Visualization of musical structure with maps

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Background in musicology. The internal structure of musical works and relations to its context belong to the major subjects of musicological efforts, be they paper based or computer aided. Currently, musical structures are described by musicologists mostly in an ad hoc manner, either textually or by tree diagrams, while existing music visualizations by software are either quite simple or very specific. Musical information is often of complex structure and could be handled better by adequate software tools.

Background in cognitive science. Knowledge maps or concept maps are tools to support cognitive representation of complex domain knowledge. They visualise domains as graphs with nodes representing concepts or objects and edges representing relations or actions. Studies have shown that concept and knowledge maps support learning better than text, and musical information has a very rich multi-dimensional structure, for which such mapping techniques are well suited. Mapping techniques, especially mind maps, are popular as software tools, but they have hardly been applied to music.

Main Contribution. The application of knowledge maps to music shows, that graph visualizations of musical structures and relations are appropriate means of creating and using musical knowledge. The relations of music within itself and to its context can be represented naturally as nodes and edges in graphs, representing musical objects or general items of information and their relations, which can be of various types. Mapping software is especially useful for non-hierarchical information, e.g. analytical relations of musical parts, and presents them in an extensible and easily accessible way. A prototype software module for musical mapping has been developed in the MUSITECH project at the University of Osnabrück.

Implications. Networked graph visualizations are appropriate tools for the creation, navigation and editing of musical information. Areas of further development include a more elaborated layout, display and navigation techniques that are adapted to the special temporal and hierarchical aspects of music.

Music is generally viewed as having a rich internal structure and a large part of musicologists' activities is directed towards finding, describing, and analysing the structure of music. Music has not only one but multiple kinds of structures in respect to rhythm, meter, melody, harmony, texture, and form, with these categories being related and each containing complex structures in itself. Knowledge from music theory, as the discipline dealing with musical structure, is often considered as very complex and abstract.

Mapping techniques are graphical methods for cognitive support using a very general approach to display and interact with complex structured knowledge. Mapping techniques have become popular in the form of software tools, because they are cognitively adequate and have been proven to support users often more effectively than text. The idea of this work is, to explore mapping as a tool for musical information, especially musical structure.

Background in musicology

The internal structure and contextual relations of musical works are central to traditional and computer aided musicological work. Currently they are either described textually or by diagrams that are mostly designed ad hoc and individually by musicologists. Existing music visualizations by software are either quite simple, e.g. a part-track raster in sequencer software, or very specific, e.g. similarity matrices (Foote and Cooper 2001).

Types of musical structures

Structural musical information can be divided into three main types, according to their primary representations.

Vector spaces are used often for musical elements. A note's duration, loudness, and pitch or the spectrum of a sound can be represented as points in a, possibly high-dimensional, space. Western music notation organises music in a two-dimensional space of time and pitch with additional information added by graphical symbols. Vector spaces generally have natural visualization for up to three dimensions. These visualizations are good for showing the properties of musical objects but showing their relations is difficult.

The second type comprises hierarchical structures. Musical form is a prominent example, as it divides works into movements, movements into sections, sections into subsections, etc. Similarly, harmonic analysis divides a piece into sections of one key, those are divided into cadences, and those into harmonic functions. Schenkerian analysis is another classic example of hierarchical structure. Hierarchical structures can be represented and visualised well in tree graphs.

The third type are non-hierarchical structures. Many musical structures do not fit well into hierarchical representation, e.g. the similarity of melodic or rhythmic motifs in paradigmatic analysis, harmonic ambiguities, or the special role of motifs in the Leitmotif technique. Even Lerdahl and Jackendoff (1984) acknowledge in their *Generative Theory of Tonal Music*, the probably most influential music theory promoting hierarchical structures, that non-hierarchical structures are important and enrich the understanding of music.

Music has also many external relations, e.g. information on the composer or analytical texts, which should be integrated into representations and tools. These are generally represented as metadata and are most often attached to complete pieces of music, but can also be used for other musical units.

Visualization of musical information

The interesting areas for visualizations are the non-hierarchical structures and the metadata. Both of can of course be combined with existing visualizations of scores and trees. The main problem is, that there is a large variety of structural models in use, which are subject to changes and extensions. Therefore a very general approach is needed, which can be adapted for particular applications.

Background in cognitive science

Concepts maps or knowledge maps are tools for supporting cognitive representation of complex domain knowledge. Mapping techniques use spatial, network-like visualisations for knowledge construction, organisation and presentation. There are a number of different variants in use, like knowledge maps, concept maps, and mind maps, which in general will be referred to as maps here. They visualise domains as graphs with nodes, representing concepts or objects, and edges, representing relations or actions.

Human memory can be understood as a network of propositions and cognitive structures and can therefore be described in terms of elements or nodes and connecting relations (Mandl and Fischer, 2000, Bernd et al., 2000). Other evidence for the usefulness of mapping for learning and recalling knowledge comes from the research area of Cognitive Maps initiated by Tolman (1948). Mandl and McAleese (1998) argue that as short-term memory is limited, off-loading has to take place when we want to work on complex tasks. They see mapping techniques as a performance aid, serving as an external memory extension and as such realizing off-loading.

