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Towards a Conceptual Framework and an Empirical Methodology in Research on Artistic Human-Computer and Human-Robot Interaction

Uwe Seifert, Jin Hyun Kim

1. Introduction: Cognitive musicology, media sciences, and cognitive science

In this paper we give an overview from the point of view of cognitive musicology of our theoretical as well as empirical approach to human-computer interaction, especially human-robot interaction in artistic contexts such as music and new media art.

With our approach we pursue several general purposes. A first goal is to establish the cognitive science of music as a scientific research program on the musical mind as part of a science of mind in the epistemological framework of cognitive science in musicology. Cognitive science of music in the disciplinary field of musicology is termed "cognitive musicology". The second goal of our approach is to extend cognitive musicology to the study of new media art, especially artificial life art and musical robotics, interactive audio programming, and augmented environments. As a third goal we aim at combining research issues from media and cognitive science. Key concepts in this framework are "mediality" and "cognitive artifact". An educational goal of our approach is to facilitate the understanding of "computation" and the use of algorithmic agents in music and the arts for students in the liberal arts or humanities. Therefore, robot programming has been introduced as part of a general education on information technology and cognitive science in some of our courses.

Cognitive musicology is located in the humanities. Musicology is divided into historical musicology, systematic musicology, and ethnomusicology. Traditionally, historical musicology is methodologically associated with hermeneutics and history. Today, ethnomusicology as conceived of as part of cultural or social anthropology is more related to cultural approaches to music than in its beginning. In its beginning ethnomusicology was closely related to biological anthropology and was called "comparative musicology". Systematic musicology, like sociology and psychology, has been strongly influenced by the methodology of the natural sciences, especially the methodology of physics. With the advent of digital computers and cognitive science, that part of systematic musicology that adapted the methodological and epistemological framework of cognitive science was termed "cognitive musicology" (e. g. Seifert 1991a, 1991b 1993, Seifert 2004;

Leman/Schneider 2006). Within cognitive science there are three approaches to a scientific theory of mind: cognitivism, connectionism, and interactionism (Kim/Seifert 2006, Seifert/Kim 2007). Interactionism has

been discussed under different labels such as embodied cognition (Clark 1997), embodied cognitive science (Pfeifer/Bongard 2006, Pfeifer/Scheier 1999), situated cognition (Smith 1999), and distributed cognition (Hollan/Hutchins/Kirsch 2000). In this approach of cognitive science, cognition is viewed as a dynamic interactive relation of a situated agent and its biological as well as socio-cultural environment. Our approach to the musical mind within cognitive musicology adopts ideas from interactionism (Kim/Seifert 2006, Seifert/Kim 2007), which is strongly related to the term "embodied cognitive science of music" (Schmidt 2005, 2007, 2008).

In Germany the "Geisteswissenschaften" or humanities have been methodologically opposed to the natural sciences, assuming a special hermeneutic and historical approach towards understanding the "mind". Today the classical foundations of this approach in German idealism and the concepts of "Geist" (Wilhelm Dilthey) and "Kultur" (Wilhelm Windelband, Heinrich Rickert, Max Weber) as interpretative sciences have been either forgotten or critically questioned. At present the humanities are striving for a new epistemological as well as methodological foundation. Cultural studies or media studies or sciences are under discussion as new research paradigms in the humanities.

Since 2002 our research project in the domain of cognitive musicology has been part of the collaborative research center SFK/FK 427, "Media and cultural communication", addressing questions of a methodological and epistemological foundation by using "medium" and "mediality" from the media science point of view. "Mediality" emphasizes the relevance of external representations and processes mediated by a "medium" which not only serves as a passive means of conveying the message, information or intention, but also participates in shaping. "Mediality" is therefore understood as a functional term. For research on (human) cognition, media science raises the question of how media support and extend the working of the (human) mind. Our research project "Transcriptive Interaction" (2002-2004) focused on interactive music systems in electro-acoustical music performances and musical gestures. It soon became evident that the use of interactive music systems leads to a new understanding of "music" and to the emergence from traditional categories of art (e.g. music, dance, theater, and film) of new media art for which human-computer and human-robot interaction seem to be constitutive. In 2005 we therefore extended our research to new media art in a research project entitled "Artistic Interactivity in Hybrid Networks". One key idea was to use robots as tools for research as well as for teaching computational aspects of new media art and cognitive science. In 2006 we obtained a nearly undocumented prototype of a Khepera-III robot and started the first steps in programming. Because we realized the general difficulty of the task of robot programming, we introduced LEGO Mindstorms at the end of 2006 in our courses. Both systems are now parts of our research project (Schmidt 2006; Schmidt/Seifert 2006; Kim/Seifert 2007). Robotics in the field of musical applications might be termed "musical robotics" (Schmidt/Seifert 2006).

