Music analysis is very often practiced and taught without any reference to, or reflection on, the premises of the methods employed. This is especially true for the area of computer-assisted music analysis, which emerged almost 50 years ago.

Computer-assisted music analysis provides analytical tools that help solve problems, some of which may be unsolvable without the assistance of the computer, as, for instance, creating comprehensive, statistically verifiable, characterizations of style, or as verifying the probability of authorship by matching a statistical profile of a specific composition with statistical profiles of composers' styles. Music analysis, carried out with the assistance of the computer, can also help to develop systematic approaches in music theory. In addition, computer-assisted music analysis plays various roles in research related to composition, acoustics and performance, including research on cognitive and formal aspects of music.

Unfortunately, most research in the area of computer-assisted music analysis during the last 50 years has been carried out, again and again, without any explicit review of preceding attempts and accomplishments. Even the most recent research bears traces of two fundamental flaws that have plagued most research carried out to date: there is no classification of methods placed in a comprehensive historical framework, nor is there any critical evaluation of those methods.

This paper fills the largest of the gaps. Based on detailed historical studies (Schüler, 2000b)—of which the source materials consist of about 1,700 published and unpublished writings, including dissertations and internal research papers from many countries—a general system of classification for computer-assisted music analysis has been developed and will be presented. This system of classification gives specific characteristics of each method in general, showing trends as well as the components and strategies of the methods.
application of the specific methodology. (For a detailed historical account see Schuler, 2000b) Evaluative comments will be given for each category.

**Approaches Drawing on Statistics and Information Theory**

Statistical and information-theoretical approaches are historically the first methods applied to computer-assisted music analysis. Even though statistical methods and information-theoretical methods are distinct from each other, in computer-assisted music analysis they are usually applied together. Statistical and information-theoretical approaches comprise frequency, mean (average), variance, standard deviation, correlation, regression, the chi square test, entropy, Markov chains, probability, redundancy, and other measurements.

An example of applying statistical methods to music analysis is the attempt to construct a statistical model of the frequency structure, especially of the relations between size and number of melodic or rhythmic units and the size of the music piece and between the length of melodic units and the length of its neighboring units. M. G. Boroda and others tried to define basic units of musical language, which allowed them to derive an algorithmically defined segmentation of compositions on their melodic level. This, in turn, made it possible to study the organization of repetition in music. The validity of such statistical relationships between melodic units within a composition was tested in a study by M. G. Boroda and P. Zörning (1990), which showed that the parameters in the specific statistical procedures applied are positively correlated with each other, and that the results are statistically significant.

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**Analyses Drawing on Set Theory**

For the analysis of atonal music, a number of computer programs draw on Allen Forte's set theory and on further developments of Forte's theory. Most of these programs comprise such standard procedures as calculating prime forms (most often using Forte names), interval vectors, number of occurrences, as well as similarity and set complex relations.

First analytical programs drawing on set theory were developed by in the early 1980s by J. Timothy Kolosick, David L. Jackson, Mary Hope Simoni, Charles H. Ruggiero and James P. Colman, and Larry Solomon. Further attempts were characterized by extending the capabilities of calculating further similarity relations. Peter Castine's Macintosh adaptation of Craig R. Harris' and Alexander R. Brinkman's "Contemporary Music Analysis Package", for instance, includes additional functions, like David Lewin's interval function and Richard Chrisman's adjacent interval vector. (See Castine 1994.)

Within the limits of set theory, specifically within the limits of each function of similarity or set relation, computer-assisted music analysis drawing on set theory is doubtless a useful tool, because it is based on the same mathematical procedures, which 'traditional' set theoretical analyses are based on. Computers help reducing the time needed for calculation, thus providing more time for the more important part of the analysis: the interpretation of set theoretical analyses.

**Other Mathematical Approaches**

In some approaches, mathematical procedures, other than those of statistical, information-theoretical and set theoretical nature, were applied to music analysis. Structural relationships can be explicated in many mathematical ways, some of which are fractal-like descriptions, formulas for symmetrical structures or for the relationships between groups of motives (describing their characteristics) as well as formulas for calculating the inner tempo of a composition, depending on meter, metrical relationships and rhythmic structures, etc.

The Swiss mathematician Guerino Mazzola (1985, 1990), for instance, is an advocate of a mathematical music theory. His main distinctions are mathematical descriptions of local musical structures and mathematical descriptions of global structures in music. He developed a theory of musical modules, which are in specific mathematical relationships with each other. While Mazzola used mathematical formulas for detailed descriptions of the manifold modular relationships, his computer system
RUBATO is able to manipulate single musical components within each complex structure of music. He, thus, has access to audible results of slight mathematical changes in his analytical descriptions of music.

Applying mathematical procedures to the analysis of music bears the danger of limiting the methodological approach to specific styles or specific cultural aspects of music etc. Mazzola's approach, for instance, can hardly be applied to non-Western, non-art music, because his mathematical relationships relate to Western art music per definition.

