Web Delivering of Music Scores

DE.4.3.1
Music Analysis and Processor Documentation

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Abstract:
This document is intended to be the user's reference manual for the use of Wedel Music Analyzer and Processor Documentation.

Keyword List:
music, internet delivering, audio format, image format, symbolic format, watermarking, protection, encryption, music distribution, copyrights, mp3, visually impaired people, speech music, Braille music, music analysis, music printing, music format.

Table of Content

1 Scope of this Document

This document is intended to give an overview and documentation on the Analysis tools of the Local Distributor's Catalogue. It explains, from the technical point of view and also from the musical point of view, the principles and the implementation of the Wedel Music Analysis tools.

1.1 Organization of this document

The first part of this document is composed of a tutorial that explains, step by step, a number of processes of interest for usage of analysis tools. After having followed this tutorial, you will be able to apply Analysis tools correctly from a purely technical point of view.

The second part of this document explains, from the musical point of view, the theoric principles on which these tools are based. You will read this part if you want to use and apply analysis tools in a musically correct manner.

1.2 Intended audience

The intended audience of this document is composed of expert users. The ability to read currently music scores is absolutely necessary. Some knowledge of principles of theory of classical music is also required: knowledge of "Theme", "Motif", together with a good knowledge of the concepts of tonality, and also a good knowledge of harmonic analysis (figured bass, cadences and so on).
On the other hand, this manual is not a treatise of music theory. Some concepts are briefly explained, and are not exposed in their whole.
For references to music theory, the user can refer to works like "Analysis"[1], by Ian Bent, the "Traité historique d'Analyse Musicale"[2], by Jacques Chailley, works of Arnold Schoenberg [3]. Users will also find in these works all needed references to theoretical works

[1] Bent, I. (1987), Analysis, Macmillan Press, London, 1987.

[2] Chailley, J., (1977), Traité historique d'analyse musicale, Alphonse Leduc, Paris, 1977

[3] Schoenberg, A., Structural Functions of Harmony, London, Faber and Faber, 1969., Schoenberg, A., Theory of Harmony, London, Faber and Faber, 1978.

2 Tutorial

2.1 Material needed

In order to follow the tutorial, you must have the following scores available in the Local Distributor's Catalog:

- Mozart's Clarinet Quintet K. 581, the Trio.
- Bach's Sarabande in D Minor

These scores are used throughout this tutorial.

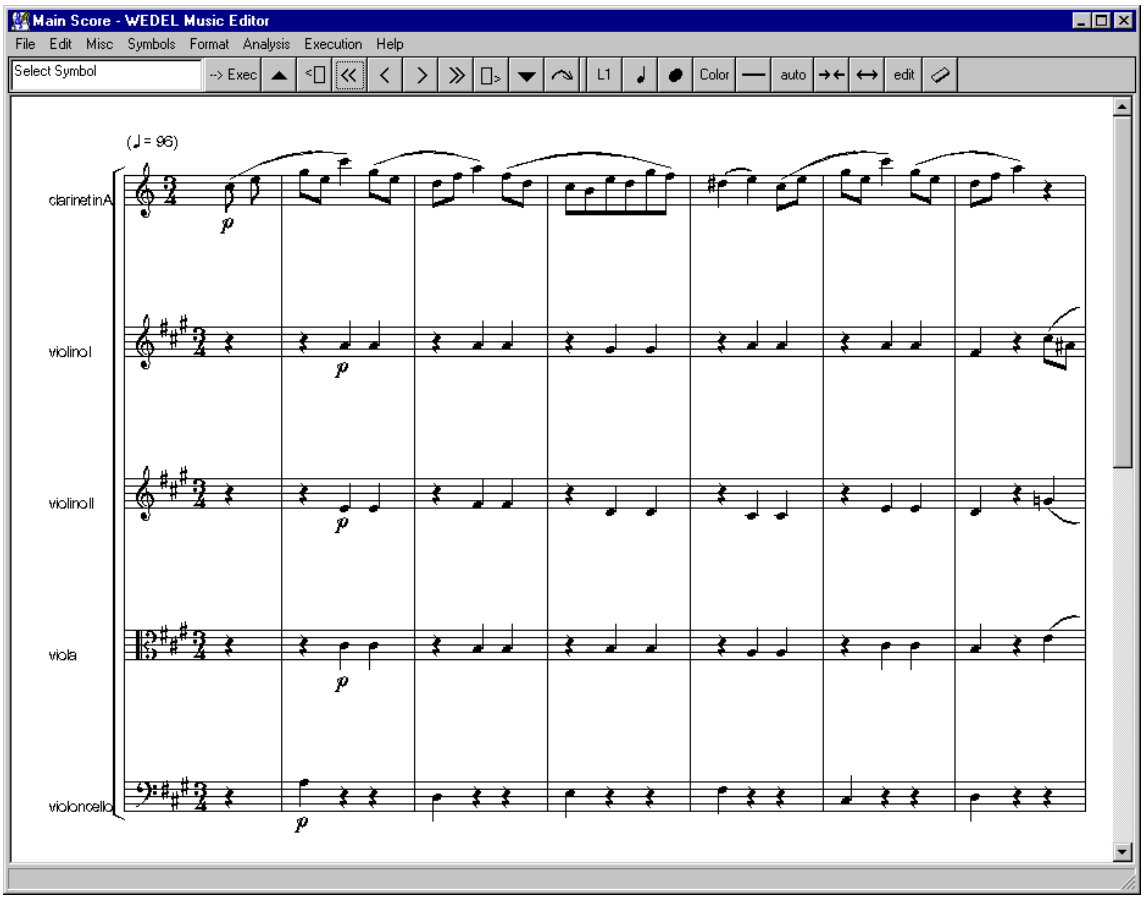
6 tutorials are described here :

Tutorial 1 : Search in the score.
Tutorial 2 : Reduction of the score.
Tutorial 3 : Figured bass
Tutorial 4 : Tonality extraction
Tutorial 5 : Extraction of motifs
Tutorial 6 : Rewrite rules
Tutorial 7 : Queries in Database

2.2 Search in the score

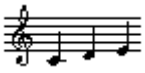
For tutorial about search tools, we will use the Mozart's Clarinet Quintet.
By using the Wedel Catalogue, open the Mozart's Clarinet Quintet, and open the main Score by double clicking on it.

The user will be presented with the following score:

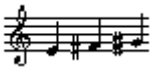


2.2.1 Melodic search

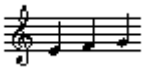
The melodic search function is able to find approximate results in the score. For example, when querying for



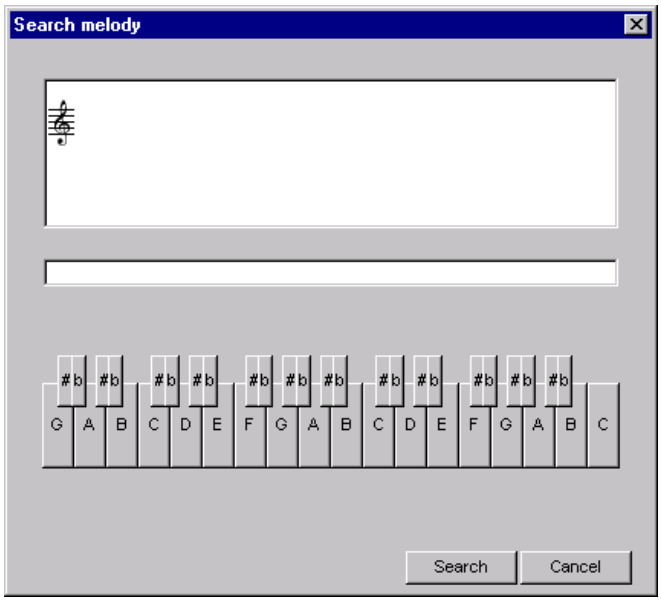
the search function will be able to find results like



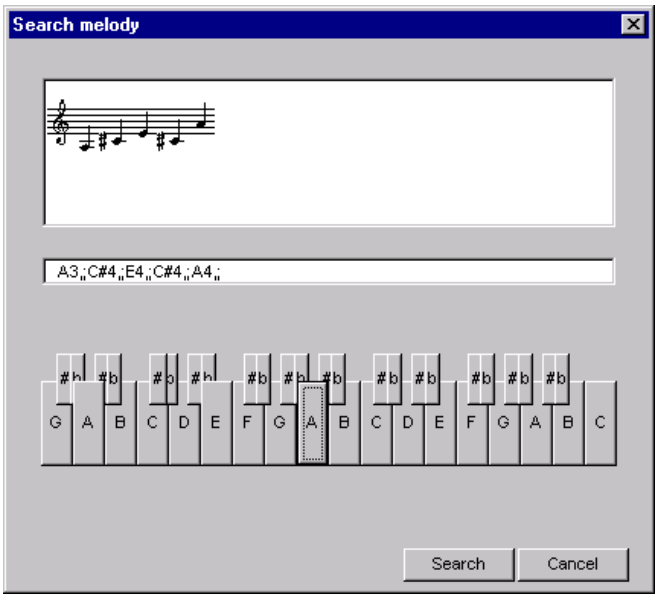
as well as



By choosing “Melodic search”, the user will be presented with a dialog using a keyboard-like interface :

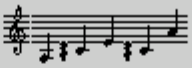


By clicking on the appropriate keys on the “keyboard”, the user can enter the following melody:



By clicking on “search”, the following results window will be shown :

Element searched



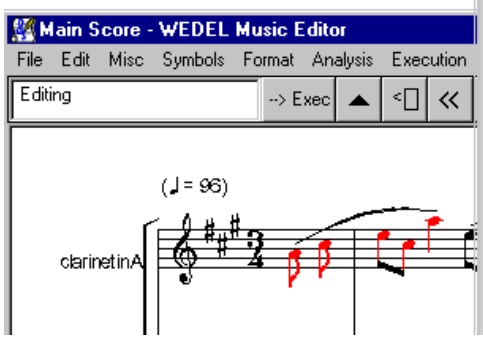
Number of occurrences found 34

Number	Form	Part	Beginning at
1	exact intervals	clarinet in A Voice0	Measure 1
2	exact intervals	clarinet in A Voice0	Measure 5
3	exact intervals	clarinet in A Voice0	Measure 37
4	exact intervals	clarinet in A Voice0	Measure 41
5	outline	clarinet in A Voice0	Measure 1
6	outline	clarinet in A Voice0	Measure 5
7	outline	clarinet in A Voice0	Measure 18
8	outline	clarinet in A Voice0	Measure 37
9	outline	clarinet in A Voice0	Measure 41
10	exact intervals	violino I Voice0	Measure 14
11	exact intervals	violino I Voice0	Measure 18
12	outline	violino I Voice0	Measure 14
13	outline	violino I Voice0	Measure 15
14	outline	violino I Voice0	Measure 16
15	outline	violino I Voice0	Measure 18
16	outline	violino I Voice0	Measure 19

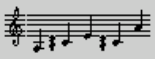
This window summarizes the results of the search.
For each occurrence in the score, it describes:

The form of approximation found. It can be “Exact notes, exact intervals, approximative intervals, outline....”.
The part in which the occurence was found.
The measure in which the occurence begins.

The number in the first column gives an access to the occurence in the score. By clicking on this number, the score will be scrolled to the correct location, and the occurence will be highlighted :



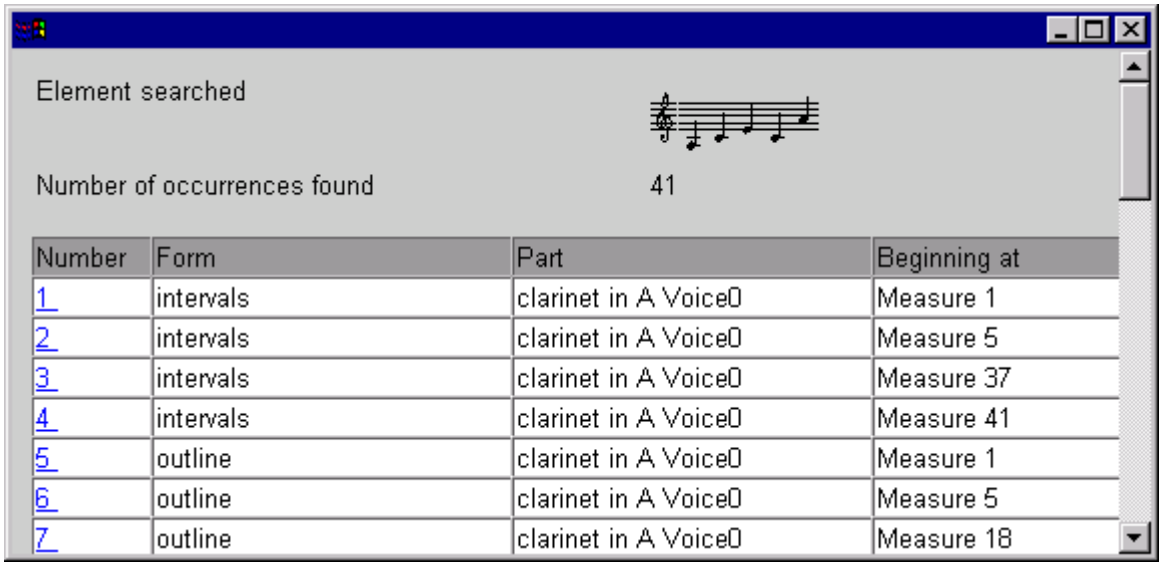
Element searched



Number of occurrences found 34

Number	Form	Part	Beginning at
1	exact intervals	clarinet in A Voice0	Measure 1
2	exact intervals	clarinet in A Voice0	Measure 5
3	exact intervals	clarinet in A Voice0	Measure 37
4	exact intervals	clarinet in A Voice0	Measure 41
5	outline	clarinet in A Voice0	Measure 1
6	outline	clarinet in A Voice0	Measure 5
7	outline	clarinet in A Voice0	Measure 18
8	outline	clarinet in A Voice0	Measure 37
9	outline	clarinet in A Voice0	Measure 41
10	exact intervals	violino I Voice0	Measure 14
11	exact intervals	violino I Voice0	Measure 18

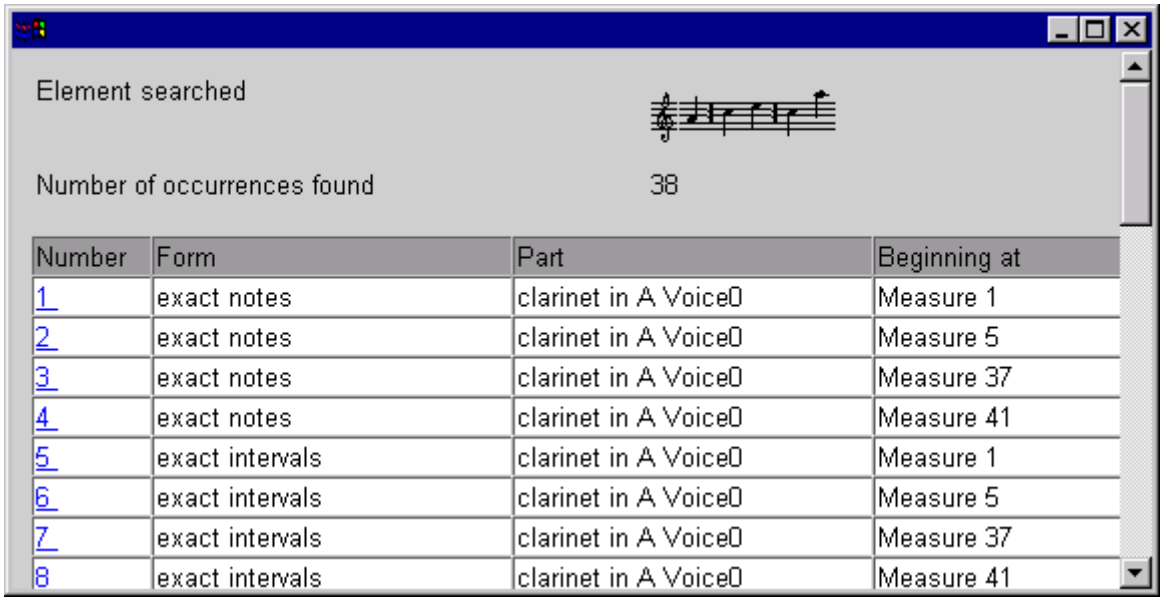
To better understand these results, just let try another search, by entering an C natural in the search instead of a C # :



Number	Form	Part	Beginning at
1	intervals	clarinet in A Voice0	Measure 1
2	intervals	clarinet in A Voice0	Measure 5
3	intervals	clarinet in A Voice0	Measure 37
4	intervals	clarinet in A Voice0	Measure 41
5	outline	clarinet in A Voice0	Measure 1
6	outline	clarinet in A Voice0	Measure 5
7	outline	clarinet in A Voice0	Measure 18

The query is not found now as “exact intervals” but as “intervals” (that is to say, as diatonic intervals).

Jus let try a last search, by entering the same search as the first, but one octave higher:

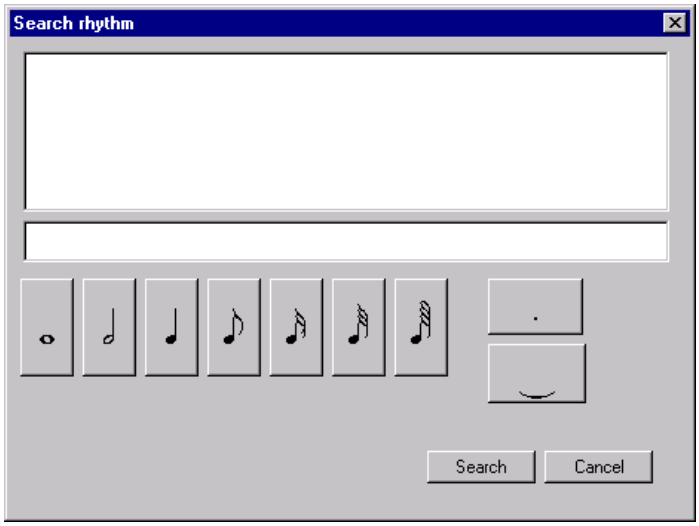


Number	Form	Part	Beginning at
1	exact notes	clarinet in A Voice0	Measure 1
2	exact notes	clarinet in A Voice0	Measure 5
3	exact notes	clarinet in A Voice0	Measure 37
4	exact notes	clarinet in A Voice0	Measure 41
5	exact intervals	clarinet in A Voice0	Measure 1
6	exact intervals	clarinet in A Voice0	Measure 5
7	exact intervals	clarinet in A Voice0	Measure 37
8	exact intervals	clarinet in A Voice0	Measure 41

The result shows that the exact notes were found in the clarinet part at measure 1.

