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ALGORITHMIC ANALYSIS AND HARMONIC DATABASE GENERATION FOR MUSICOLOGISTS

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ABSTRACT

Harmony is an integral part of both the musicology and conservatory curricula. This article discusses some technical aspects of the "Learning Harmonizer" project aiming at developing a pedagogical tool for the hybrid teaching of this discipline. It can be used by teachers in class to help students complete exercises on their own, or to correct exercises on blackboards. In fact, in addition to a hybrid classroom, the tool will offer hybrid teaching with e-learning. Students will be able to do their homework with the help of the tool, which will help them complete all the exercises, even if they have difficulty. The teacher will also be able to monitor students' personal investment and performance in their work at home and in class. This will make it easier for the teacher to know which students are struggling, giving up or to identify notions not acquired by a majority. For this purpose, it is necessary to work on large corpora. But, analyzing and studying an entire corpus takes a lot of time and energy, which is why we have developed tools that do this automatically.

This article presents two modules of this projet, one to analyze many scores, and the other to extract the harmonic sequences used by the composers of the scores. The Music21 toolbox [1] is used to analyse the scores, and an oracle is built using the VMO library [2] to extract the harmonic sequences.

We analyze tones, modulations, chords and foreign notes. And we transcribe these analyses into Baroque and Anglo-Saxon notation. This tool can be used independently of the harmony teaching tool. Indeed, it could be used to teach musical analysis, another subject in the curriculum.

In addition to their usefulness in the Learning Harmonizer project, they enable the automatic generation of databases of analyzed scores and chord sequences appropriate to the composer's writing style. These databases can be used by musicologists and other computer music researchers for their projects and teaching.

1. INTRODUCTION

Harmony is a combination of several elements that "go well together". In the field of music, and more specifically

in Western music theory, harmony is the art of studying the construction of chords. This is known as the study of the vertical dimension of music.

The use of computers is becoming increasingly common in the classroom, and offers a number of pedagogical advantages. In the Learning Harmonizer project, we propose tools for developing software architectures for the teaching of music writing in universities and conservatories [3]. In this article, we won't go into the socio-political issues surrounding our project.

By its interdisciplinary nature, this project will draw on work from a variety of fields, including musicology and computer science.

1.1 Motivation

The aim of the Learning Harmonizer project is to propose solutions to help teachers teach and students learn harmony.

The problems encountered by teachers that we deal with are :

- the difficulty of individually correcting all students' work
- knowing whether students understand the concepts
- tackling the entire program in a given timeframe

In fact, teachers are sometimes faced with large classes. In such conditions, they can only make very few individual corrections, which are costly in terms of class time. As a result, they are not always able to pinpoint concepts that students have failed to grasp, since a sample that is too small is not representative of what the class as a whole has learned.

The problems encountered by our students are as follows:

- Assessing one's own progress
- Identifying weaknesses and strengths
- Knowing whether the solution found could be correct even if it does not appear in the teacher's answer sheet
- Needing help with exercises outside the classroom
- Needing more independent practice
- Breaking away from rules when working on creative projects

1 The question of individualized corrections also has a major 59
2 impact on students. They are a good indicator of progress, 60
3 and put their weaknesses as well as their strengths into per- 61
4 spective. What's more, in music as in many other subjects, 62
5 there is no single solution to a given problem. In traditional 63
6 teaching, if the teacher has not corrected each student's 64
7 work individually, the student will have only the teacher's 65
8 single correction to use for self-assessment. This method 66

9 only allows them to analyze the differences between their
10 work and the single correction available to them.
11 Another problem encountered by students is having to wait 67
12 for the next lesson to get the correction when they have 68
13 difficulty doing the exercise. This makes it much harder 69
14 for students to memorize and understand concepts. Some- 70
15 times, a single intervention by the teacher would be enough 71
16 to help the student. However, the teacher cannot provide 72
17 individualized support for each student between lessons.

18 1.2 State of the art

19 Several tools for teaching music already exist.
20 Some are aimed at teachers and students in music
21 schools/conservatories for teaching music theory and even
22 instrumental practice. Others are aimed more at people
23 wishing to become music professionals.