Hierarchical Approaches
Hierarchical approaches to music analysis try to apply reduction procedures to music in a sense that different hierarchies of musical structures show certain dependencies as well as, on a high abstraction level, large-scale relationships (especially melodic and harmonic relationships). The basis for hierarchical approaches to music analysis is twofold: linguistic methods, especially those from the structuralistic grammar developed by Noam Chomsky, and Heinrich Schenker's concept of musical grammar. Regarding to those two main approaches, "hierarchical approaches" can be divided into "transformational analyses" and "Schenkerian analyses". Both methodological approaches comprise different abstraction levels, which can be obtained by applying certain abstraction rules.

Michael Kassler's research during summer 1964 (Kassler 1964) was the first approach to computer-assisted Schenkerian analysis. It was preceded by further attempts by Kassler as well as those by Stephen W. Smoliar and others. All these approaches have in common the explication of Schenker's reduction rules as logical algorithms.

But while most Schenkerian and Transformational (computer-assisted) analyses are directed at the analysis of melodic organization, only a few aim at the rhythmic organization of music. Andranick S. Tanguiane (1992) proposed a transformational approach to rhythm analysis with the goal of developing an efficient technique for finding and classifying rhythmic patterns. Tanguiane formulated rules of "timing accentuation"; the accentuated events calculated were then used to segment a series of time events into so-called "rhythmic syllables", which were, in turn, basis for a generative grammar of rhythmic syllables. The author finally suggested a definition of time as a "characteristic of the generative rhythmic phrase which generates the given sequence of time events" (ibid., 85).

Spectral Analysis
In some cases of performance-based music analysis, spectral analysis is involved. Usually in those approaches, the sound spectrum is broken up to identify, for instance, the chord structure. While spectral analysis has been used in pure sound analysis for several decades, it became part of structural analysis of music not before the late 1980s and early 1990s.

As Mark Leman, Dirk Moelants has been using, for much of his research, spectral analysis of performed music for basic tasks of his structurally oriented, analytical research. In a most recent article (Moelants 2000), for instance, he used an onset detector to extract tone or chord onsets that are perceptually relevant, before he analyzed timing in contemporary music performance. This approach made it possible not only to show how problematic the rhythmic performance of total serial music is, but also how the performance of rhythmically complex music can be an object of the analysis of rhythm perception in general.

Cognitive and Artificial Intelligence Approaches
Computer-assisted approaches of music analysis that draw on cognitive research and artificial intelligence use computer systems to simulate functions that are usually associated with human intelligence. Those functions include reasoning, learning, and self-organization (or self-improvement). Artificial intelligence approaches can exist in forms of neural network systems or expert systems. With neural networks (net-like connections of units [neurons]) as a class of dynamic systems, music theorists are trying to simulate the architecture of the human brain. Activities in single units of this network entail changes in the whole system. On the contrary, the goal of expert systems is to solve problems by drawing inferences from a knowledge base acquired by expertise; expert systems process information pertaining to a particular application and perform functions in a manner similar to that of a human who is an expert in that field.

Approaches drawing on artificial intelligence and cognitive research are, towards the end of the 20th century, more and more part of interactive music systems that combine both, analysis and composition. Robert Rowe (1996), for instance, described an approach to transfer the human concepts of underlying musicianship to computer programs, so that interactive music systems become more 'musically'. Real-time pattern matching, as Rowe's dynamic programming algorithms include, identifies salient patterns from a music stream—here: a MIDI stream—and to flag subsequent occurrences of the same sequences (ibid., 57),
which, in turn, can contribute to further analyses or even produce a musical response as part of a real-time performance. The inherent 'intelligence' of the system lies in the procedures derived from music perception, as a ratio scale, for instance, captures aspects of rhythm perception. With regards to melody, certain intervallic relationships allow the system, within certain limits, to recognize certain patterns as 'perceptually' the same (see ibid.).

Combined Methods

In some applications of computer-assisted music analysis, several methodological approaches are combined in one computer system. Those systems are oriented towards interactivity, so that the user can choose which methods of music analysis to apply, depending on the goal of the specific research.

The largest project of computer-assisted music analysis with combined methods is Dorothy Susan Gross' "set of computer programs to aid in music analysis" (Gross 1975). This set of programs combines statistical analysis and set theoretical analysis; different analytical methods can be used separately via user-controlled switches.

Final Remarks

A general methodological classification of computer-assisted music analysis has been introduced here. However, in music analysis in general, the reflection on the methods used and the awareness of how they affect the outcome and the goal of the analysis is most important. Every method of music analysis has its advantages for certain goals of the analysis. But every analytical method has also its limits. It is most crucial to know both, as well as to know when to apply which method. For methods of computer-assisted music analysis, the integration of traditional and computer-aided methods seems to be most crucial.

References