2.2.2 Rhythmic search

The rhythmic search function is able to find approximate results in the score.
By choosing the “Search rhythm” menu, the user will be presented with the following dialog :

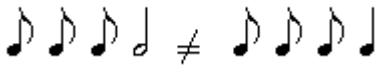


By using the appropriate buttons, the end-user can enter a rhythm.

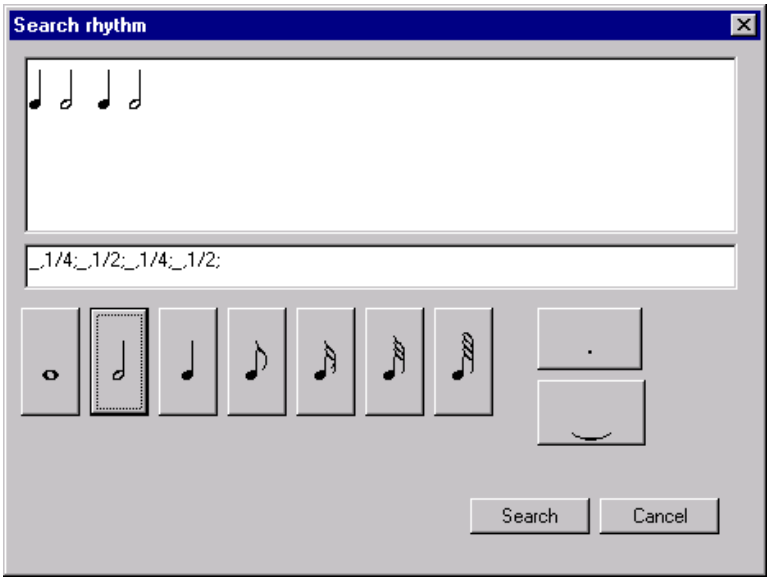
 is to be used to tie the last note to the preceding.

 is to be used to put an augmentation dot after the last note being entered.

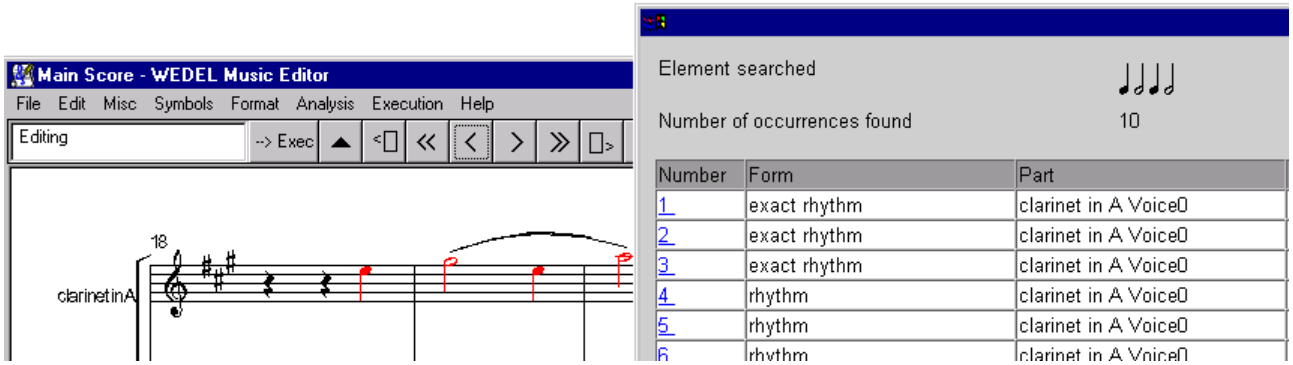
The duration of the last note is taken into account in the search. That is to say that the two following rhythms are not considered the same:



Just try the following search into Mozart's Trio of Clarinet Quintet:



A window will be shown listing the results of the search.



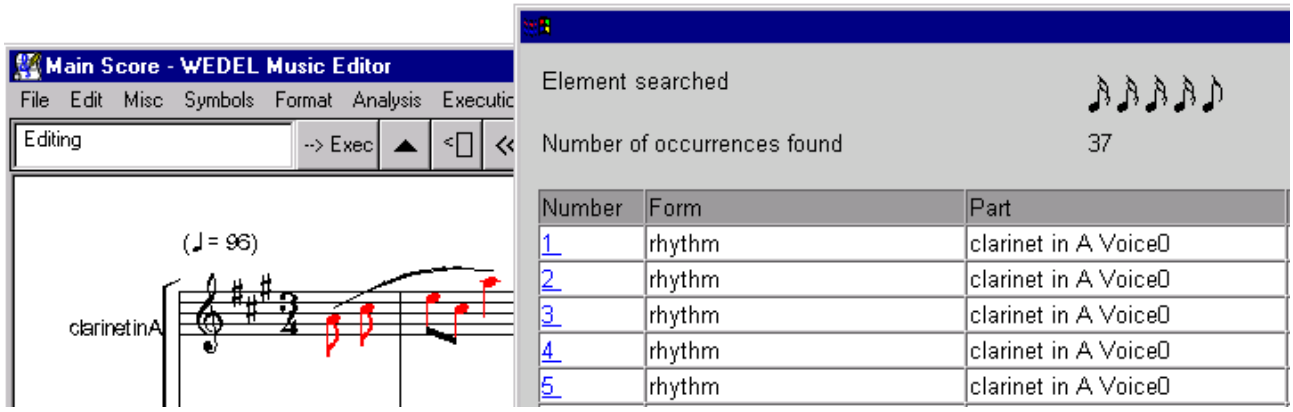
This window summarizes the results of the search.
For each occurrence in the score, it describes:

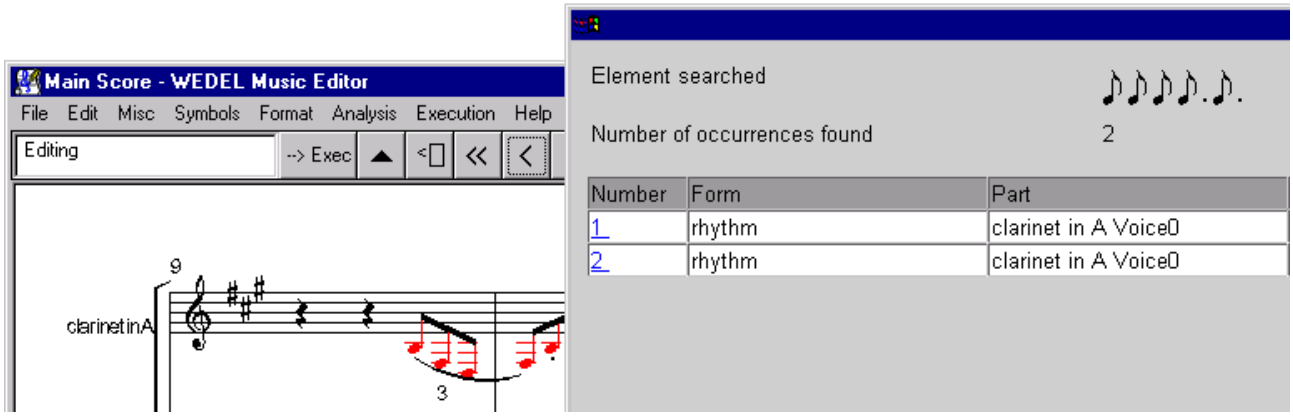
- The form of approximation found. It can be “Exact rhythm” or “Rhythm”.
- The part in which the occurence was found
- The measure in which the occurence begins.

The number in the first column gives an access to the occurence in the score. By clicking on this number, the score will be scrolled to the correct location, and the occurence will be highlighted.

The search engine is able to find the searched rhythm, as an exact rhythm, or as an approximate rhythm, as an augmented or diminushed one.

Here are some examples of approximate rhythms.





2.2.3 Search of harmonic pattern

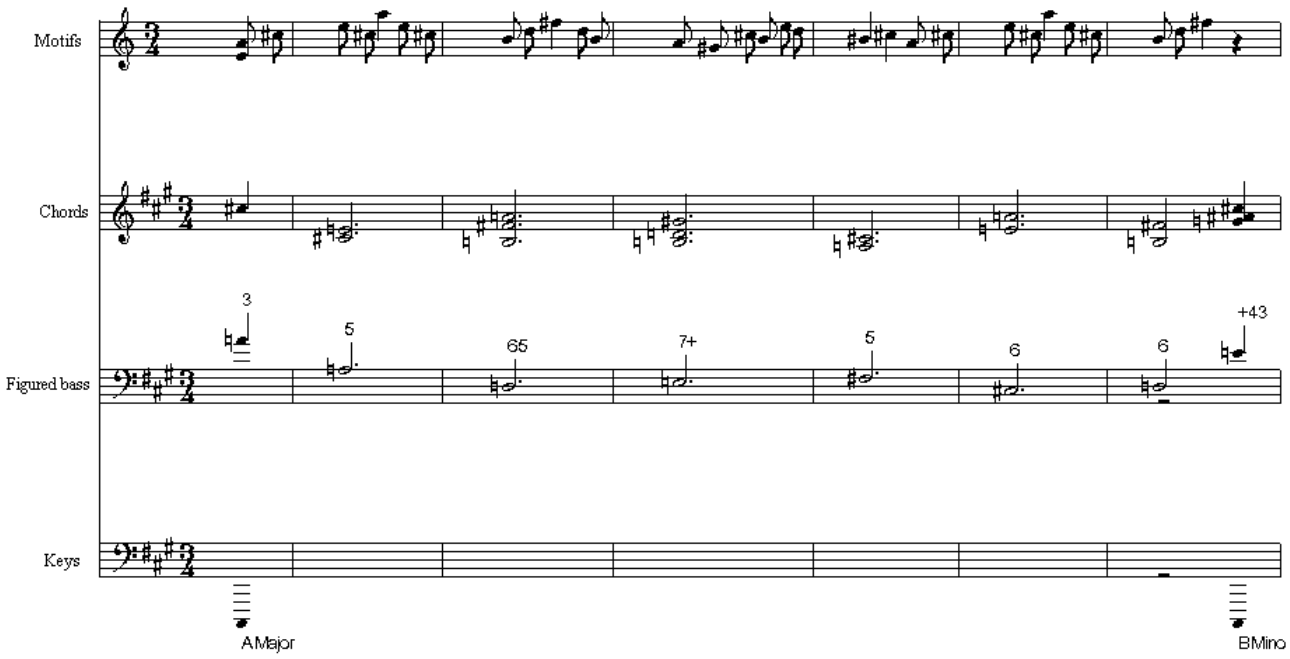
2.3 Reduction

Reduction of the score is based onto the detection of main motifs, production of figured bass, and detection of tonalities. For more details about each of these processes, see below in related sections.

The process of reduction produces in the score four new parts :

- A first part which will show the main motifs detected, only one at once. When two or more motifs are detected for the same measure, the longest is retained.
- The second part is a realization of the figured bass, as a summary of the notes of the chord, excpept for the bass which is presented in the part below.
- The third part show the figured bass. The figured bass is based on the current harmony rules, which can be defined by using the appropriate menu item (see §2.4.3)
- A fourth part shows the tonalities extracted from the score

Here is the result of reduction applied to Trio of Clarinet Quintet by Mozart (first measures), using standard harmony rules:



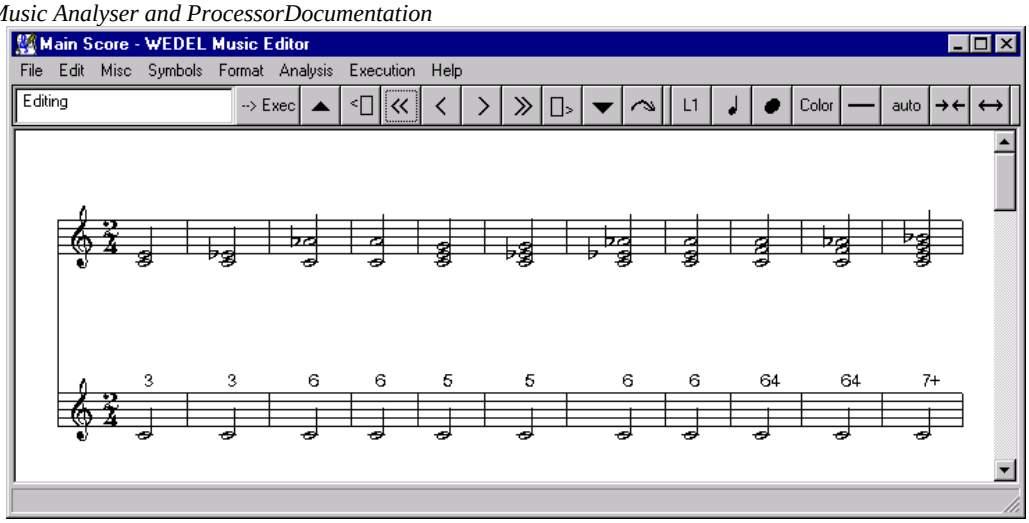
2.4 Figured bass

The menu item “figured bass” can be used to extract a figured bass from the score. Extraction of figured bass follows the “default harmony rules” which can be defined using the appropriate menu item (see §2.4.3)

2.4.1 Harmony rules

A set of harmony rules defines a set of templates – expressed as chords – and, for each of these chords, a bass together with a figure.

Here is an extract of the harmony rules defined as “Standard” in the standard installation of a Local Distributor :



This set of chords follows as nearest as possible harmony practices at the end of 18th Century. It contains 3 sounds chords as well as 4 sounds chords (Seventh chords), and 5 sounds chords (Ninth chords).
The notation of figures follows the conventions of figured bass as stated in the treatises, with the following exceptions: figures are written from left to right and not from top to bottom, and a slash following a figure indicates that this figure is diminished.

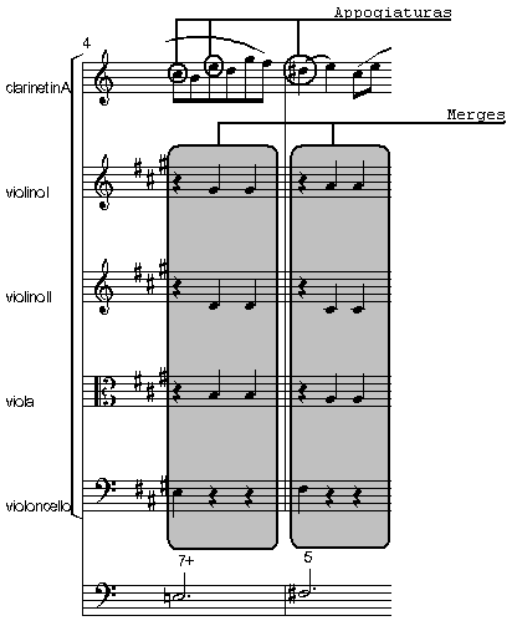
7+ is for $^{7}_{+}$, 65/ is for $^{6}_{5\!\!/}$.

2.4.2 Process

The process of extraction of figured bass does the following:

- Elimination of melodic notes (passing notes, appogiaturas)
- Merge of successive harmonies by comparing them with chords in current harmony rules.
- Production of figured bass part.

The process can be illustrated with the following example, extracted from Trio of Clarinet Quintet by Mozart, measures 4 and 5, and using the “Standard” harmony rules:



In the measure 4, the notes “A, C# and B#” (written C, E and D#) in the Clarinet part are recognized as appogiaturas and are eleminated from harmony.

In these two measures, the harmony on the three beats are merged. One can make the remark that in measure 5, there is no common note between the first beat and the following. The harmonies are merged since there is a template in the Standard harmony rules which follows exactly the result of the merge.
For more details on this process, refer to §3.2.3 “Figured Bass”, in the second part of this document.

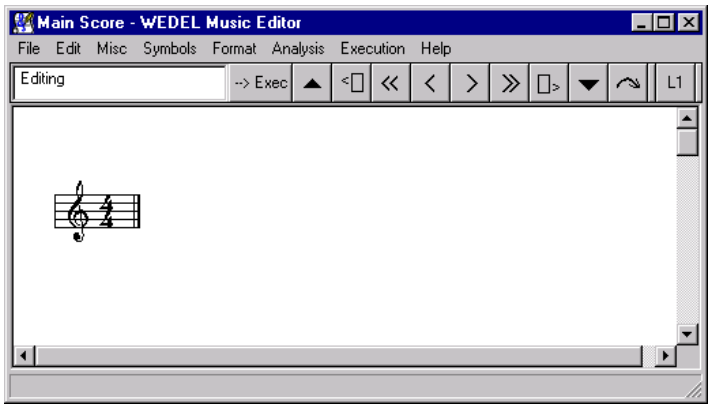
2.4.3 Defining and applying different harmony rules

2.4.3.1 Defining harmony rules

We will define a new set of harmony rules by suppression of non-dominant 7th and 9th chords in the Standard set of harmony rules.

