My Little Convnet: Tensors are Magic

Final Report for CS39440 Major Project

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Declaration of originality

In signing below, I confirm that:

- This submission is my own work, except where clearly indicated.
- I understand that there are severe penalties for Unacceptable Academic Practice, which can lead to loss of marks or even the withholding of a degree.
- I have read the regulations on Unacceptable Academic Practice from the University's Academic Quality and Records Office (AQRO) and the relevant sections of the current Student Handbook of the Department of Computer Science.
- In submitting this work I understand and agree to abide by the University's regulations governing these issues.

Name .....

Date .....

Consent to share this work

In signing below, I hereby agree to this dissertation being made available to other students and academic staff of the Aberystwyth Computer Science Department.

Name .....

Date .....

Acknowledgements

I am grateful to...

I’d like to thank...

Abstract

Include an abstract for your project. This should be no more than 300 words.

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Chapter 1

Background & Objectives

1.1 Introduction

This project is an investigation into training Artificial Neural Networks for the purpose of image classification and labelling. We will explore alternative approaches in computer vision to solve this problem arriving to the what is considered the current state of the art in machine learning comparing it to a number of different alternatives both contemporary but also historical.

1.1.1 Motivation

Perhaps the first question we might wish to ask ourselves is why we wish to embark on this project in the first place. Computer vision is field of computer science in essence involving extracting information and building models of the real world, this might involve sensors, cameras or perhaps even audio.

There are numerous applications and types of computer vision. The problem we are looking in particular is identifying images and labelling them extracting metadata from the image itself. Naturally this has many applications. Self-driving cars, search engines, and any problem where we need a computer to be able to identify images.

Our interest is particularly related to image acquisition and labelling. Suppose a user has a large set of images and you are looking for a particular one. They know what it is but not its title. Or perhaps its title does not hold semantic meaning to them, but wish to search the semantics of the image itself.

1.1.2 Machine Learning and Pattern Recognition

To solve this problem computer scientists set out to devise a set of 'rules' and algorithms that were good at solving these problems. Eventually it became apparent that no single algorithm could solve the problem for all sets of cases as the 'rules' change between cases. The rules that define a cat are different than what defines a dog and so on so one would have to write rules for each edgecase. Where you needed to solve this kind of problem one would analyse the data they expect to receive and think of features they are interested in extracting. This approach is still used for some CV problems.

A solution that emerged for this was machine learning (ML), that is sets of algorithms that could be used to derive the rules based on data. Most machine learning algorithms work by identifying patterns in the data either via statistical analysis as in Bayesian Learning or other means. Suppose you have a set of data describing cats and dogs. Cats are small, but there is both small and large types of dogs, most cats have pointed ears while some dogs have floppy ones. A machine learning algorithm would process a set of examples of cats and dogs then derive patterns that can be used to classify them.

1.2 Background

1.2.1 SVMs and other Machine Learning Alternatives

1.2.2 Artificial Neural Networks

Artificial Neural Networks(ANN) are a type of machine learning inspired by the way some biological organisms process stimulus and learn. In essence an ANN is a very naive emulation of a 'meat computer' with the biological processes being replaced with mathematical approximations of the actual process of biological neurons.

Being that these are only approximations, they have several components which help them function and emulate select processes of real neurons.

1.2.2.1 Advantages and Disadvantages of ANNs

ANNs have many advantages and disadvantages to conventional ML methods some of the most important ones include:

- They do not require a feature extraction step
- Can easily be applied in many different problems

It is possible to apply ANNs in to solve many problems by just feeding in appropriate training data and get reasonably accurate results in some cases, matching the state of the art for that problem. As for disadvantages:

- They are difficult to train both in terms fo requirements and speed.
- It is comparatively difficult to gain insight on why a neural network has learned something.

Recent advances in ANNs have greatly improved on both of these areas. GPU compute in particular has made training quite large neural networks practical on consumer computers. There is also very active research at the moment in improving insight and visualising neural network decisions. We will talk in more detail about all of this later in our report.

1.2.2.2 Datasets

With most methodologies having data to test against is important. With ML, data is what drives the whole process so to produce any sort of solution to this problem one needs to decide on the

dataset to use. For classification problems a dataset might be a set of inputs and outputs, separated in a set to train on and a set to test performance against afterwards.

For our network we are looking at datasets with actual images with associated labels. There is several of that type of image dataset, we will discuss them in more detail in a later section of this report.

1.3 Analysis

To complete this project we must solve a number of problems and answer a number of questions. As part of our analysis we identified some of them while several others would emerge as we embarked on our project.

1.3.1 Types of ML and ANN architectures used in the past

To start we should look at what models have been successful in the past for this kind of problem. After all this area has several decades of research behind it which we would not be able to replicate from scratch.

Looking at older results also enables us to get a baseline for what our model might be capable of doing and provides goals to hit or exceed. For this report we will be looking at SVMs, Multi Layer Perceptrons (MLP) and Convolutional Neural Networks (CNN)

1.3.2 Architectures of CNN

We need to decide on the architecture of our neural network. For CNN choices appear to be relatively simple with most networks opting for very similar architectures.

