a CNN algorithm. Some of the other paper discuss different applications of CNN but in the field of image recognition

and demonstrate how CNN is used in the real world to solve problems.

(Le, Jaitly, Hinton 2015; Zhang 2018) This paper talking about RNN and how RNN is used to solve problems. RNN is a powerful and natural method to map a sequence of input to a sequence of output. The second paper by Zhang discusses how CNN has been widely used in the field of image recognition, but there are still limitations of the current CNN image classification paradigm. For example, CNN cannot handle images with different sizes correctly. Thus, Zhang proposed a new paradigm named Scaled Recurrent Neural Network(SRNN) that is based on RNN embedded in the current paradigm, which is able to solve leftover problems of CNN.

Methodology

Due to fast development of artificial intelligence and neural network,multiple algorithms are applied in the field of image recognition. Performance can be different based on various implementation of algorithm and training environment. This project aims to analyze the performance of two different algorithms: Convocational Neural Networks(CNN) and Recurrent Neural Network(RNN).

The data set we're using is Fashion-MNIST. Fashion-MNIST is a dataset of Zalando's article images, which consists of 60,000 examples and a test set of 10,000 examples(Han Xiao, 2017). Each image is a 28×28 grayscale image, and each has a label associated from different classes of clothing. This data set is a great selection for image recognition since it differs from MNIST which is too easy and overused and doesn't represent modern computer vision tasks. In addition, Fashion-MNIST contains a large number of training and testing sets and should be able to yield a reasonable result in term of algorithm comparison.

The first algorithm is CNN, which is a fully connected network such that each neuron in one layer is connected to all neurons in the next layer. It simplifies complex patterns derived from training data. CNN has complex architectures and it is usually constructed with four types of layers: convolutional layers, pooling layers, non-linear layers, and fully connected layers (Hijazi et. al. 2015). The purpose of the convolutional layers is generally to extract the features of the input. According to Hijazi(2015), the pooling layers are to reduce distortion and noise that may affect the process of image classification. Non-linear layers relies on activation function to match similar identification in each hidden layer. In the CNN algorithm we used in this project, the activation function used is ReLU. Lastly, the fully connected layer is the final layer that combines all the previous features and determine a target output based on the information (Hijazi et. al., 2015).

A simple and abstract mathematical formulation of CNN structure can be represented by the following:

$$x^1 \rightarrow w^1 \rightarrow \dots \rightarrow x^{L-1} \rightarrow w^{L-1} \rightarrow x^L \rightarrow w^L \rightarrow z$$

This simple formulation demonstrates how CNN proceed forward layer by layer. x^1 is the initial input and it goes through process with weight w^1 . This process will continue until it outputs x^L . In the CNN algorithm chosen for this

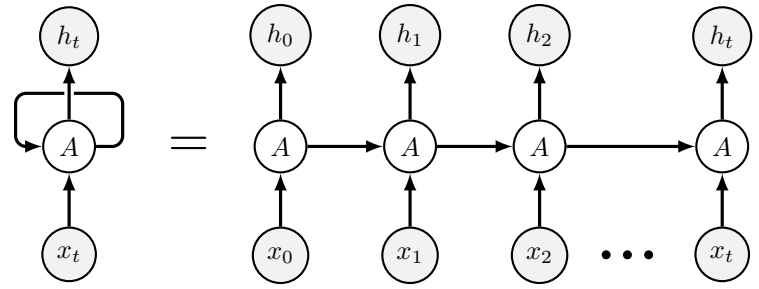
paper, it will be using two built-in Conv2D layer provided by Keras (Simonyan, 2015). The first Conv2D layer creates a convolutional kernel with a 3-by-3 kernel size and uses ReLU as the activation function with the input shape matching the Fashion-MNIST dataset. Following the first Conv2D layer, there is another Conv2D layer using ReLU activation function again. Then, the algorithm applies MaxPooling2D to find the max from a non-overlapping 2-by-2 block to filter out noise and distortion in the dataset while maintaining the features. A Dropout layer is used with a rate of 0.25 for the resulting neural network to have better generalization and be less likely affected by data overfitting. Then the algorithm will apply a Dense layer which is also known as a fully connected layer to connect and combine previous features and produce an output. The following is sample code for Convolutional Neural Network obtained from Xiao:

```
1 num_classes = 10
2 input_shape = (1, img_rows, img_cols)
3 model.add(Conv2D(32, kernel_size=(3, 3),
4     activation='relu',
5     input_shape=input_shape))
6 model.add(Conv2D(64, (3, 3), activation='relu'))
7 model.add(MaxPooling2D(pool_size=(2, 2)))
8 model.add(Dropout(0.25))
9 model.add(Flatten())
10 model.add(Dense(128, activation='relu'))
11 model.add(Dropout(0.5))
12 model.add(Dense(num_classes, activation='softmax'))
```

CNN is considered as a good choice for image recognition problems in general. It is widely applied in related problems. Also, as stated in related work section, it has several known advantages regarding to image recognition problem, such that the influence of image distortion on prediction result will be avoided. Thus, we will evaluate its performance in this paper.

The second algorithm is RNN. RNN uses neural network to map an input sequence to an output sequence. In another word, it is designed to solve problems in term of predicting sequence. RNN is generally a good choice when dealing with classification problem. Since this report is working on image classification, RNN is chosen as one of the algorithm.

