Computational Musicology
A Survey on Methodologies and Applications

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Résumé. Cet article traite de l'utilisation de l'informatique dans les études de musique. Il présente une introduction aux différents aspects de la musicologie computationnelle et aux récents développements dans ce domaine. Il passe en revue les principales applications de l'informatique en musicologie historique et en analyse quelques exemples et leurs implications. Ensuite sont décrites les applications de l'ordinateur aux études analytiques en ce qui concerne leurs aspects méthodologiques. Des exemples de systèmes d'analyse automatique sont expliqués avec les conclusions théoriques que l'on peut en tirer. L'article s'achève par une analyse rapide de développements envisageables dans le futur.

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1. Introduction

Computer applications to music cover a wide range of musical activities: sound processing, composition, psychoacoustic, music printing and musicology. For the applications concerning the musicological field a new heading was created: computational musicology. But what computational musicology does mean? It is evident the analogy to computational linguistics but the content of computational musicology, in the field of music obviously, could be comparable both of literary and linguistic computing. In fact, computational musicology studies concern not only with theoretical studies but also with the creation of musical repertoires in machine readable form, historical and musical databases and other. The computational musicology applications range from studies on musical historical texts to musico-cognitive studies; evidently, the degree of use
and implication of the utilization of the computational methodologies varies drastically from one application to another.

The current situation of the computational musicology studies is well established. Musicological studies using computer appear quite regularly in the international journals of the field. In addition, an important publication in which the major activities in this field are reported is published yearly by the Center for Assisted Research in the Humanities of Menlo Park, USA, since 1985, titled *Computing in Musicology*. Another publication on this field is *Computers in Music Research*, published by the Wisconsin Center for Music Technology, in which theoretical and applicative issues are also viewed in respect to their educational use.

A study group on musical data and computer application has been established in the International Musicological Society and recently organized a round table on the New Methodologies in the Study of Melody at the IMS XIV International Symposium in Madrid in 1992. In addition, computational musicology studies are well represented in the two editions of the Conference on Computers in Music Research (Lancaster: 1988 and Belfast: 1991): in this conference the musical research part in the computer applications to music is emphasized rather than the compositional and sound processing ones.

In the recent years various books (Marsden and Pople: 1991; Balaban et al.: 1992, Hewlett and Selfridge-Field: 1992) and journal special issues (Camurri: 1990, Camilleri: 1992) in which aspects of computational musicology are treated have been published.

In this article I will briefly summarize the various fields of application and focus on some examples in each topics. In some cases the examples rely upon works carried out by myself and my colleague at my Institute.

2. **Historical musicology**

In the field of historical musicology we can single out two main areas: (1) musical repertoire in machine readable form, (2) databases of musical text and/or historical and bibliographical information, and thematic catalogues.

2.1. **Musical repertoires in machine readable form**

It is self-evident, but often not so obvious, the importance of the realization of musical repertoire in machine readable form. The first implication of creating
repertoires in machine readable form is the possibility to realize modern critical edition at low cost. In fact, a musicologist can carry out all the editing process by himself, taking care of all details and saving a considerable amount of money in the publication budget. By this way, several editions, of so called minor composers, have had the possibility to be printed because of the small budget required. In this case the major importance is due to the advent of musical printing programs. However, the important side effect of using them is the following one: if the printing program provide a readable and explicit encoding scheme then the amount of data representing the particular repertoire can be used, in principle, by other scholars who do not need to re-enter all the music into another format. An experience on this application has been realized at the Divisione Musicologica CNUCE-CNR, Florence, where the critical edition of the Second Book of Madrigals by Luca Bati (Gargiulo: 1991) has been realized by musicologist Piero Gargiulo. The files containing the 21 madrigals are stored in the computer facilities of our Institute at other users disposal. All the material is encoded in Score code, the alphanumeric code of the printing program Score, which is plain ASCII, well structured and with a defined and interpretable meaning for each symbol used. Therefore, a musicologist who would like to analyze these madrigals using computer can utilize the already encoded material.

Large musical repertoires in machine readable form have been created at the Center for Assisted Research in the Humanities. One of these projects is aimed at encoding the complete works of J.S. Bach using an encoding scheme which is alphanumeric but uses an internal representation which allows to store all the facets, in addition to pitch and duration, of printed score.