1.3.3 Variables to test and optimise

We will need to investigate different ways we can vary our model and attributes that we can change in order to limit the scope of the research area. This process involves, reading documentation for our solutions as well as research into the technology we are using to determine the highest value optimisations to make.

1.3.4 Are CNNs ready for market?

One other interesting question to answer as a conclusion is whether CNNs are ready to be deployed in commercial products and services. Is it possible to produce something robust enough for such uses?

1.4 Research Method

Chapter 2

Experiment Methods

This section should discuss the overall hypothesis being tested and justify the approach selected in the context of the research area. Describe the experiment design that has been selected and how measurements and comparisons of results are to be made.

You should concentrate on the more important aspects of the method. Present an overview before going into detail. As well as describing the methods adopted, discuss other approaches that were considered. You might also discuss areas that you had to revise after some investigation.

You should also identify any support tools that you used. You should discuss your choice of implementation tools or simulation tools. For any code that you have written, you can talk about languages and related tools. For any simulation and analysis tools, identify the tools and how they are used on the project.

If your project includes some engineering (hardware, software, firmware, or a mixture) to support the experiments, include details in your report about your design and implementation. You should discuss with your supervisor whether it is better to include a different top-level section to describe any engineering work.

Chapter 3

Experiment Implementation

To implement our experiments we need to make a series of decision.

3.1 Choice of Platform

To start we need to decide how we are going to implement the neural networks. This involved several steps, of course one would be tempted to write their own implementation for an ANN, however that might be a major project on its own so a better solution is required.

We would like to minimise implementation effort in parts that do not improve the final project as much as possible so a library of some sort is necessary.

3.1.1 Criteria of a Framework

For our framework we wanted something that is both performant but also easy to use. We also want support for the latest ANN features while it needs to work on our workstation.

3.1.2 Performance

One of the greatest developments of the past 8 years in ANNs and machine learning in general is the advent and wide availability of parallel computing. Specifically GPU compute solutions like nVidia's CUDA technology have been invaluable in making Deep Neural Network research viable offering orders of magnitude better training times. Our frameword must run on a GPU.

3.1.3 Ease of use

We would like a library that makes testing an idea quickly, two modern candidates emerged at that point Google's new Tensor Flow software was one of them and was our favourite for the early parts of the project. Keras was another. Both use Python to define models and a backend implementation to do processing

3.1.4 Features

We were not looking for specific features in this part of our project, what we were looking for however was a framework that is used in current research and is geared towards experimental CNNs both Keras and Tensor Flow support similar advanced CNN features which makes them fairly equivalent as a choice. They were both alpha software when the project started but so are most libraries in the field as CNNs are fairly new. We initially settled on Tensor Flow.

3.1.5 Platform Support

Most of the frameworks for this task are designed to work on Linux primarily. Tensor Flow works on Linux and OSX. This was a problem when we were running Windows on our main machine so the initial solution was to run Tensor Flow on a Virtual Machine with Linux Mint. This initially appeared to work well but we quickly discovered issues with this approach. To get good training performance CUDA is required. However CUDA requires a direct connection to the graphics adapter.

A solution we considered was to use Intel's VT-d and pass the PCI-E device of the GPU directly to the VM using the integrated Intel GPU in Windows instead allowing us to use it under a VM but this proved to be too complicated to set up and any other solution was equally complex. We had to abandon Tensor Flow. Keras, supported Windows as well so we ended up switching our efforts to that. This was relatively early on in the project's lifecycle so we could afford to make the change.

3.2 The Stack

In our architecture we ended up having several layers of software contributing to our final software stack.

3.2.1 GPU Drivers and CUDA

Chapter 4

Results and Conclusions

This section should discuss issues you encountered as you tried to implement your experiments. What were the results of running the experiments? What conclusions can you draw from these results?

During the work, you might have found that elements of your experiments were unnecessary or overly complex; perhaps third party libraries were available that simplified some of the functions that you intended to implement. If things were easier in some areas, then how did you adapt your project to take account of your findings?

It is more likely that things were more complex than you first thought. In particular, were there any problems or difficulties that you found during implementation that you had to address? Did such problems simply delay you or were they more significant?

If you had multiple experiments to run, it may be sensible to discuss each experiment in separate sections.

Chapter 5

Critical Evaluation

Examiners expect to find in your dissertation a section addressing such questions as:

- Were the requirements correctly identified?
- Were the design decisions correct?
- Could a more suitable set of tools have been chosen?
- How well did the software meet the needs of those who were expecting to use it?
- How well were any other project aims achieved?
- If you were starting again, what would you do differently?

Such material is regarded as an important part of the dissertation; it should demonstrate that you are capable not only of carrying out a piece of work but also of thinking critically about how you did it and how you might have done it better. This is seen as an important part of an honours degree.

There will be good things and room for improvement with any project. As you write this section, identify and discuss the parts of the work that went well and also consider ways in which the work could be improved.

