DEGREE PROJECT IN TECHNOLOGY,
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Template

KTH Thesis Report

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Abstract

This is a template for writing thesis reports for the ICT school at KTH. I do not own any of the images provided in the template and this can only be used to submit thesis work for KTH.

The report needs to be compiled using XeLaTeX as different fonts are needed for the project to look like the original report. You might have to change this manually in overleaf.

This template was created by Hannes Rabo <hannes.rabo@gmail.com or hrabo@kth.se> from the template provided by KTH. You can send me an email if you need help in making it work for you.

Write an abstract. Introduce the subject area for the project and describe the problems that are solved and described in the thesis. Present how the problems have been solved, methods used and present results for the project. Use probably one sentence for each chapter in the final report.

The presentation of the results should be the main part of the abstract. Use about ½ A4-page. English abstract

Keywords

Template, Thesis, Keywords ...

Abstract

Svenskt abstract Svensk version av abstract – samma titel på svenska som på engelska.

Skriv samma abstract på svenska. Introducera ämnet för projektet och beskriv problemen som löses i materialet. Presentera

Nyckelord

Kandidat examensarbete, ...

Acknowledgements

Write a short acknowledgements. Don't forget to give some credit to the examiner and supervisor.

Acronyms

NN	Neural Network
ANN	Artificial Neural Network
SNN	Spiking neural network
IF	Integrate and Fire
LIF	Leaky-integrate-and-fire
HH	Hodgkin–Huxley

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Chapter 1

Introduction

Provide a general introduction to the area for the degree project. Use references!

Link things together with references. This is a reference to a section: 1.1.

The human brain is comprised of more than 80 billion neurons. Each of these neurons can have thousands of connections to other neurons.. Between these connection, information travels as electrical impulses that interact with the neurons own polarity. With the careful arrangement the human brain is capable of vastly different and complex things. Tasks that are still next to impossible to recreate on machines and algorithms. Moreover many tasks lack the human speed, precision, flexibility or a combination of them.

Spiking neural networks mimic the inner workings of the brain. They are often dubbed the third generation of Neural Networks (NNs). On the contrary the more traditional

1.1 Background

Present the background for the area. Give the context by explaining the parts that are needed to understand the degree project and thesis. (Still, keep in mind that this is an introductory part, which does not require too detailed description).

Use references[1]

[1]You can also add footnotes if you want to clarify the content on the same page.

Neuro stuff very rapid developmen tremendous progress, m things are successful v NNs. Then list fields th work well. E.g pattern recognition bioinformat neuroscienc With spikin neural netw they are be the state of art feedforw networks b the gap is closing. Th are already fields where they are ex

Detailed description of the area should be moved to Chapter 2, where detailed information about background is given together with related work.

This background presents background to writing a report in latex.

Example citation [**Jones2017**] or for two authors: [**Jones2017**, **Liu2017**]

Look at sample table 1.1.1 for a table sample.

Table 1.1.1: Sample table. Make sure the column with adds up to 0.94 for a nice look.

SAMPLE	**TABLE**
One	Stuff 1
Two	Stuff 2
Three	Stuff 3

Boxes can be used to organize content

Development environment for prototype

```
Operating systems
computer: Linux - kernel 4.18.5-arch1-1-ARCH
android phone: 8.1.0

Build tools
exp (build tool): version 55.0.4

...
```

1.2 Problem

NN have excelled at many fields
Fields where they are not fit
aka temporal data
They have ways to compromise on that
-> reference
Spiking nn inherently temporal
more natural choice
However they also have problems

like the following:::: reference!!

1.3 Purpose

The purpose of the degree project/thesis is the purpose of the written material, i.e., the thesis. The thesis presents the work / discusses / illustrates and so on.

It is not “The project is about” even though this can be included in the purpose. If so, state the purpose of the project after purpose of the thesis).

Probably delete as a own paragraph but mention smth like that.

1.4 Goal

The goal means the goal of the degree project. Present following: the goal(s), deliverables and results of the project.
Goal is to write a SNN that can deliver good performance in solving a task that sucks with a conventional NN. We test the performance of a SNN and a conventional NN for linear dynamic systems.
The performance of of the SNN should be close to equal to conventional control schemes and better than conventional NNs.
Ideally the SNN has desired features like small number of spikes, precision, learning, poisson distribution etc. more find references.
Ideally we stress the network by removing many neurons and see the performance. maybe to recreate the performance of the one paper..
Potentially find the optimal minimal network in the network. The paper dass der Typ aus louvain vorgestellt hat.