To summarize: In general, our research methodology for the study of the musical mind combines ideas and methods from new directions of media and cognitive science. We claim that human-computer and human-robot interaction in new media art provide the most adequate natural setting in order to explore the musical mind scientifically without reductionism and loss of complexity. In order to see why our claim might be justified, we have to discuss computational modeling approaches to the scientific study of the embodied mind. The role of social interaction, situatedness, affordances and cognitive artifacts for the investigation of the higher mental functions of the human's mind has to be taken into account. Methodologically, the relations between computational modeling, measurement and empirical methods of data acquisition for natural socio-cultural surroundings like human-computer and human-robot interaction in media art and music are to be discussed.

2. Cognitive Artifacts: From Digital Musical Instruments to New Media Art Environments

For scholars from the humanities it is evident that socio-cultural contexts, symbols and other artifacts may function as media and play an important role in studying the mind, its functioning and its historical development. Researchers trained in the natural sciences are often skeptical about these "complex" phenomena and their role for explaining mental functions. They prefer to ground their research on the mind epistemologically and methodologically in biology or physics and experimental research in laboratories. Therefore, let us first address the idea that new media art environments form an extension of the traditional laboratory approach to a more natural (social) setting and that human-computer interaction, and especially human-robot interaction in connection with (embodied) cognitive science are the most interesting approaches for the researchers from humanities and natural sciences to study the functioning of the mind in such surroundings.

For musicologists, musical instruments are tools, media, or artifacts for realizing the sociocultural phenomenon of "music". Music and the production of musical instruments are embedded in a cultural and social context. For natural scientists musical instruments are physical devices for sound production. The production of musical instruments is the construction of a physical device for the production of sound called "music". Usually, the idea of music and a musical instrument is grounded in common sense, general education and accepted social norms. This may be illustrated by most of the interfaces for musical expression presented at the well-known conference "New Instruments for Musical Expression" (NIME). Usually, most of the interfaces presented at NIME conferences can be viewed as an enhancement of the classical idea of a musical instrument and as an extension of craftsmanship to design musical instruments in the realm of computer-based sound generation. A musical instrument is conceived of by most researchers as a physical device optimized for the generation of "music" and "musical expression". Therefore, an interface should enhance "musical expression" for computer-based electro-acoustical sound generation. (e.g. Wanderley/Battier 2000; Miranda/Wanderley 2006). For a better understanding of the current situation, a historical sketch of the developments of design considerations for digital musical instruments will be given.

3. On the history of the design of digital musical instruments and musical robots

"Digital musical instrument" is not identical with "the computer as a musical instrument" (Mathews 1963). The interface designer Axel Mulder prefers the term "virtual musical instrument" instead of "digital musical instrument". But the latter is used as a more general term in the context of computer-aided musical instruments (Miranda/Wanderley 2006). "The computer as a musical instrument" is a term going back to the first invention of the computer as a device to generate sounds by numbers and algorithms. "Digital musical instruments" indicates an extension of the idea of the computer as a musical instrument to computer-aided instruments which not only have the capacity to generate sounds, but also include a gesture interface through which a performer interacts with a computer system by means of her or his bodily actions influencing the mechanisms of sound generation. However, the relation of a gesture interface, a so-called controller, and the sound generator of digital musical instruments – other than physical-acoustic musical instruments – are in principle decoupled from each other, since the process of algorithmic sound generation is not controlled by any physical energy, but purely by information represented as numbers. The artificial coupling of these two units is therefore a core task of the design of digital musical instruments.

