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of the requirements for the degree of
MAI (Computer Engineering)

Declaration

I hereby declare that this project is entirely my own work and that it has not been submitted as an exercise for a degree at this or any other university.

I have read and I understand the plagiarism provisions in the General Regulations of the University Calendar for the current year, found at <http://www.tcd.ie/calendar>.

I have also completed the Online Tutorial on avoiding plagiarism 'Ready Steady Write', located at <http://tcd-ie.libguides.com/plagiarism/ready-steady-write>.

Signed: _____

Date: _____

Abstract

There isn't a human on this earth who can triumph over Deepmind's AlphaGo in the game of Go, however this does not quite make AlphaGo super-intelligent in that a child may beat it at draughts.

University of Oxford philosopher Nick Bostrom defines super-intelligence as "any intellect that greatly exceeds the cognitive performance of humans in virtually all domains of interest" and we are yet to develop a single AI that can adapt to our varying needs or outperform us across several tasks. Obtaining a more general intelligence requires Lifelong Learning (LL) or more simply, an AI that can remember and learn from all of its life experiences like we do, as opposed to mastering a single environment. These traits are a necessity if we want to create AI's that can master more than a single environment.

Reinforcement Learning (RL) is the primary learning technique employed by AlphaGo and recent techniques for Lifelong RL (LLRL) have shown great success in getting an RL agent to generalise over one or two tasks. The problem with an RL agent such as AlphaGo learning multiple tasks however, is that each task's information must be stored in memory, and the more complex the task, the more information that needs to be remembered. We can see how scalability becomes an issue if an AI has to master more than a handful of tasks.

This thesis proposes the Kullback-Leibler Policy Chain approach which aims to help an RL agent to generalise over multiple tasks in a scalable manner. The proposed method of LLRL draws upon techniques from the field of Information Theory that will allow an agent to gauge the importance of memories inherited from previously learned tasks. Inheriting useful information from previously completed tasks could be considered more scalable than storing each and every memory.

This thesis concerns the Kullback-Leibler Policy Chain method which helps an AI to generalise over several tasks in a scalable manner. Properties of the Kullback-Leibler divergence are exploited across specific policies to create a dependence between them. The need to store historic policies as some existing methods do is then greatly reduced with the introduction of a pseudo running total or a chain of these policies. Within this policy chain, we can say that the youngest link (i.e. policy for most recent task) will inherit the prevailing memories from older policies throughout the chain.

Acknowledgements

Thanks Mum!

You should acknowledge any help that you have received (for example from technical staff), or input provided by, for example, a company.

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Nomenclature

A	Area of the wing	m^2
B		
C	Roman letters first, with capitals. . .	
a	then lower case.	
b		
c		
Γ	Followed by Greek capitals. . .	
α	then lower case greek symbols.	
β		
ε		
TLA	Finally, three letter acronyms and other abbrevia- tions arranged alphabetically	

If a parameter has a typical unit that is used throughout your report, then it should be included here on the right hand side.

If you have a very mathematical report, then you may wish to divide the nomenclature list into functions and variables, and then sub- and super-scripts.

Note that Roman mathematical symbols are typically in a serif font in italics.

1 Introduction

This is a L^AT_EX template for the preparation of your dissertation.¹ The objective is to provide clear guidance to you, the students, and also to provide uniformity to the project reports, to facilitate equitable grading.

If you replace the contents with your own work, then it will have the correct font, margins, chapter, section, table, figure, equation and appendix styles. In addition, the referencing formats are set up as recommended. It also does tables of contents, figures and tables automatically.

This document has examples of how to do most things in L^AT_EX, but you should really read the “*Not So Short...*” guide mentioned later to get a proper appreciation of its capabilities.

1.1 Fonts, sizes, justification

Throughout the document, a sans-serif font should be used. The font size should be 12 pt for main text. The text should be left justified and without hyphenation. Avoid italics and boldface in the main text. These font requirements comply with TCD policy on accessibility.

The page number should appear at the bottom of each page starting at 1 on the first page of the Introduction chapter.

1.2 Headings of sections and subsections

Chapters should be divided into appropriate subsections. The section should be numbered sequentially from 1 within each chapter (e.g. 1.1, 1.2, 1.3 etc.).

¹For more about L^AT_EX, please go to page 8. By the way, you should avoid having too many footnotes. This is just to show you how easy it is to create one.

1.2.1 Subsection name style

The subsections if used should be numbered sequentially within each section. You should really try to avoid using subsubsections, but if you do they should not be numbered.

Subsection

This is a subsection. The asterisk after the command means it won't be printed with a number.

1.2.2 Length of the report

The page margins are set to 2.54 cm top, bottom, left and right. There may be a table or figure for which it is sensible to deviate from these margins, but in general the main text should be formatted within the specified margins.

The body of the report should be organized into several chapters. There are a number of chapters that you must have: an introduction; a background or literature review chapter; and a conclusion chapter. The focus of the other chapters will depend on your specific project.