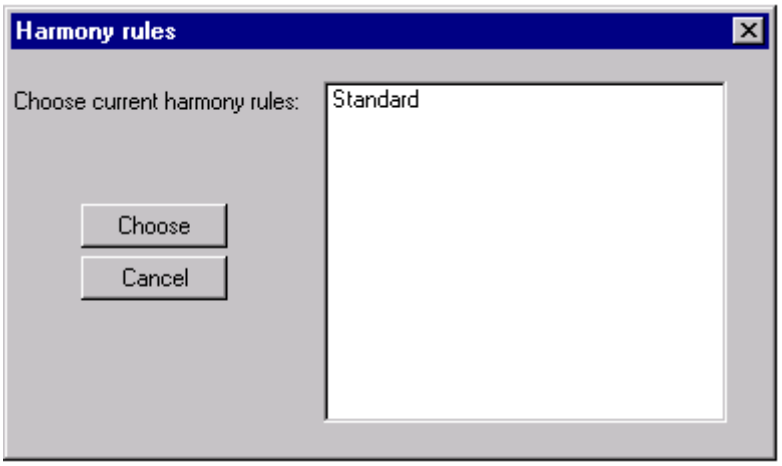
- Launch the Wedel Editor.
- Open a new, empty object (the name of that object is useless).
- Open the main score.

You must get a new, empty score :



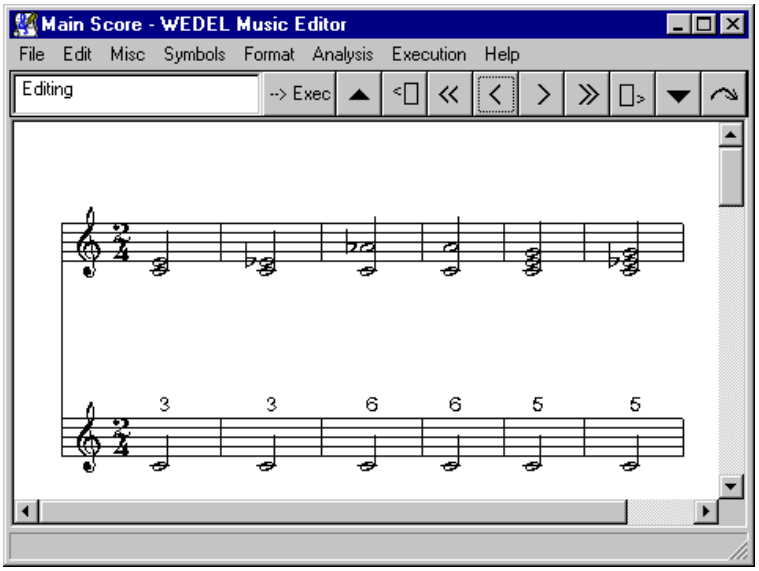
- Select menu item “Harmony rules : Load”.

You must be presented with a Dialog showing something like :

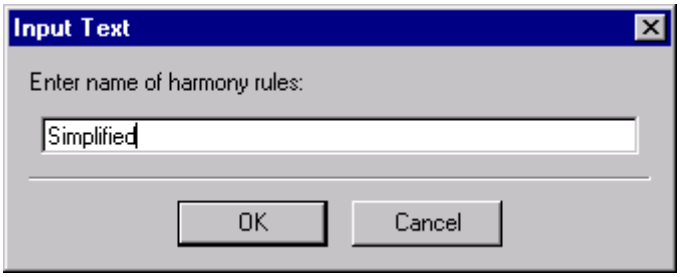


Select “Standard” and click on “Choose”.

Now the score must present the harmony rules as a set of chords, each one presented by measure, the template chord being on the upper part and the resulting figured bass in the lower part :



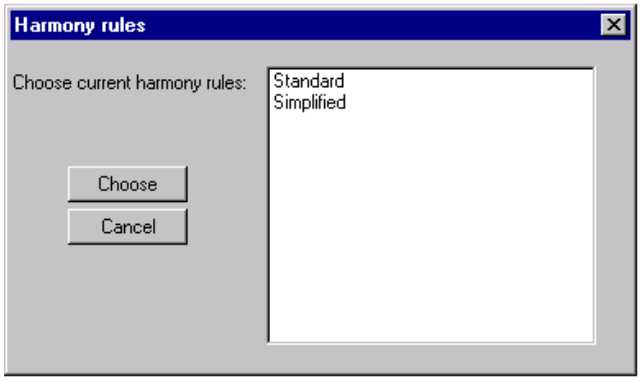
This set of chords is composed of 34 templates – 34 chords. Some of them are composed of 4 sounds chords, 5 sounds chords and so on.
Just remove all the non-desired chords, that is to say each chord after the 17th measure, by using the "Cut a measure" tool. This will remove all chords but 2 sounds chords, 3 sounds chords, and Dominant 7th.
Save this set as "Simplified":
Choose the menu item "Analysis : Harmony rules : Save as".
Type "Simplified" in the appearing dialog, and click "Ok" :



Now you can apply these new rules on the Mozart's Quintet :

- Close the current Wedel object – don't save it, it's useless.
- Open the Mozart's Clarinet Quintet.
- Open the score.
- Choose the menu "Analysis : Harmony rules : Set default harmony rules..."

You will be presented with a dialog like :



where the name of the newly registered rules will appear.

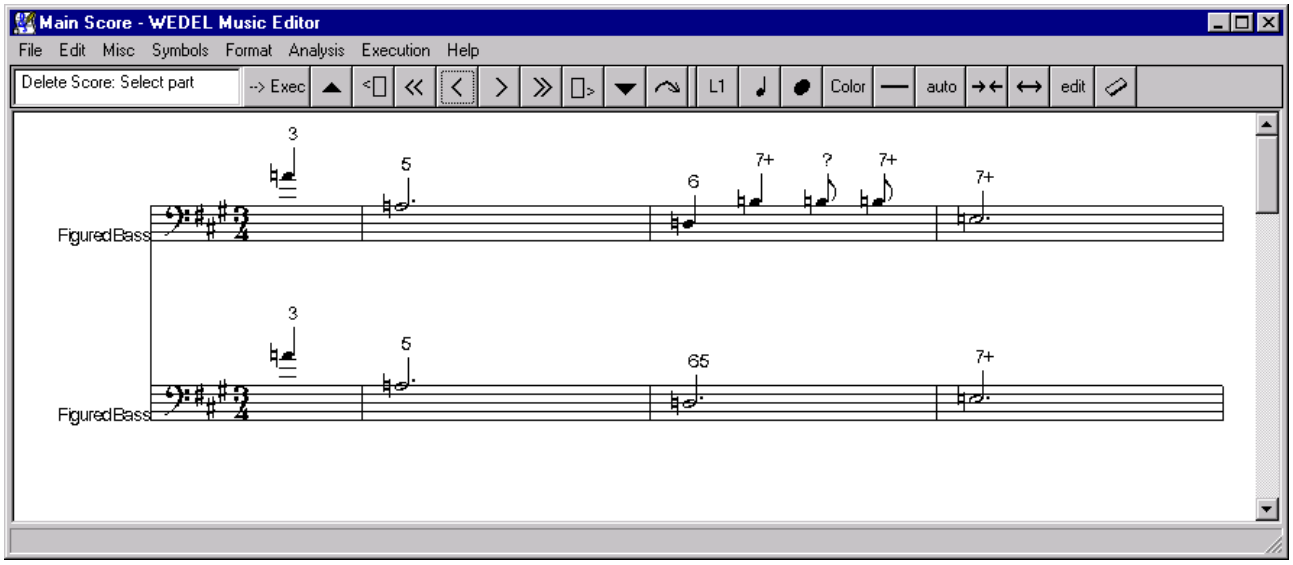
- Select the "Simplified" item.

- Click on “Choose”.
- Select the item “Analysis : Figured Bass”.

Now apply the standard harmony rules :

- Choose the menu “Analysis : Harmony rules : Set default harmony rules...”
- Select the “Standard” item.
- Click on “Choose”.
- Select the item “Analysis : Figured Bass”.

Now, check the resulting Figured Bass parts. The higher one was generated with the simplified harmony rules, the lower with the Standard harmony rules :



A number of differences can be checked throughout the score, specially in measure 3, 23 and following.

2.5 Tonality extraction

Tonality detection is based onto Figured Bass. To apply tonality detection, you must first apply extraction of figured abss.
The process of tonality detection is detailed in the second part of this document, §3.3.

2.6 Extraction of main motifs

Extraction of main motifs is based onto thue detection of repetitions in the score. Repetitions are detected in particular “descriptors” – musical descriptions and descriptors are documented in the §3.1 in this document.

2.6.1 Default extraction of main motifs

The default extraction of main motifs is based onto the detection of repetitions in the “intervals and rhythm” descriptor.

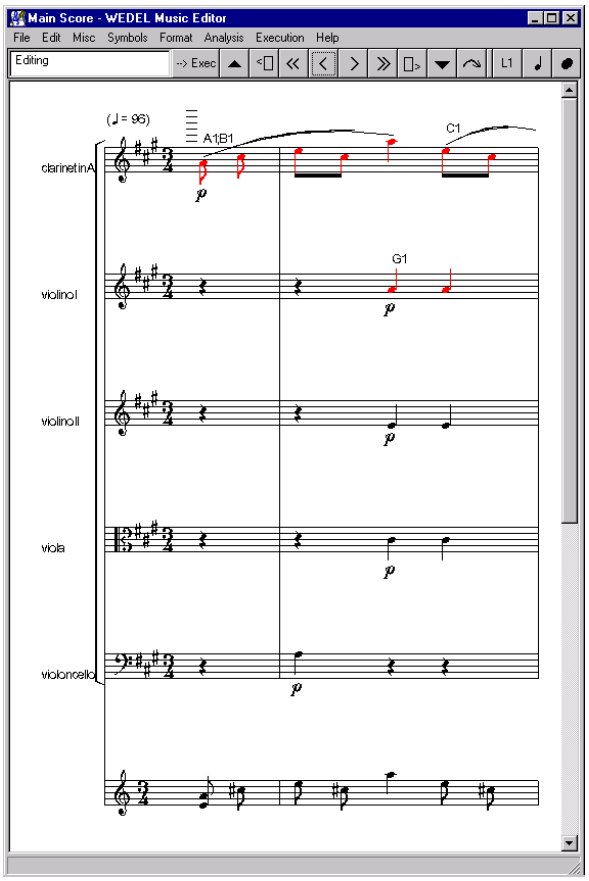
This descriptor is based on rhythm and diatonic intervals expressed only with the interval itself, and without the characterization of the interval as “just, minor or major” . Thus, motifs which are repeated with transposition are found, together with motifs repeated with change of mode (minor to major, and conversely).

2.6.1.1 Extraction of motifs

Let us try this extraction of motifs on the Mozart's Trio of Clarinet Quintet:

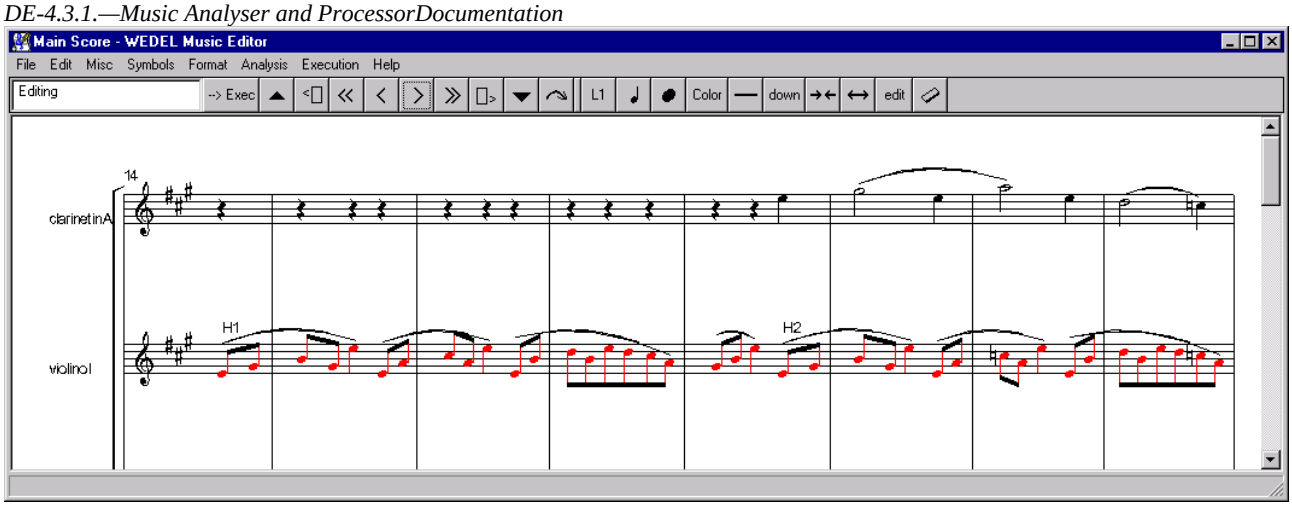
- Close the current Wedel Object
- Open Mozart's Trio of Clarinet Quintet
- Open the main score
- Launch the extraction process, by using the menu item "Analysis : Motifs".

A new part will be added to the score, below the violoncello part, and main motifs found are highlighted in the score, and labelled each with a letter (in caps), with a number that represents the indice of the occurence of the found motif.



2.6.1.2 Insensitiveness to mode

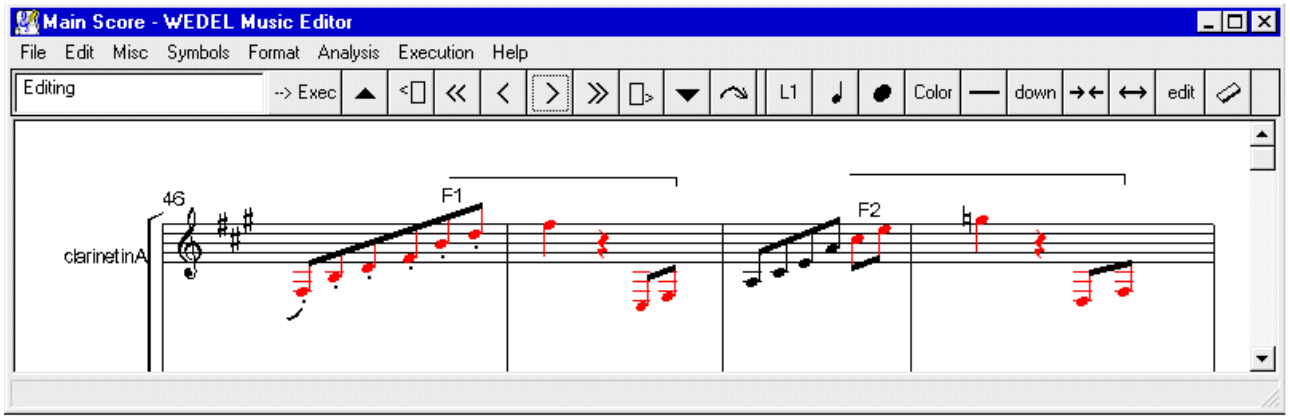
To see how motifs are detected independently of their mode (minor/major), go to measure 14 and check the Violin I part.
You must see that a motif H is detected and that two instances are highlighted here (labeled here H1 and H2 – depending on the implementation, the labels can be slightly different)



These two occurences of the same motif are slightly different : the first, labeled H1, is expressed in A Major. The second, labeled H2, is expressed in A minor, with C naturals instead of C sharp.
The default repetitions detection process, based on rhythm and diatonic intervals, is not sensitive to this difference.

2.6.1.3 Insensitiveness to transposition

To see how motifs are detected independently of the transposition, go measure 46, and check the Clarinet part. You will see that a motif, named “F” is detected here twice and labeled F1 and F2 :



The motif is detected here, regardless of the transposition, and regardless of the exact intervals : in the second occurence, the motif comprises a diminushed fifth (from C sharp to G natural), instead of the perfect fifth comprised in the first occurence.

2.6.1.4 Limit of the principle applied to detection of motifs

We will use the same example, of this motif labeled F, to show the limit of the principle of detection of motifs, as based on repetitions detection : a human analyst would not say here that this motif is “a main motif”.

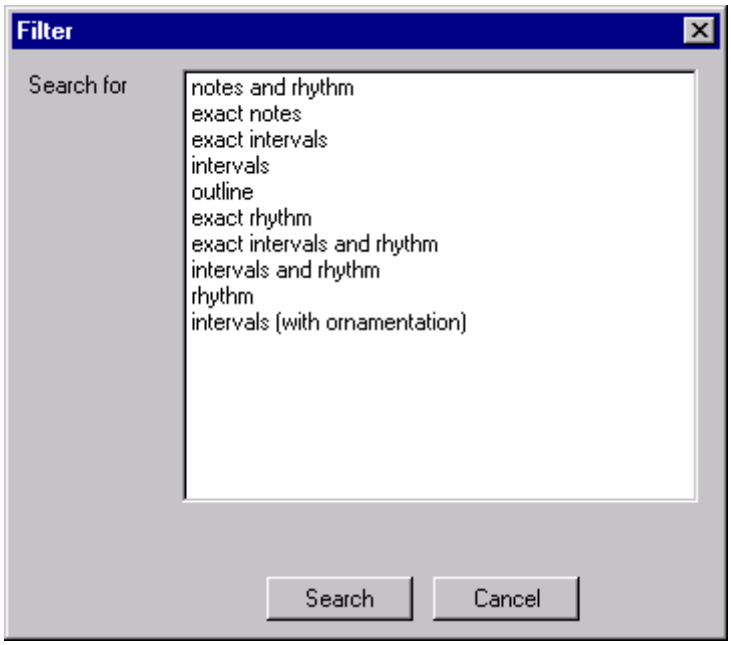
2.6.2 Custom detection of motifs

2.6.2.1 Applying a different detection of repetitions

By using the menu item “Analysis : Particular motifs”, you can apply the detection of repetitions on another descriptor than the default application descriptor (which is “intervals and rhythm).

