# CAEPIA-App Competition: Sharpmony: A Computational Intelligence based tool for 4-part harmony

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***Abstract*—Sharpmony [1] is the first AI-based APP that provides a set of tools for music harmony students and teachers. On the one hand, a kernel has been developed with the assistance of experts in the area, that encodes classic harmony rules. This kernel allows to automatically detect errors in SATB scores that students develop when learning four-part harmony in music conservatories. Secondly, the kernel is part of the fitness function that an evolutionary algorithm uses to automatically provide solutions to this kind of composition exercises. Finally, a Deep Learning approach is used to capture handwritten SATB scores, so that students can take a photograph of their composition exercise, and then automatically enter the review process within Sharpmony, that will finally offer a PDF with errors detected.**

**After the tool was published in Google Play in 2019, 12 institutions and more than 1800 students are using Sharpmony, with several million chords, notes and errors checked.**

***Index Terms*—Evolutionary Algorithms, Deep Learning, Expert System, Music Composition.**

## I. Introduction

In classical music, the study of harmony is one of the key elements for students to develop their music composition skills. Western music has developed and evolved a set of harmonic rules that are learned and applied by all students enrolled in professional music conservatories. These rules, which began their development, more or less formally, in the *Renaissance*, were definitively established in the *Baroque*, with the study of counterpoint and fugue, Bach being the main composer of the period. In addition to instrumental music, Bach developed a whole series of choral compositions, in which the overlapping of voices require skill and mastery in harmonic development.

Thus, in the period that followed, *classicism*, the study of four-voice choral harmony -composed of four voices: Soprano, Alto, Tenor and Bass (SATB), is consolidated; and new rules emerge that establish the novelty of the music of this period.

[1]For Downloading Sharpmony, search it at Google Play, or directly go to https://n9.cl/fuv7a and link video https://youtu.be/ThSV8qMILIQ

It is therefore classicism's set of rules the one that is currently studied in the subjects Harmony 1 and 2. Students must thus compose SATB chorales in their third and fourth year of professional music education. The study of harmony thus consists of taking a melody as the starting point, melody that is assigned to the Soprano, and the student must compose the rest of the voices following rules that state what is allowed and not allowed. Similarly, students can begin with a figured Bass and try to develop the other voices.

The rules affect both the intervals between voices and the melodic movements that each voice develops in combination with the rest of the voices, as well as chord progressions.

To the best of our knowledge, and although the problem of SATB composition has been previously addressed in the Artificial Intelligence literature, there have been no attempt to develop a useful APP that allows both students and instructors to improve the learning process by means of Artificial Intelligence techniques.

## II. Brief description of the main functionality of the App

Sharpmony is therefore the first APP that provides a series of tools that make it easier to harmony students to improve their learning curve. On the other hand, teachers are provided with an improved APP specially designed for instructors, together with a cloud infrastructure that allows them to assign tasks, authomatically check exercises and keep a record of their students improvements. Namely, Sharpmony provides:

- A Deep-learning based tool for capturing and analyzing hand-writen SATB scores.
- A simplified score editor for SATB harmony.
- An AI-kernel based tool to review students exercises.
- A series of tools that allow teachers to assign exercises to students and check their progress.
- An Evolutionary Algorithm that allows teachers to evolve solutions to problems.

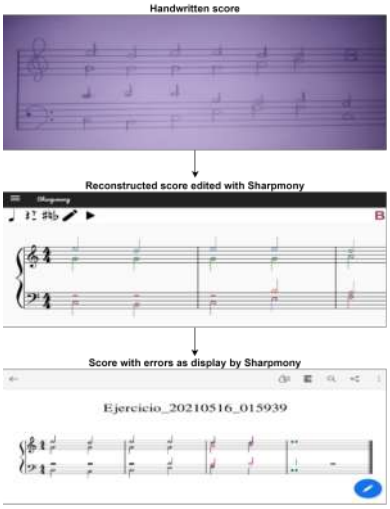


Fig. 1. Student exercise and its authomatic review provided by Sharpmony

In order to better understand what Sharpmony offers, we show in figure 1 an example of choral harmony exercise developed by a student, what sharpmony produce once Optical Music Recognition is applied, and finally, harmony errors detected by the kernel.

As we notice, four different voices are present in SATB exercise, which produce a chord progression. The main goal for students is to be able to compose four-part harmony exercises with no errors.

Thus, taking into account the way students work, sharpmony provides:

- An Optical Music Recognition method to enter handwritten SATB scores, as well as an score editor.
- The tools allowing interaction with teachers: Managment of teachers assignments, edition of scores to solve the exercises, etc.
- Connection with the kernel in charge of checking exercises.

All these tasks requiere not only the APP (what the student uses), but also a cloud infrastruture that centralize the management of institutions (conservatories), users, exercises, etc: the backend in the cloud required for everything to properly work.

On the other hand, considering teachers, Sharpmony provides:

- A method to assign exercises to students or group of students.
- The required tools to check exercises and the authomatic reviews provided by Sharpmony.
- We also provide AI based composition methods that authomatically solve SATB problems.