The body of the report must be no more 60 pages for MAI. This does not include the front matter, references list and any appendices. In other words, from the first page of the Introduction to the last page of the Conclusions chapters must be less than 60 pages for MAI.

If you exceed these page limits or deviate significantly from this format, you will lose marks.

1.3 Contents of the Introduction

The introduction presents the nature of the problem under consideration, the context of the problem to the wider field and the scope of the project. The objectives of the project should be clearly stated.

1.4 Contents of the background chapter

The second chapter is typically a literature review, or survey of the state of the art, or a detailed assessment of the context and background for the project. The exact nature of this chapter depends on the topic and/or methods of the project. It is essential that the work of other people is properly cited. This will be discussed in detail in chapter 2 below. Note that you should use references wherever is appropriate through the report, not just in the literature review chapter.

1.5 The Conclusions chapter

The final chapter should give a short summary of the key methods, results and findings in your project. You should also briefly identify what, if any, future work might be executed to resolve unanswered questions or to advance the study beyond the scope that you identified in Chapter 1.

2 Figures, Tables and Referencing

It is very important to properly refer in the text to any figures, tables or previously published work that you are discussing. Adequate and consistent referencing is one of the criteria which will be used to assess your project report.

2.1 Figures

Graphs, pictures and other images should be included in your report as a numbered, captioned figure. An example is given in Figure 2.1.

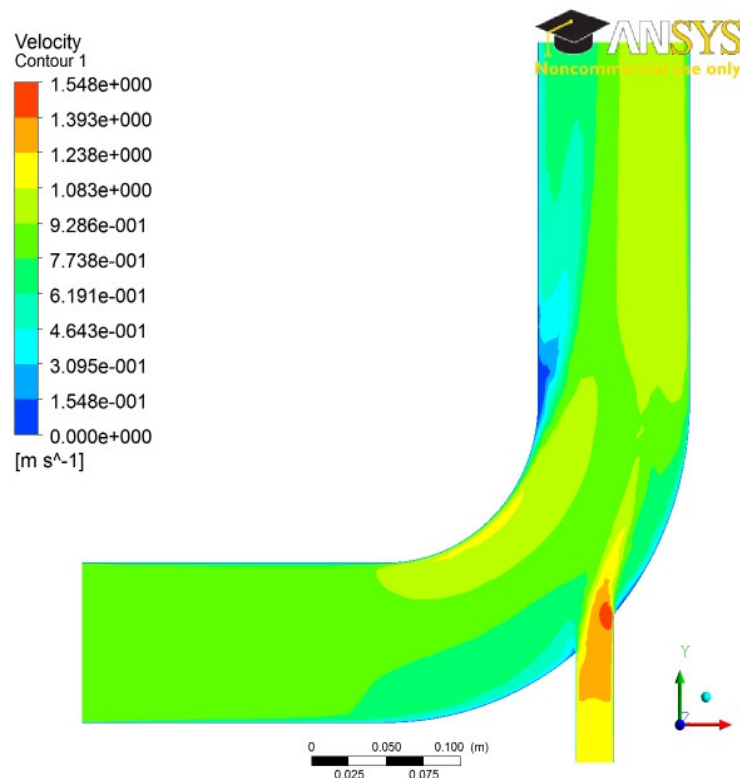


Figure 2.1: Velocity distribution on the mid-plane for an inlet velocity for case 1.

The figure and caption should be centred. The figure numbering starts at 1 at the beginning of each chapter. The caption should provide a brief description of what is

being shown. The figure should appear in the document after it is referred to in the text. No figure should be included which is not referred to in the text. Ensure that the size and resolution of images imported from software are sufficient to read any text.

2.2 Tables

Tables are an important way of displaying your results; Table 2.1 is a sample table, adapted from the Master/Doctoral Thesis template at <http://www.latextemplates.com/cat/theses>, which was generated with this code:

```
\begin{table}[b]
\caption{The effects of treatments X and Y on the four groups studied.}
\label{tab:treatments}
\centering
\begin{tabular}{l l l}
\toprule
\textbf{Groups} & \textbf{Treatment X} & \textbf{Treatment Y} \\ \midrule
1 & 0.2 & 0.8 \\
2 & 0.17 & 0.7 \\
3 & 0.24 & 0.75 \\
4 & 0.68 & 0.3 \\
\bottomrule
\end{tabular}
\end{table}
```

Tables are numbered in the same way as figures. Typically tables also have a short caption, but this is not universally true. The number and caption appear above the table, not below as with figures. Again, no table should appear in the report which has not been referred to in the text. Tables should come after they are discussed in the text. The exact formatting of the table depends somewhat on the content of the table, but in general, the text in the table should be the same font and size as the main text.

Table 2.1: The effects of treatments X and Y on the four groups studied.