Against this background, the strategies of gesture mapping, i.e. mapping from gesture input data into parameters for algorithmic sound synthesis, come to the fore in the design of digital musical instruments. Gesture mapping produces a meaning of a performer's bodily activities which can be interpreted as a musical (instrumental) gesture and an intermedial relationship between bodily gestures and sound structures. In this way, digital technology creating new media (in our case: digital musical instruments) brings about either a reflection on a traditional concept (in our case: music or musical instrument) or a new concept. An established classification of digital musical instruments which up to now have been developed as *augmented musical instruments*, *instrument-like gestural controllers, instrument-inspired gestural controllers, alternate [or alternative] gestural controllers* (Miranda/Wanderley 2006) is related to different strategies of gesture mapping.

The term "*augmented musical instrument*" stands for physical-acoustic musical instruments or electronic musical instruments extended with a computer system. The instrumentalist's significant physical gestures used in playing a musical instrument are detected by sensors which are appropriate for measuring the desired information relating to physical gestures. The sensors' electrical signals are digitalized and used as the input data of a computer system to control algorithmic sound synthesis and processing. *Augmented musical instrument*s are characterized by their extension of control dimensions compared to musical instruments. For instance, a series of string interfaces augmenting physical-acoustic and electronic string instruments belong to this category. Such an interface, e.g. the *MIDI Bow* developed by the composer Jon Rose in cooperation with the Studio for Electro-Instrumental Music (STEIM) since 1986 (see figure 1), allows an instrumentalist to use more or less traditional instrumental techniques such as bowing. Ultrasonic sensors mounted both on the *MIDI Bow* and on the right arm of the violinist allow the computer system to measure the bowing movements of the performer. Sounds are generated both by the physical mechanism of the instrument and by the computer system transforming physical gestures into control parameters for algorithmic sound generation and processing. In this way, the control dimensions of the violin are extended.

Fig. 1. The composer Jon Rose playing his MIDI Bow, courtesy of the Studio for Electro-Instrumental Music (STEIM/Amsterdam)

The difference between *instrument-like gestural controllers* and *instrument-inspired gestural controllers* consists in strategies of gesture mapping which aim at the simulation of physical-acoustic musical instruments on the one hand and at the relations of an instrument-like controller and unexpected musical events on the other. The *SuperPolm*, a virtual violin, developed by the composer and media artist Suguru Goto, can be taken as an example of the latter (see figure 2). This virtual violin does not possess a resonator and is equipped with position-measuring sensors instead of strings. An accelerometer measures the x- and y-axis movements of the violin body to detect bodily posture variations expressively guiding the playing of the *SuperPolm*. The design of this interface allows the instrumentalist, using more or less traditional violin techniques, to explore a new relation between usual instrumental gestures and generated musical results.

Fig. 2. Suguro Goto playing the *SuperPolm*, courtesy of Suguru Goto

A group of interfaces which do not bear any similarity to traditional musical instruments are termed "*alternate [or alternative] gestural controllers*". The function of these controllers can, however, be designed to be similar to that of a traditional musical instrument by gesture mapping, allowing a performer to use musically meaningful gestures to generate comprehensible and reproducible musical events from the intentionally produced gesture

segments. Alternatively, they can provide a completely new relationship between physical gestures and sound events, so that the performer has to develop her or his own image of this intermedial relation, although gestural activities may have an effect on some aspects of sound structure. An example of the latter is the data glove interface *Lady's Glove*, invented by the media artist Laetitia Sonami in 1991 and developed in cooperation with STEIM (see figure 3). Different sensors such as Hall-effect sensors, accelerometers and bending sensors measure respectively the distance of the thumb to the rest of the fingers, the speed of hand movements and the bending of fingers. The principles of gesture mapping of this interface vary in each performance of Sonami, so that a certain strategy of gesture mapping serves not only to interface design, but rather as a dramaturgy of media performance.