A good example of the structure of several encoding schemes is found in the 1987 Directory of Computer Assisted in Musicology (Hewlett and Selfridge-Field: 1987) where the same musical incipit has been encoded by different systems and their facets are discussed.

2.2. Musical databases

Databases often represent the first approach of the musicologist who uses the computer. Storing, retrieval and comparing information are operations that musicologists have done manually for years. The possibility to automatize at different degrees these operations can improve the search speed and the accuracy of the research.

As mentioned before, one can distinguish between two main kinds of music related databases; databases of historical bibliographical or any other type of
textual content, and databases of musical information, containing musical text as
the primary source on which to execute searches and comparisons.

An interesting research dealing with the realization of a textual database
has been carried out by Sandra Pinegar (1991) as a part of her doctoral thesis
at Columbia University, USA. Thema is a textual database whose content
are transcriptions from thirty-seven thirteenth and early fourteenth century
manuscripts of Latin treatises of mensurable music. Thema main feature is
that the transcription should accurately represent the original text as in a
photographic facsimile, i.e. using the same line length, paragraph signs, and
other elements. Thema uses a system of numerical tagging that encodes the
abbreviations. It allows a series of operations such as a comparison between
two or more different texts. The materials of Thema is transportable as ASCII files
in order to allow different operations on them ranging from word processing
to concordance indexing or word-crunching. Another similar example of textual
database based on the same subject is the Thesaurus Musicarum Latinarum, a
project realized by Thomas Mathiesen at Indiana University (Mathiesen: 1992).
TML encoded texts are not the original manuscripts but their modern editions
and the historical period treated is from Middle Age to Renaissance. TML has
an encoding scheme to store and represent the musical incipits and the database
facilities are available through the computer network. By this way, remote users
can easily access the database content and perform searches.

However, musicological text based databases are of different kinds of
content. They concern with information on musical sources, newspaper musical
articles in a well defined period, or notational images of a particular musical age,
only to quote a few. Thus far, we have dealt with textual information. Anyway,
musical databases can have the musical texts as main part of their content and
not just the incipit as we have seen in TML.

Normally, these databases are analytically oriented, the musical text is
stored with the purpose of performing some types of analytical searches on it.
Therefore, the border between analytical programs based on comparative and
quantitative techniques and the one based on databases is very fuzzy. Two very
important researches of this kind, based on very different repertoires, are related
to the systems Scribe and Esac/Mappet.

Scribe is a database of fourteenth century music developed and maintained
at La Trobe University, Australia, realized by John Stinson (1992). Its content is
formed by 4,408 fully encoded works. Scribe allows to enter, using an alphanumeric code, the chant melodies and displays them in mensural and staff notation.
The database allows to execute search and operations with different criteria
and display the result in two forms: (1) files which can be re-read with some commercial database program, (2) printout which are realized through a plotter and realized in neumatic notation. The comparison of a corpus of Dominican chant with 105 Cypriot chants by means of Scribe facilities has yielded some hypotheses about the composition of late medieval chant (Stinson: 1992).

The work carried out at Essen University by Helmut Schaffrat and his associates produced a software package for the encoding, analysis, retrieval and comparison of melodic repertoire of any kind. It also comprehends a useful program, Estaff, which allows further analytical operations and the display of melodies in staff notation.

The first point to stress in respect to the software of the Essen group is that it is easy-to-use and truly operational. The problem many software have is that they are operational only for the research group who conceive them, and thus their use is limited. On the contrary, this software package is used, in addition to the Essen group, by other scholars for different purposes.

The Essen software has been primary conceived for German folksongs and Chinese melodies but it could be used to process any kind of melodic repertoires. Essen database contains more than 10,000 melodies. In this brief description I would like to bring out some features of this software. The melody is represented in Esac notation, an alphanumeric code which uses numbers to represent scale degree and lines to represent duration (each line added to a number indicates the multiplication of the basic duration unit which is specified together with the tonic in the KEY field). In Figure 1, a melody (Wanderers Nachtlied by Karl Collan) is displayed both in staff notation and in the analytical output realized by the program. The analytical output contains the whole melody, in the field MEL, together with other analytical information. As we can see, each analytical result and the melody itself are placed within square brackets and specified by a three letter field. For instance, the field FOP (form of pitch) indicates the interval sequence in each phrase labelling them with a letter. A sequence denoted with 'av' indicates the first phrase labelled 'a' with a variation. It is the same for the field FOR (Form Of Rhythm).