24 There are many tools available for teaching and learning
25 solfège, sometimes called musical training (FM). One of
26 the pillars of musical training is ear training, from pitch
27 and rhythm recognition to musical analysis. EarMaster [4],
28 for example, is a tool for learning to recognize pitches and
29 rhythms so as to be able to identify themes and works.
30 But this tool doesn't stop there: it also offers reading,
31 rhythmic and singing exercises. So you can practice
32 the fundamentals of musical training on your own. A
33 version of the software is available for music schools and
34 conservatories, with a teacher interface. Teachers can then
35 create their own exercises. Deepsofège [5], Solfeggio [6]
36 and Troubadour [7] are also available for learning music
37 theory.

38 Other tools have also been designed for learning an
39 instrument. Students sometimes need advice between
40 lessons, and unfortunately have to wait until the next
41 lesson for the teacher to unblock the situation. Digital
42 Violin Tutor (DVT) [8] has been designed to address this
43 problem. It is based on 3D visualization of the gesture
44 using an avatar that reproduces the movements recorded
45 on video, error tracking displayed on a piano roll and a
46 2D animation representing finger positions on the violin
47 fingerboard. We can also mention other tools for learning
48 the piano and guitar with Yousician [9] or the flute with
49 the anthropomorphic robot WF-4 [10]. 105

50 A number of these tools can be used independently. This
51 can create a number of difficulties in the learning process.
52 Students need to be organized and practice regularly
53 without outside prompting. However, only a certain
54 percentage of students will achieve this. What's more,
55 students may become weary of difficulties that cannot be
56 solved by the tool itself. The intervention of a teacher is
57 often essential in the learning process. It is a guide on
58 the path to acquiring knowledge and skills. A tool alone 114

cannot replace traditional teaching, but a tool can help
teachers. This is what we call hybrid teaching.

1.3 A software for teaching harmony

In this section the pedagogical method of the project is de-
tailed and a usage scenario of the tool in the classroom is
proposed. At last, we introduce some technical modules
needed to develop the generation process and that are con-
sidered later in this paper.

1.3.1 Pedagogy at the center of the project

The pedagogy at the centre of the project combines hybri-
dation of the classroom, with a concept of guidance en-
abling students self-sufficiency, and the proposition of sev-
eral solutions encouraging students' creativity.

1.3.1.1 An hybrid classrooms

The aim of this project is to propose a pedagogical tool
for harmony that fits in with the process of building hybrid
classrooms and hybrid harmony teaching. Hybrid teach-
ing is a form of training that combines face-to-face lessons
with e-learning. A hybrid classroom is an environment
where the teacher can alternate between traditional teach-
ing and teaching using one or more IT tools (tablet, com-
puter, etc.).

In this project, e-learning helps meet certain needs of the
students, in particular self-sufficiency. Between lessons,
they sometimes need guidance and hints to help them
complete homework assignments. Whereas in traditional
teaching, students have to wait for the teacher to correct
their work on the blackboard before they can copy the
correction, sometimes without really understanding it. E-
learning allows them to get help when they express the
need, to unblock a problem and enable them to complete
the entire exercise.

As part of the e-learning program, students will also have
access to a set of exercises selected by the teacher from
a database, enabling them to train independently. Each
student can therefore learn at his or her own pace, both
individually and collectively. This is called differentiated
teaching.

1.3.1.2 Individualized correction

In conventional harmony teaching, where the teacher only
corrects a small sample of exercises performed by the stu-
dents, he or she does not have sufficient data to know
whether the concepts are understood when the students do
not express their misunderstandings or difficulties in class.
To provide an answer to this problem, the tool will carry
out an individualized correction of all exercises, then, in a
second step, they can be transcribed into statistics and sent
to the teacher interface in the form of diagrams. So, at a
glance, the teacher will know which concepts need to be
re-explained in class.

This feature should enable the teacher to save time dur-
ing the lesson, while allowing not just a small group, but
all students to benefit from individualized corrections. In
particular, this will enable more active group correction in
class. Students will have an individualized correction in
front of them, enabling them to share their solution orally

1 with the whole class, and thus feed into the correction
2 made on the board. This will encourage oral participation
3 and help establish fairness and a climate of trust between
4 all students. The teacher won't be correcting only on the
5 basis of his or her own solutions, but can combine them
6 with those of the students.