The ability to orient in a physical space (spatial thinking) can help to orient in a knowledge space if they contain similar criteria, like constant local relations between objects. Using this similarity, new resources can more easily be integrated and memorised (O'Reilly and Rudy, 2001).

Scientific results on classical mapping

The advantages of mapping compared to presentation and elaboration of texts and especially on summaries are frequently emphasised. Concept and knowledge maps have been shown to improve learning compared to using text (Jonassen 1992, O'Donnell et al. 2002). Schnotz (2002) pointed out that pictorial information can more easily be transformed to mental models, i.e. it is cognitively more adequate. Pictorial representations are more economic because concepts have to be introduced only once. Bernd et al. (2000) and

O'Donnell et al. (2002) emphasise that the memorization of central concepts is supported (especially if a learner has little previous knowledge or learning deficits) and motivation is raised. In the case of learning detailed knowledge, text and mapping are equally suitable. Bernd et al. (2000) found that motivation and memorization increase even more if the learner constructs the map himself rather than just reading a presented map. Further positive effects occur if start and goal nodes of an exploration-path in an expert-map are given. This can be used to increase effectiveness and efficiency of learning. Fischer and Mandl (2000) pointed out that it is in general useful to enhance expert-maps with instructions. Thereby the learners assumptions are lead into a direction where it is less probable that important aspects are overlooked.

Sturm and Rankin-Erickson (2002) found out that mapping also helped in text-production if it was used to collect and structure central thoughts. A study of Grillenberger and Niegemann (2000) showed that the efficiency and acceptance of mapping was directly correlated with how good the technique is mastered. Thus it is necessary to introduce a learner to the technique to reach good results. A multitude of empirical facts encourage the use of mapping-techniques. Most of these results can be applied to mapping-software as well as the traditional *paper-and-pencil* method.

Mapping software

Realising maps by software leads to several additional new possibilities. One aspect of computational mapping is its higher flexibility (Mandl and Fischer, 2000), e.g. the possibility to get an overview by just showing selected subsets of the map. By this means, complexity is reduced and thus memory relieved (Bernd et al., 2000). The general ability to divide between data and visualisation leads to higher flexibility of the application. Another advantage is that mapping-software can modify maps easily (Mandl and Fischer, 2000). Software enables archiving, propagation and duplication of knowledge maps and also contributes to their reuse (Mandl and Fischer 2000, Gaßner and Hoppe 2000). Software can support interactive generation and modification of the visualization and the underlying data, and computer networks open up the possibility of truly collaborative and synchronous work in distant locations. Finally there is a plenitude of applications like automatic modelling, diagnosis, analysis and retrieval of knowledge (Gaßner and Hoppe 2000, Janetzko and Strube 2000).

Musical maps

Given the rich structures of music and the results on mapping tools, it seems desirable to utilise the potential of mapping for musical structures. This entails two questions: which structures should be visualised and how. Basically, as pointed out earlier, mapping is beneficial for complex non-hierarchical information, but generally any musical information is well suited for mapping that can be expressed in terms of objects (e.g. notes, chords, motifs, sections) and their relations (e.g. similarity, succession, contrast, harmonic function). Primarily numerical properties are less appropriate, as they are usually designed to abstract from structures, e.g. spectral centroid of sound or the average number of notes per bar.

Mapping musical information

Maps have several parameters that can be used to visualise information. The first general decision is what are the objects to be represented by nodes and what are the relations represented by edges. Musical objects can be musical units of varying size from a note to a composer's collected works, more abstract concepts like harmonic function, or parts of musical pieces like a motif, a chord, a theme, a section, or a voice. Relations of musical objects can be even more diverse. From containment and succession, over similarity, rhythmic and harmonic relations, to attached metadata there is a wide range of interesting relations.

Graphical node displays can vary in size, colour, and textual description, edge displays can have different lengths and graphical forms, which may represent different parameters of the objects. A particularly interesting way of using map visualizations is the combination of different musical parameters, e.g. form and harmony, in one e.g. form and harmony, in one map to show their relations.

The display of high-dimensional data as musical structures on a screen or on paper involves dimension reduction. This usually means that not all constraints concerning the length of the edges can normally be satisfied. To find an approximate solution, physical force models are used, like springs or rubber bands. For the results, it is obviously important, how parameters are mapped to edge length. An alternative approach are Kohonen networks, which have been used for browsing music archives (see Pampalk et al., 2003), but they are not as flexible for user interaction.

Musical mapping software

A prerequisite for visualization of musical structure by software is the representation of musical structures as data. The object oriented modelling of musical structure is a central issue in the MUSITECH project (Gieseking and Weyde, 2002). The object model allows to represent musical structure in a very flexible manner. The basic building blocks are predefined classes for elementary objects like notes, container objects for structural units, and metadata objects that can be attached to containers.