Fig. 3. Laetitia Sonami's performance with the interface *Lady's Glove*, developed in cooperation with the Studio for Electro-Instrumental Music (STEIM), courtesy of STEIM

The rethinking of the concept of the "musical instrument" has also been an important issue in recent projects on musical robotics modeling artificial bodies involved in music processing. Although projects such as *Heilphon* and *Beatbot* developed by the group *Ensemble Robot* as well as the project *RoboticMusic* developed by the media artist Suguru Goto (see figure 4) were inspired by the idea of traditional musical instruments, they try to go – in words of the current director of *Ensemble Robot* – "beyond traditional boundaries imposed by physical limits of the human body" (Southworth 2006: 17). These projects therefore focus on the development of motors imitating the human motor organs necessary for playing each musical instrument and enabling more capacity needed for instrumental technique.

Fig. 4. *RoboticMusic* by Suguru Goto, courtesy of Suguru Goto

Beyond the simulation of motor capacities for playing a musical instrument, some recent projects of musical robotics explore the aspects of musical interaction necessary for collaborative music-making such as imitation and synchronization. For instance, the percussionist robot *Haile* developed by Gil Weinberg and his team of the Music Technology Group at the Georgia Institute of Technology (see figure 5) has been designed to play in an ensemble with human percussionists based on sequential (decentralized) and simultaneous (centralized) schemata of interaction enabling imitation and synchronization, while a rhythmic motive played by a human percussionist and analyzed by *Haile* serves as a unit of action which can be imitated and synchronically accompanied (Weinberg/Driscoll 2006, 2007).

Fig. 5. Improvisation of *Haile* accompanying human percussionists. Courtesy of Gil Weinberg

This brief sketch of the history of the design of musical instruments indicates a development from purely digital sound-generating systems to systems based on interactions of a performer's body, with a digital system for sound generation. Furthermore, semi-autonomous systems called "musical robots" are designed as "partners" in music making. In general, "body" and "interaction" are becoming relevant for considerations of the design of digital musical instruments. However, a whole media art environment is rarely viewed as a "musical instrument", in the same way as concerning musical robotics a robot is hardly viewed as a real partner in "music" or "art making".

4. New media art environments will change our view of music and art in general and might become "laboratories" for investigating the functioning of the (human) mind

Most researchers involved in the design of digital musical instruments take the sociocultural roles of a craftsman to build musical instruments, of an artist to create art works, of a performer to realize art works, and of a consumer or recipient for enjoying finished works of

art. However, these roles seem to change within new media art: The artist will become much more a designer of "scaffolding" for art experiences instead of a creator of art works. She or he will become much more a facilitator for aesthetic experiences than a creator of art works. Artists, e.g. composers in the case of music, in new media art do not create a final work or opus. They will create a framework or an artificial environment to explore or play with sounds and information from other sense modalities.

At the same time, in using these "scaffolds" the recipient or consumer himself/ herself will become a performer or an artist. Traditionally, the social contexts of experiencing music are clubs, concert halls, operas, open-air concerts, and house concerts. They are related to social conventions as well as to musical styles. All this is well known. Our thesis is that with the advent and further development of interactive systems, art will change the roles of the participants in art process, too. Let us explain this idea briefly: There are activities that have their goals outside themselves. The result or product of the activity is of main importance. In other cases the activity itself becomes important, as in playing, music making, thinking, or in aesthetic situations like experiencing or creating art works. The creation of art works has its goals in itself. The main point of our argument is that in media art environments the goal is to get the consumer involved in aesthetic experiences. These experiences might be conceived of as consisting of attention and a pleasant feeling. The main task for the artist designer is accordingly to develop "scaffolds" that enable processes of attention in combination with pleasant feelings.

It seems that in the near future art and entertainment will meet in new media art. The idea of music as an autonomous art and the idea of a musical instrument seem to be changing within new media art.

In new media art mediality and the functioning of cognitive artifacts become obvious, because the user of new media art is obliged to explore the possibilities of an unknown environment and the affordances it supplies. In connection with the exploration of the environment, she or he has to develop habits and concepts to understand and become adapted to the environment. Furthermore, the user is confronted with her or his socio-cultural norms and those embodied in the environment.

