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Artificial Neural network for musical *Cantus Firmus* evaluation

Red neuronal artificial para la evaluación de *Cantus Firmus* musicales

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Abstract

This paper presents a neural network for the evaluation of musical cantus firmus. The network is trained with a dataset of a variety of exercises already solved both correctly and incorrectly. The network can evaluate the quality of a Cantus Firmus based on a variety of factors, including the melodic contour, the harmonic progression, and the rhythmic structure. The network is shown to be effective in evaluating the quality of cantus firmus, and it has the potential to be used in a variety of applications, such as music composition and music theory education. In recent years, Artificial Intelligence has developed a lot, which has had applications ranging from video games to social networks. In large industries such as Google and Bytedance have been given the task of developing software that can compose or help compose music. The software called ORB COMPOSER can compose different styles of music starting from a structure given by the user, as well as Chat GPT, which now lacks the ability to write the music but can write the lyrics of a song with the general structure needed.

Neural network, Cantus firmus, IA

Resumen

Este artículo presenta una red neuronal para la evaluación de Cantus Firmus musicales. La red se entrena con un conjunto de datos de una variedad de ejercicios ya resueltos tanto correcta como incorrectamente. La red es capaz de evaluar la calidad de un Cantus Firmus basándose en diversos factores, como el contorno melódico, la progresión armónica y la estructura rítmica. La red se muestra eficaz en la evaluación de la calidad de los cantus firmus, y tiene potencial para ser utilizada en diversas aplicaciones, como la composición musical y la enseñanza de la teoría musical. En estos últimos años, se ha desarrollado mucho la Inteligencia Artificial, la cual ha tenido aplicaciones que abarcan desde videojuegos hasta redes sociales. En grandes industrias como Google y Bytedance se han dado a la tarea de desarrollar software que pueda componer o ayudar a componer música. El software llamado ORB COMPOSER puede componer diferentes estilos de música iniciando desde una estructura dada por el usuario, así como Chat GPT, que por el momento carece de escribir la música, pero si puede escribir la letra de una canción con la estructura general necesaria.

Red neuronal, Cantus firmus, IA

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I. Introduction

Music, as a universal form of expression, has undergone a profound transformation with the advancement of emerging technologies. In particular, the analysis of melodic structures, such as the Cantus Firmus in classical music, has been essential to understanding the complexity and richness of musical compositions throughout history.

A *Cantus Firmus* is a melodic line that is used as the basis for a polyphonic composition. The Cantus Firmus is often a pre-existing melody, such as a folk song or a hymn. The Cantus Firmus can be used in a variety of ways, including as the main melody, as a countermelody, or as a bass line.

According to Chang and Chen (2020), Cantus Firmus is a fixed melody that has played a very important role in the transition from monophony to polyphony in western music. With a fixed melody from hymns, composers began to experiment with the possibilities to add on voices on top of it, and gradually shaped into one of the most fundamental theories in the traditional western music: the counterpoint. Although by the time of the High Renaissance, the mechanism of Cantus Firmus was gradually replaced with the more equal imitative counterpoint among voices, it had become an important pedagogic method in the most significant counterpoint textbook in the seventeenth century: Gradus ad Parnassum by J. J. Fux. This method stresses the use of a clearly ruled, simply formed Cantus Firmus as a learning basis for species counterpoint. An example is shown in Figure 1.

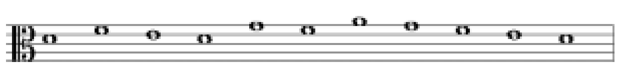

Figure 1 A famous Cantus Firmus by J. J. Fux

The evaluation of Cantus Firmus is a subjective task. There is no single definition of what makes a good cantus firmus. However, there are several factors that are generally considered to be important, such as the melodic contour, the harmonic progression, and the rhythmic structure.

In the context of artificial intelligence (AI) and deep learning, there has been a significant shift in the way we approach music evaluation.

Sturm *et al* (2019), argues that the convergence of music and AI opens up new possibilities for musical analysis, offering more efficient and accurate methods.

Historically, the Cantus Firmus has been subject to meticulous analysis using traditional methods, but the ability of neural networks to learn complex patterns introduces a novel and promising perspective. Wu *et al* (2020), argues that neural networks provide a powerful tool for unraveling melodic complexities and revealing connections that could escape conventional analytical methods.

In recent years, there has been a growing interest in the use of machine learning for the evaluation of music. Machine learning algorithms can be used to learn patterns in data, which can then be used to make predictions or classifications.

As Apollo (2022) suggests, the application of artificial intelligence in music not only expands our analytical tools, but also raises fundamental questions about creativity, interpretation, and the preservation of musical heritage.