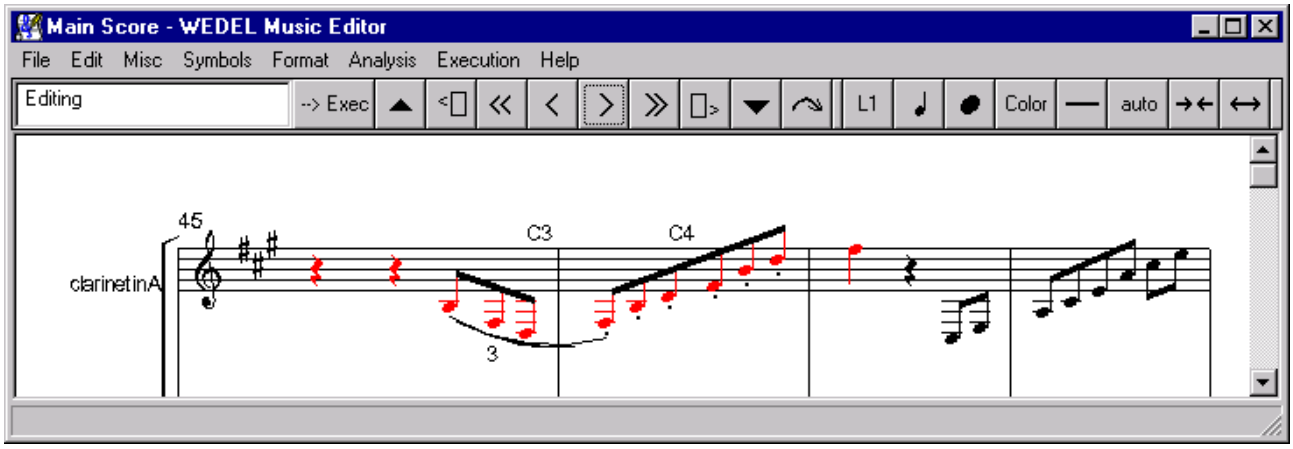
First close the current score and Wedel object (to avoid conflicts with previous detection of motifs).
Open Mozart's Trio of Clarinet Quintet.
Open the main score.
Select the menu item "Analysis : Particular motifs".

You will be presented with the following dialog :



Select the item "Exact intervals"
Launch the process by clicking on "Search"

By checking the results in the score, you will see that they are quite different from the previous one obtained with the standard process.
Particularly, by checking the Clarinet part at measures 45 and following, you will see that the motif previously detected as "F", and labeled F1 and F2, disappeared. Instead of this motif, a motif named "C", and labeled as C3 and C4 is detected :



NB : the exact motif detected here is the motif comprised of the notes D, Fsharp, B, D and F sharp. The reason why it was not detected in the previous process is that the duration of the last note is not the same, and cannot be detected with a process which takes into account the rhythms. As we applied the detection to exact intervals, the rhythm is not taken into account and that repetition is now detected.

2.6.2.2 Applying detection of repetitions on Figured Bass

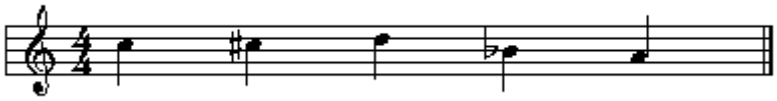
The filter dialog presents the descriptors which are actually present in the score, on which a detection of repetitions can be done. This dialog can be slightly different of the above presented one, for the reason why some different descriptions can be available, depending on the version of the Analysis tools, and depending on the previous operations done on the score.
In the case where, for example, a Figured Bass was already generated, you will see here a supplementary filter available, presented as “Figured Bass”.

Generate the Figured Bass by selecting the menu item “Analysis : Figured Bass”.
Select the menu item “Analysis : Particular motifs”.

2.7 Rewrite rules

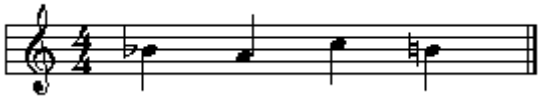
2.7.1 Purpose of rewrite rules

Rewrite rules can be used for detection of some particular movements in the score, and generation of a new part.
One main application of rewrite rules is the detection of cadences, as applied to a figured bass. But another possible application can be the detection of particular melodic movements, such as these movements known as “Signature”, or “Earmarks”.
An example of such a movement is the well-known earmark :



which can be found in Mozart’s work, but also in works of authors from 19th Century, like Schumann, or Mendelssohn.

Another example is the “Bach’s signature” :



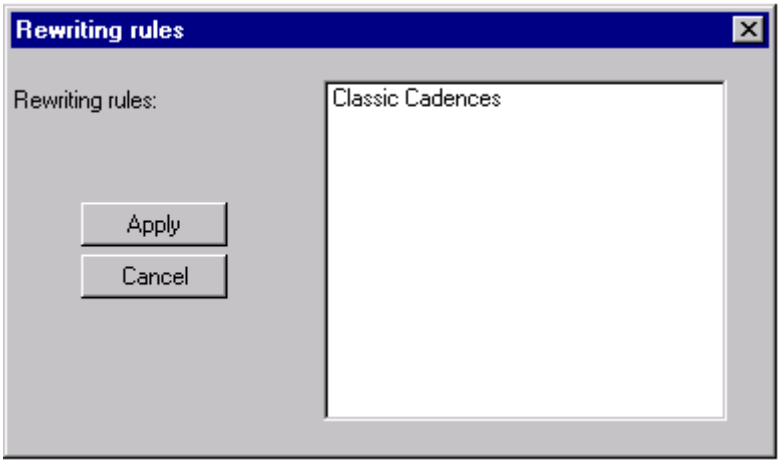
In the curse of this tutorial, we will show how to define a rewrite rule based on these signatures or earmarks, and apply them.

2.7.2 Applying a rewrite rule : cadences detection.

In this tutorial part, we will learn how to apply a rewrite rule.
We will use the “Classic cadences” rewrite rule, which is installed with every Local Distributor.
Cadences detection apply on a Figured Bass. To apply cadences detection, the Figured Bass must be present.

Open the Trio of Clarinet Quintet by Mozart.
Open the main score.
Verify the current harmony rules :
Choose the menu item “Analysis : Harmony rules : Set default harmony rules…”
Select “Standard” and click “Choose”.
Choose the menu item “Analysis : Figured Bass”
Choose the menu item “Analysis : rewrite rules : apply”.

You will be presented with a dialog like :



Select “Classic Cadences” and click “Apply”

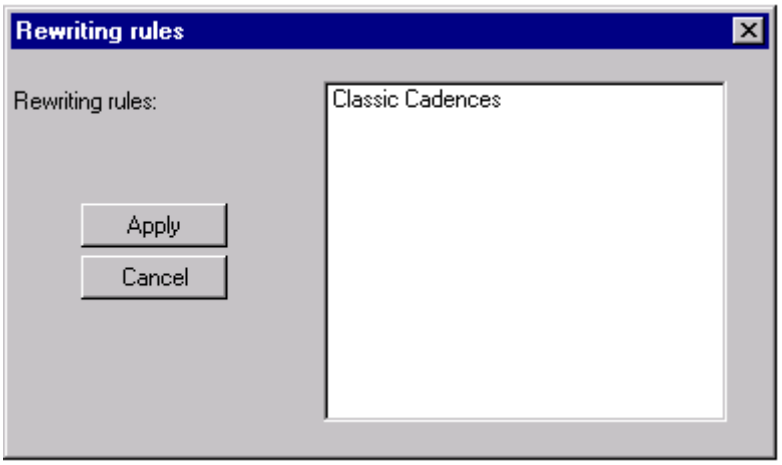
Two cadences will be detected in the first 16 measures of the Trio : a “Disrupted Cadence” at measure 4 and a “Perfect Cadence” at measure 12-13.
These cadences are summarized on a new part appearing below the Figured Bass.

2.7.3 Checking rewrite rules

Now, we will show how a rewrite rule – here, “Classic Cadences” – is defined.

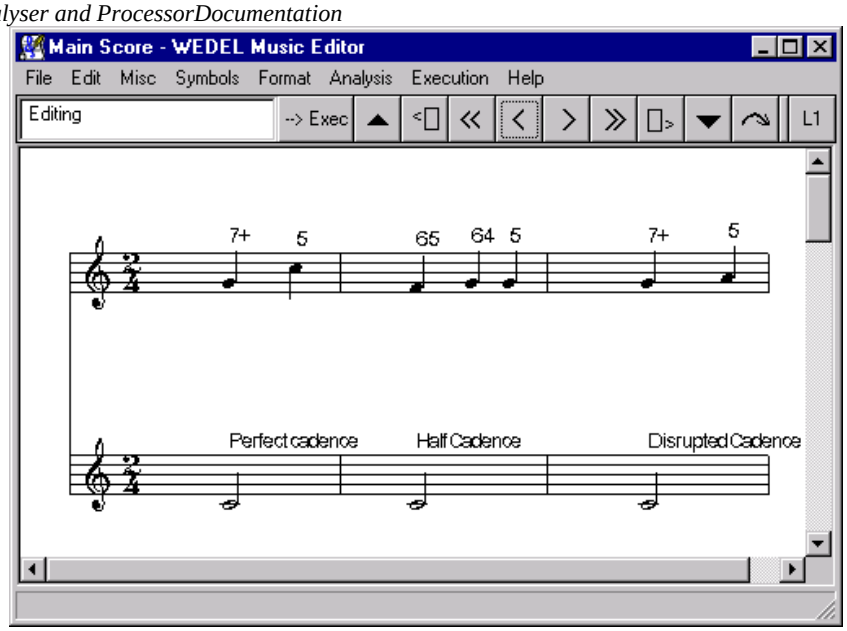
Close the current Wedel Object and open a new, empty one (the name is useless).
Open the main score.
Select the menu item “Analysis : Rewrite rules : Load”

You will be presented with a dialog like :



Select “Classic Cadences” and click “Apply”.

Now the score will present the definition of the rule itself:



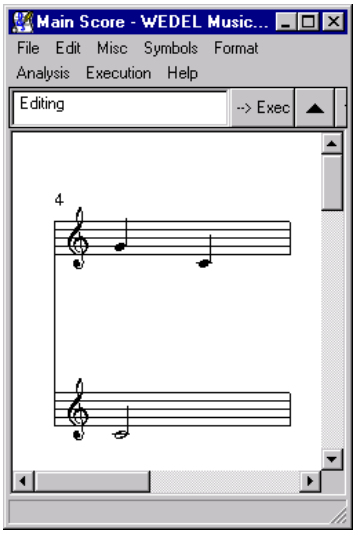
Each measure of the score defines a particular "rule". The upper part defines the movement to be detected in the score. The lower part shows the result that is to be inserted in the new part to be created as a result of the process.
In this particular rule, "Classic cadences", the first measure defines the "Perfect Cadence", the second measure defines the "Half Cadence", the third defines the "Disrupted Cadence", that is to say, leading from a 7^{th} of dominant chord to a VIth degree chord.

These rules are those which has been applied previously to the Trio of Clarinet Quintet by Mozart.

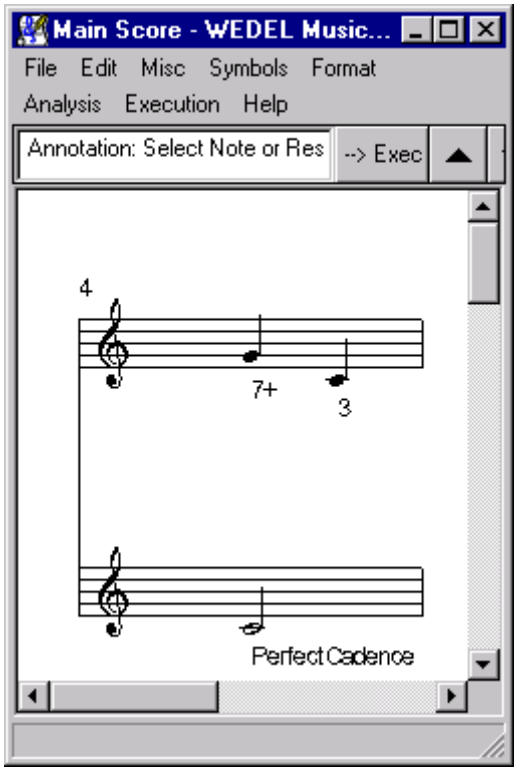
2.7.4 Modifying rewrite rules

To show how end-users can modify rewrite rules, we will add a new cadence to these rules.

In the measure 4 of the actual score – defining cadences -, add the following notes :



By using the "Annotation" tool, add the following annotations to these notes:



NB : as our Figured Bass makes sometimes difference between a 5 chord and a 3 chord, perfect cadences using a 3 chord on the tonic are not detected until now. With this new rule, such cadences will be detected.

By using the menu item “Analysis : Rewrite rules : Save as”, save this rewrite rule as “Extended”.

We will try now to apply this new set of rules to Mozart’s Trio of Clarinet Quintet.

Close the current score and open Mozart’s Trio.
Open main score.
Create the Figured Bass
By using the menu item “Analysis : Rewrite rules : Save as”, apply first the “Classic Cadences” rule, and second the newly created “Extended” rule.
Check the resulting parts.

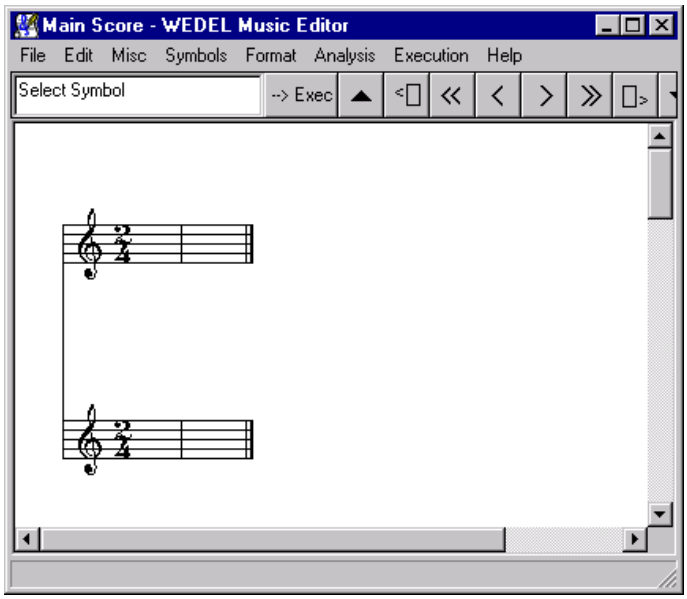
You will see a number of differences in measure 27 and following, where a number of cadences leading to a 3rd chord have been detected.

2.7.5 Creating a new rewrite rule

In this example, we will create a new rewrite rule for detection of Bach’s and Mozart’s signatures.
This rule will be composed of two single rules : the first for Bach’s signature, the second for Mozart’s signature.

2.7.5.1 Create a new score for editing a new rewrite rule

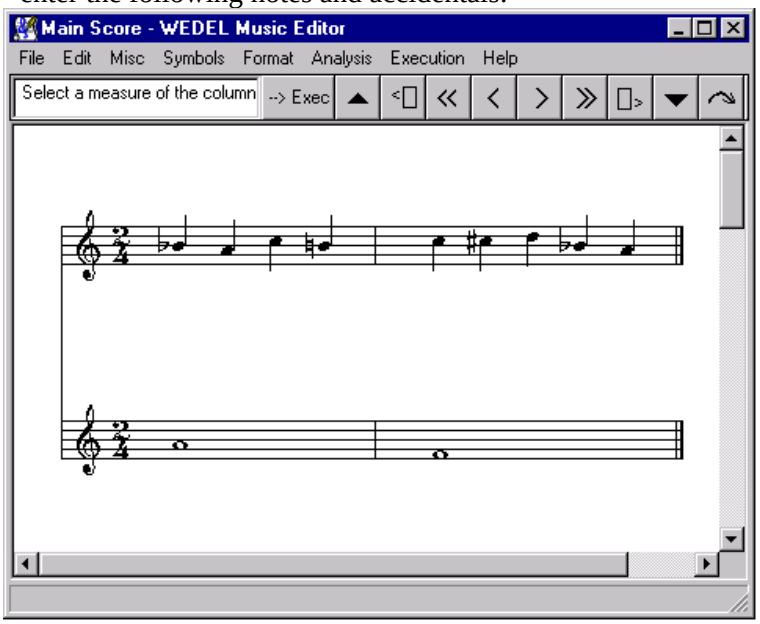
Close the current score, and open a new, empty Wedel object (the name is useless).
Open the main score.
Create a new part, below the first part.
Create a new measure.



A rewrite rules' score is composed of two parts: the first part defines the motifs to be found in the score, the second part defines the result of application of the rule.
A rule is composed of one or more measures : each measure defines a single rule, and applies independently of previous and following measures.

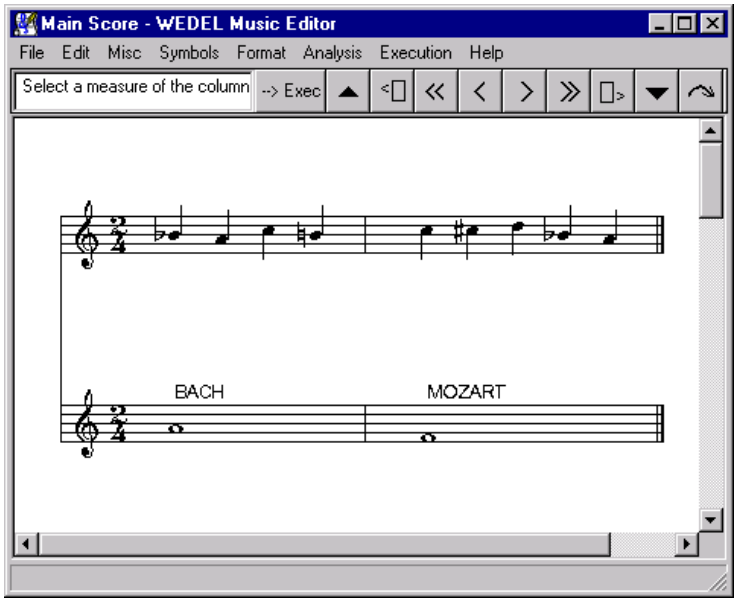
2.7.5.2 Defining rules

By using Wedel tools – enter the following notes and accidentals:



NB : the time signature is not significant here.