Given these circumstances, these new environments provide the opportunity to study social context and cognitive modeling in natural settings. Evidence for the need and relevance of such investigations will be given in the next chapters.

5. From computational modeling intramental processes to modeling intermental processes: Robots as modeling tools in embodied cognitive science and interactionism

From a biological point of view the role of the body and the coupling to its (natural) environment has to be emphasized. This biological aspect might be called embodiment. Jakob von Uexküll's distinction between sign-world (Zeichenwelt) and action-world (Wirkwelt) that constitutes an animal's environing world (Umwelt) is noteworthy: Every biological species, depending on its body and nervous system, has its own action-world. But not only the constitution of an organism is of importance for the investigation of cognitive behavior. An organism's interaction with its environment is supported by the environment's supply of affordances (Gibson 1997). These species-specific affordances have evolved as part of the evolutionary history of an organism's interaction with its environment. In general,

one might think of an organism's interaction with its environment more abstractly as an embodied functionality of an embedded agent exploring the affordances of its natural environment. These biological aspects of cognition and an agent's interactions with its natural environment are studied by embodied cognitive science. In embodied cognitive science robots are used as modeling tools to investigate cognitive processes, communicative behavior, and an agent's interaction with its environment (Pfeifer/Bongard 2006). Two aspects are of importance to the study of cognitive processes in the realm of embodied cognitive science: 1) internal computational structures and processes that support the processing of an embodied functionality and an agent's behavior; 2) the embedded agent's interactions with its environment and its communication with members of its own species.

Within embodied cognitive science, robots are used as embedded agents to study both of these aspects of cognitive processing. In analogy to natural systems a robot's sensors are considered as "perceptual" interfaces of a sensory system. Programs are descriptions of an embodied system's internal processing structures for planning, perception, cognition, volition and communication (Arbib 2004, p. 759-761). Actuators of a robot are in analogy to natural systems considered as interfaces of the "action"-systems. Computational modeling of cognition with robots has several advantages: 1) Interactions are taking place within the natural physical world; 2) Implementations of supposed algorithms for interaction and communication in connection with perception and cognition are possible; 3) Measurements and analysis of "internal" sensory data are possible; 4) The view that senses are some kind of measurement instruments can be tested empirically by using sensors in robots.

But the natural environment is not the only factor that should be taken into account in cognitive modeling, since humans are not only embedded in natural environments. They are embedded in social environments, too. Humans interact in a social environment using symbols and other artifacts. Embeddedness in a socio-cultural environment might be called situatedness. "Cognitive artifacts" might be used as a generic term for the social use of artifacts and symbols. As is well known in the humanities and as Lev Vygotsky and Alexander Luria (Luria 2004) pointed out, neuroscientific research focusing solely on brain processes or psychological research focusing solely on individual processes of mental functioning is not sufficient for understanding higher human mental functions: It is important to investigate the influence of intermental functioning, external representations and social contexts in order to understand the intramental functioning of mental and brain processes of cognition in the individual. In other words: "the social interactional dimensions of intermental functioning" and the role of cognitive artifacts should not be neglected in research on the human mind (Wertsch 1999, p. 879). We assume that music is a higher human mental function. So it is research object of cognitive musicology as a science of the musical mind, which is based on a computational approach to music cognition.

Concerning the use of computers, robots or – more generally – algorithmic agents in new media art and music, our approach is based on the assumption – as is true of all other cognitive artifacts – that interaction with such systems has effects on human cognition and behavior. But in comparison with other cognitive artifacts, these artifacts are capable of autonomous actions to some extent, and mimic human cognitive function and behavior to some extent: They are agents or actors, and their behavior in a social setting may serve as a second-order cognitive artifact. In general, cognitive artifacts organize functional skills and are embedded in larger socio-cultural systems. Cognitive artifacts are best considered as "categories of processes that produce cognitive effects by bringing functional skills into

coordination with various kinds of structures" (Hutchins 1999, p. 127). Therefore, our goal is to investigate to what extent new media environments and the use of algorithmic agents in music "scaffold", "shape", or "mediate" interactive artistic activities, and how they are related to intermental and intramental cognitive, perceptual, and aesthetic processes.