7 Thanks to this tool, all students can benefit from an individ-
8 ualized correction in which their errors are explained. This
9 will enable them to see how they are progressing. What's
10 more, the tool will enable them to observe more solutions
11 and examples based on their own unique approach to har-
12 mony. This will also help to fuel their own creativity.

13 1.3.1.3 Guidance module

14 Depending on the settings made by the teacher, the tool
15 will be able to correct the student's assignment step by
16 step, enabling the student to avoid errors that could have
17 repercussions on the rest of the exercise, sometimes mak-
18 ing it completely wrong. Teachers can therefore choose
19 whether to allow students to be guided step by step, on
20 demand or not at all, depending on their own teaching
21 choices. In all cases, the tool will not provide the stu-
22 dent with the right answer, but it could, for example, sug-
23 gest a list of solutions. This list could include false an-
24 swers. In designing this feature, we'll be drawing inspi-
25 ration from spell-checking software such as Antidote [11],
26 which, unlike the spell-checkers in text-editing software,
27 doesn't provide the answer, but invites the user to ques-
28 tion him or herself to find the answer on their own, and
29 thus learn from it. If they choose an incorrect answer, a
30 message is displayed explaining why the answer is incor-
31 rect, i.e. which rules have been broken. Students who have
32 given a wrong answer can then make another proposal.

33 Each time the student makes a mistake, the system incre-
34 ments a list in which each element corresponds to a notion.
35 This then generates a diagram which is sent to the teacher
36 for pedagogical follow-up once all the students have com-
37 pleted the exercise. After a certain number of unsuccessful
38 attempts, the system completes with a correct answer, en-
39 abling the student to continue.

40 If the teacher does not choose step-by-step guidance and
41 the system detects too many errors even before correct-
42 ing the student's entire assignment, a message will be dis-
43 played inviting the student to ask for help via the integrated
44 guidance module. Whether the teacher chooses to use step-
45 by-step guidance or some other method, the system records
46 the time spent by each student on the assignment and the
47 progress made, enabling the teacher to analyze the data and
48 detect any lack of work, and above all any demotivation of
49 one or more students.

50 1.3.1.4 Encouraging creativity

51 A major advantage of this teaching method is to encour-
52 age students' creativity by presenting a greater number of
53 examples inspired by the styles of the composers studied.
54 Solutions that are considered false by harmony textbooks,
55 but used by composers, can then be tackled. In this way,
56 we hope to reverse the trend and allow the discipline to fuel
57 students' creativity.

58 To bring this project to a successful conclusion, appropri-

ate technical solutions has to be proposed. The analysis
algorithm and rule extraction module presented in this ar-
ticle are two examples.

62 1.3.2 Usage scenario

63 In this subsection, we present a possible scenario for using
64 the system in a university undergraduate class. Figure 1
65 shows the system's block diagram.

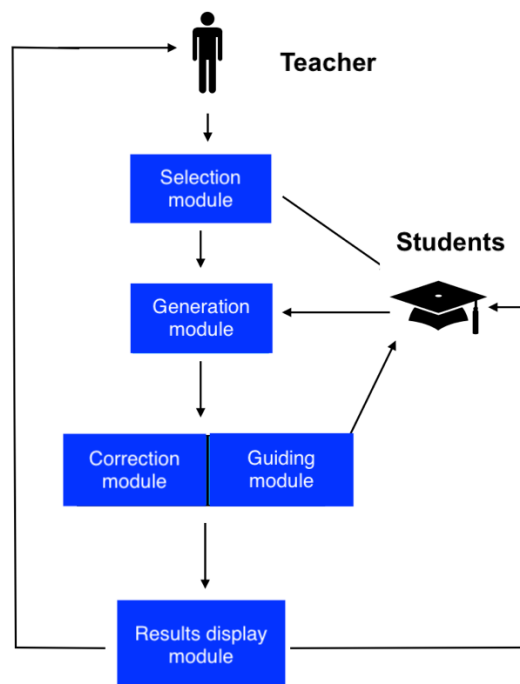


Figure 1. Usage scenario diagram

66 First, the teacher fills in all the parameters in the dedi-
67 cated interface. For example, the teacher chooses these
68 parameters:

- 69 • Composer: J. S. BACH
- 70 • Notions to include: the chord of fifths and its two
71 inversions
- 72 • Notions to exclude: dominant seventh, species sev-
73 enth, ninth and their respective inversions with and
74 without fundamental
- 75 • Step-by-step guidance

76 The software then suggests exercises that meet the
77 teacher's criteria, taken from the catalog provided in the
78 system. The teacher can then choose the one he or she
79 wishes. The teacher then checks that all students are
80 logged into the student interface and ready to do the ex-
81 ercise.

82 The students can then begin the exercise. A guidance mod-
83 ule and a correction model will enable them to interact with
84 the system. The guidance module, depending on the pa-
85 rameters chosen by the teacher, can suggest solutions to the
86 student at each stage of the exercise, or when requested, or
87 not at all. It's up to the teacher to choose between the three

1 guidance modes for each exercise.
 2 The correction module can be set to different levels, allow-
 3 ing teachers to adapt it to each student, within the limits of
 4 their pedagogical choices. Thus, when set to maximum, it
 5 provides feedback on the student's work, even if it is en-
 6 tirely correct.
 7 The teacher can make a global correction of the exercise
 8 on the blackboard, focusing on the notions revealed by the
 9 system as being the least understood. The teacher has the
 10 choice of working out the correction on his own, having
 11 the system generate one and explain it to him, or building
 12 it with the class. The teacher is free to apply the teaching
 13 method he or she considers most appropriate at any time.

14 1.3.3 Building the generation process

15 To meet these needs, and in the light of examples of the ap-
 16 plication of artificial intelligence to music generation, we
 17 have considered several technical options.

18 To enable teachers to select composers according to their
 19 pedagogical choices, we are planning to build a database
 20 that will group together a set of musical scores classified
 21 into corpora and labeled according to their composer, with
 22 each composer not belonging to the same stylistic trend.

23 We intend to use the Music XML format, which preserves
 24 the nature of the intervals, instead of the MIDI format to
 25 build our database. For example, if we consider the inter-
 26 val between the notes "C" and "E#", we have an augmented
 27 third. But if we consider the interval between the notes "C"
 28 and "F", we have a perfect fourth. The MIDI values of "E#"
 29 and "F" are identical.

30 Our system must be able to reproduce the way composers
 31 write from a corpus. We therefore plan to use a deep learn-
 32 ing technique because this technique has already proved its
 33 worth in completing existing sequences using inpainting.

34 This will meet the need for student guidance and correc-
 35 tion. However, the system must be part of a pedagogical
 36 approach, and therefore be capable of explaining the gener-
 37 ation obtained. The problem of explanation for neural
 38 networks is still in the research phase. For this task, we
 39 therefore plan to experiment with a coupling between a
 40 neural network and a rule-based system. The rule-based
 41 system should be able to analyze the generator's output to
 42 extract the rules used in the sequences or to detect errors.
 43 This module can also be used to correct student produc-
 44 tions. Figure 2 shows the sequence of modules. Between
 45 the generator and the corrector is an analysis module, de-
 46 signed to harmonically label the sequence. This module
 47 will also be used to analyze students' work, making our
 48 system interactive.

49 We have chosen to base the generator on the DeepBach
 50 neural network created by Gaetan Hadjeres [12], which can
 51 take XML files as input. What led us to choose this partic-
 52 ular network is its ability to perform inpainting, as opposed
 53 to other neural networks we have studied. As the program
 54 was developed as part of a thesis within the LIP6 Labora-
 55 tory in the ASIM Department of the Université Pierre et
 56 Marie Curie, under an MIT license, it can be modified and
 57 reused. What's more, there's a plug-in to integrate it with
 58 the free, open-source score-editing software MuseScore.