By using the "Annotation" tool, add the following text to the second part:



2.7.5.3 Saving rewrite rules

This new rewrite rule can now be saved by using the menu item “Analysis : Rewrite rules : Save as”.
Save this new rule as “Signatures”.

The newly created rule is now stored in the Local Distributor’s Database (saving the actual score is useless).

This newly created rule can be reopened later for adding more signatures.

NB : applying this rule gives no result neither on Mozart’s Trio of Clarinet Quintet nor on Bach’s Sarabande.

2.8 Queries in database

To make queries in the content of the database, the description of the content must first have been written to the database. It’s the purpose of the menu “ExportWNF”.

2.8.1 Exporting musical description to Database

To avoid problems of violation of copyright, the whole content of the score is not exported to the database when exporting musical description.
Only parts generated by analysis tools can be exported to the database. These are, for example, main motifs, Figured Bass, Tonalities, or even results of rewrite rules applied to the score.

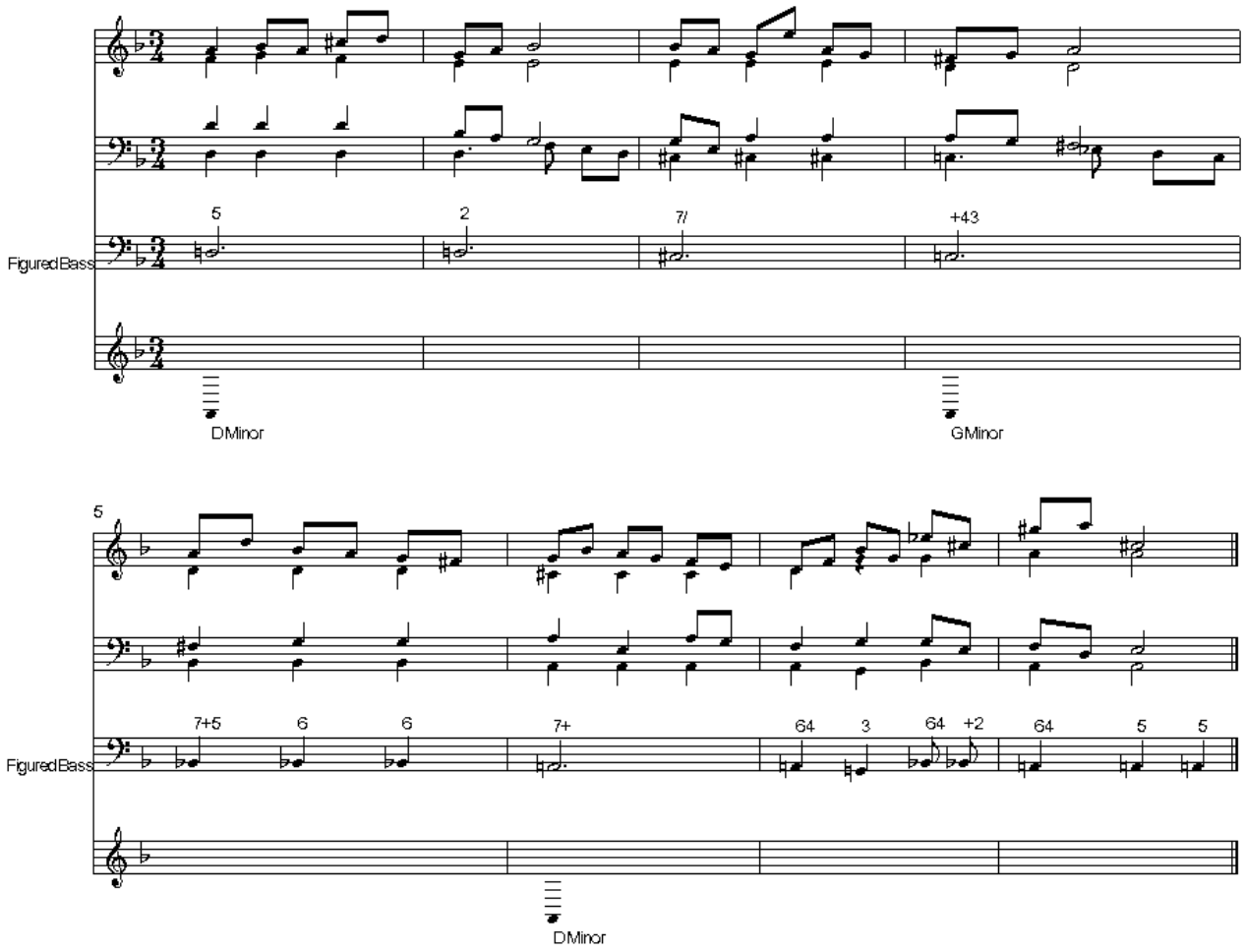
So, before making an “ExportWNF” operation, you must first apply analysis processes.

In this example, we will export correct description for Mozart’s Trio and Bach’s Sarabande, in order to retrieve them using musical queries.

2.8.1.1 Generation of musical description for Bach's Sarabande in D minor.

Close the current Wedel object.
Open Bach's Sarabande in D Minor.
Generate the Figured Bass and Tonalities by using the appropriate menu items.

Check the resulting parts, which will looks like :



Export this in the database, by using the appropriate menu item "ExportWNF".

NB : with this extract from Bach's Sarabande, the extraction of main motifs is useless. The reason is as follows : extraction of main motifs is based onto detection of repetitions. As the actual score is only an extract from Sarabande, the main motifs cannot be easily detected.

2.8.1.2 Generation of musical description for Mozart's Trio of Clarinet Quintet.

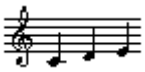
Close the current Wedel object
Open Mozart's Trio of Clarinet Quintet
Open main score.
Generate a Reduction of the score – or, alternatively, generate the Figured Bass, Main motifs and Tonalities parts.

Check the result, before exportation.

Export these analysis parts by using the appropriate menu item "ExportWNF".

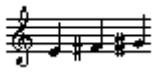
2.8.2 Melodic query in the Database

As for the melodic search in the score, the melodic query function is able to find approximate results in the database. For example, when querying for

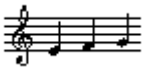


,

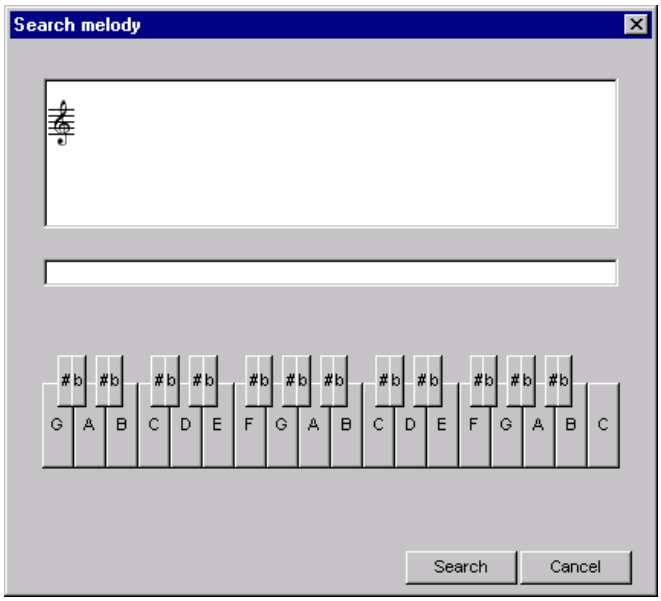
the search function will be able to find results like



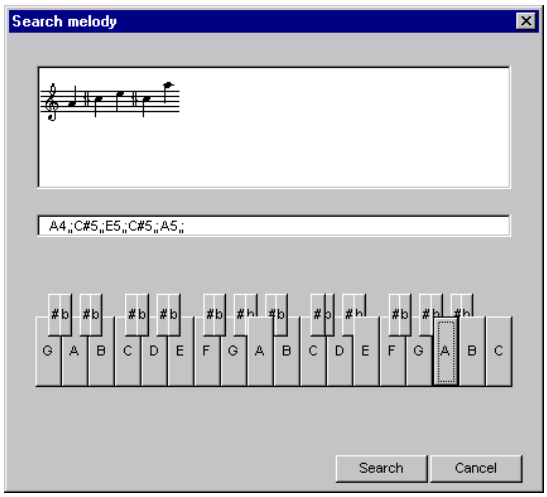
as well as



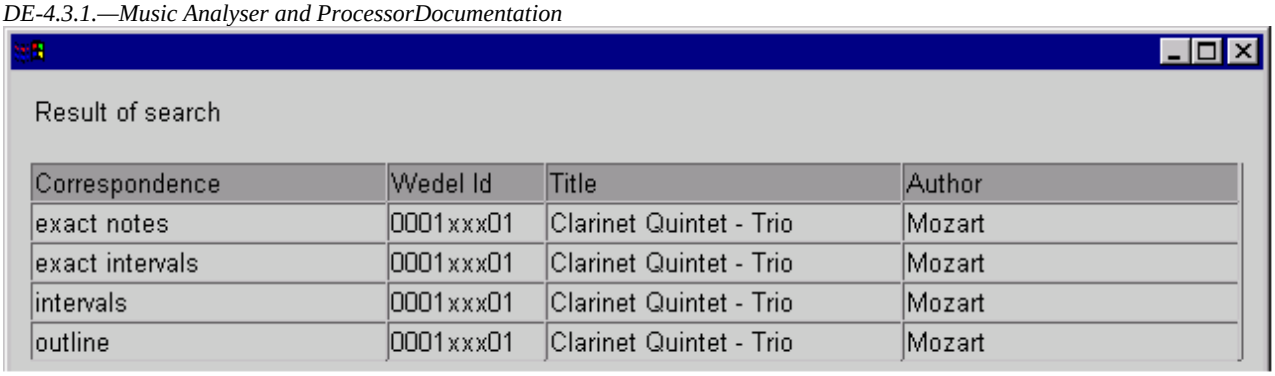
By choosing “Analysis: Search in database : Melody”, the user will be presented with a dialog using a keyboard-like interface :



By clicking on the appropriate keys on the “keyboard”, the user can enter the following melody:

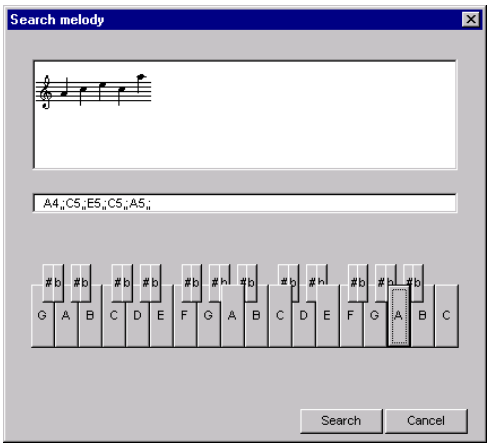


By clicking on “search”, the following results window will be shown :

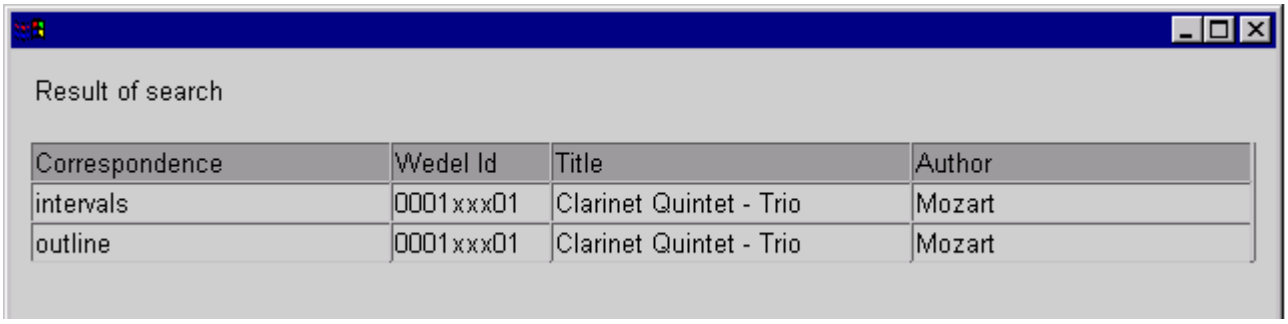


These results shows that a corresponding melody have been found in Mozart's Trio, as exact notes, intervals, exact intervals, and outline.

To better understand these results, let us try another query, with the same notes, but without accidentals:



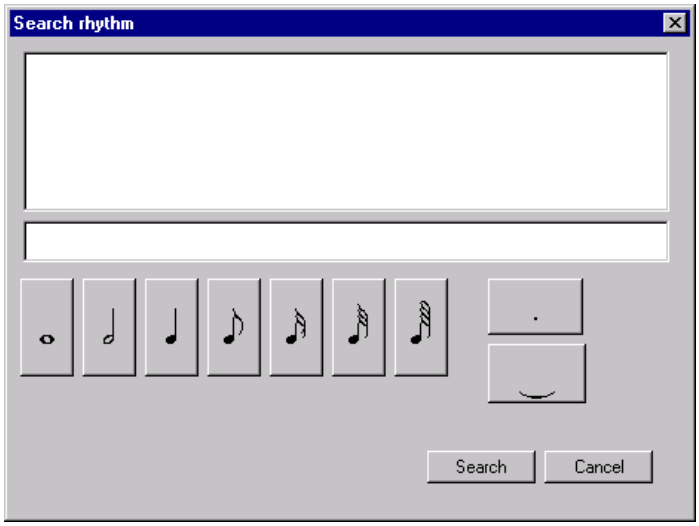
The results window will show that only approximate intervals and outline have been found as corresponding object in the database :



NB : for more information about the exact meaning of terms "Exact notes, intervals, outline", refer to the §3.1 in the second part, "Musical descriptions".

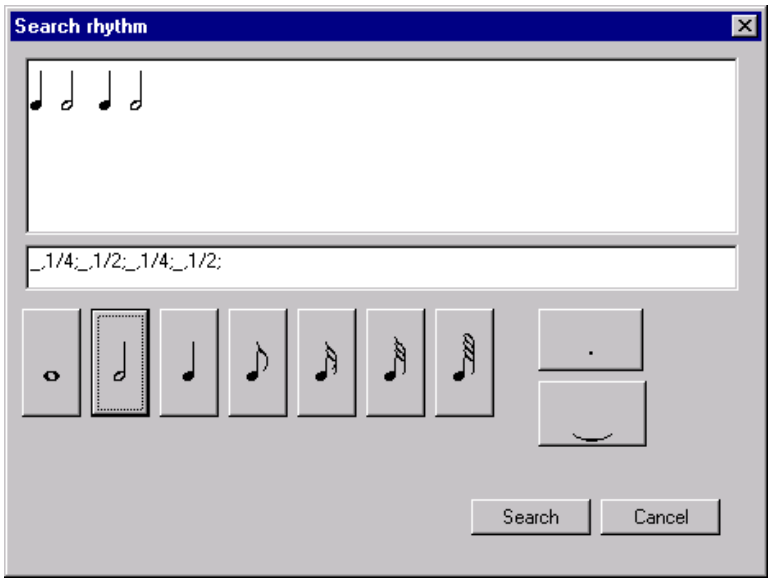
2.8.3 Rhythmic query in the Database

The rhythmic query function is able to find approximate results in the database.
By choosing the "Analysis : Search in Database : Rhythm" menu, the user will be presented with the following dialog :



By using the appropriate buttons, the end-user can enter a rhythm.

Just try the following query:



A window will be shown listing the results of the search. For each occurrence in the database, it describes:

The number in the first column gives an access to the occurence in the score. By clicking on this number, the score will be scrolled to the correct location, and the occurence will be highlighted.

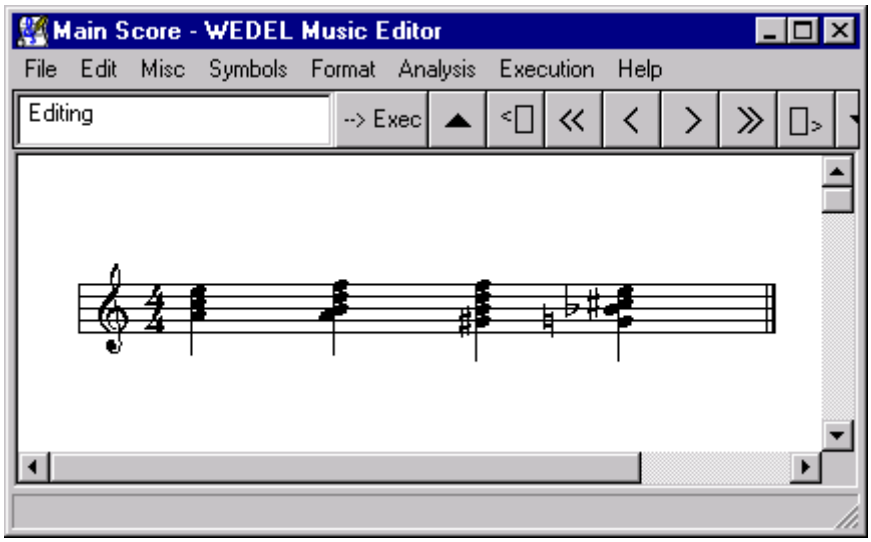
The search engine is able to find the searched rhythm, as an exact rhythm, or as an approximate rhythm, as an augmented or diminushed one.