Recent work on the use of machine learning for the evaluation of music has focused on a variety of tasks, including the evaluation of melodies, chord progressions, and entire compositions. For example, Xu *et al* (2003) used a support vector machine to automatic musical genre classification which is very useful for music indexing and retrieval. Osmalskyj *et al* (2012) used a neural network to present an effective machine learning based method using a feed-forward neural network for chord recognition. The method uses the known feature vector for automatic chord recognition called the Pitch Class Profile (PCP). Costa, Soares and Silla (2017) used a convolutional neural network (CNN) to evaluate music genre recognition, comparing their method against handcrafted features and SVM classifiers, obtaining promising results. Most existing neural network models for music generation explore how to generate music bars, then directly splice the music bars into a song. However, these methods do not explore the relationship between the bars, and the connected song has no musical form structure and sense of musical direction (Liang, Wu and Yin, 2019).

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Consequently, we propose a neural network that, based on training with correctly and incorrectly designed Cantus Firmus data, can interpret new exercises according to its training and learning, providing a resource to learn in an abstract way how a melody or a musical phrase is formed.

This article delves into the fascinating intersection between music and AI, specifically exploring the use of a specialized neural network for the evaluation of musical Cantus Firmus. By adopting an AI-based approach, we seek not only to improve the efficiency of analysis, but also to deepen our understanding of the evolution and interconnectedness of melodic structures over time.

However, to the best of our knowledge, this is the first paper to present a neural network for the evaluation of musical cantus firmus. This study not only seeks to enrich the discipline of musicology, but also to contribute to the broader conversation about the harmonious integration of technology into artistic expression.

II. Objective and goals

The aim of this project is that our neural network evaluates the organization of the basic melodic line, which is the cantus firmus. This as an aid to interest in relation to software development collaborations and music theory, as well as a learning support for music-theoretical study.

This research makes use of a neural network capable of evaluating the organization of the basic melodic line (cantus firmus), which was fed with manually evaluated exercises to feed the network with correct and incorrect exercises for good training. The main objective was the classification of these exercises for musical interpretation, which generated very good results.

Also, within this research, the suitability of different computational algorithms for the analysis of musical exercises was analyzed in order to obtain relevant information from different tools, which generated a better tendency to use a multilayer perceptron neural network.

III. Methods and materials

The aim of this study is to predict whether a Cantus Firmus is correct or not, derived from the analysis values, using the multilayer perceptron neural network for predictive purposes. In this context, a multilayer perceptron neural network is chosen as the central framework to address the problem at hand.

Fully connected multilayer perceptron can in some circumstances have high classification accuracy and discriminatory power in Cantus Firmus classification using the correct variables.

The evaluation of the Cantus Firmus through a neural network requires the feeding of this network for its training. To this end, 130 Cantus Firmus exercises were performed to evaluate the characteristics they require to function. Exercises were designed with no errors, others with some errors and a few with enough errors to make it clear that they are not functional, in this way, the training model of the neural network will interpret and evaluate with a numerical percentage the new exercises.

A. Multilayer perceptron neural network

In the present work we use a neural network known as multilayer perceptron that belongs to the group of unidirectional networks organized in layers and with supervised learning.

According to Muñoz (2010), the multilayer perceptron (or some of its variants) is currently considered to be the most widely used in practical applications. This model uses the backpropagation algorithm, and its popularity is since thanks to the paradigm that constituted its hidden layer, it is considered capable of learning any type of function or continuous relationship between a group of input and output variables.

The flexibility and learning capacity of the multilayer perceptron make it a valuable tool in solving complex problems, as in this case. Its effective application depends on the proper selection of architecture, activation functions, and training techniques, paving the way for future research and applications in various scientific domains.

B. Neural network structure

The structure of the neural network depends on the characteristics to be evaluated, so the following general characteristics were used to design a good cantus firmus:

- Tonality
- Mode
- Extension of the Exercise
- Climax
- Variety
- Leaps
- Coherence
- Final Cadence
- Unresolved Melodic Tension (Dissonant Intervals)
- Direction
- Continuity
- Balance
- Vocal Register
- Repetition of a note
- Repetitions Groups of notes (sequences).

C. Materials

In the development of the network, computer equipment with high information processing capacity was used, using basic software such as Excel and specialized software such as Python in GoogleColab, where different configurations and applications were programmed and tested to carry out the research.

IV. Development

This was a descriptive cross-sectional investigation, in which 130 correct and incorrect Cantus Firmus exercises were available for network training. Each exercise contains 15 features mentioned above, which generates a structure of 15 neurons in the input layer and 1 in the output layer for our neural network, and where each feature is evaluated from 1 to 3, where:

- 1 is a good rating
- 2 is average
- 3 is a bad rating

For each exercise, it is evaluated according to its design, in case the exercise does not have any error, the output (Y) would have a value of 1, in case of lowering the value of this evaluation, Y will decrease.

For the feeding of the network, we turned to specialists in music theory to design and supervise the exercises performed, this delayed the project a little due to the investment of time for the design of the exercises, however, we obtained more than expected with more features, giving more enrichment to the basic understanding of the Cantus Firmus and therefore a better feed for our multilayer perceptron.

Before starting the training, a scaling was done to the data set, what the following lines of code do is to take the training data and scale it giving a range between 0 and 1 (figure 1):

```
from sklearn.preprocessing import MinMaxScaler
scaler= MinMaxScaler()
X_train= scaler.fit_transform(X_train)
```

Figure 1 Code lines for scaling data set
Own elaboration, with the use of the Google Colab

Although the original training set handled small data, this method gave a better reflection in the loss data, improving the training.

