# Project report

# TITLE

***Author:***
Guillaume Steimer

***Supervisors:***
Emmanuel Franck
Vincent Vigon
Laurent Navoret

**M2 CSMI 2020-2021**

**UFR de Mathématiques et d'Informatique**

**Université de Strasbourg**

# Contents

# Introduction

The use of machine learning and especially neural networks is widespread throughout the world. It is a fast-developed and sophisticated tool used in various fields such as automotive with improved guidance systems or autonomous cars. We find artificial intelligence in manufacturing with predictions of systems breakages or in medicine with improved computer-assisted tomography (CAT scan) and Magnetic resonance imaging (MRI) captures.

Their success is based on mimicries with the human brain: their elemental units: the artificial neurons are a replicate of real brain neurons and they are organised in layers and structures similar as the arrangements of brain cortex. With enough time and computational power, a neural network can learn patterns and significant features in various data and apply this training to make precise prediction.

For instance, a popular challenge named ILSVRC (ImageNet Large Scale Visual Recognition Challenge) where competitors opposes their neural notwork model on the detection and classification at large scale using the database ImageNet. It is a database composed of more than 14 millions of hand-annotated pictures spitted in more than 20 000 categories, from the least accurate as musical instrument or mammals to the most specific as zooplankton or bird's-nest fungus. While a human achieve a 5% precision on the classification of those images, GoogLeNet-v4 reached a 3.1% precision.

Despite their impressive results in several fields, neural networks struggles to learn the basic laws of physics. In this project, we will try to develop neural networks based solution to put in equations the observations of physical phenomena. We will rely on analytical mechanics, more specifically on Hamiltonian mechanics. It provides a solid basis for theorising this field of science.

This internship takes place in the MOCO (Modélisation et Contrôle) team of the IRMA (Institut de Recherche Mathématique Avancée) in Strasbourg. This team is specialised in the analysis of partial differential equations, control theory, high performance computing and statistics. It is supervised by Emmanuel Franck, Laurent Navoret and Vincent Vigon who work on the use of machine learning for numerical simulations.

The report presents, in addition to the research carried out, the results that have been obtained.

# 1 Hamiltonian mechanics

Here, I will make a brief introduction on the analytical mechanics. Thus, we will make a brief introduction on the problem. We will explain that we will focus on the simple gravity pendulum throughout the project and that we rely on a main article [1].

## 1.1 A generalisation of Newton mechanics

We start by studying the pendulum using Newton mechanics ans explain its limitation on more complex / real word cases.

## 1.2 Elements of theory

We lay down the theoretical basis needed to understand the situation and some interesting properties / theorems.

## 1.3 Applications

We introduce different algorithm to generate data. Starting with the Eulerian scheme, then Euler symplectic. We add examples.

## 2 Prediction of a simple pendulum dynamic

Actual neural networks to predict the motion of the pendulum. We should talk about the failure of training a model that uses newton mechanics.

# A Road map

In this section, we talk about the work carried out during the project at different milestones.

## A.1 Deadlines

Below are the main deadlines of the semester project:

- The $13^{\text{th}}$ of November 2020: the *version 0* of the report is due, it should present a road map and the work that is to be done,
- the $5^{\text{th}}$ of January 2021: the *version 1* has to be deposed. In it, there should be most of the work of the project,
- the $19^{\text{th}}$ of January 2021: the *version 2* has to be deposed. It shall be an almost finished report. It is the time for final results and last corrections.

## A.2 On the $13^{\text{th}}$ of November 2020

On this date, the *version 0* of the report is due. Here is what has been done:

- I have familiarised myself with the theory of Lagrangian an Hamiltonian mechanics. To achieve this, I have at my disposal a writing of M. Franck and the researches made on Internet ($\sim$ 15h),
- Redaction of the report ($\sim$ 2h).

The next steps are:

- read and understand the main article [1]($\sim$ 4-5h),
- code the different scheme to generate data (first order euler, euler symplectic...) ($\sim$ 3-4h),
- Build a first neural network that do not use Hamiltonians and show that it cannot work ($\sim$ 2-3h),
- Try to reproduce the results of the article ($\sim$ 7-9h).

## A.3 Resources

I use OVERLEAF to write and compile my report in LaTeX. I might switch to an other interface in order to use some continuous integration.

Programs are developed in PYTHON and executed on GOOGLE COLAB. This is due to the fact that a great part of the code will rely on Keras and Tensorflow. Therefore, it has to benefit of some computational means as GPUs available for free on that platform. When not on the platform, I should use a Docker environment to provide a standardised environment of execution.

The versions of the programs are managed and stored in GITHUB.

As a consequence of the pandemic of *COVID-19*, my supervisors and myself use GMAIL and GOOGLE MEET to communicate. We also share a folder in GOOGLE DRIVE.

## References

[1] Hamiltonian Neural Networks. https://greydanus.github.io/2019/05/15/hamiltonian-nns/.