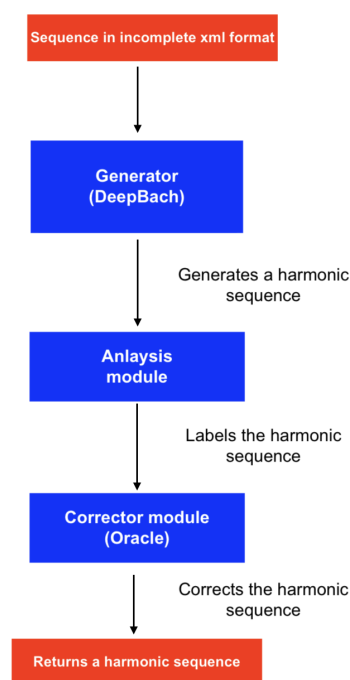


Figure 2. Central module of the generation and correction process

59 In contrast, the corrector takes the form of a factor oracle
 60 built with the Python module designed by WANG (Cheng-
 61 i) [2].

62 All the modules making up this architecture can be used
 63 independently for learning (e.g. the analysis module), but
 64 also for new IT projects, as they will all be open source.

2. ANALYSIS MODULE

66 In this section we present the harmonic analysis module
 67 we have developed. First, we'll explain its objectives and
 68 the choices we've made to achieve them. Then, we'll talk
 69 about the database we chose and used in the development
 70 and testing process. Next, we'll look at the module's in-
 71 ternal architecture. Finally, we'll explain how we intend to
 72 scientifically validate our work.

2.1 Purpose of the analysis algorithm

74 The purpose of the analysis module is to analyze a score
 75 provided in MusicXML format in order to return several
 76 lists with the harmonic analysis of the piece. It will re-
 77 turn the following lists: harmonic analysis in Anglo-Saxon
 78 notation, harmonic analysis in Baroque notation, chord de-
 79 gree analysis and tonality and modulation analysis. To do
 80 this, it will also calculate the value of the harmonic fre-
 81 quency. If the frequency is a quarter note, the lists will be
 82 made up of one element for each time step equal to a quar-
 83 ter note.

84 We first developed the analysis algorithm for two reasons:
 85 to build a database for the rule extractor algorithm and to
 86 analyze the scores/exercises written by the students to offer
 87 them an individualized correction. It will be used in several
 88 places in our architecture: to develop multiple modules, to

1 correct the students and to collect data in order to extract
 2 statistics useful to the teacher in adapting his course to the
 3 level of his class.
 4 Doing such a job manually would be extremely time-
 5 consuming, so we decided to automate it. Moreover, it
 6 is desirable to be able to generate a database for several
 7 composers, so as to offer more exercises that could be per-
 8 formed. Adding new features will therefore be quicker and
 9 easier, taking a longer-term view of the project.

10 2.2 Data used

11 To design the analysis tool, a corpus was needed to try out
 12 and think about the functionalities to develop. As this tool
 13 is part of a development of the "Learning Harmonizer", the
 14 score corpus has also to be suitable for this one. In the 1st
 15 years of teaching harmony, it's J. S. Bach's style of writing
 16 and the type of work called Chorals that is often used.

17 The corpus consists of 339 J. S. Bach chorales for four-part
 18 choir. As writing for choir and string quartet is not entirely
 19 similar, we have chosen to select only a portion of the 413
 20 chorales written by Bach during his lifetime. As four-part
 21 choral formations are more often approached before instru-
 22 mental formations, we have selected these.

23 We used the corpus available in the Music21 toolbox [13],
 24 programmed in Python and comprising 363 chorales by
 25 Johann Sebastian Bach. We have removed chorales for in-
 26 strumental or vocal training that do not strictly contain four
 27 voices. We therefore removed 12 chorales, leaving 339 to
 28 form our data set.

29 Here are the chorales we removed from our data sam-
 30 ple : bwv112.5-sc, bwv248.9-1, bwv248.23-2, bwv227.7,
 31 bwv248.42-4, bwv251, bwv299, bwv315, bwv41.6,
 32 bwv437, bwv8.6, cpebach.h186

33 His database is available online on GitHub [14].

34 2.3 Analysis algorithm design

35 There are different techniques for notating harmony in mus-
 36 ic. There's Baroque notation, which uses Arabic numerals
 37 for chords and Roman numerals for degrees, and Anglo-
 38 Saxon notation, which is often used in jazz.

39 We have designed an analysis module that enables har-
 40 monic analysis of XML score files. The algorithm is shown
 41 in Figure 3 and is available on GitHub [15]. It will be used
 42 to build the analyzed corpora that will be input to the rule
 43 extraction module.