Another relevant field is the one labelled FOC (Form Of Contour) in which the contour of each phrase is represented. Alphanumeric code is used to indicate the different kinds of contour and the comprehension and comparison of these results is facilitated by another program which allows their graphic display. In the staff notation example, realized by this program (Estaff), the content of the fields FOP, FOR and FOC are displayed on the right side. FOC field content is also displayed in graphic notation.
Another important feature of the Essen software is that all the results are stored, as we have seen, in a database format and more precisely in the ASKSAM
one. Therefore, subsequent searches can be performed and results from different repertoires can be merged and compared.

In addition of these facilities, one of the programs of the package allows the display of some analytical results and of the melodies in staff notation; but it also serves as an analytical notepad where the analyst can single out interesting fragments, store them, retrieve and compare.

3. Analytical studies

In the last two examples, and especially in the last one, we have seen as the database application whose content is made up of musical texts are, de facto, analytically oriented. In fact, we can see the Essen group software useful for diachronic comparison and for incipit storing also, but its utilization is mainly analytical.

The use of computational methodologies to build up systems to analyze music represents an important contribution for the music theory studies. This kind of application has twofold implications that, in certain cases, are both present in the system: (1) creating systems to assist the musicologist in carrying out the analytical task, (2) studying the theory and its analytical system by its implementation in a computer program.

As far as the first case is concerned, we can think of a particular kind of theory, set-theory for example (Forte: 1973), whose implementation makes its use easier for the analyst (Castine: 1992) because of the series of operations whose manual execution is slow and can produce mistakes. Another example of such a kind is the harmonic analysis program realized by Ferkova (1992). It labels chords, individuates keys and regions and their relationships by means of a functional theory of harmony implemented in the program.

The case in which the realization of a computational analytical system has as a purpose the investigation of a theory also, can be well represented by some works using Artificial Intelligence techniques. I present some examples of this case later, but before I would like to describe two operational methodologies which play a different role in designing a computational system for musical analytical tasks. Figure 2 displays the two types of methodology.

In the right diagram, an homogeneous repertory is scrutinized and its observation yields a set of rules which represents the structural features and regularities of this corpus. The set of rules is then implemented in a computer program whose task is to generate some musics which presents the same stylistic
or structural features of the corpus under investigation. In the case of wrong results, \emph{i.e.} a music with some structural features not stylistically pertinent with the corpus, the corpus is re-observed to individuate the missing features, the set of rules is re-formulated and the computer program is updated. The path can be travelled over again several times in order to have the proper results. In this case, the results are the rules which describe the characteristics of the repertoires; the computer is used only as a tool to assist the theorist in his research work. The implementation of the rules in a computer program serves as a mean to test the hypotheses formulated (rules) due to the fact that the computer do not perform any interpretation on them: thus, wrong rules give wrong results and it allows the theorist to investigate the unexplained parts of his formulations. This approach is called generative due to the fact that the theory test process is realized by generating a piece of music.

In the other diagram, the left one, the content of the software is a theory with its analytical system but it serves to perform an analysis on a musical piece. Thus, the results are a series of analytical information on the piece, \emph{i.e.} the feature of its rhythmic structure, whose degree of pertinence demonstrates the value of the theory in describing a particular structural feature. In the case of non-pertinent results, the theory will be re-scrutinized and improved. Therefore, this kind of methodology allows the building of applicative systems, performing an analytical task, but has also the 'side effect' to corroborate or invalidate the theory which it is based upon.

An example of generative grammar based system is due by the work of Baroni and his associates (1984, 1992). The research work investigated melodic repertoires such as melodies of Bach chorales, French chansons of XVII century, and Legrenzi's Cantatas. In the last repertoire the relationships among harmony, melody and text is also taken into account (Baroni \emph{et al.}: 1992). The study of three different melodic repertoires has the purpose to bring out the relationships...
between the theory of melody general facets and repertoires peculiarities, and the comparison of micro-structure elements.