We decided to develop an APP given the kind of devices that usually young students use: hand-held devices. Moreover, students typically use android based devices, so we first developed an Android version of Sharpmony, although we hope to have the iOS version ready for the next accademic year. Yet, a series of additional tools are available on the project website [2], so that instructors can perform managment operations, such as deciding the kind of error controls to be checked on exercises, create and manage group of students, etc.

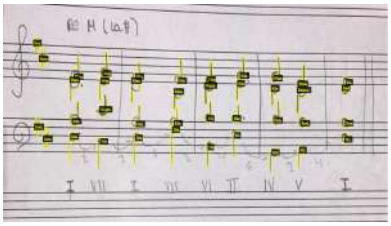

Fig. 2. Object segmentation for the learning process

## III. I.A. Technique(s) on which it is based: Computational Intelligence applied to 4-part harmony learning

A series of IA techniques have been applied to develop every tool included within Sharpmony. Particularly, i) a Deep Learning approch has been applied to the OMR tool; ii) a Kernel with harmonic rules have been developed, thus providing an expert system developed using functional programming, that is then iii) embodied within a fitness function of an Evolutionary Algorithm. We include below a summary of the algorithms used as well as references to papers that describe them with more detail.

### *A. Deep Learning applied to SATB handwritten scores*

Four general stages have been applied to build the Optical Music Recognition System that Sharpmony provides:

- First, we proceeded to create our repository consisting of photographs of the handwritten scores, to which the segmentation process is applied.
- These already segmented scores have then been used to train a pre-trained deep convolutional neural network, and finally a classification of the various symbols contained in each image of the repository is obtained. This procedure is performed in a first training stage for our problem.
- Then, the testing stage is performed on unknown images for the network.
- Finally, once the trained network is ready, a server is set up with a python version of the trained network, in charge of receiving photographs taken by Sharpmony APP, and converting them to an MusicXML file.

Figure 2 shows a segmented handwritten score used during the training step.

On the other hand, figure 3 shows a sample of detected objects in a score. Although the quality of results in the current implementation is high, around 90%, errors produced must be fixed before the score is analyzed. This will be necessary

[2]https://sharpmony.unex.es

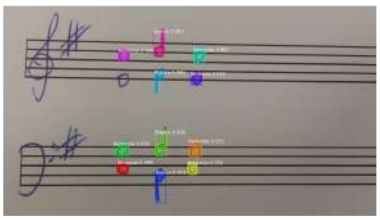

Fig. 3. Object recognition result

until 100% is reached in the optical music recognition process. Although we are optimistic about the results we may reach in the comming months, we have developed and included within Sharpmony a frendly score editor, that allows students to check the MusicXML produced, as well as directly edit a new score from scratch (figure 1 shows the score editor in the center).

Figure 4 shows the architecture of the OMR layer within Sharpmony. Detailed information about the Mask-R-CNN model applied in this stage is provided in [1], whose final result is an MusicXML standard file.

### B. Classical harmony rules kernel

Once the MusicXML file is ready, the AI kernel in charge of checking harmonic rules is applied to the exercise. A server is in charge of receiving MusicXML files, checking all rules previously selected by the teacher, and providing a PDF version of the score with wrong notes and chords marked with different colors associated with rules broken.

Figure 1 shows the score reviewed, with some notes marked with colors, corresponding to notes that do not comply with the rules.

Specifically, errors corresponding to *Distances greater than octave between voices (light yellow), Incorrect Cipher (mustard yellow), Parallel Octave-Fifths (red) and incorrect chords (olive green)* are marked. All the rules have compiled by our experts team, music instructors working in Professional Music Conservatories in Extremadura. More information about the error controls is available in the website.

### C. Evolving 4-part harmony scores

As described above, we developed a kernel with the harmonic rules we had selected. This kind of expert system is then embodied within a fitness function that is used by a Genetic Algorithm to provide solutions to any melody we may write in Sharpmony.

We decided not to provide this powerful tool within the standard version of Sharpmony because of two main reasons: i) On the one hand we want students to develop their hability to compose SATB scores, and providing a tool that solve the problems is not desirable; ii) Because of the difficulty of the problem, hours or days are required to find solutions of quality.

The evolutionary algorithm employed is based on the results already published in [2], which interested readers may check for every detail of the algorithm configuration. Basically, the algorithm works in a two-stages approach:

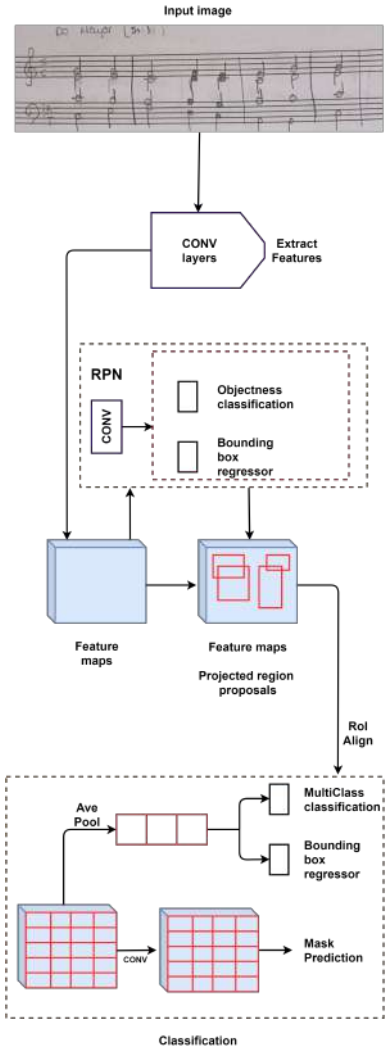


Fig. 4. Mask-R-CNN

- First, the algorithm tries to find a progression of chords that fits the melody provided. This means that for each of the notes in the melody, a suitable chord must be found, and the series of chords must be *reasonable*, (such as II-V-I progression).
- Second, once the progression is available, a distribution of chord notes must be found so that the number of rules broken are minimized in the score. The kernel within the fitness function is in charge of evaluating results.

The evolutionary algorithm, as well as the Deep Learning based algorithm, are run on a server hosted by the University of Extremadura. Given that computing resources are limited, and the large number of users registered (more than 1800) we cannot provide yet the tool to all of them. Instead, we are working with teachers to polish the tool, analyse solutions provided by the evolutionary algorithm, and find new ways to

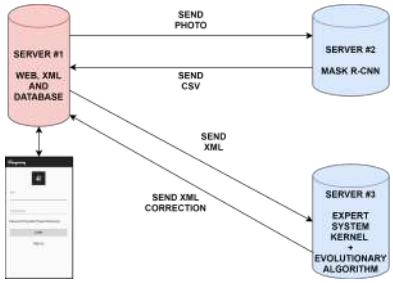


Fig. 5. Sharpmony Cloud Infrastructure

reduce computing time.

## IV. Technologies and tools used

The development of the application has been natively programmed from scratch, for Android (already available in Google Play, Spanish and English versions) and iOS (under development) devices using the proprietary technologies offered by each platform, offering a unique user experience and a lightweight application size so that it can be run on a wide variety of mobile devices. MusicXML has been used as an open standard for XML-based music notation, thus offering compatibility with a wide variety of music score editing tools (such as Finale, Sibelius, Musescore, Noteflight, etc.).

On the server side, the back-end system is hosted by the University of Extremadura. Three different servers are in charge of each of the componentes required to support Sharpmony tasks, as depicted in figure 5.

The genetic algorithm as well as the Kernel (Expert System with harmonic rules, that is also part of the fitness function) has been developed using the Common LISP programming language. There are several reasons behind choosing functional and symbolic programming as the framework (check for instance [3]), mainly due to the highly symbolic and redundant nature of music representation within scores. Although music is made up of different sounds that are mixed together, and every sound can be analyzed by means of its frequency, the way music is represented is highly redundant and symbolic (for instance, a frequency of 440Hz can be described as notes A, Gx or Bbb).

For the development of both the backend and the frontend of the web platform, the PHP-based Yii 2.0 framework has been used.

Finally, for client-server communication, a REST web service has been developed, which is consumed by the application through the HTTPS protocol for secure data transfers.

## V. Usefulness and feasibility of the App

The mobile application is one of the main factors behind the use of Sharpmony by 12 institutions and 1800 students. Although the main functionality of the kernel had been developed several years ago, and we began was tests with some students by means of a file sharing service in 2015, we could not reach a wide audience until the Android APP was completed by 2018. Moreover, although the score editor and the kernel in charge of scores reviews were available a year ago, we have only very recently added the Computational Intelligence based tools described above, that allow to both evolve a composition (only for teachers), and capture and convert handwritten scores into MusicXML standard files, that allows further editing and correction, if necessary, in the app itself, or thanks to the compatibility offered, in a third party tool.

The music notation editor has been specifically designed to be used by both conservatory students and users with no previous experience in music notation software. Unlike the tools available for music editing, with a fairly expensive learning curve, the APP developed is specially adapted to beginner users, and to Harmony and Composition subjects of professional conservatories, removing much of the usual complexity of the editors, and keeping only the elements necessary for this type of exercises.

Two types of benefits associated with each of the application's user profiles can be highlighted:

- In the case of students, they can send exercises to be reviewed, either from a photograph or using the editor, as many times as necessary, without waiting for their teacher to correct the exercises in class. Thus, the system allows a review history, and the student can apply the correction/improvement cycle as many times as he/she wishes until an error-free exercise is achieved.
- Teachers can propose exercises in the APP, associate them to groups of students previously configured, select harmony rules to be applied during the authomatic review process, and finally check the exercises developed by the students. In addition, they can use the tools to automatically solve through evolutionary procedures, and use the results in more advanced conservatory subjects: such as composition fundamentals, choir, etc.

We plan to launch the iOS version of Sharpmony in September 2021, and hope to reach a much wider audience, thus allowing Sharpmony to be the standard tool for learning 4-part harmony.

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[2] F. Fernández de Vega, "Revisiting the 4-part harmonization problem with GAs: A critical review and proposals for improving." Proceedings IEEE CEC 2017: 1271-1278

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