1.5 Benefits, Ethics and Sustainability

Describe who will benefit from the degree project, the ethical issues (what ethical problems can arise) and the sustainability aspects of the project.

Use references!

1.6 Methodology

Introduce, theoretically, the methodologies and methods that can be used in a project and, then, select and introduce the methodologies and methods that are used in the degree project. Must be described on the level that is enough to understand the contents of the thesis.

Use references!

Preferably, the philosophical assumptions, research methods, and research approaches are presented here. Write quantitative / qualitative, deductive / inductive / abductive. Start with theory about methods, choose the methods that are used in the thesis and apply.

Detailed description of these methodologies and methods should be presented in Chapter 3. In chapter 3, the focus could be research strategies, data collection, data analysis, and quality assurance.

We build a SNN for a control problem and check it for performance as mentioned above. In addition we design a conventional controller and compare the result. IF we have the time for it we put a conventional NN to it too. We see the performance compared to the others and look at the specs we mentioned above. The SNN is trained by learning using STDP rule. We can compare the learned weights with the optimal weights when we have our own optimal controller/ we simulate our trajectory. For our approach we use a balanced spiking network.

1.7 Stakeholders

Present the stakeholders for the degree project.

1.8 Delimitations

Explain the delimitations. These are all the things that could affect the study if they were examined and included in the degree project. Use references!

1.9 Outline

In text, describe what is presented in Chapters 2 and forward. Exclude the first chapter and references as well as appendix.

Chapter 2

<Theoretical Background>

In this chapter, a detailed description about background of the degree project is presented together with related work. Discuss what is found useful and what is less useful. Use valid arguments.

Explain what and how prior work / prior research will be applied on or used in the degree project /work (described in this thesis). Explain why and what is not used in the degree project and give valid reasons for rejecting the work/research.

Use references!

2.1 Use headings to break the text

Do not use subtitles after each other without text in between the sections.

2.2 Related Work

You should probably keep a heading about the related work here even though the entire chapter basically only contains related work.

Here just what has been done for each of the headlines
Previous efforts were already made to control dynamic systems with Spiking neural networks (SNNs).

List here also efforts with other concepts apart from Balanced Networks

Neural networks in general spiking neural networks and their differences and what they are better for. neuron models, iwazishi neuron and maybe one more mein neuron model und warum ich es ausgewaelt habe: einfach zu implementieren. Bereits fuer dynamische systeme verwendet, Nachteile dieses modells. Vlt vergleich mit einem anderen modell. Ganz kurzer ausflug in die regelung von dynamischen systemen.

What is a neural network? -> not here ref a paper. kurze erkl'rung in der einfuerung in der einfuhurng vlt auch hodgekin huxley erwaehen :)

2.3 Dynamic systems

2.4 Neuron model

2.4.1 Biological Neuron model

The most biologically accurate model of neuron spiking is the Hodgkin–Huxley (HH) model. The HH-model considers the neuron with its ion channels. The membrane acts as a capacitance and the travelling ions in each ion channel contribute a current to the overall membrane potential. These ion gates are voltage dependent and are defined positive in direction out of the cell.
A particular ion channel for ion X can be modelled as

$$I_X = g_X \cdot (V - V_X) \tag{2.1}$$

These currents are summed summed for the different ion channels in question, most commonly for Sodium, Potassium and a leak current. In reality there are a plethora of different channels and channel properties[1]. The V_X are the equilibrium potentials for each of the channels and can be computed using the Nernst equation [5].

Add a reference to monograph

$$C\frac{dV}{dt} = g_{Na} \cdot (V - V_{Na}) + g_K \cdot (V - V_K) + g_l \cdot (V - V_l) \tag{2.2}$$

Do model the voltage dependency of the ion channels, the conductances are described with gating variables, usually called n, h and g for Na-Activation, Na-Inactivation and K-activation respectively. One gating variable is set between $[0, 1]$ and models the permeability of said gate. Multiple gates are used to fit to each ion channel in order