2.8.4 Query for an harmonic progression

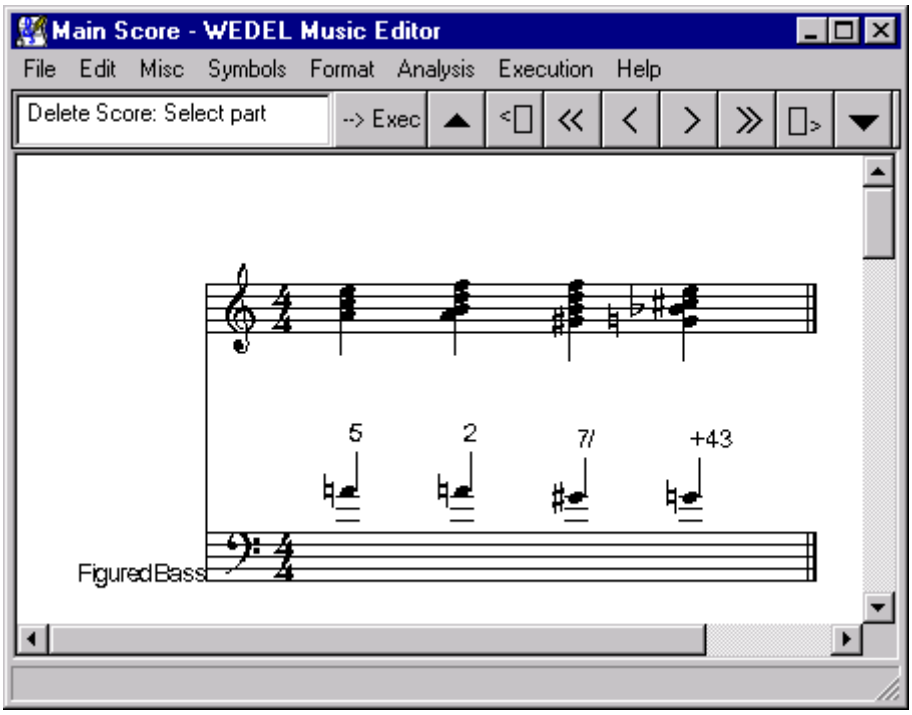
We will demonstrate here the possibility of doing a query on a harmonic progression.

For doing this kind of query, we must create a new, empty Wedel score.

Close the current Wedel object
Open a new, empty one.
Open the main score.
By using appropriate tools, enter the following notes:

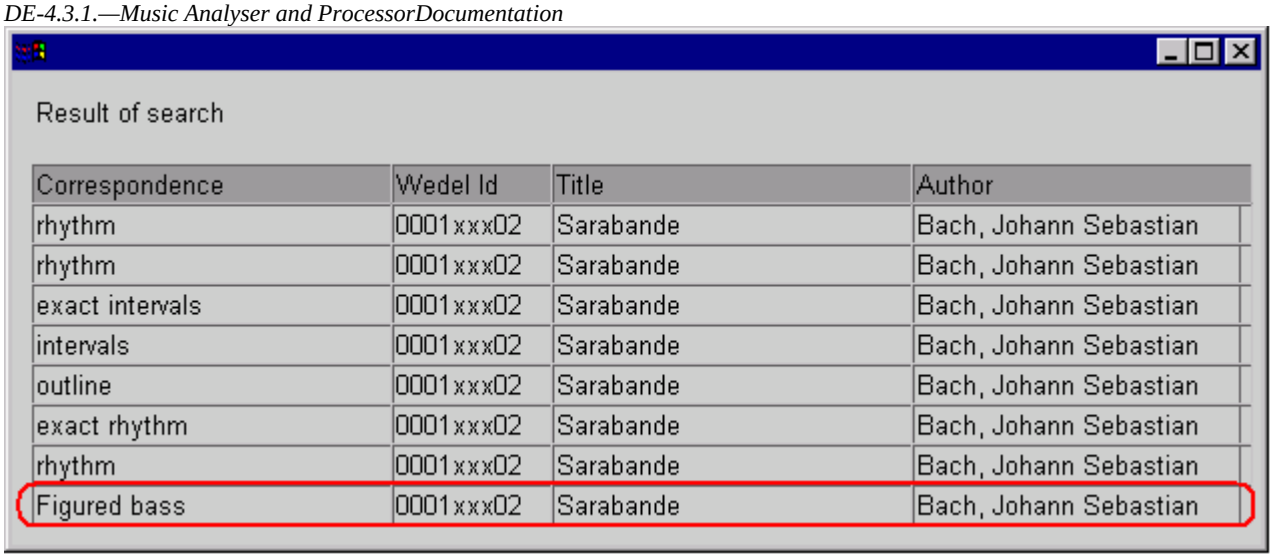


By using the menu item “Analysis : Figured bass”, create the Figured bass corresponding to this chords sequence:



By using the menu item “Analysis : Search in Database : General search...”, launch a query in the database.

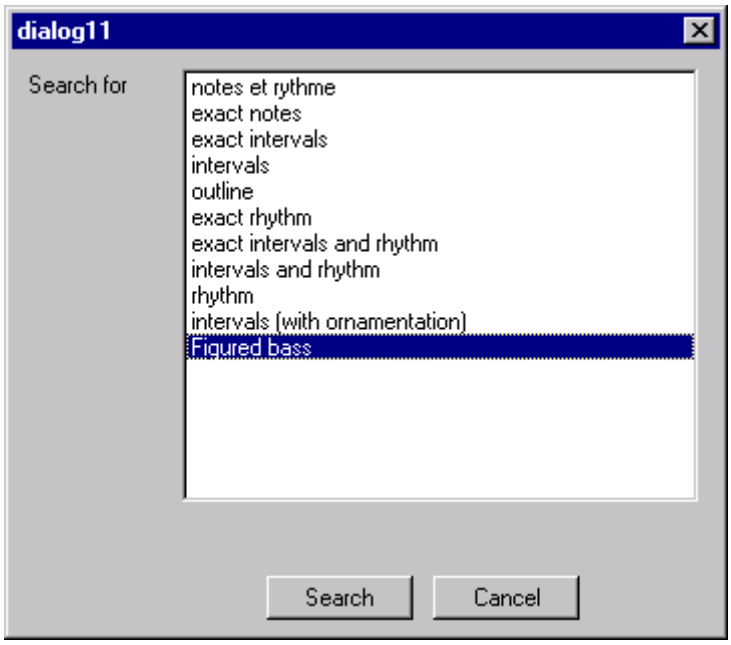
A window will be shown, summarizing the results of the query :



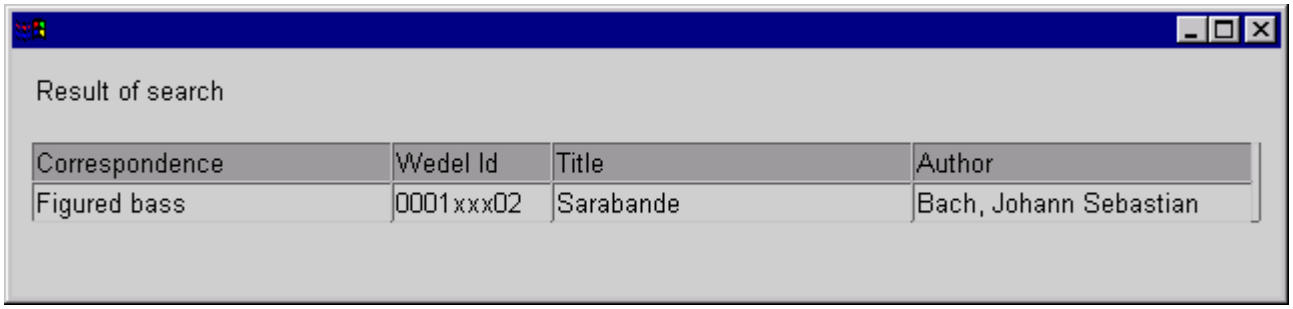
The result highlighted here shows the same Figured Bass found in the Sarabande. Other correspondences are found (rhythm, intervals, outline...).

The menu item “Analysis : Search indatabase : Particular search” can be used to do a refined search in the database on particular forms of music.

This menu leads to a list of possible correspondences to be searched throughout the database :



In this list, you can select one or more types of descriptions. You can select only “Figured bass”, and only the scores containing the same figured bass will be found :

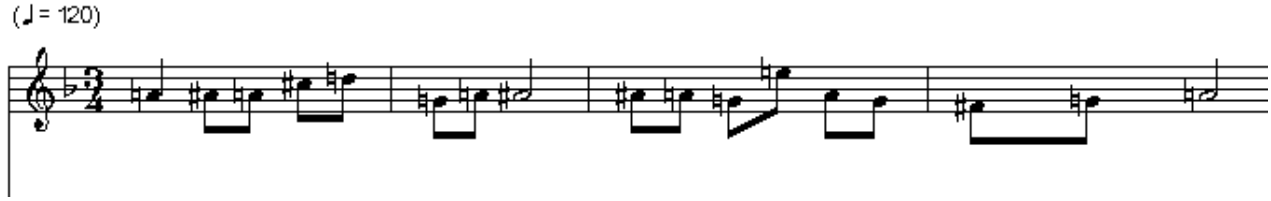


2.9 Enharmonic spelling

The menu item “Enharmonic spelling” does a spelling of a score, by correcting accidentals from sharps to flats or flats to sharps, according to principles and practice of classical style.
This menu item can be particularly used for correcting the result of a MIDI import.
In MIDI, notes in sharps and flats are not differenciated. A C sharp and a D flat shares the same notation. A program doing a MIDI import cannot in principle, makes the differenciacion between these two notations.

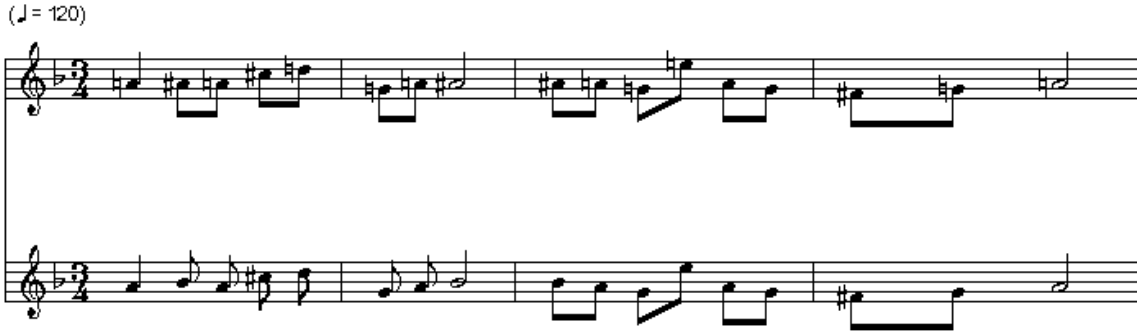
The “Enharmonic spelling” tool does an enharmonic spelling of notes.

Just examine the result of the possible import of Bach’s Sarabande, as you can get it by first exporting it in MIDI, create a new WEDEL object, and reimport the Sarabande from MIDI.
You can gain a result like this, showing the 4 first bars of the first part:



Apply on this result the menu item “Analysis: enharmonic spelling”.

You will gain, in a new part added to the score, a result like the following :



You can verify that the all the A sharp of the first part have been corrected in B flat. This conforms to the original spelling of this Sarabande.

Generally speaking, the enharmonic spelling tool does the correction of the misspelled notes with an average success of 90 to 95 percent, for music of the classical style.

3 Musical principles and technics

In this chapter, the musical principles and technics used in Analysis tools are described. Users will read carefully this part of the documentation when wanting to apply correctly musical analysis tools.

3.1 Musical descriptions

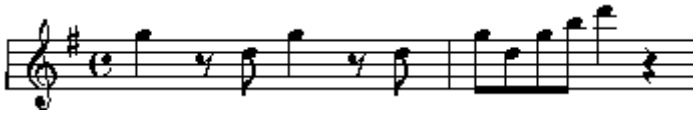
Musical descriptions are encountered everywhere in analysis tools : they are encountered in results of search, in extraction of motifs, in queries in database, and so on.
They are of particular importance and they have to be carefully studied.

3.1.1 Purpose of musical descriptions from the musical point of view

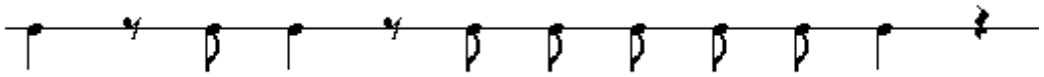
Musical descriptions are descriptions of a part of the score – a voice for example – while describing only a particular aspect of the voice. It can be, for example, the description of intervals of the voice, but also the rhythm of the voice, or even, the outline of the voice, a descriptor known also by its french name “contour”.

3.1.1.1 Melodic and rhythmic descriptions

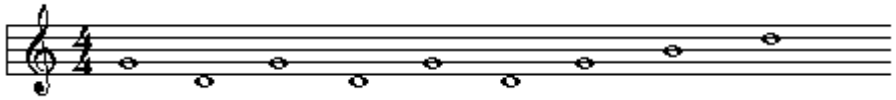
Here is a motif (part of a well-known Theme), together with some different musical descriptions :



Rhythmic description:



Melodic description:

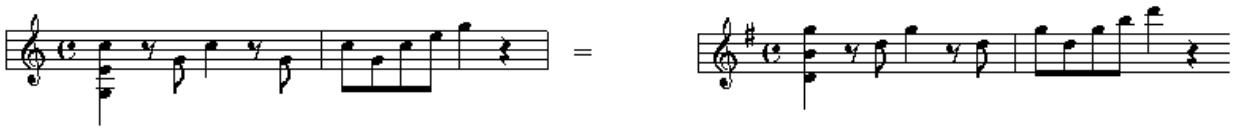


3.1.1.2 Intervals description

Other forms of descriptions are also useful, like a description of the same voice in form of intervals, like the following :

Descending Fourth, Ascending Fourth, Descending Fourth, Ascending Fourth, Descending Fourth, Ascending Fourth, Ascending Third, Ascending Third.

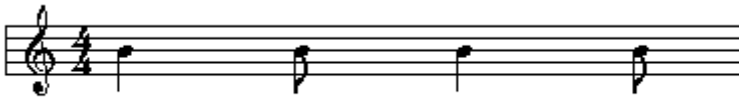
The interest of this description is that it describes relative heights. Thus, two instances of the same theme, but in different tonalities, can be compared from this point of view and found the same,as they have the same intervalic description :



3.1.1.3 Relative rhythm

The same principle as for the intervals description can be applied to rhythm. Rhythm can be described, for each note, as its relative duration compared to the previous note.

The following rhythm :

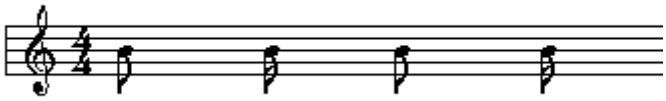


can be expressed as :

½, 2, ½

as the second note is the half of the previous one, and the third is twice long as the second, the fourth being half of the third note.

The following rhythm has exactly the same “relative rhythm” description as the previous one:



3.1.2 Practical applications of musical descriptions

After this brief review of musical descriptions, we hope that their musical applications are quite evident.
For example, in fugues, the main theme (known also as subject) is expressed in different manners throughout the fugue, transposed, and sometimes with modifications of rhythm – augmentation or diminution.
This is not only true for fugues, but also for several musical production, even for popular music.

Thus, the musicologist analysing a piece of music can be interested in founding a particular melodic motif, regardless of its transposition.
He can also be interested in founding rhythmic motifs, regardless of the exact value of the rhythmic unit.

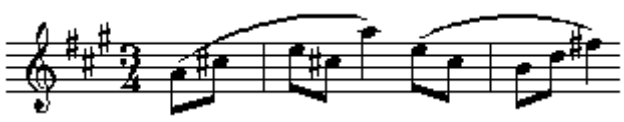
In addition, a process of recognition of repetitions can be applied on these relative musical descriptions to find main motifs.

3.1.3 Implementation in Wedel Analysis Tools

In Wedel Analysis tools, formalized descriptions of the score are implemented, called descriptors.
Descriptors describes a particular aspect of the score, or of part of the score.

3.1.3.1 Notes and Rhythm – voice descriptor

Notes and rhythm describes the exact notes, expressed with the letter corresponding to the note in English notation, with its accidentals, octave, together with rhythm expressed as a fractional number.
For the following example :

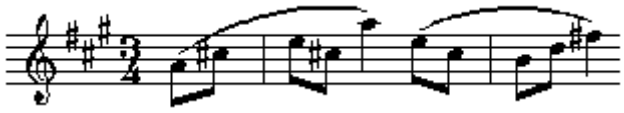


Here is the corresponding description in Notes and rhythm:

A4,1/8;C#5,1/8;E5,1/8;C#5,1/8;A5,1/4;E5,1/8;C#5,1/8;

3.1.3.2 Exact notes – voice descriptor

In the notes descriptor, only notes are encoded, without rhythm.
For the same example :



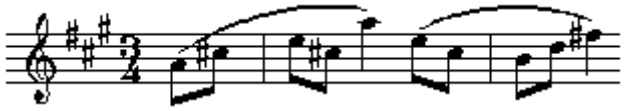
Here is the corresponding description in Exact notes:

A4;C#5;E5;C#5;A5;E5;C#5;

3.1.3.3 Exact intervals

In the exact intervals descriptor, intervals only are encrypted. The intervals are encoded with the corresponding figure (a 3 for a third and so on), with the qualifier of this interval (as m for minor, M for major, J for exact, a – for diminished, a + for augmented), and with the direction (a < for ascending intervals, a > for descending intervals).

For the same example :



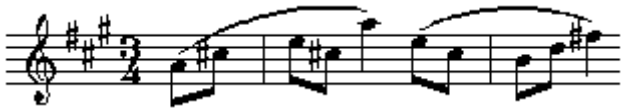
Here is the corresponding description in Exact intervals:

3M<;3m<;3m>;6m<;4J>;3m>;2M>;3m<;3M<;

3.1.3.4 Intervals

The intervals descriptor is the same as the Exact intervals descriptor, with this difference that the qualifier, - minor major and so on – is not included.

