the specific gestures represented in terms of event generators. These generators were edited using graphical notation tools. The Petri net subsystem was used for the mapping of the actual performance rules that governed the system's "interpretation" of the raw musical data. The final production was described using several Smalltalk- and C-based tools that generated and edited mixing scripts for a real-time digital signal processors at EMS.

Conclusions

My current development effort is aimed at extending the MODE to include still more tool paradigms for new notations, and alternate procedural, stochastic, and knowledge-based algorithmic composition abstractions. My works-in-progress (of which there are several) involve new tools based on context-free generative grammars, other kinds of rule bases, and performance mapping using fuzzy logic.

I strongly believe that, in the future, broad multi-paradigm composition environments will replace the current crop of single-purpose, single-representation tools, and will provide musicians with ever more flexible, scalable, and multi-level facilities for music composition, realization, performance, and production.

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Cognitive Modelling in Ethnomusicology: Challenges, Caveats and its Relevance for Computer Music

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Abstract

A distinction is made between cognitivism and materialism, and between constructivism and ecologism and it is argued that a materialistic and ecological approach may provide an original step towards a characterization of the cultural environment in which music is embedded. The argumentation is based on the notions of causative model and auditory images. The conclusion is that a profound immersion in a culture may allow one to map out the conceptualizations of music at a semantic level, while the modelling approach may allow one to map out the mental representations and cognitive dynamics at the level of auditory images.

1 Introduction

Does computational modelling of music cognition contribute to the study of music as a cultural system? According to the Finish ethnomusicologist P. Moisala, cognitive modelling appears to be in contradiction with the ethnomusicological approach because of its adherence to materialistic epistemology. In reaction to [10] she says [19, p. 9]: "According to materialistic epistemology, it is possible to believe that physiological musical material digitally transmitted into an expert system includes all the information involved in human musical processes. On the other hand, the elimination of cultural and situational contextual factors from the computational modelling is also a natural result of the limitations of such a study method." Accordingly, the relationship between music and culture is problematized in ethnomusicology, and "computer simulations do not fit into the field of "cognitive ethnomusicology" because they either eliminate cultural and contextual influences (symbolism) or do not problematize the interaction between culture and music (subsymbolism)" [19, p. 17].

The claim that cognitive modelling does not fit in ethnomusicology, because it fails to integrate cultural aspects, is unjustified. In this paper we show that cognitive modelling may indeed contribute much to the study of music as a cultural phenomenon. More specifically, we

argue that (i) the materialistic epistemology associated with so-called subsymbolic modelling paradigm may provide a step towards a better definition of the cultural environment in which music is embedded and (ii) that such an enterprise may cope well with some old and recent tendencies in ethnomusicological research. The general tenet of this paper is that cognitive modelling provides a challenge to ethnomusicology, which should be understood within the well-defined caveats of an ecolo-cognitive theory of music.

2 Cognitive Issues in Ethnomusicology

To start with, it is useful to make a distinction between the interest in cognition on the one hand, and cognitive modelling on the other. The latter is indeed a rather recent phenomenon associated with the advent of the computer as a tool for simulation. Furthermore, the concept of cognition has different interpretations in ethnomusicology. In general terms, it makes sense to distinguish between:

- cognition as process (related to perception and perceptual learning),
- cognition as conceptualization of world views (related to the musical reflections of myths, nature and society),
- cognition as instrument in observation (related to the emic-etic problem).

Cognition as process was one of the central issues of the early German *comparative musicology*, while both cognition as conceptualization of world views and cognition as instrument in observation was one of the concerns of the anthropological oriented American ethnomusicology.

3 The Use of Computers in Ethnomusicology

According to Nettl [20, p. 391], the effects of technology have been surprisingly small in ethnomusicology. The field is nevertheless growing and the availability of computer techniques for sound processing has been a source for new and interesting developments.

Although Lomax [14] used already computers for classification and statistical analysis, the interest of the ethnomusicological community in computers is more recent phenomenon. Its application, however, is manyfold. Computers have been used for archiving melodies [22], for sound recording and psychoacoustic analysis [15, 2, 3], and in rare cases also for cognitive modelling.

Some interesting attempts to use computer modelling by means of *interactive* field work have been undertaken by J. Kippen and B. Bel. [7] describes a expert system, known as the Bol Processor, that has been used to make a sort of linguistic analysis that is built up during interaction with Indian drum players. In later reports about this project, it was acknowledged that the use of interactive computer modelling is not that simple [8]. "... we succeeded in implanting our own preconceived ideas about musical structure which ultimately biased the analysis".