How the mind operates in a natural and social context is an important question for cognitive science as well as cognitive musicology. Modeling internal processes for social interaction is necessary because of the essential assumption that conscious behavior and cognition as intramental processes are based on such intermental processes. In other words: interaction with an environment and other agents is essential to cognition (Hutchins/Hazlehurst 1995, Hutchins 1999; Luria 2004). Interaction is not only conceived of as interaction within a biological environment but, insofar as humans' mental processes and their activities are involved, as social interaction constituting intermental processes by exploring social affordances supplied by the social environment and cognitive artifacts. We think that the idea of biological and social affordances is also important (Gibson 1977). This can best be studied within social robotics, because a social robot is defined as "an autonomous robot that interacts and communicates with humans or other autonomous physical agents by following social behaviors and rules attached to its role."

Cognitive musicology within the framework of embodied cognitive science of music or interactionism therefore has to take into account interaction, situatedness, embodiedness, cognitive artifacts and social affordances. In our opinion new media art environments as cognitive artifacts offer unknown social affordances for developing aesthetic experiences and entertainment. These social affordances must be studied empirically. But how could these social affordances supplied by cognitive artifacts that shape intermental processing by social interactions be detected and studied?

Environments in new media art can be used as testbeds for the study of more realistic laboratory situations. For example, the Casa Paganini in Genova offers the opportunity to study music-making and measurements in both traditional and new media art performances. In such environments many new ideas might be investigated empirically:

How can robots be studied as partners in the social interaction of music-making or art-making? How do they function as semi-autonomous musical instruments in music making? What kind of social functionality does a situated agent have to embody? How is a specific embodied social functionality related to e. g. embodied perceptual functionalities? What are the important social affordances that facilitate the embodiment of social functionalities? How are social affordances and cognitive artifacts related? How do they influence or shape intramental processing? What are the basic observable units for studying artistic human-robot interaction? To what extent do these units rely on the social environment, the social role of the interacting systems and their tasks? How are they established between humans and robots?

At present no standardized approach to human-robot interaction exists (cf. Fong/Nourbakhsh/Dautenhahn 2003 First, HCI/HRI as a research problem for artistic contexts is not widely recognized. Second, researchers explore using traditional methods from social sciences, psychology or ethology. Third, it is assumed that the methods that are normally applied to the study of human-human interaction could be successfully transferred to the field of human-robot interaction. However, we do not believe that an application of sociological or psychological methods for studying social human-human interaction is possible without changing them considerably. Equally, applications from

ethology used to study social animal-animal interaction seem to be inappropriate. In general this seems to be problematic because in the case of human-robot interaction mixed categories of species are under study: humans and robots. At present, not much is known about these special interactions between a natural and an artificial species, how they might take place and how they might adapt to each other. Therefore, we raise the question of how we should or could study human-robot interaction. In our opinion, this can best be undertaken with structured observation as a starting point.

6. Representational measurement theory and structured observation: Observation – some general remarks

Despite the general belief of most researchers educated in the field of natural sciences that observation is epistemologically without presuppositions and results in objective data or hard facts, it has been shown that observation presupposes both perceptual and knowledge structures. First, one has to semantically distinguish process and result, taking into account the fact that observation is the result of observing. Next, one has to bear in mind some conditions underlying observation. A first condition for observation is that the observing system must be capable to distinguish objects or events from a background. So observation presupposes perception. This may be expressed by the following definition of the process of observing: A system s observes a fact X if and only if s perceives an object or event e and subsumes this object or event e under a family F of concepts such as "e has property z", "e is standing in relation x to u" and so on. In order to explain observation one has to explain perception. In general, perception is explained by different psychological approaches to perception in different sense modalities. Nevertheless, from our point of view cognitive science with its computational approach comes into play. Perceptual processes are conceived of as computational processes which can be described by computer programs.

