**6CCE3EEP/7CCEMEEP**

**Individual Project Submission 2021/22**

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**Degree Programme: Electronic Engineering with Management**

**Project Title:**

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**Word count:**

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**Originality Avowal**: "I verify that I am the sole author of this report, except where explicitly stated to the contrary."

**Abstract or Executive Summary**: This is a half to one-page summary of your report (rather than your project) listing your problem statement and main findings.

**Contents Page**: It is very useful to have a high-level contents page, list of figures and tables in your report as well as a list of appendices. It will also help you when you structure the report.

**Introduction**: Your introduction really sets the scene for the report. It should be a clear statement of what the project is about, a summary of the background and context and summarise what you set out to achieve.

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**Report**: The next part of the report might be then broken into chapters such as methodology, findings, specification, requirements, design etc. The aim of the section as a whole is to describe the work you've done, justify your approach and explain how you arrived at your conclusion. You might also analyse the technical findings of your work.

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**Professionalism and Responsibility:**It is important that you consider the professional influences on your project such as standards and competencies. You can also discuss general ethics, sustainability, cyber-security or other issues applicable to the project.

**Bibliography**: a list of all your references following the acceptable [college citation format.](https://libguides.kcl.ac.uk/reference)   
(Martin et al., 2020) or (Salas & D’Agostino, 2020) for two authors. For every in-text citation, there must be a reference list one: APA

**Appendix**: additional useful information that won't be marked but provides some completeness E.g. tables of data, additional graphs etc

# **Abstract**

This report sets out a scalable method for harmony recognition utilizing the Neural Engineering Framework (NEF) developed by Eliasmith & Anderson.

A proof-of-concept is shown, along with results utilizing a restricted dataset with four different learning rates over 10 epochs.

Three different approaches to consider the seriousness of error were taken

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# **Introduction**

# **Background**

The nature of this project is interdisciplinary, and as such, basic knowledge of each area will benefit the reader to fully understand how each aspect connects to the other in a meaningful way.

Key words will be in bold and will be referenced throughout the report.

The current literature in the subject of harmony recognition is vast, but so is the complexity of the problem. Considering the several steps inherent to the problem; from the processing of the audio, to design choices of classification algorithms, to the scope of the solution, and the choice of databases, there were many unexplored aspects which were considered and utilised.

Most importantly, this model differs in its scope and approach. That is, it is focused solely on the piano, in utilising a biologically plausible approach for analysing the data and learning, and in being able to classify harmony within a significantly higher number of possible outputs. Further to the last point, contrary to most of the research which focuses on pre-determined structures of musical chords, which can be given by 24 different values (Cheng et al., 2008), the model focuses on any possible combination of notes within a piano. Given that a piano has 88 notes, of which three are selected at a time to make up the chord, there are combinations possible.

On top of that, only recently have machine learning methods (rather than relying on signal processing techniques and pattern matching), began to be used. The work done by (Fujishima, 1999), laid ground to the most used signalling processing technique within this subject: Pitch Class Profiles.

## Harmony theory

A musical **note (or tone)** is, in its most simple terms, a frequency. For example, when a string in a well-tuned guitar is plucked, it oscillates at this frequency and produces a sound. Now, if two strings are plucked at the same time, the interaction of such frequencies creates new patterns of oscillations, and subsequently new sounds. Such sounds are dependent on how far apart the frequencies between these two notes are. It was defined that every note with a frequency ratio of 2 (or 0.5) to a subsequent note would be denoted as an **octave**, as due to their closely related harmonics they sound extremely similar to the human ear.For example, given a note with a frequency of 440Hz, both 880Hz and 220Hz would be **octaves** of this frequency.

Every octave is denoted by the same letter, accompanied by a number to denote the frequency. Considering the example above, 440Hz is denoted “A4”, whereas 880Hz and 220Hz are “A5” and “A3”, respectively.

In the Western world, the most common way to divide the range of frequencies between two octaves is in 12 equally spaced frequencies on the logarithmic scale. The frequency ratio of an interval can be written as , where is the number of notes between the two frequencies, this is called an **interval** ( can also be called as the number of **semitones** between the two notes).

In figure 1 below, this is shown for a range of frequencies. Note that the “accidentals” (# and b) accompanying some of the notes are a matter of how the labelling system was devised, but matters not for the purpose of this report, as frequencies and ratios will be mostly used.

Table

Description automatically generated

Figure 1: Notes, their octaves, and their frequencies[[1]](#footnote-1)

## For example, between C1 and D1 we have two **semitones** (), which in terms of the frequency ratio is equivalent to the ratio between G4 and A4: in both cases their ratio is .

When two or more notes are played simultaneously, we call it harmony. Naturally, the more frequencies that

## Neural Networks

## Neural Engineering Framework & Nengo

The Neural Engineering Framework (**NEF**) is a methodology that allows the construction of large-scale, biologically plausible neural models of cognition (Eliasmith & Anderson, 2003). Instead of setting connection weights between **neurons** manually or through some learning rule, the NEF solves for these according to the function you desire to compute. For example, say the function is defined as , the framework will compute the **weights** that best approximates this function (method will be discussed later). In the case where such function is not known, traditional methods can still be utilised.

In 2014, Bekolay et al. developed an open-source Python package called **Nengo**, implementing NEF for building and simulating such models. All the models utilised were built on Nengo, following the NEF.

#insert here the actual math behind NEF

Consequently, the learning methods within the framework are distinct from that of traditional machine learning (Stochastic Gradient Descent generally).

## Literature and General Remarks

The current literature in the subject of harmony recognition is vast, but so is the complexity of the problem. Considering the several steps inherent to the problem; from the processing of the audio, to design choices of classification algorithms, to the scope of the solution, and the choice of databases, there were many unexplored aspects which were considered and utilised.

Most importantly, this model differs in its scope and approach. That is, it is focused solely on the piano, in utilising a biologically plausible approach for analysing the data and learning, and in being able to classify harmony within a significantly higher number of possible outputs. Further to the last point, contrary to most of the research which focuses on pre-determined structures of musical chords, which can be given by 24 different values (Cheng et al., 2008), the model focuses on any possible combination of notes within a piano. Given that a piano has 88 notes, of which three are selected at a time to make up the chord, there are combinations possible.

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# **Report**

## Methodology

### The dataset

## Framework

## Design

Findings

# **Conclusion**

# **Professionalism and Responsibility**

# **Bibliography**

Eliasmith, C., & Anderson, C. H. (2003). Neural engineering: Computation, representation and dynamics in neurobiological systems. Cambridge, MA: MIT Press.

Heng-Tze Cheng, Yi-Hsuan Yang, Yu-Ching Lin, I-Bin Liao and H. H. Chen, (2008). "Automatic chord recognition for music classification and retrieval," 2008 IEEE International Conference on Multimedia and Expo, pp. 1505-1508, doi: 10.1109/ICME.2008.4607732.

Engineering ToolBox, (2003). *Notes, Octaves and Frequencies*. [online] Available at: https://www.engineeringtoolbox.com/note-frequencies-d\_520.html [Accessed Day Mo. Year].

# **Appendix**

1. Engineering ToolBox, (2003). *Notes, Octaves and Frequencies*. [online] Available at: https://www.engineeringtoolbox.com/note-frequencies-d\_520.html [Accessed Day Mo. Year]. [↑](#footnote-ref-1)