If cognitive research is indeed making sense in ethnomusicology, then an analysis of the basic assumptions with respect to the current state of the art in cognitive research and the possible role of cognitive modelling is at its place. Would cognitive modelling be of any help in the determination of the physiological-based or cultural-based status of "inherent patterns"? Can cognitive modelling be of any help in clarifying the distinction between musical (cultural determined schemata) and non-musical (purely physiological) perception? Would it be of help in clarifying the notion of schemata? What kind of modelling should be conceived of if one wants to avoid the pitfalls of preconceived ideas? All these questions should be answered with thorough consideration of past attempts and failures. In what follows, we give an analysis of the basic assumptions of cognitive modelling. Aspects such as representation, dynamics and relationship to the environment are central.

4 Modelling Music Cognition

The above survey shows that cognitive issues in ethnomusicology have been around since the very beginning of this discipline.

In the second half of the 1980ies a revival of the cognition-as-process paradigm can be noticed, based on a renewed psychoacoustical and Gestalt theoretical framework. This is an important development which is related to the availability of new methods (computer simulations) and a more detailed knowledge of the auditory system. Within this context, it makes sense to make a distinction between two developments in cognitive ethnomusicology. One approach is inspired by cognitive anthropology and the idea that a profound immersion in a culture may allow one to map out the conceptualizations of music at a semantic level. The other approach is inspired by cognitive science and the idea that psychological research, combined with cognitive modelling may allow one to map out aspects of the auditory imagery. Both approaches are not exclusive, but the analysis in this and the following sections will focus exclusively on the hard approach. The question is: how far does it go in modeling music cognition, and to what extend can it give an account of cultural influences on music?

Although we intend to explore the consequences of materialist modelling to ethnomusicology in the next sections of this paper, it is instructive to start with a short description of cognitivism—which is often associated with functionalism.

4.1 Cognitivism

Cognitivism has its roots in the philosophy of Descartes, Locke, Hume, and many other philosophers that deal with the human mind and related issues in epistemology. It is based on the idea that cognition has an autonomous status which is independent from the physical carrier (the human brain). Mental states are thereby considered to be *functionally* related to other mental states, irrespective of the actual physical carrier. Fodor [4] has much contributed to the modern version of this philosophical viewpoint. According to his *symbol-based* interpretation of functionalism, music cognition would have a formal nature in that processes, which we call cognitive, are operating on properties of the musical representation. The notion of *representation* is important to understand this position: a representation is something that stands for something else. Like notes in a score are representing the sounds of music, this theory assumes that the mental representation of music is pointing to features and properties of the outer world. Like notes in a score are symbolic entities, it is assumed that the entities of the mental representation are symbols. A typical characteristic of symbols is the separation between form and content: the referent of the symbol is its content, the actual appearance of the symbol is its form. Thus, according to cognitivism, cognitive processes operate on the formal properties of the representation, nl. the *symbols*. Hence the idea that human cognition is symbol-manipulation [21].

In addition to symbol-manipulation, the cognitivists assume an *interpreter* that is operating on the contents of the symbol and that is assigning *meaning* to the representation. The status of this interpreter has never been very clear but this notion is related to rather ill-defined concepts such as "self", "individual" and "intention". To summarize: the cognitivist theory of mind is very similar to an interpreted logical theory, where all inferences are based on formal properties of the representation, and where an interpretator is making a mapping to the outer world.

Much of the work which is done in the field of "Artificial Intelligence applied to Music" underscribes this approach. Music cognition has been modelled in terms of a rule-system that is operating on notes [13, 5, 6, 18, 16]. Other approaches, in which rule-based systems have been replaced by connectionist models, have often adopted a similar position with respect to representation in that the units of the model are assigned a meaning by the programmer of the connectionist model. In Bharucha's model of chord facilitation [1], a connectionist model is specified in which node-units stand for notes, chords and keys. The connections between the different node-units stand for constraints between different types of node-units. In this model the basic units have been "hand-made" in the sense that it was the programmer himself who first attributed meaning to the formal unit in the connectionist network. In a second stage, he assigned the constraints between the units in terms of connection efficacies.

The approach assumes the existence of small units (epistemological atoms) that form the basis for the description of the represented concepts. The method, called "methodological solipsism" [4] is characteristic for the cognitivist: the maker of the model assumes an interaction between the world and the musical mind, but he/she does not feel the need to model this interaction in the praxis of his/her cognitive research. He/she is not denying the existence of the outer world (and adopts realism), but he/she is in between the outer world (or musical environment) and the model. Cognition is believed to be autonomous: it can be modelled independently from the constraints of the environment in which it developed. For methodological reasons, he/she acts as a gateway between model and musical environment. Summarizing, the cognitivist approach has a high degree of freedom in modelling the cultural environment because the interpreter (programmer) acts both as a filter and interpreter: he/she selects the categories, and defines their relationships. The role of *interpreter* is therefore essential.