For the same example :



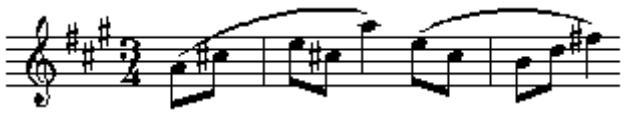
Here is the corresponding description in Intervals:

3<;3<;3>;6<;4>;3>;2>;3<;3<;

3.1.3.5 Outline

In the outline descriptor, only the general outline of the voice is encoded. Intervals less than or equal to a major second are encoded with 1, the unisson with a 0, others with 2. The direction is encoded with < for an ascending interval, and a > for descending intervals.

For the same example :



Here is the corresponding description in Outline:

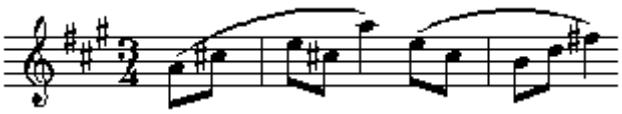
2<;2<;2>;2<;2>;2>;1>;2<;2<;

NB : this is very similar to the outline or “contours” descriptor found in MPEG7 standard.

3.1.3.6 Exact rhythm

The “exact rhythm” descriptor encodes the rhythm of notes, in the form of a fractional number. For a quarter note, as 1/4, for a eighth note, as 1/8 and so on.
Tuplets are taken into account in this encoding. For a eighth note in a triplet, the value is 1/12.

For the same example :



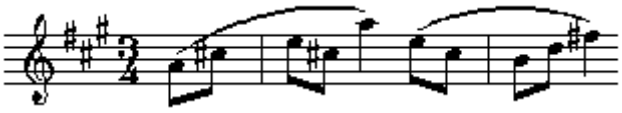
Here is the corresponding description in Exact rhythm:

1/8;1/8;1/8;1/8;1/4;1/8;1/8;1/8;1/4;

3.1.3.7 Exact intervals and rhythm

In this descriptor, the exact intervals are encoded together with the duration of the note, encoded as “exact rhythm”.

For the same example :



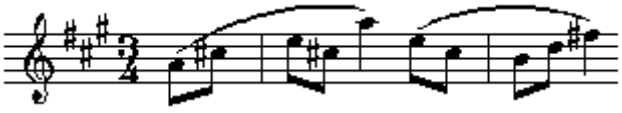
Here is the corresponding description in Exact intervals and rhythm:

3M<,1/8;3m<,1/8;3m>,1/8;6m<,1/8<;4J>,1/4;3m>,1/8;2M>,1/8;3m<,1/8;3M<,1/8;

3.1.3.8 Intervals and rhythm

In this descriptor, the intervals without qualifiers are encoded together with the duration of the note, encoded as “exact rhythm”.

For the same example :



Here is the corresponding description in Exact intervals and rhythm:

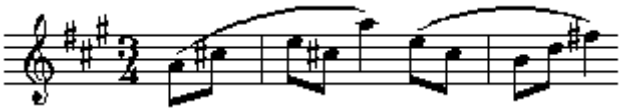
3<,1/8;3<,1/8;3>,1/8;6<,1/8<;4>,1/4;3>,1/8;2>,1/8;3<,1/8;3<,1/8;

NB : this descriptor is the descriptor used by default for application of detection of repetitions.

3.1.3.9 Rhythm

This descriptor can be considered as a "relative rhythm" descriptor. The rhythm of each note is encoded in fractional value, relative to the fractional value of the preceding note.
That is to say, if Fi is the fractional value of note i, Fri = Fi / Fi-1 is the relative fractional value of note i.

For the same example :



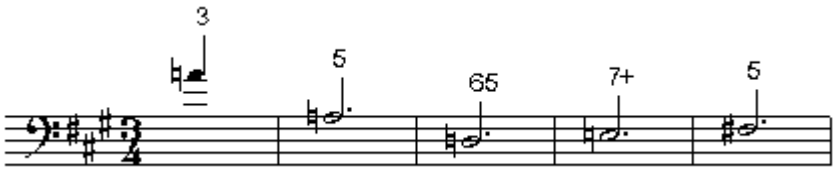
Here is the corresponding description in Rhythm:

1;1;1;2;1/2;1;1;2;

3.1.3.10 Figured Bass descriptor

In the Figured Bass descriptor, a voice is encoded in form of exact intervals, together with the figure of the chord.

For the following example :



The corresponding encoding is as follows:

8j>,3;5j>,5;2j,65;2j,7+;

The same type of encoding is used for tonalities as extracted from the score.

3.2 Figured Bass

3.2.1 Principle

The figured bass is a very old principle, described in several treatises, starting from "Del sonare sopra il basso" by Agazzari (1607). The aim of the figured bass was, in principle, oriented towards interpretation. Rameau turned it into a genuine theory of tonality with the introduction of the fundamental concept of root. Successive refinements of the theory have been introduced in the 18th, 19th (e.g., by Reicha and Fetis) and 20th (e.g., Schoenberg) centuries. For a general history of the theory of harmony, one can refer to Ian Bent[4].

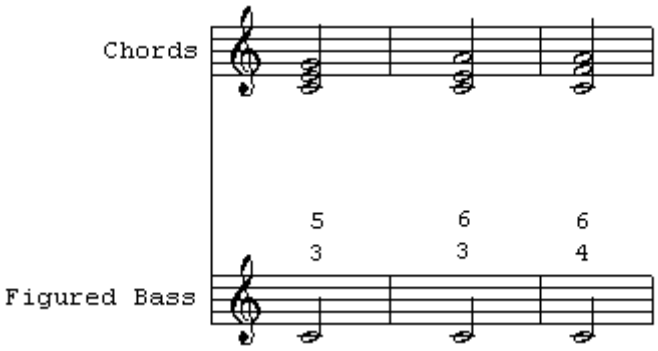
The principle of figured bass can be shortly described as follows:

Each chord is described with two elements :
- A bass note
- A set of figures, describing the other notes of the chord, expressed by the mean of their interval with the bass.

For example, a classic major triad with the notes C – E – G will be presented with the note "C" (as the bass note), and the figures 3 for the E and 5 for the G.

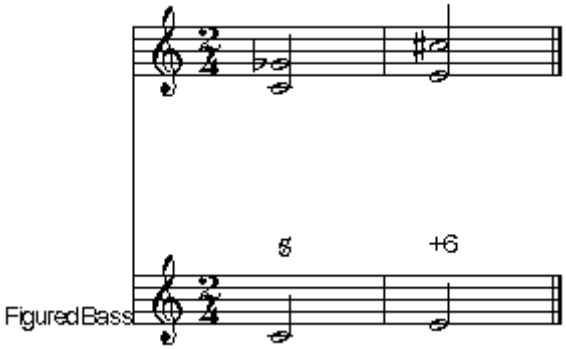
[4] Bent, I. (1987), Analysis, Macmillan Press, London, 1987.

Here is an example showing some classic chords together with the corresponding Figured Bass:



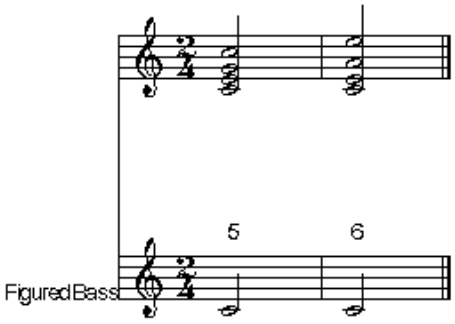
Some conventions are to be added to this simple principle:

A diminushed interval is shown with a / . For example, a ♯ figures a diminished fifth.
A + before a figure means that this note is the leading note.

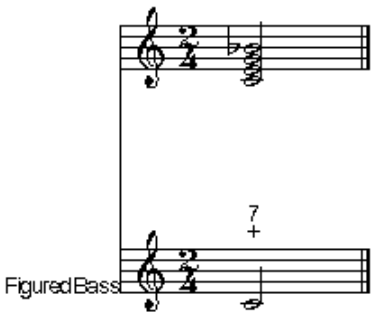


Some notes are not expressed:

The Octave is never expressed (each chord can contain the octave of the bass).
The third is the most of the time not expressed (a chord containing the third and the fifth is simply figured with a 5). This means that for a chord which does not contains a second or a fourth, the third can be added to the chord, even if not figured.



As the third is not expressed, a + alone means that the third of the chord is the leading note.
Some figures are simplified. For example, here are the figures for a dominant seventh chord, which contains the third, which is the leading note, the fifth and the seventh:



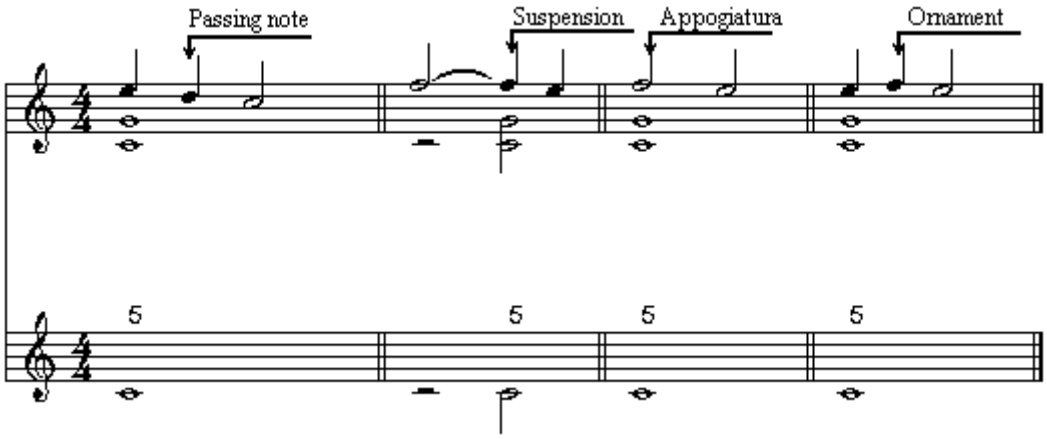
A supplementary convention states that an accidental before a figure indicates the accidental to be allowed to the note. This convention is not followed by our system.
In addition, in our system, figures are not placed on top of each other, but beside.

3.2.2 Melodic notes

In classic harmony, some notes are not part of harmony, these are purely melodic notes. Their role is ornamental.

The theory recognizes as melodic notes passing notes, appogiaturas, suspensions, and ornament.
One common characteristic of all these notes are that they must lead with a conjunct degree to an harmonic note. This is known as “natural resolution” of melodic note.

Here are some examples of melodic notes, with natural resolution :



In some cases however, exceptions to his rule can be found, especially in music of the late 19th Century, but also in purely classical music. This kind of resolution is known as “exceptional” resolution.
Our process of harmonic reduction being based on the recognition of melodic notes based on the rule of natural resolution, presence of non natural resolution can lead to a failure of the harmonic reduction process.

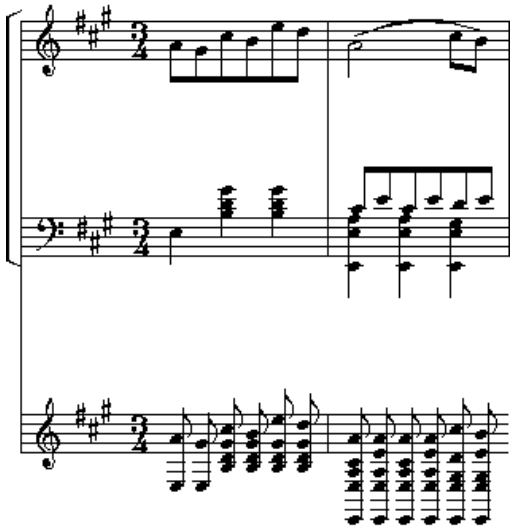
3.2.3 Extraction of Figured Bass

In this chapter, the process leading to the extraction of Figured Bass is presented. This process is hidden to the user, but the user is likely to know about details on this process, in order to be able to understand limitations and possible failures of the system.

3.2.3.1 Description of the process

3.2.3.1.1 Clusterisation

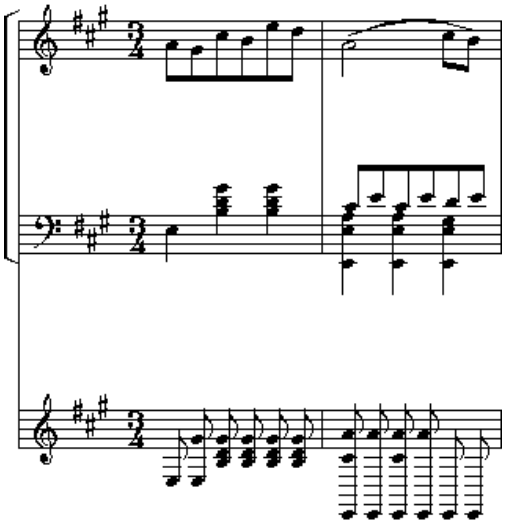
The first step of the process is a *clusterisation*. All notes present at the same while are grouped together in a *cluster*, like in the following example, where the result of the clusterisation step is shown on the third staff:



3.2.3.1.2 Identification and temporary suppression of melodic notes

In a second step, the possible melodic notes are temporarily suppressed, that is, notes that are not really part of harmony, like suspensions, appogiaturas, passing notes and so on.
These notes are suppressed on the basis of the melodic movement with the following note: if this movement is not more than a major second, the note is recognized to be a possible melodic note, and is temporarily suppressed from clusters.

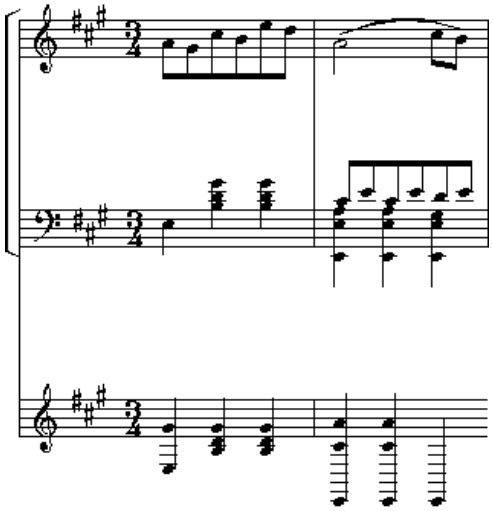
In the following example, the result of this suppression is shown on the third staff:



3.2.3.1.3 Aggregation (merge of successive chords)

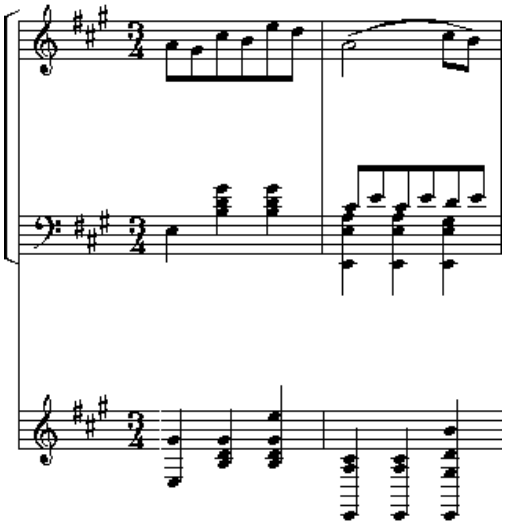
The process of horizontal aggregation extensively uses the set of chords that the user has selected.
We begin the process of aggregation by comparing two consecutive clusters. They are considered the same if the sounds composing the two clusters are the same, regardless of their octave, i.e., each sound of the first cluster belongs to the second, and each sound of the second belongs to the first. In this case, the two clusters are merged in one.

If they have not been merged, the process performs a union of both clusters and compares the result against the each chord in the set of chords. If the union, except for the possible ornamental notes, can be exactly mapped to a chord, the two clusters are merged into one.



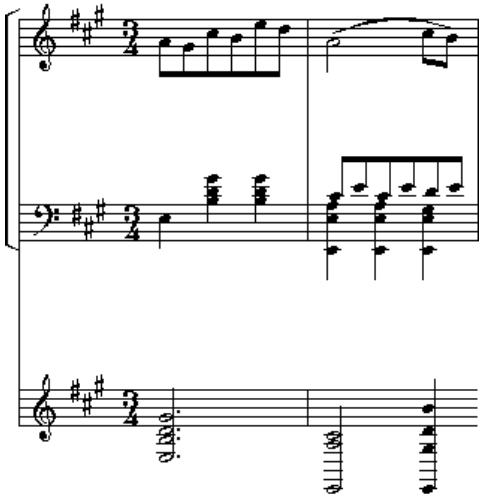
3.2.3.1.4 Standardization

A second attempt is then made to merge successive clusters, if the result of the merge, including the possible ornamental notes, can be exactly mapped to a chord. In this case, the two clusters are merged into one, and the ornamental notes are now considered to be harmonic notes.



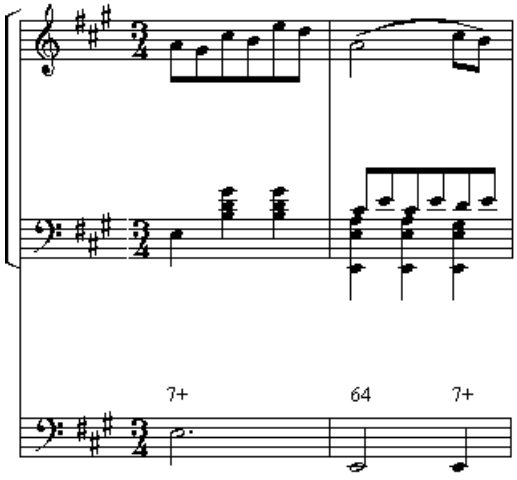
3.2.3.1.5 Repeated aggregation and standardization

The process of aggregation–standardisation is first repeated by beat, and by measure, until no more merge can be made.
The final result on the above example is shown here:



3.2.3.1.6 Production of figured bass

Finally, a new part is created with the computed bass, together with the figures corresponding to the figures of the chords defined in the currently used harmony sety fof rules. This result is the only result which is shown to the end user.