Map visualisations can help to utilise and enhance the object model and thus a prototype has been developed in MUSITECH to explore the potential of mapping software for musical structures.

Examples

Some examples shall illustrate how the implemented mapping tool supports visualisation of musical structure. A first example is the display of a form scheme, with the relations of temporal succession and containment as shown in figure 1 for a sonata form. It shows the succession of the motifs in the themes, the themes in the sections and the sections in a movement with succession relations in red and containment in blue. The length of the succession edges corresponds to the time between the connected objects. Graphs of this type can be used to study the relations between motifs themes and sections.

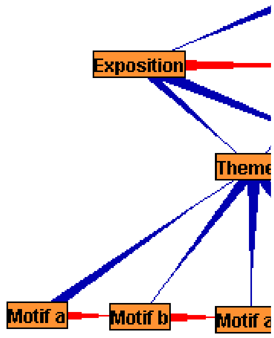

Figure 1: A sonata form as a networked map.

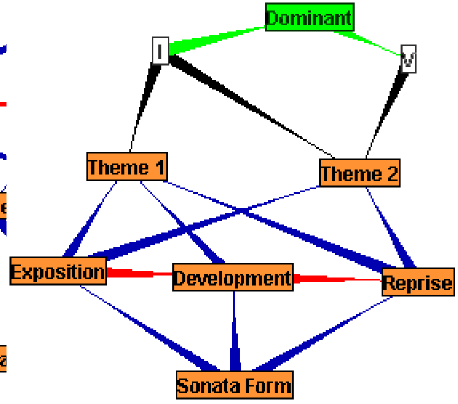

Figure 2: Sonata form and harmonic structure.

This map can be enhanced by introducing harmony. Here the degrees I and V are relevant, and they have the special relation of V being the dominant to I. This can be introduced by adding further nodes and edges as shown in figure 2. The new types of objects and edges used for harmony are marked by different colours.

Map visualisations offer the opportunity to use different forms of visual information display (e.g. scores, images, sound) and the connection to editing modules. An example can be seen in figure 3, using the score and image components of the MUSITECH framework.

Interaction and navigation

Mapping software should realise the above mentioned advantages of dynamics and interactivity. Maps are generated automatically from existing data, and can adapt to changing data. They support interactive exploration by showing and hiding nodes and edges automatically or controlled by the user and adjusting the position of nodes during and after user interaction. A relaxation algorithm based on that of the Touchgraph project (www.touch graph.com) is used to generate the layout automatically. The user can move and zoom the complete map or drag the individual nodes to change their position.

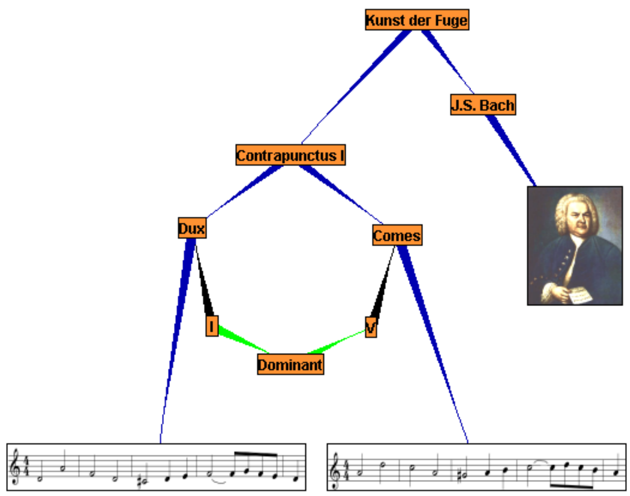

Figure 3: Visual displays and metadata.

A map can contain interactive content. The simplest is to display additional information in tool-tips or playback the musical content of nodes on mouse-click. Depending on the application, a map can give access to the complete playback and editing modules of the MUSITECH infrastructure.

The navigation of knowledge maps in software makes the mapping of musical structure particularly useful. By showing and hiding parts of the map, based on type or proximity, different views on musical structures can easily be obtained for highlighting different aspects. Tests with the prototype showed, that specifically for music it would be useful, if the map could be integrated with objects marked up in a score, piano-roll, spectrogram or waveform display. It would also increase usability if the map could be laid out in a standard tree or time-line format where applicable. For educational applications predefined paths for traversing the map would be of interest.

Conclusions

Mapping can be a cognitively adequate tool for handling information on musical structures. Like with other abstract matters, the visualization and the interaction help users to create and use internal cognitive representations. In music there is a particular need for this, because it contains complex non-hierarchical structures.

The prototype software for mapping musical structure shows, that it is an appropriate means of creating and using musical knowledge. The relation of music within itself and to its context can be represented naturally as nodes and edges in graphs, representing musical objects or general items of information and their relations, which can be of various types with various attributes.

Musical mapping software can utilise and extend mapping techniques. It is useful for displaying and manipulating network-structured information, e.g. analytical relations of musical parts. This first exploratory work on musical mapping software showed that some extensions of existing mapping methods are desirable for music.

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