This approach has been also applied to other repertoires such as jazz improvisation (Giomi and Ligabue: 1991), and on the first phase of Kippen and Bel study (1991) of tabla improvisations. Another type of knowledge based musical system which could be placed halfway between the two kinds of methodology described above is represented by the work of Ebcioglu on the Bach's Chorales. It is based on a large body of rules formalized after the observation of a musical corpus. The system has the purpose to investigate and performs two tasks: (1) the harmonization in Bach's Chorale style of a given soprano voice, (2) the realization of the Schenkerian analysis graph in which the hierarchy among the melodic elements is represented.

Ebcioglu's Choral system (Ebcioglu: 1987, 1988) is also a good example in using expert systems for musicological applications and possesses several interesting features. The first aspect is given by the application of multiple viewpoint strategy. It consists in viewing, and thus harmonizing and analyzing the chorale by means of different approaches. Each viewpoint has its own production rules, heuristics, and constraints. The five viewpoint are the chord-skeleton, fill-in, time-slice, melodic string, and Schenkerian analysis view. The last part is the analysis part of the system and its main interesting feature lies in the integration of assumptions from Schenkerian, Lerdahl and Jackendoff, and Ebcioglu own theories on the analysis of voice leading and prolongation. Incidentally, Ebcioglu's work with the adoption of multiple viewpoint (which underlies different methodological approaches) is a very promising experience on the possibility to integrate distinct theories strategies. The parallel he made between heuristic and the personal unconscious musical knowledge, is a point to deepen as to enlighten some interesting facets on the high-level musical knowledge.

This system, beyond its interesting theoretical aspects has also an applicative aspect; Choral harmonizes a soprano voice of a chorale and produces also the relative Schenkerian analysis graph. In the following figure are shown four bars of a Chorale. One is harmonized by Ebcioglu's program and the other one by Bach. In addition, the Schenkerian graph with the hierarchical grouping of the soprano voice is displayed.

Another work based on integration of theories and expert systems is the one focused on musical grouping structure carried out by myself and my colleagues (Camilleri, Carreras, Duranti: 1990). In the study of musical segmentation, the integration of theories of partitioning (from micro level to macro level) can solve some crucial problem in this subject. We have endeavoured to relate the
rules extracted and reformulated from Lerdahl & Jackendoff’s theory (1983), the more exhaustive framework in this subject, to rules derived from psychological investigation, musical semiotic analysis (especially taxonomic one) and other.

This research work starts from the aforementioned considerations and pursues two purposes: (1) the creation of an analysis environment, to be improved and amplified as to allow other kinds of analysis (tonal harmonic analysis), (2) the testing and improvement of the content of the theory already developed, and the verification of the possibility of an integration of different theoretical assertions.

As I already mentioned, from a general theoretical point of view, concerning musical segmentation, a rule system has been formulated starting from Lerdahl and Jackendoff’s theory (for the metric and rhythmic aspects), and integrating it with other assertions belonging to different approaches. This perspective is, on our view, very important both for the modelisation and implementation of musical knowledge. If we think of music analysis not only as the labelling and classification of musical entities but as a process of reasoning about music (thus placed at a higher cognitive level) we should take into account the way a piece can be scrutinized by means of several analytical concepts integrated into a general framework. In addition several disciplines developed in the latest twenty years, for instance semiotic of music, music perception and cognition studies, new music theories share more fundamental notions than is normally assumed, such as one of symbol.

The rule system formulates a measurable definition of group boundaries by weighting the role of several musical parameters (interval, metrical position, dynamics, and so on). This metric should represent the perceptual space in which the parameters are mapped out. Studies on perception of the grouping structure were employed in order to include facets determining group boundaries like
pivot-note, melody direction, and others. Musical semiotics hypothesis on “iconic similarities” and recognition of basic musical units were used to enhance the notion of parallelism in the attempt of taking into account the indeterminateness of segment likeness. Furthermore, the notion of parallelism, completely undefined in Lerdahl & Jackendoff’s theory, is formulated by classifying through rules some similarities related to musical parameters (interval contour, rhythmic figure, and so on). Within these categories, the system decides whether two musical segments include some mutual relationships and, thus, belong to a group of higher level or a segment is a transformed repetition of the other.