The structure that obtained the best projection of the training results contains 5 hidden layers and with the Relu activation function for each neuron, as well as the use of the mean square error (mse) function, using 27 epochs. Parameters that yielded the most optimal results.

V. Results

Considering the theoretical and practical background of companies that develop musical projects through Deep Learning, we could infer that it is very feasible to perform the evaluation of the Cantus Firmus through the neural network. In the case of the method used, favorable results are shown with respect to training, since not so many epochs or hidden layers were needed for this.

Using the developed software, the following results were obtained: as can be seen in Table 1, the percentage of similarities of the peaks found, as well as their identification, are observed, thus finding the metabolites existing in the samples studied.

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	Loss	Val_loss
0	0.714899	0.612902
1	0.374907	0.296497
2	0.099398	0.138149
3	0.034382	0.091973
4	0.01793	0.062721
...	...	...
24	0.001586	0.014308
25	0.001413	0.013691
26	0.001397	0.01367

Table 1 Results generated on peaks in each sample
Own Elaboration

Where "Loss" indicates the loss for future predictions with the training data and gives a value of 0.0013 and "Val_loss", which indicates the loss for future predictions with new data is 0.0136, giving a difference of 0.0123.

Figure 2 shows the gradient showing the losses of values already mentioned indicating a good training of the network.

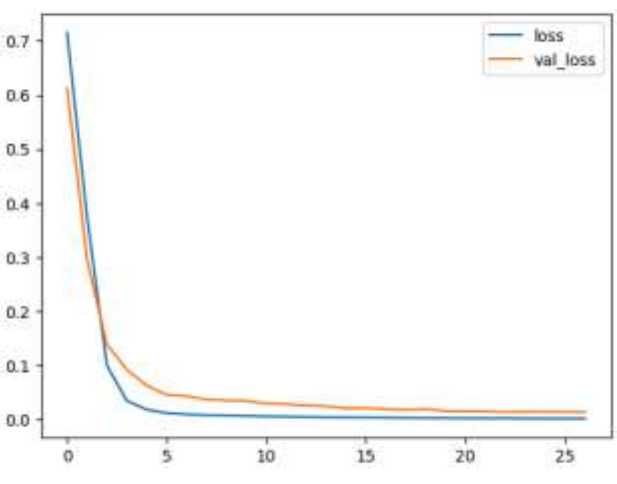

Figure 2 Gradient of learning for CFs
Own elaboration, with the use of the Google Colab

In addition, it is observed that there is approximately 0.1 difference when comparing actual data with the prediction, as seen in the following line of code, Figure 3:

```
mean_absolute_error(Y_test,predictions)=0.1021727874187323
```

Figure 3 Code lines for scaling data set
Own elaboration, with the use of the Google Colab

Given the results, the trained neural network makes accurate predictions for approximately 90% of the new exercises to be evaluated.

However, it should be considered that when designing a cantus firmus, one error can trigger another, i.e., if there are poorly performed jumps, it not only affects the jump, but also the continuity and balance, for this reason it is considered that the remaining 10% may be a side effect of this phenomenon.

With these results, it will be possible to classify the correct Cantus Firmus exercises from the incorrect ones, and thus be able to determine characteristic patterns that will help in the analysis of this type of melodic elements.

VI. Acknowledgments

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VII. Conclusions

According to the development of the Cantus Firmus evaluation project through neural networks, the objectives, both general and specific, have been successfully achieved. It is worth noting that, to reach the general objective, a database was developed with evaluations of designed cantus firmus, followed by the creation of a neural network. This network was trained using the database to subsequently assess new exercises.

Moreover, the created neural network performs very accurately in evaluating exercises with the same training data, with minimal losses. However, when evaluating new exercises, it exhibits a loss close to 10%. Nevertheless, these results clearly demonstrate that the evaluation and training processes are functional, and there is potential for developing various applications, some of which could be used daily.

As recommendations, one can consider exploring a different data analysis approach using the same database, providing an alternative structure that could prove useful and robust during training.

Additionally, expanding the scale of the database to include a greater variety of Cantus Firmus could enhance the training process. Another suggestion is to augment the neural network's architecture (such as adding more hidden layers and exploring different activation functions), as well as exploring the use of alternative network types capable of categorizing exercises based on their training characteristics. In the latter case, tests were conducted with various structures, resulting in minimal overfitting that, in the end, impacted the final gradient.

Future jobs

For future work, a more comprehensive development could be dedicated to assisting music school students interested in evaluating Cantus Firmus (and, in a more extensive development, assessing counterpoint) as a complement to the teachings of their assigned instructors. Additionally, there is the potential to explore the use of recurrent neural networks for the development of musical composition systems, like the initiatives undertaken by various mentioned companies.

In any of these scenarios or others, this work lays the groundwork for planting a seed of knowledge that can branch out into feasible projects based on specific areas of interest or emerging opportunities. By establishing a solid foundation, these projects can be executed in alignment with the needs and proposals that may arise.

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