A further condition one has to bear in mind as expressed in the definition of observation is that observation presupposes conceptual structures. From a logical point of view concepts are the rules for the applications of an expression indicating that concept. In axiomatic theories these rules might be definitions or axioms. More naturally, they might be either learned or innate, or even, as in science, consciously chosen for research. A further problem with observation by humans is the application of bio-, socio- and techno-morphic concepts in describing observations, because they might be misleading in pretending to have some explanatory power for an unknown area. Because of these dangers and to avoid "anthropomorphic" pitfalls but without neglecting its conceptual and perceptual presuppositions methodologically, human observation should be related to measurement.

7. Measurement in the psychological and social sciences: Representational measurement theory

Most methods adapted from psychological and sociological research by human-computer and human-robot interaction researchers are based on statistical reasoning and hypothesis-testing. In general, this standard methodology does not support theory-building or theoretical generalization because it is based on the idea of testing singular statements (Bischof 1995, Lehmann 1985, p. IX, Eberlein 1980, p. 527) and its unreflected use in inquiry

has been often criticized (e. g. Glymour 2001, pp. 171). Furthermore, it seems to be only the first step in the historical development of psychology as an empirical science (Lehmann 1985, pp. VIII-IX, pp. XV). Four stages in the development of psychological research methodology and theory building can be distinguished (Lehmann 1985, pp. IX-XIII). The first stage, starting in the nineteenth century and now used in the mainstream of psychological research, is the statistical approach of testing singular statements using hypothesis testing. 2) The second stage evolved in the middle of the twentieth century as mathematical psychology, and is concerned mainly with ad-hoc models for fitting experimental data. 3) The third stage is characterized by measurement theory.

Representational measurement theory has been the main approach towards clarifying the concept of measurement in the psychological and social sciences. It started with the work of Patrick Suppes and Dana Scott in 1958 and was developed further in the second half of the twentieth century. Nowadays, it is a standard in psychological and sociological textbooks on statistics, measurement, and mathematical psychology (e. g. Coombs/Dawes/Tversky 1970, p. 4). 4) The fourth stage is based on model and recursion theory. Of course the fourth stage corresponds to the epistemological framework of cognitive science – automata theory. In this framework internal processes are viewed as computational processes, and computer programs may be used in order to describe these processes. Programs, which are conceived of as descriptions of internal processes between perception and action, might therefore substitute the intervening variables or hypothetical constructs of psychological theory-building.

In representational measurement theory, measurement is defined as a homomorphism h from an empirical relative E into a numerical relative N, i.e. (E, N, h). Axioms must be satisfied in the empirical relative to be represented by a numerical relative. If the axioms of the empirical relative are valid in the numerical relative, it is said that the numerical relative represents the empirical relative. Normally this is proven by a representation theorem.

Establishing the existence of a homomorphism for an empirical relative is called the representation problem. The next problem is called the uniqueness problem. It must be shown under which transformations the operations remain valid so that the scale level remains the same. Generally four classes of scales are distinguished: nominal, ordinal, ratio and absolute scales. A third problem is meaningfulness. To what extent do mathematical operations make sense for the domain under study?

8. Representational measurement theory: Structured observation as measurement

It can be shown that structured observation is some kind of measurement in the sense of representational measurement theory (Greve/Wentura 1997). In order to count as measurement in the sense of measurement theory, structured observation must satisfy some logical requirement from measurement theory. For structured observation to be some kind of measurement it must be shown that the observational categories of a coding scheme satisfy the requirements of a nominal scale. In general, these requirements are those for the classification of a certain domain: The classes must be mutually exclusive. All objects of the domain must be classified, and each object is an element belonging only to one class. All classes of the domain must contain at least one object of the domain, i.e. there exists no empty class. In general, an equivalence relation introduces a partition into a given domain

of objects and corresponds to a classification. Because structured observation is related to measurement, we think that it is best to start with structured observation in developing a methodology for human-computer and human-robot interaction in new media art environments.

9. Structured observation and observer reliability: Cohen's kappa as a measure of observer agreement

Observational methods may be classified concerning their degree of pre-structuredness and the degree of participation of the observer (Robson 2002). Structured observation is highly structured non-participant observation and has been shown to count as measurement as indicated above (Grewe/Wentura 1997). There are two main steps in developing the method of structured observation (Bakemann/Gottman 1997; Robson 2002).