[1] See `channelpedia.epfl.ch` for an extensive list

to match experimental data and the model behaviour.
Gates have first order dynamics of the form

$$\frac{dn}{dt} = \alpha_n(1-n) - \beta_n n \tag{2.3}$$

for e.g the n gate. The other gates' dynamics are analogous. The functions α and β are voltage but not time dependent. The discussion of initial values as well as functions for $\alpha_p,\ \beta_p\ \ p = (n,h,m)$ can be found in [2] or [5]. The gates for each ion channel's conductance are found to be

$$\begin{aligned} g_{Na} &= \bar{g}_{Na} n^4 \\ g_K &= \bar{g}_K m^3 h \end{aligned} \tag{2.4}$$

and give form to the final model

$$\begin{aligned} C\frac{dV}{dt} &= I(t) - \bar{g}_{Na} n^4 (V - V_{Na}) - \bar{g}_K m^3 h (V - V_K) - g_L(V - V_L) \\ \frac{dn}{dt} &= (1-n)\alpha_n(V) - \beta_n n(V) \\ \frac{dm}{dt} &= (1-m)\alpha_m(V) - \beta_m m(V) \\ \frac{dh}{dt} &= (1-h)\alpha_h(V) - \beta_h h(V) \end{aligned} \tag{2.5}$$

We did not define a gate for the leak term as it is assumed constant.

2.4.2 "IF and LIF"

In contrast of the HH model in eq. (2.5), the simplest models of neurons are the Integrate and Fire (IF) and Leaky-integrate-and-fire (LIF) models.

IF Neurons IF Neurons, as the name implies, integrate the incoming current over time.

$$\frac{dV(t)}{dt} = \frac{1}{C} I(t) \tag{2.6}$$

The membrane voltage is governed by the incoming current spikes of connected neurons and the membrane capacitance. The neuron potential does not change without a change of input current and thus presents as a perfect integrator of the input.

LIF Neurons In contrast to that the LIF neuron contains a leak term on the RHS which brings the voltage back to its resting potential over time. The model can be expressed as

$$\tau \frac{dV(t)}{dt} = -(V(t) - E_r) + RI(t), \tag{2.7}$$

where $\tau = RC$ is the time constant the composed of the membrane resistance R and the membrane capacitance C and the resting potential E_r. In the absence of input $I(t)$ the voltage settles on the membrane potential E_r.
The input $I(t)$ encapsulates external inputs as well as a sum of Dirac functions indicating a spiking neuron

$$I(t) = \sum_k \delta(t - t^k) \tag{2.8}$$

and t_k being the time of the k-th spike. When the membrane voltage exceeds the threshold potential $\bar{v}$, a spike is sent out by the neuron and the voltage sets back to its reset voltage v_{res}.

This is not correct. Fo weights, bu the same ti only when are more th neuron

2.4.3 Izhikevich Neuron

While the above models deliver a useful and cheap simplification, they lack in accuracy. The Izhikevich model [4] of the neuron tries be the of both worlds in terms of efficiency and accuracy. It is comprised of 2D ODEs with the membrane potential v as

$$\begin{aligned} \frac{dv}{dt} &= 0.04v^2 + 5v + 140 - u + I(t) \\ \frac{du}{dt} &= a(bv - u). \end{aligned} \tag{2.9}$$

With the chosen factors, the neuron experiences a spike when $u \geq 30$mV, in which case the neuron resets to

$$\begin{aligned} u &\leftarrow u + d \\ v &\leftarrow c \end{aligned} \tag{2.10}$$

The parameters describe a scale of recovery, b sensitivity, c the reset potential of v and d the reset of variable u. Depending on these parameters one can achieve different behaviours of the neuron e.g. regular spiking, fast spiking and low threshold spiking to name a few [4].

Maybe shit explanation which coul extended o

2.5 Neural Networks

2.5.1 Biological Neural Network

2.5.2 Artificial Neural Networks

2.5.3 Spiking Neural Networks

A spiking Neural network is one step closer to a biologic representation of a brain. Instead of conveying information using a gradient in conventional NNs, information is propagated using discrete spikes of excitation, similar to biological neurons. Hereby one can distinguish between several ideas of implementation.

2.5.4 Poisson-Networks

2.5.5 Liquid state machines

2.5.6 GLM

2.5.7 Balanced Networks

Balanced networks differ from the previous approaches that they closely track excitation an inhibition. The derivation of its behaviour is adopted from [1] and [3].
We s

2.5.8 Learning: SGD and STDP

Key to give any NN the ability to solve a task, it is integral to learn/train the network. The adaption of synapse weights is necessary to accomplish any functionality based on the underlying data[6]. There are various ways to train a network. The most fundamental distinction can be made between supervised, unsupervised and reinforcement learning rules. One needs to remember that Artificial Neural Networks (ANNs) and SNNs require completely different learning algorithms because of their different transport of information.
For a review

Supervised Learning methods

Gradient based methods require differentiability and therefore continuity, thus are only applicable for ANNs.