Although RNN is usually hard to train, it is able to store information in the form of activation and it is able to learn sequential data. The reason for this is that, after feeding one datapoint, it will generate a state that contains some useful information from this datapoint, and use it as input when feeding the next datapoint. Thus, neural network will understand the sequential relation between datapoints, and generate its output accordingly. Below is a mathematical representation of RNN:



In the RNN algorithm chosen for this paper, it will be using one SimpleRNN Layer with 100 hidden units. It selects random normal distribution with standard deviation 0.001 as its initial weight distribution or kernel initializer and identity matrix with gain 1.0 as its recurrent initializer. Then, the algorithm will apply a Dense layer or fully-connected layer with 10 classes and activation function softmax. The following is sample code for Recurrent Neural Network:

```
1 num_classes = 10
2 hidden_units = 100
3 model.add(SimpleRNN(hidden_units,
4     kernel_initializer=initializers.RandomNormal(stddev=0.001),
5     recurrent_initializer=initializers.Identity(gain=1.0),
6     activation='relu',
7     input_shape=x_train.shape[1:]))
8 model.add(Dense(num_classes))
9 model.add(Activation('softmax'))
```

RNN is considered in this paper because of its recurrent feature. RNN is able to discover the internal sequential relation between images. We believe that the history information or state will help us classify current image and improve recognition performance.

Two algorithm can be compared in lots of different aspects. For neural network algorithms, two aspects are relatively important indicators of performance: Accuracy and Resource Usage. For accuracy, this project will test the prediction accuracy using different values of parameters for each algorithm. For example, we will test the influence on accuracy if we change the number of training epochs each algorithm will run in test. Related result will be concluded by comparing two algorithms distribution of prediction accuracy. For resource usage, given the same training set and parameters, time efficiency and space efficiency will be considered and compared. For example, we will test the difference of time and memory used by running two algorithms with the same number of epochs. We set up two test environments with Windows 10 operating system and MacOS Mojave. To test these two algorithm efficiently, we use TensorFlow with GPU support on Windows 10 and TensorFlow with CPU on MacOS while running python in bash terminal. Following are the configurations of Windows 10 and MacOS system respectively:

```
1 System: Windows 10
2 CPU: i7-6700hq Memory: 8G
3 GPU: GTX 960m Memory: 2G
4 TensorFlow: tensorflow-gpu v1.14.0
5 CUDA: v10.0.130
```

6 cuDNN SDK: v7.6.1.34
7 Python: v3.7.3 64bit

For your information, CUDA and cuDNN SDK are softwares required to run TensorFlow with GPU support on Nvidia graphic card in Windows 10 testing environment.

1 System: MacOS Mojave version 10.14.4
2 CPU: i5-7267u Memory: 8G
3 GPU: Intel Iris Plus Graphics 655 Memory: 1536MB
4 TensorFlow: tensorflow 1.13.1
5 Python: 3.7.3 64bit

References

- MarketsAndMarkets 2017 *Image Recognition Market*. Retrieved From: <https://www.marketsandmarkets.com/Market-Reports/image-recognition-market-222404611.html>
- Dachis, A. 2019. *Googles EfficientNet Offers up to a 10x Boost in Image Analysis Efficiency*. Retrieved From: <https://www.extremetech.com/computing/292272-googles-efficientnet-offers-up-to-a-10x-boost-in-image-analysis-efficiency>
- Figure 1: Quartz 2017 *Image Recognition Using Scale Recurrent Neural Network*. Retrieved From: <https://arxiv.org/pdf/1803.09218.pdf> arXiv:1803.09218
- Xiao, H; Rasul, K; Vollgraf, R. 2017. *Fashion MNIST: a Novel Image Dataset for Benchmarking Machine Learning Algorithms*.
- Hijazi, S; Kumar, R; Rowen, C; IP Group; Cadenc 2015. *Using Convolutional Neural Networks for Image Recognition*. arXiv:1708.07747.
- Cios, K.; Shin, I; 1995. *Image Recognition Neural Network: IRNN*.
- Simonyan, K.; Zisserman, A.; 2015. *Very Deep Convolutional Networks for Large-Scale Image Recognition*. arXiv:1409.1556.
- Razavian, A S.; Azizpour, H.; Sullivan, J.; Carlsson, S. 2014. *Very CNN Features off-the-shelf: an Astonishing Baseline for Recognition*. IEEE.
- Chen, Y N.; Han, C C.; Wang, C T; Jeng and Fan. 2018 *The Application of a Convolutional Neural Network on Face and License Plate Detection*. IEEE.
- Lo, S.; Chan, H.; Lin J.; Li H.; Freedman, M.; Mun, S.; 1995 *Artificial Convolutional Neural Network for Medical Image Pattern Recognition*. Elsevier Science Ltd.
- Le, Q.; Jaitly, N.; Hinton, G.; 2015 *A Simple Way to Initialize Recurrent Neural Network of Rectified Linear Units*. arXiv:1504.00941
- Hou, L.; Wu, Q.; 2016 *Fruit Recognition Based On Convolutional Neural Network*.
- Xiao, H; Rasul, K; Vollgraf, R. 2017 *Fashion-MNIST*. Retrieved From: <https://github.com/zalandoresearch/fashion-mnist>
- Dong-Qing Zhang 2018 *ImageNet Large Scale Visual Recognition Challenge Results*.