44 First, the musical data is extracted from a file in Music
 45 XML format, i.e. the pitches and rhythms of the various
 46 parts (voices). Then the data is normalized to obtain a list
 47 of chords with a time step of a sixteenth note (a quarter
 48 beat).

49 To analyze chords, the context in which they are played is
 50 used. Two kinds of notes must be identified : the foreign
 51 notes that are not part of the same harmony, and the real
 52 notes that are part of the harmony, but are played before or
 53 after the chord.

54 Once the foreign notes have been analyzed and replaced in
 55 the table for each chord by the real notes, the system re-
 56 duces the data set to the essential elements. We no longer
 57 need to observe chords with a time step of a sixteenth note.

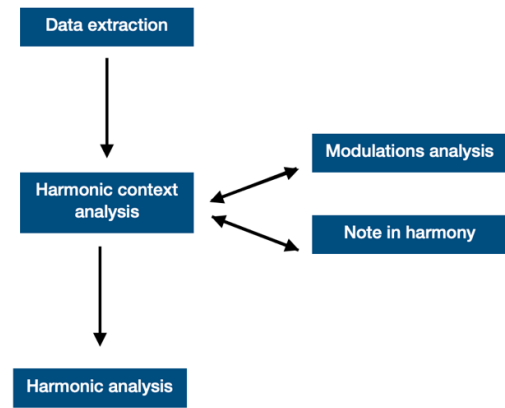


Figure 3. Analysis algorithm

58 For example, we'll keep one chord in four if the harmonic
 59 frequency is quarter-note, or one in two if the frequency is
 60 eighth-note, and so on.

61 In order to give the Baroque cipher of a chord, the key in
 62 which it is played is needed. Indeed, the degree of a chord
 63 depends on the key, and may be a first degree in one key
 64 and a fifth degree in another. In harmony, the sequence of
 65 degrees is important and is the subject of numerous rules.
 66 The system then creates a table showing the key in which
 67 each chord is played.

68 Once the harmonic context is known, it's possible to start
 69 analyzing the chords. The module begins by constructing
 70 a table with the Anglo-Saxon cipher of all chords. Then, it
 71 does the same with the Baroque cipher, but in two tables:
 72 one for the cipher and one for the degrees.

73 Finally, this module returns all these lists: one for mod-
 74 ulations, one for degrees, one for Baroque ciphering and
 75 one with Anglo-Saxon ciphering. The last one is used as
 76 oracle input. Here is an extract of the result, lists and file,
 77 generated by the algorithm on the chorale BWV 2.6 in G
 78 minor :

79 Below is a list of chords in MIDI notation for each time
 80 step. In this example, a quarter note.

```

81 [[69, 66, 62, 50], [70, 67, 62, 55],
82 [69, 66, 60, 57], [67, 67, 62, 58],
83 [74, 70, 67, 57], [74, 69, 62, 54],
84 [70, 67, 62, 55], [69, 66, 62, 50],
85 [72, 68, 63, 48], .....]]
  
```

86 This second list represents the analysis of the song's
 87 tonality at each time step. This makes it possible to visu-
 88 alize modulations and is essential for degree analysis. For
 89 example, in C Major a C chord is the I (1st) degree of the
 90 scale, and in F Minor it's the V (5th) degree of the scale.

```

91 [<music21.key.Key of g minor>, ...
92 <music21.key.Key of g minor>,
93 <music21.key.Key of g minor>,
94 <music21.key.Key of d minor>,
95 <music21.key.Key of d minor>,
96 <music21.key.Key of d minor>, ...
97 <music21.key.Key of g minor>, ...]
  
```

1 Finally, we have the analysis in Anglo-Saxon notation, 43
 2 with one element per time step. Here we have the first 3
 3 bars of the chorale BWV 2.6 in G minor.

4 Hermonic analysis
 5 ['D', 'Gm', 'F#dim/A', 'Gm/B-',
 6 'Gm/A', 'D/F#', 'Gm', 'D',
 7 'A-/C', ... , 'D']

8 This module generates also a a MusicXML file with the
 9 annotations and opens it in Muscorescore. The annotated
 10 score is displayed on Figure 4. We've designed a plug-in
 11 that allows it to be used outside our global project.