Explain gradient methods. The derivative of the weights and biases is used for the derivative of the cost function. Efficient methods for building the derivative exists. With reference!

Unsupervised Learning methods

STDP

Reinforcement learning

Here explain th¸e conpects for each of the NNs
Give references for the STDP variances

Chapter 3

<Engineering-related content, Methodologies and Methods>

Describe the engineering-related contents (preferably with models) and the research methodology and methods that are used in the degree project.

Most likely it generally describes the method used in each step to make sure that you can answer the research question.

3.1 Engineering-related and scientific content:

Applying engineering related and scientific skills; modelling, analysing, developing, and evaluating engineering-related and scientific content; correct choice of methods based on problem formulation; consciousness of aspects relating to society and ethics (if applicable).

As mentioned earlier, give a theoretical description of methodologies and methods and how these are applied in the degree project.

was ist meine research question?

zusammensetzung von den beiden systeme: dynamisches system und neuronales netz. mehr oder weniger die herleitung kopieren aus dem paper. Dann mit learning von den gewichten.

Here I describe what how it needs to be done. So this is the place for the derivation The concept and the process whatever that means Later there comes the how I implemented

it. Here is what we needs to be implemented.

Here very detailed explanation of the Balanced network for this problem
Very detailed way for the regular NN for this problem Basics of the controller design used in this comparison aka LQG controller
Method of learning the weights for the SNN Method of comparison

Chapter 4

<The work>

Describe the degree project. What did you actually do? This is the practical description of how the method was applied.

4.1 Creating the SNN

How do we make the SNN MAtlab Balanced spiking network (say why to use that) maybe pseudo code Ideally some theorem (convergence???) Simulation? nein kommt in den naechsten part

4.2 Creating the NN

4.3 Creating the regular Controller

Chapter 5

<Result>

Describe the results of the degree project.

Chapter 6

<Conclusions>

Describe the conclusions (reflect on the whole introduction given in Chapter 1).

Discuss the positive effects and the drawbacks.

Describe the evaluation of the results of the degree project.

Describe valid future work.

The sections below are optional but could be added here.

6.1 Discussion

6.1.1 Future Work

6.1.2 Final Words

Todo list

- Neuro stuff, very rapid development, tremendous progress, many things are successful with NNs. Then list fields that work well. E.g pattern recognition, bioinformatics, neuroscience. With spiking neural networks they are behind the state of the art feedforward networks but the gap is closing. There are already fields where they are excel compared over normal NN. 1
- Maybe put some exact numbers here and a source 1
- Sounds vague 1
- List here also efforts with other concepts apart from Balanced Networks . . . 6
- Add a reference to a monography. 7
- This is not truly correct. Forgot weights, but at the same time only when there are more than 1 neuron 9
- Maybe shitty explanation, which could be extended on. 9
- Make clear distinction between forward nns and ann. Bcs apparently they are not the same! 10
- Put this reference in and say its is copied partly from them 10
- Explain gradient methods. The derivative of the weights and biases is used for the derivative of the cost function. Efficient methods for building the derivative exists. With reference! 11

If you are using mendeley to manage references, you might have to export them manually in the end as the automatic ways removes the ”date accessed” field

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[1] Boerlin, Martin, Machens, Christian K. **and** Denève, Sophie. "Predictive Coding of Dynamical Variables in Balanced Spiking Networks". **in**: *PLOS Computational Biology* 9.11 (14 **november** 2013). Publisher: Public Library of Science, e1003258. ISSN: 1553-7358. DOI: 10.1371/journal.pcbi.1003258. URL: https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1003258 (**urlseen** 20/09/2022).

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[5] Johnston, Daniel **and** Wu, Samuel Miao-sin. *Foundations of cellular neurophysiology*. Cambridge, Mass: MIT Press, 1995. 676 **pagetotals**. ISBN: 978-0-262-10053-3.

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Appendix A

First Appendix

This is only slightly related to the rest of the report

Appendix B

Second Appendix

this is the information