Groups	Treatment X	Treatment Y
1	0.2	0.8
2	0.17	0.7
3	0.24	0.75
4	0.68	0.3

2.3 Equations

All equations should be numbered sequentially. Do not restart the numbering at the beginning of each chapter. Unlike figures and tables, you may not need to refer to every equation in the text. You should take care to format equations properly. Do not simply try to use plain text. Use the equation layout facilities. An example of how equations should appear is shown in Equation 1. Here is the code for it:

```
\begin{equation}
\text{trm{div}}(\underline{u}) = \frac{\delta u}{\delta x} + \frac{\delta v}{\delta y} +
\frac{\delta w}{\delta z} = 0
\label{sampleequation}
\end{equation}
```

$$\text{div}(\underline{u}) = \frac{\delta u}{\delta x} + \frac{\delta v}{\delta y} + \frac{\delta w}{\delta z} = 0 \quad (1)$$

2.4 Referencing published work

It is important to give appropriate credit to other people for the work that they have shared through publications. In fact, you must sign a declaration in your report stating that you understand the nature of plagiarism. As well as avoiding plagiarism, citing results or data from the literature can strengthen your argument, provide a favourable comparison for your results, or even demonstrate how superior your work is.

There are many styles to reference published work. For example, the parenthetical style (which is also called the Harvard style) uses the author and date of publication (e.g. “Smith and Jones, 2001”). There is also the Vancouver (or the citation sequence) style, which is shown in this document. In the Vancouver style, the publications are cited using a bracket number which refers to the list in the References section at the end of the report. The references are listed in order that they are cited in the report. A variant is name sequence style in which the publications are referenced by number, but the list is arranged alphabetically. For example, the text might say: several studies have examined the sound field around tandem cylinders generated by flow(? ?), while other investigations have focused on the effect of an applied sound field on the flow(?). Papers from conference proceedings(?), books(?) and technical reports(? ?) can be dealt with in the same style.

The Vancouver style has the advantage that it is a little more compact in the text and does not distract from the flow of the sentence if there are a lot of citations. However, it

has the disadvantage that it is not immediately clear to the reader what particular work has been referenced.

It actually does not matter which particular referencing style is used as long as three important considerations are observed:

- the referencing style used throughout the document is consistent;
- all material used or discussed in the text is properly cited;
- nothing is included in the reference list that has not been cited.

This template has a suitable referencing style already set up – you should use it and use the built-in BibTeX system to manage your references. See above for examples of how to cite a reference and look in the `sample.bib` file to see BibTeX references. Remember Google Scholar and other search engines will give you BibTeX references for lots of academic publications. Otherwise, you can easily make up your own based on the examples in that file.

3 L^AT_EX

seeing L^AT_EX, or more properly “L^AT_EX 2_ε”, is a very useful document processing program. It is very widely used, widely available, stable and free. Famously, T_EX, upon which L^AT_EX is built, was originally developed by the eminent American mathematician Donald Knuth because he was tired of ugly mathematics books(?). Although it has a learning curve (made much less forbidding by online tools and resources – see below), it allows the writer to concentrate more fully on the content, and takes care of most everything else.

While it can be used as a word processor, it is a *typesetting* system, and Knuth’s idea was that it could be used to produce beautiful looking books:

*L^AT_EX is a macro package which enables authors to typeset and print their work at the highest typographical quality, using a predefined, professional layout.*¹

L^AT_EX has great facilities for setting out equations and a powerful and very widely supported bibliographic system called BibT_EX, which takes the pain out of referencing.

Three useful online resources make L^AT_EX much better:

- (1) An excellent online L^AT_EX environment called “Overleaf” is available at <http://www.overleaf.com> that runs in a modern web browser. It’s got this template available – search for a TCD template. Overleaf can work in conjunction with Dropbox, Google Drive and, in beta, GitHub.
- (2) Google Scholar, at <http://scholar.google.com>, provides BibT_EX entries for most of the academic references it finds.
- (3) An indispensable and very fine introduction to using L^AT_EX called “*The not so short introduction to L^AT_EX 2_ε*” by ?) is online at <https://doi.org/10.3929/ethz-a-004398225>. Browse it before you use L^AT_EX for the first time and read it carefully when you get down to business.

¹This is from ?). Did we mention that you should minimise your use of footnotes?

Other tools worth mentioning include:

- `Draw.io` – an online drawing package that can output PDFs to Google Drive – see <https://www.draw.io>.

4 Evaluation

5 Conclusion

A1 Appendix

You may use appendices to include relevant background information, such as calibration certificates, derivations of key equations or presentation of a particular data reduction method. You should not use the appendices to dump large amounts of additional results or data which are not properly discussed. If these results are really relevant, then they should appear in the main body of the report.

A1.1 Appendix numbering

Appendices are numbered sequentially, A1, A2, A3... The sections, figures and tables within appendices are numbered in the same way as in the main text. For example, the first figure in Appendix A1 would be Figure A1.1. Equations continue the numbering from the main text.