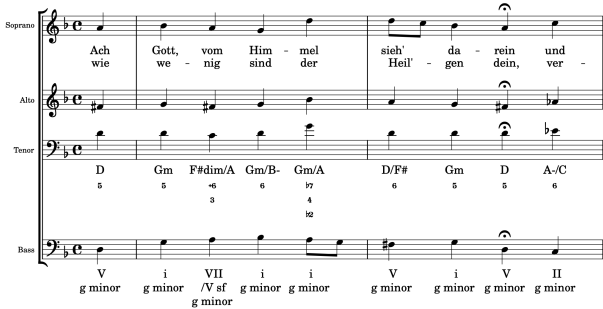


Figure 4. Choral BWV 2.6 analysed by algorithm

12 2.4 Algorithm validation

13 To validate our algorithm, an automatic comparaison is
 14 performed with the analysis carried out by the American
 15 musicologist Christopher Czarnecki, published in the book
 16 J.S. Bach 413 Chorales: Analyzed [16], used as a refer-
 17 ence. To do this, we've transcribed his analysis into a CSV
 18 file, more precisely the anlyase in Anglo-Saxon notation.
 19 It would be interesting to label various types of possible
 20 error to obtain detailed statistics.

21 We have already carried out a few manual comparisons on
 22 the BWV 1.6 , BWV 2.6 and BWV 14.5 choruses, and the
 23 algorithm's success rate is 90% on this limited sample. We
 24 have observed that the algorithm has difficulties with for-
 25 eign notes and the exact location of modulations. It does
 26 not systematically produce errors in these two areas. Most
 27 of the time he can detect that there is a foreign note and
 28 find the one that actually belongs to the chord. And in the
 29 majority of cases, he can locate modulations to within a
 30 few beats.

31 Next, we'll run an automatic test on a sample of one hun-
 32 dred chorales. We also hope to achieve a success rate of
 33 90 %. Based on these initial results, we will then try to
 34 improve the algorithm to obtain optimal results. In partic-
 35 ular, we plan to improve the detection of foreign notes and
 36 modulation.

37 3. RULES EXTRACTION MODULE

38 In this section we present the rule extraction module [17].
 39 First, we'll explain why we've chosen to use the oracle
 40 technique. Then, we'll talk about the database we used to
 41 build and validate the oracle. Finally, we'll look at how we
 42 validated the module.

43 3.1 Choice of technique: VMO

44 In a previous research project carried out by the first au-
 45 thor [18], a manual rule extraction method has been pro-
 46 posed. On the basis of this work, and with a view to ex-
 47 tending it to a larger database, ways of automating the pro-
 48 cess have been studied.

49 This previous work has led to the design of a mobile ap-
 50 plication, Learning Harmoniser [19], which harmonizes a
 51 melody note by note in the style of MOZART. In this mo-
 52 bile application, the analysis was based on sequences of
 53 two consecutive chords. However, certain rules of music
 54 writing require to take into account longer sequences. We
 55 therefore plan to distinguish harmonic sequences between
 56 short sequences (two chords) and long sequences (an ex-
 57 ample of which is the anatole, which is made up of four
 58 chords).

59 The method is based on identifying the harmonic se-
 60 quences of two or more consecutive chords used by a com-
 61 poser or in a musical genre. The algorithm must therefore
 62 memorize the sequences already encountered, so as not to
 63 add them to the list again. And the final objective is to
 64 predict the next chord according to the note of the melody
 65 and the preceding chord or chords, as illustrated in Figure
 66 5. This method being quite similar to what an oracle can
 67 do, we automated it using the Python module designed by
 68 WANG (Cheng-i) [2].