Review the discussion on the Evaluation section from the lectures. A recording is available on Blackboard.

Appendices

Appendix A

Third-Party Code and Libraries

If you have made use of any third party code or software libraries, i.e. any code that you have not designed and written yourself, then you must include this appendix.

As has been said in lectures, it is acceptable and likely that you will make use of third-party code and software libraries. The key requirement is that we understand what is your original work and what work is based on that of other people.

Therefore, you need to clearly state what you have used and where the original material can be found. Also, if you have made any changes to the original versions, you must explain what you have changed.

As an example, you might include a definition such as:

Apache POI library The project has been used to read and write Microsoft Excel files (XLS) as part of the interaction with the clients existing system for processing data. Version 3.10-FINAL was used. The library is open source and it is available from the Apache Software Foundation [2]. The library is released using the Apache License [1]. This library was used without modification.

Appendix B

Ethics Submission

This appendix includes a copy of the ethics submission for the project. After you have completed your Ethics submission, you will receive a PDF with a summary of the comments. That document should be embedded in this report, either as images, an embedded PDF or as copied text. The content should also include the Ethics Application Number that you receive.

Appendix C

Code Examples

3.1 Random Number Generator

The Bayes Durham Shuffle ensures that the psuedo random numbers used in the simulation are further shuffled, ensuring minimal correlation between subsequent random outputs [6].

```
#define IM1 2147483563
#define IM2 2147483399
#define AM (1.0/IM1)
#define IMM1 (IM1-1)
#define IA1 40014
#define IA2 40692
#define IQ1 53668
#define IQ2 52774
#define IR1 12211
#define IR2 3791
#define NTAB 32
#define NDIV (1+IMM1/NTAB)
#define EPS 1.2e-7
#define RNMX (1.0 - EPS)

double ran2(long *idum)
{
  /*-------------------------------------------------*/
  /* Minimum Standard Random Number Generator        */
  /* Taken from Numerical recipies in C              */
  /* Based on Park and Miller with Bays Durham Shuffle */
  /* Coupled Schrage methods for extra periodicity   */
  /* Always call with negative number to initialise  */
  /*-------------------------------------------------*/

  int j;
  long k;
  static long idum2=123456789;
```

```
static long iy=0;
static long iv[NTAB];
double temp;

if (*idum <=0)
{
  if (-(*idum) < 1)
  {
    *idum = 1;
  }else
  {
    *idum = -(*idum);
  }
  idum2=(*idum);
  for (j=NTAB+7;j>=0;j--)
  {
    k = (*idum)/IQ1;
    *idum = IA1 *(*idum-k*IQ1) - IR1*k;
    if (*idum < 0)
    {
      *idum += IM1;
    }
    if (j < NTAB)
    {
      iv[j] = *idum;
    }
  }
  iy = iv[0];
}
k = (*idum)/IQ1;
*idum = IA1*(*idum-k*IQ1) - IR1*k;
if (*idum < 0)
{
  *idum += IM1;
}
k = (idum2)/IQ2;
idum2 = IA2*(idum2-k*IQ2) - IR2*k;
if (idum2 < 0)
{
  idum2 += IM2;
}
j = iy/NDIV;
iy=iv[j] - idum2;
iv[j] = *idum;
if (iy < 1)
{
  iy += IMM1;
}
```

```
  if ((temp=AM*iy) > RNMX)
  {
    return RNMX;
  }else
  {
    return temp;
  }
}
```

Annotated Bibliography

[1] Apache Software Foundation, "Apache License, Version 2.0," http://www.apache.org/licenses/LICENSE-2.0, 2004.

This is my annotation. I should add in a description here.

[2] ——, "Apache POI - the Java API for Microsoft Documents," http://poi.apache.org, 2014.

This is my annotation. I should add in a description here.

[3] H. M. Dee and D. C. Hogg, "Navigational strategies in behaviour modelling," *Artificial Intelligence*, vol. 173(2), pp. 329–342, 2009.

This is my annotation. I should add in a description here.

[4] S. Duckworth, "A picture of a kitten at Hellifield Peel," http://www.geograph.org.uk/photo/640959, 2007, copyright Sylvia Duckworth and licensed for reuse under a Creative Commons Attribution-Share Alike 2.0 Generic Licence. Accessed August 2011.

This is my annotation. I should add in a description here.

[5] M. Neal, J. Feyereisl, R. Rascunà, and X. Wang, "Don't touch me, I'm fine: Robot autonomy using an artificial innate immune system," in *Proceedings of the 5th International Conference on Artificial Immune Systems*. Springer, 2006, pp. 349–361.

This paper...

[6] W. Press *et al.*, *Numerical recipes in C*. Cambridge University Press Cambridge, 1992, pp. 349–361.

This is my annotation. I can add in comments that are in **bold** and *italics and then other content.*

[7] Various, "Fail blog," http://www.failblog.org/, Aug. 2011, accessed August 2011.

This is my annotation. I should add in a description here.