4.2 Materialism

The alternative position has less degrees of freedom but it allows an alternative account to representation and musical imagery in particular.

The materialist position holds that the autonomous status of cognition—associated with the notion of epistemic atoms and methodological solipsism—does not give a good picture of what cognition is about. It holds that cognition is *causally* related to the physical world by means of an auditory system whose representational states can be associated with the notion of auditory *images*. Rather than *pointing* to objects in the musical environment, images are *reflecting* properties of the physical signals. By *learning processes*, invariant information in the images are extracted and stored in more stable knowledge structures, which are called *schemata*. Auditory *grouping* at the peripheral level segregates the acoustical input into streams, leading to images of "sonorous objects". Concepts at higher levels are thus formed by self-organization and association. In this conception, the causal chain from environmental stimulus to auditory image is critical. Materialism assumes that these is no reason to assume that the images have a status which is different from physical systems. Even a schema is a mere response structure which is itself to be described as a physical system. In order to know the structure of the schema, one must test the responses of the organisms with signals of the environment. Such an organisms can be modelled provided that also the environment is modelled. As such, finding out the response structure of the model is similar to the way in which mental representations are recorded from humans. This is done by presenting signals and recording the responses. The responses are then analysed and particular structures can be inferred. The materialist position assumes that there is some sort of isomorphism between the schema-responses or responses of knowledge-structures to stimuli from the environment, and brain states. In the context of this paper, however, it is not necessary to go deeper into this discussion (See e.g. [23]).

5 Modelling in relation to the cultural environment

The difference is best understood by looking at how both approaches are dealing with the musical environment:

- In the *constructivist* approach, the environment is assumed to be independent from the model, and the connection with the environment is mediated through the programmer.
- In the *ecologist* approach, the environment is taken to be an integral part of the model.

5.1 Constructivist Modelling

In constructivist modelling, the environment is not necessarily restricted to a purely musical environment. As the programmer is mediating between the model and the environment, he/she is responsible for the categorical selection. To some extent this situation reflects the etic position in the context of antropological studies. Applied to modelling, however, the position becomes explicit in that a limited set of well-defined categories must be specified *a priori*. This attitude is similar to Lomax's coding technique. In Lomax's study [14], the listener has to rate some 37 parameters, among which the "overall rhythmic scheme (one-beat, simple meter, complex meter, irregular meter, free rhythm,...)". The listener has to choose a value for the parameter which is then translated into a number. Apart from the conceptualization of sound, cultural premises, including religious belief, conception of space and time, can be associated with particular units of a model, and it is furthermore possible to define correlations between these units and a representation of the musical environment (pitch-distribution in time, timbre, rhythm). The constructivist approach thus allows flexibility in modelling: nearly anything can be modelled provided that the appropriate categories are related to each other. It is up to the programmer to interpret the input as well as the output to the model.

5.2 Ecologist Modelling

Compared to constructivist modelling, the ecologist approach seems to be far more restricted in that the cognitive model depends on the representation of an environment. In modelling terms, this means that the computer environment needs to reflect the real environment as good as possible. The use of apriori categories and symbolic representation is thus not appropriate, categorical structures are developing by self-organization on the basis of exposure to the environment. In a former paper [9], we have related this viewpoint to a so-called *psychomorphological* approach of music cognition. It assumes that the cognitive processes are based on an adaptation of the brain structures to the environment both ontogenetically (neural architecture has been developed on an evolutionary basis) and philogenetically (fine-tuning of the neural architecture is achieved by exposure to the environment).

In what follows, we discuss a framework in which the materialistic and ecological viewpoint is related to the study of cultural aspects. What we want to exclude in modelling are:

- the use of *apriori* categories,
- the distinction between *form* and *content* of a representation,
- the *solipsist* attitude in modelling, ...

The approach is based on:

- causative models
- direct perception
- perceptual learning by self-organization

- context-dependent processing of information

In the absence of an overall multi-modal model of the human senses, this approach implies a number of limitations. The most severe limitation is that the current causative models are restricted to only one input-modality which is the auditory input modality.