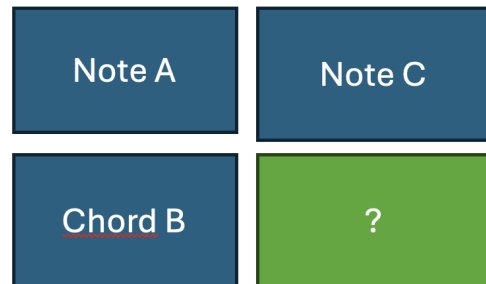


Figure 5. Oracle prediction illustration

69 3.2 Preparation of database

70 To feed the oracle, we used the analysis of the J. S. Bach
 71 corpus performed with our analysis algorithm. As we
 72 have done in the past, we have extracted from our analy-
 73 sis essentially the chords in Anglo-Saxon notation and the
 74 melody sung at the same time as the chord. his database is
 75 available online on GitHub [20].

76 Tonality doesn't influence harmonic rules, but modes do,
 77 we standardized the corpus, i.e. we transposed all the
 78 chorales to either C major or A minor. If we hadn't done
 79 this, we'd have had to sort the chorales by key and would
 80 have obtained a much smaller number of rules for each
 81 separately. By normalizing the database, all we need to
 82 do when using the oracle is to transpose the rules obtained
 83 according to the tonality of the exercise.

3.3 Validation of the algorithm

To validate the algorithm, we used two sets of test data, one being positive, i.e. comprising only valid sequences, and the other one comprising valid or false sequences, but assumed to be mostly invalid. Let P be the positive set and N the other one. The two sets are built from the database, i.e. from the corpus of Bach chorales transposed to either C major or A minor. The set P is built by randomly selecting one million sequences of consecutive chords, and the set N by taking the same number of sequences of chords, with these chords each taken at random which must be either false or valid.

Concerning the positive sequences, the tests check that the oracle recognises all the elements in P . This test has been applied to one million sequences with a 100% success rate on sequences of varying size from two to ten.

Concerning the set N , we assume that the rate of false sequences is higher than the rate of valid sequences. Tests on selecting one million sequences give a rate of 91,4% false sequences for sequences of length two, which corresponds to our expectations. In other words, the oracle recognizes 8,6% of the elements in N . The same test was performed using longer sequences. The set size is always one million sequences. Let L denote the length of the sequences. For $L = 3$, we obtain a rate of 99.994% of false sequences, which corresponds to our expectations. With $L = 10$, we obtain 100% success for positive sequences and other sequences. The longer the sequences, the higher the percentage of success for both tests as shown in the table 1. All these tests can be performed by the readers using the rule extraction module [17].

Length L	Positive P		Other sequences N	
	True	False	False	True
2 chords	100%	0%	91,4%	8,6%
3 chords	100%	0%	99,7%	0,3%
4 chords	100%	0%	99.994%	0.006%
5 chords	100%	0%	99.9998%	0.0002%
6 chords	100%	0%	100%	0%
...
10 chords	100%	0%	100%	0%

Table 1. Percentage of algorithm success depending of sequences length.

At last, the oracle is used to answer two questions: is the sequence recognisable? And is the sequence false? We have also checked that each element obtains consistent answers to these two questions, i.e. one true and one false, with a 100% success.

4. CONCLUSIONS

4.1 Summary of work carried out

To conclude, this paper presents two main modules of the Learning Harmonizer project : the analysis module and the rule extraction module. We are now at the stage of bringing together the three modules that make up the generation process, in order to test it on a few selected hamony exercises.

We are currently designing the user interface that will give visual feedback on the harmonization generation tests of selected harmonic exercises.

4.2 Next step

The next step would be to formalize a set of selected harmony rules. We plan to select the most complex ones that will require more explanation for students to understand.

In parallel, hundreds of harmony exercises extracted from "300 Textes et Realisations" written by RAYNAUD Jean-Claude [21] have been encoded in MusicXML format by the first author. Then the exercises need to be labeled according to the notions they cover. We are currently developing the first version of the selection module, which will need to be modified each time we add a new composer.

The guidance and correction modules will then be develop using the modules that make up the generation process. It will mainly involve interface design work.

4.3 Project outlook

We hope that this project will not only advance the pedagogy of harmony, but also initiate students earlier in their curriculum, ideally from the 2nd cycle onwards, i.e. from around the 4th year of music (depending on the school).

In order to validate and/or improve the system, we plan to have our architecture tested by various audiences: students at Bordeaux Montaigne University, band students at Bordeaux Conservatory and 2nd cycle music students at Mérignac Conservatory.

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