From the analytical point of view, the program output presents the hierarchical structure of the group subdivision into different levels together with the elements (sequences of notes and sequences of groups) contained in each one of them.

Figure 4 shows an example of a grouping structure of Schubert’s Lied Das Wandern as detected by the system. If we carefully examine the segmentation at certain points we can discover some useful indications on the behaviour of the rule system. The point marked with A shows that the system infers that the interval leap represent a group boundary between two groups at lower hierarchical level. Point B and C represent the decision of the system due to the evident parallelism of the two musical segment at a higher level. At last, point D shows an activation of the rule which takes into account a change of dynamics as a relevant sign of a group boundary.

The tool selected for the implementation of the expert system was the shell ESE of IBM. The shell accepts production rules of the type IF/THEN, and the forward and backward chaining inference strategies; these two strategies are dynamically activated during the processing of the knowledge base by recalling special control statements. Various types of control statements are available and provide the means for accessing external data, for communicating with the user through an interface that may use graphics, for directing and conditioning the execution process.

An extension of this work is the realization of an expert system prototype for the harmonic analysis using another part of the Lerdahl & Jackendoff theory, the time-span reduction (Camilleri, Carreras and Giomi: 1992).
An analytical work based on an ethnic repertoire, tabla improvisation, presenting interesting features is carried out by Kippen and Bel (1989). The ground facet, due to the peculiarity of the repertoire, is the attention in avoiding the inclusion of the personal bias of the analyst, from his western based perspective, to the assertions of the native informants. For this reason the system is supplied by music examples of improvisations performed by the informants and from these it abstracts the regular repertoire features by means of an inference engine. The testing phase is realized through improvisations realized by means of the rules abstracted by the system from the examples.

4. Further perspectives and conclusions

In this brief survey, we have seen the various applications of computer to musicology and described their methodological implications, mainly in respect to analytical studies. In this last field the applications of the latest computational paradigm, i.e. neural network or connectionist systems, can provide a relevant tool to by-pass a crucial problem: the representation of the musical score in symbolic format. In fact, the musical text supplied to a large number of analytical programs is not the real representation of what is heard by the analyst but it is the codification of its sign in the score. In this case, the sounding dimension, and all its relationships with the musical structural features, is lost. System based on connectionist architecture can provide a useful framework to 'interface' sounding properties with high level ones, i.e. harmony. A very promising research on this subject is carried out by Leman (1992) who tries to discover harmonic features of a piece of music starting from its sounding content. The input of the system is taken from CD and the data are sent to an 'ear model' which computes the relevant information subsequently sent to a system which related them to the harmonic structure. By this way it is possible to study the relevance of the relationships between psychoacoustical properties and their implications in the harmonic structure of a piece.

In the other field of computational musicology, an important step to improve the data acquisition is given by the realization of system for the Optical Character Recognition of music. Several research works have been developed on this subject but none of them has reached the level of applicative use (Hewlett and Selfridge-Field forthcoming presents an exhaustive survey on OCR for music). Another aspect of this problem is the code with which the scanned music will be stored.
To solve this and other problems of utilization of music corpora in machine readable form the creation of transcoding program is desirable: it could allow the researcher to easily access the corpora written in the major encoding language.

We have also seen as the musicological work, in all its aspects, can be carried out by using computers. Musical databases can help musicologists either to make cross references to a corpus of documents and to scrutinized similar features on different musical corpora. Moreover, music printing programs allow musicologist to execute all the editing task by themselves and thus make the realization of critical edition easier.

In the field of analytical studies, besides its applicative use, the computer application can bring about an investigation of the theory used. Therefore, in this subject the computer is not only a tool but a methodological instrument whose use yields effects on the improvement and re-definition of the theoretical formulations. Computational musicology is actually a field in continuous development whose effects, in terms of easy-access to musical corpora, analytical tools, database realization and other, will represent an important contribution to the musical studies for the years to come.

Bibliography


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