6 A Framework for Modelling in Cognitive Ethnomusicology

Given the constraint of mono-modality, it is clear that any answer to the question whether computer modelling can say something about non-musical cultural influences (religion, world view, action patterns) will be indirect. It is then useful to decompose the modelling environment into the following levels:

- The Human Information Processing System. Similar to the laws of physics, we may assume that the causative input systems (auditory system, visual system, olfactive system) as well as the brain dynamics which carries the representation of the outer world at higher cognitive levels are universal and thus in principle the same for the members of different cultures. The following levels are then distinguished:
  - Sensory Information Processing: eyes, ears, and other sense organs are the same for the members of all cultures.
  - Perceptual Information Processing: the *dynamic principles* which underlay grouping and perceptual mapping are the same for the members for all cultures.
  - Cognitive Information Processing: the *dynamic principles* which underlay perceptual learning, categorization and association are the same for the members of all cultures.
- The Physical Environment. The nature of the acoustical environment can be described at the level of the waveforms. This is the same for all cultures. The properties of the waveform can be studied at a purely physical level, e.g. by making Fourier analysis or any kind of signal manipulation technique. The physical environment is also identical for all cultures over the world and the choice of representation can be related to universal human constraints. For example, a sampling rate of 44.1 kHz and 16 bit resolution is sufficient to capture all relevant signals of the musical domain within the computer environment.
- The Musical Environment. From the present mono-modal point of view, the musical environment is made of acoustical signals. The acoustical analysis of these signals may show differences between cultures. For example, in some cultures the musical environment is based on instruments with inharmonic overtones, while in other cultures, only harmonic instruments are used. Some cultures use polyphonic settings, while other cultures use monophonic settings, and so on... Obviously, these differences will be reflected at the level of the auditory images, and these images may ultimately lead to quite different categorical schemata.

  The question of what kind of musical environment should be included into the model varies from culture to culture and it will ultimately depend upon the choice made by the programmer. The obvious choice is to represent the musical environment as accurate as possible. The fact that tones, played in a particular succession, or at the same time, contribute to a context, may be an important factor. The perception of that context may be a central cue for meaning formation in a particular culture. Other applications may center on isolated aspects of the musical environment, such as tones [2].

In the ecological approach, the selection of the musical environment is an intricate question which should be considered with great care. But assume that a representative selection of music

can be made, how does the model relate to influences of the non-musical cultural environment? It is clear than an answer to this questions will be indirect: by showing which aspects are determined by auditory mechanisms it is possible to obtain information about aspects that are non-acoustical as well. For example, by means of learning models, one may show that perceptual categories are emerging from the acoustical environment and that they correspond with psychological categories (e.g. obtained by means of cognitive structuralist methods) [11]. By relying on principles of auditory grouping, one may show the emergence of musical objects at the level of auditory imagery [24]. Such categories can be called cultural (since they are determined by the musical environment) but they are inherently acoustical because they dependent on (a) acoustical properties and (b) properties of the auditory system. By showing that such a categorization process is possible at a purely auditory level, one obtains an indirect argument that certain characteristic properties are not non-musical–in other words: that they are constrained by the feedback of auditory principles. Typical examples are the use of scales and rhythm patterns: their properties are largely dependent on the use of particular instruments and the constraints of auditory perception.

Of course, one may argue that the use of this or that particular instrument is determined by a religious influence, so that the categorization process is ultimately non-musical. We believe that such an argument misses the point in that the development of the musical environment is always also non-musical. What constitutes the musical environment is dependent on a historical development in which the non-musical influences have found an acoustical sediment. The present approach is the first to acknowledge such influences. The relationship between auditory and non-auditory constraints are often intricate, but that is exactly the reason why this materialistic and ecological approach is a well-come addition to the antropological approach: musical conceptualization is not limited to semantic categories, but involves a number of constraints that are imposed by auditory principles.

7 Ethnomusicology and Music Research

The relevance to computer music is that ethnomusicology may provide keys to build up cognitive reference frames that can be used in music research as tools for analysis and composition. Of particular relevance is the idea that the musical environment in different cultures has lead to schemata or cognitive representations which are very different form those of the Western culture (in which harmonic tonality plays an important role). With computer tools, it is now possible to explore new musical environments and schemata which may have an appeal that is founded in perceptive and cognitive principles. Once such a cognitive frame is known, it can be used as a generating device or as a control mechanism for feedback in interactive computer systems.

8 Conclusion

In this paper we have explored the challenges and caveats of cognitive modelling in ethnomusicology. Contrary to the claim that the materialist epistemology is neglecting the role of cultural and situational contextual factors in music, we found that this approach may provide fruitful insights in the way in which people of different cultures have organized their musical imagery. Acoustical contextual dependencies are well preserved in acoustical recordings and although this mono-modal representation implies a limitation of the inter-modal musical premises (including dance or self-movement and visual aspects), the proposed approach makes it nevertheless possible to clarify some intricate questions of musical performances in different cultures.

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