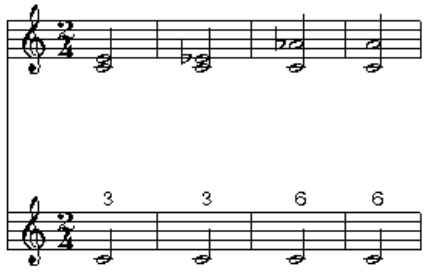
3.2.3.2 Harmonic reduction : Tips and techniques

In this chapter, a number of tips and techniques are explained, first to examine a number of possible failures of the system, and second to give the user the ability to define himself his own set of harmony rules.

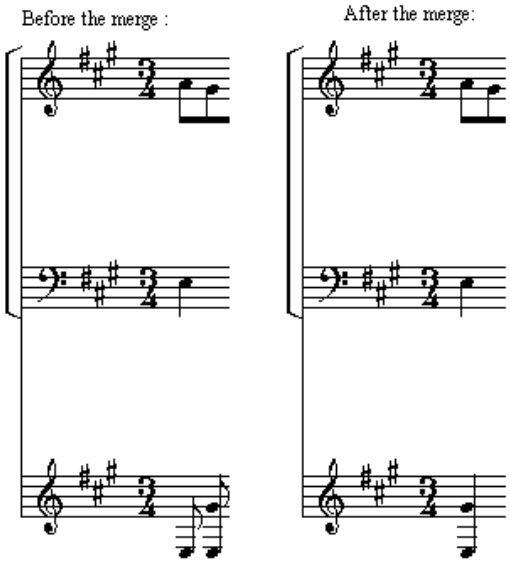
3.2.3.2.1 Ankle chords

Ankle chords are used in harmony rules to give the process the ability to make first aggregations of notes, which are not true chords, but which can be considered as the seed of a complete chord.

In our “Standard” set of chords, we defined four simple two-notes chords:



These chords are not really complete chords, but are used by the process to merge successive clusters. By using the same example as above, we show here how the simple third chord is used to merge two clusters, by merging the two first eighth-note clusters of the first bar:

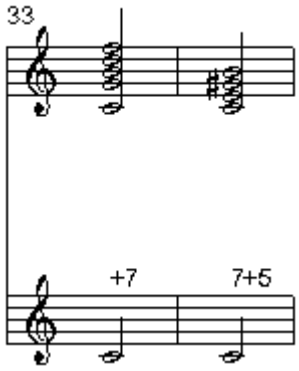


This can be considered as correct with classical harmony, since two successive notes with an interval of third or an interval of sixth are commonly heard as a whole.

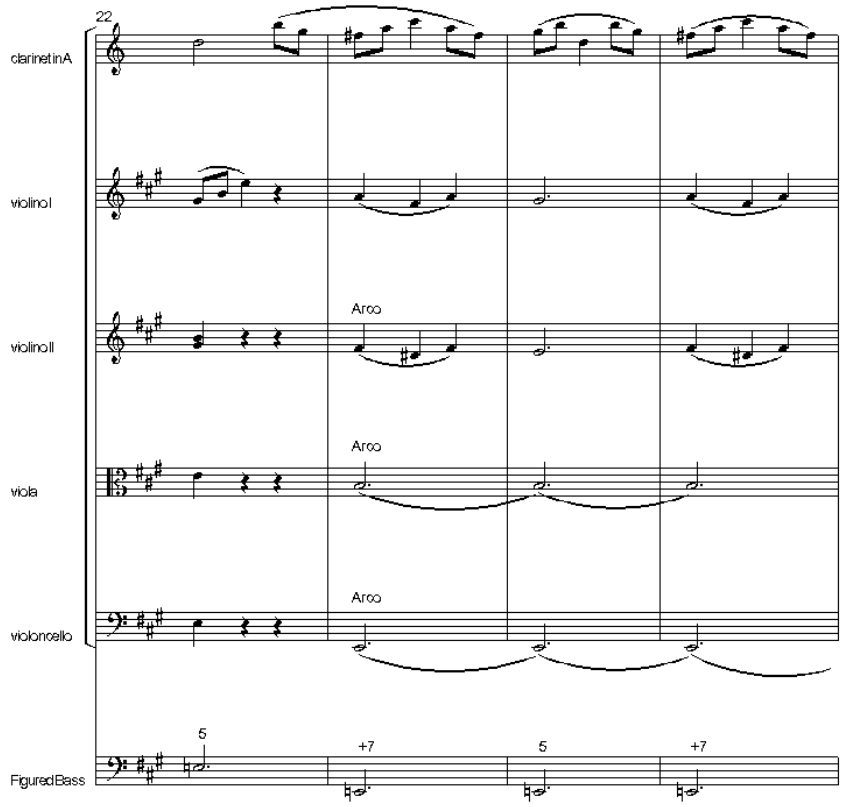
Instead, we have not defined a two-notes chord comprised of an interval of fifth. Two successive notes with an interval of fifth are commonly heard as a strong functional succession, known as cadence. This is surely only true with classical harmony.

3.2.3.2.2 Extended chords

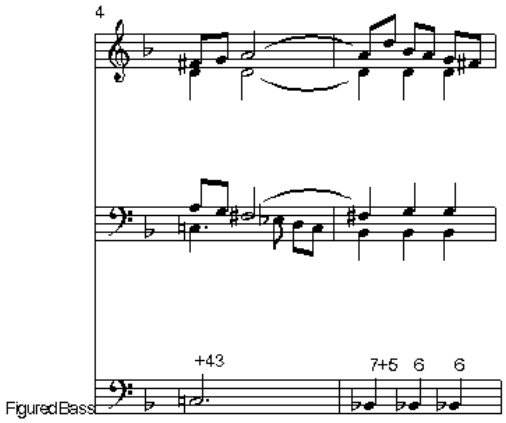
Extended chords are chords which are not really supported by the theory, but which are of use.
We have defined in our “Standard” rule two chords which cannot be considered as really standard:



Nevertheless, these chords are frequently used.
The first is commonly used as a dominant-seventh chord on the tonic, expressed as a pedal, as can be shown in the following example extracted from the Clarinet Quintet by Mozart, in measures 23 and 25:



The second chord is very less frequent, but happens when there is a double suspension on the tonic, on the sixth chord following a +4 chord on the dominant, as shown in this example of Sarabande in D minor by J.-S. Bach (on the first beat of measure 5):



NB : we have not defined in our “Standard” harmony, the well-known “augmented 6th” chord, of use in the romantic (and also sometimes by Mozart).

3.2.3.2.3 Figures definition strategy.

NB: To understand this chapter, the user must be familiarized with the technique and the general aims of rewrite rules.

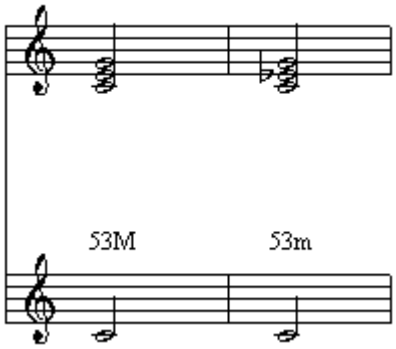
Figures can be redefined by the end user, and used in a different way than in classical harmony.

Figures used in classical harmony are conventions, and slightly different conventions can be used to serve a different strategy, in particular when used to be the source of rewrite rules.

The user can choose between two different strategies when defining his own set of rules:
He can choose to make the distinction between two chords, or instead using the same figures for two different chords which can be considered to be very near each other.

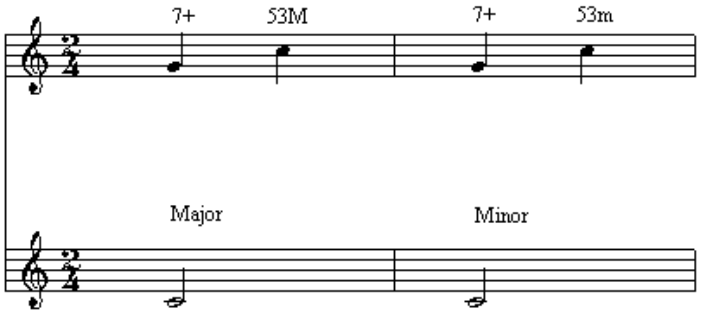
Let us examine the possible consequence of this choice:

When defining the figure for a fifth chord, we can choose to distinct between a chord with a minor third and a major third, like in this example:



The consequence of this choice is that, when applying a rewrite rule defining cadences, the user can make the distinction between a cadence in a Major key and a minor key.

By defining as a rewrite rule for cadence, he can define it as follows:



By using a rewrite rule of this kind, and extending it to other currently used sequences of chords, the end-user is ensured to retrieve the tonalities used together with their mode.

A contrario, the end user interested in the search for cadences will base his own rewrite rule on a simple 7+ 5 movement. To this end, he will certainly use a more simpler way of defining the 5th chord, making no difference between the two forms.

The two strategies are possible with the Analysis tools, and probably more different strategies, by combining harmony rules and rewrite rules in subtle interacting processes.

3.3 Tonality recognition

3.3.1 General principles

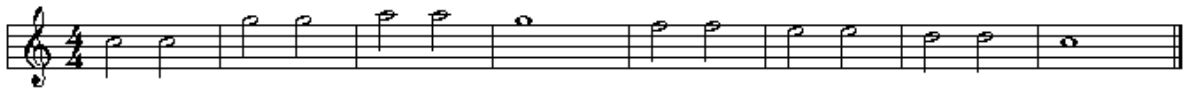
Tonality recognition is a complex process. Rules of tonality recognition are not firmly stated, and tonality recognition is for the musician the result of a complex learning process, where experience plays the first role.

Let us examine some of the problems raised by tonality recognition, which are the non completeness of the scales used, the use of extra-key notes, and the use of modulations, or changes of keys.

a) Non completeness of scales used.

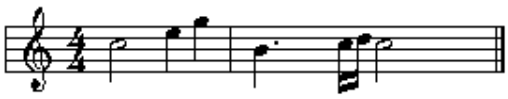
In principle, tonality can be deducted from the scale used. The following examples shows non-complete scale extracted from the musical litterature. Nevertheless, the tonality is very clear in each of these examples for a musician.

Mozart, “Ah vous dirai-je Maman”:



In this example, the B is not used, and, strictly speaking, we are not able to know if the tonality is C Major or F Major. Nevertheless, the tonality is undoubtedly C Major for a musician.

Mozart, Sonate in C Major:



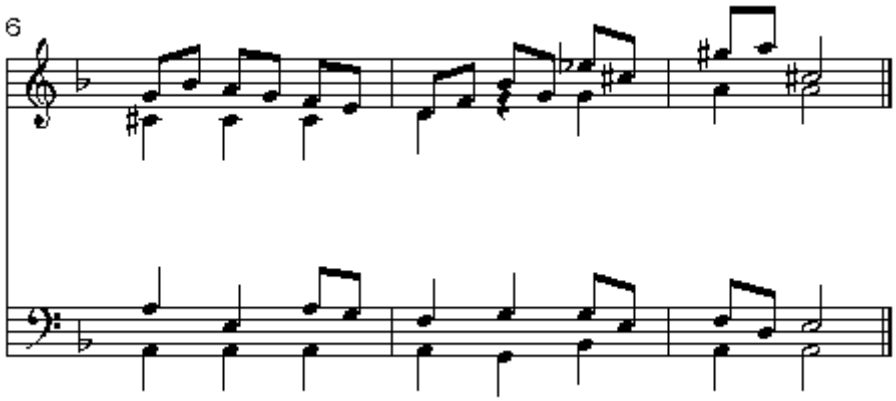
Strictly speaking, the tonality can be here C major or G Major, as the F is not used. The experienced musician recognizes easily C Major.

NB : we have not exposed here the complete theme, which makes use of the complete scale. Nevertheless, the tonality is clearly exposed in these two measures.

b) Use of notes out of tonality

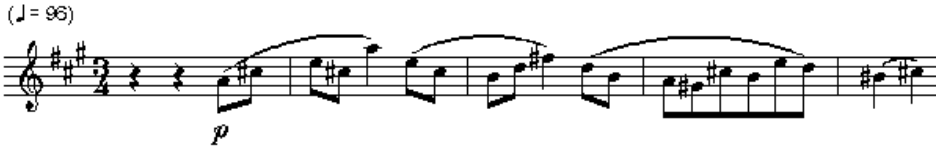
The use of extra notes, out of the tonality, is very frequent. Here are some examples of such notes:

Bach, Sarabande in D minor, measure 6-8:



Despite the E flat in bar 7 and G sharp in bar 8, the tonality is undoubtedly D minor.

NB : The E flat is very frequent in D minor, and currently known as “Neapolitan sixth”.
Mozart, trio of Clarinet Quintet (clarinet part):



In this example, the B sharp found at measure 5 is out of the A major key, which is the key of the

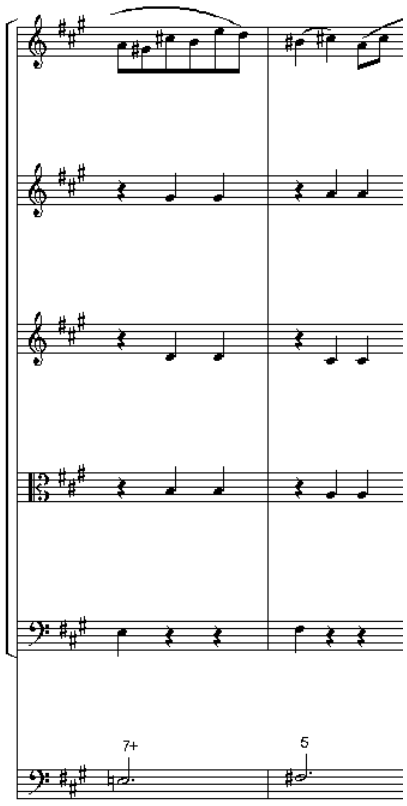
c) Modulations

Modulations, or changes of key, are so often used in classical music that it’s difficult to find music without changes of key.
In principle, new keys are introduced by the mean of a significant note, that is, a note which doesn’t belong to the previous key, and is the 7th or the IVth degree of the new key. This note must not be introduced as a melodic note (a passing note, an appoggiatura…), but instead must be introduced as a harmonic note.
To recognize correctly a change of key, melodic notes must be differentiated from real harmonic notes.

3.3.2 Implementation in Wedel Tools

3.3.2.1 Principle of implementation

We have chosen to develop a process where tonality recognition is based on the figured bass, for some different reasons:
First, the figured bass extraction process is a process where purely melodic notes are filtered and suppressed from the score. In this process, the notes out of the tonality are already filtered, like in the following example from Trio of Clarinet Quintet by Mozart (in the second bar):

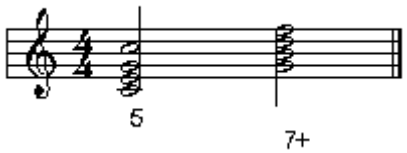


In this example, the B sharp on the first beat of the second bar is out of the tonality. This note being filtered out of the harmony by the figured bass extraction process,
Second, the figured bass extraction process, as shown above, is already a process in which successive regions are already merged, grouping sets of notes as pertaining to the same chord.

3.3.2.2 Process description

For each chord of harmony rules, a set of possible keys is defined. These keys are applied to the figured bass. Two successive chords are merged in one if there is at least one tonality in common. The process is successively repeated until there is no tonality in common between two successive chords.

Let us examine a very simple example:



In this example, for the chord of fifth on a C, with the major 3, the set of possible keys are:
C Major, E minor, F Major, F minor, G major (and even B minor and B Major, where C Major is the "Neapolitan sixth").

For the chord a dominant seventh on a G, the set of possible keys are :
C Major, C minor.

The only common key to these two regions being C Major, the C Major key is applied to the whole bar.

NB : *The set of keys are for now only defined in "Standard" rules. The end-user's interface for defining it is in development.*

3.3.2.3 Theoric requirement

This process is based on a strong theoric requirement : this requirement states that music is composed of musical sections, with each of them composed of at least one and at most one key signature.
This means that there are no "doubtful sections", which can be analyzed in two or more different keys.
In fact, one can see in applying the process of tonality detection to the Trio of Clarinet Quintet by Mozart, there is a small section

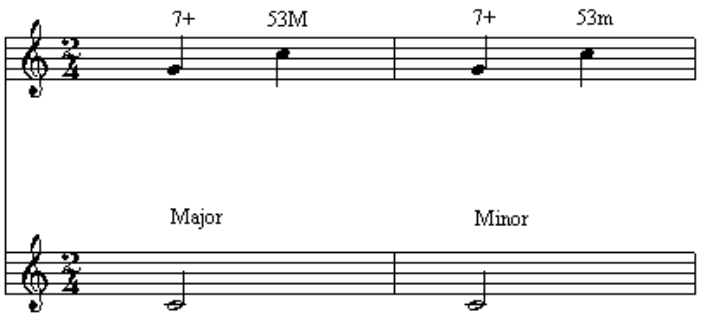
3.3.3 Other process of tonality recognition, using rewrite rules

3.3.3.1 Rewrite rules

We have already shown in §2.7 how rewrite rules can be used to define a process of cadence recognition. We have also shown in §3.2.3.2.3, Figures definition strategy, how a rewrite rule could be used for defining a process of tonality recognition.

The process can be defined as follows:

Identify and encode some commonly used successions of chords, like successions known as composed of a dominant-seventh chord followed by a triad.



Apply this rewrite rule on an already generated Figured Bass, using a Figured Bass where the distinction is made between major and minor triads (NB : to this end, the “Standard” figured bass can be used, with a simple redefinition of figures).