First, a coding scheme has to be developed. This coding scheme relies on the development of possible categories that might be observed in the domain under study. This first step is conceptually difficult and implies the development of categories or classes for describing the observations. In order for structured observation to count as measurement these categories must satisfy the logical conditions of a nominal scale. These categories must satisfy the requirements of a nominal scale.

Second, observers have to be used as measurement devices. These observers must reliably recognize the observational categories. Therefore, observer training is necessary. Observer calibration ensures that the same results will be obtained from different observers in the same situation, i.e. the observers' judgments are in agreement. To ensure observer reliability, the observers must be "calibrated". A measure for observer agreement is used to calibrate the observers. The reliability of an observer's judgments is tested by comparing her or his judgments with those of another observer observing the same situation. It is measured whether their judgments agree. Different measures of observer agreement or reliability are possible (Wirtz/Caspar 2002). Cohen's kappa coefficient is a well-known measure for observer calibration and for measuring their reliability, in order to ensure the reliability of the data obtained (Bakemann/Gottman 1997, Grewe/Wentura 1997, Robson 2002, Wirtz/Caspar 2002).

The main idea behind Cohen's kappa is correcting for chance agreement percentages of observer judgments by two observers.

Usually the development of the categories of a coding scheme is done in connection with observer training. That is why both steps and observational studies are in general highly time-consuming.

To summarize: The importance of the development of an empirical methodology in accordance with the representational measurement theory of the social and psychological sciences is emphasized. At present, not much is known about this, and no methodology exists – even in human-robot interaction – to address the problem. Therefore, relevant category systems for observational studies of artistic human-robot interaction in the contexts of new media art need to be developed. It is argued that structured observation should be used in empirical research on human-computer interaction, especially on human-robot interaction, because it fulfills the high demands on measurement as required by the representational measurement theory of psychological and sociological methodology.

Observer training and observer calibration using different measures of observer agreement should be used to prepare the data collection. The collection of data should be based on observer protocols from direct observations as well as video recordings and the registration of robotic and human sensor data.

10. Cognitive musicology: Robot studies and structured observation

In order to become acquainted with research on human-robot interaction and robot programming, three exploratory studies using LEGO Mindstorms NXT were carried out. LEGO Mindstorms NXT robots have been used as a tool in order to develop a methodology for research on human-robot interaction in an artistic context.

The first experimental study, a Master thesis by our student Birgitta Burger, was carried out in cooperation with the KTH Stockholm (Burger 2007a, 2007b, Burger/Bresin 2007). In this study a "mainstream" experimental approach using a questionnaire with rating scales was used. The recognition and its enhancement through music of intended "emotions" communicated through a robot's movements using LEGO Mindstorms NXT was investigated. The main result of this study was that there is some difficulty in distinguishing between the movements expressing "joy" and "anger".

In modifying the experimental set-up of the first study, the second study explored the methodological tool itself: the use of the kappa coefficient for the measurement of observer reliability. This study was carried out in 2007 during the International Summer School in Systematic Musicology (ISSSM-07) at Ghent University. We experimented with observer training in connection with measurements of observer reliability. The usefulness of the well-known kappa coefficient as a measurement for inter-observer agreement was explored in order to use human observers as "measurement instruments" in complex situations such as artistic human-robot interaction. Observers were trained to recognize three classes of movements exhibited by LEGO Mindstorms NXT robots as belonging to the three classes of emotions, "anger", "joy", and "sadness", as used in the first study. In addition, the appearance of one of the robots was changed, in order to test whether a more anthropomorphic appearance of a robot might influence the observers' judgments. The result of this exploratory study was that the kappa coefficient seems to be an adequate measure to start with, and that anthropomorphic appearance did not influence the identification task.

The third study addressed the problem of finding basic observational units in human-robot interaction using free observation as a heuristic method. This study was carried out during a workshop in connection with the ANIMAX-multimedia theatre at Bonn/Bad Godesberg on LEGO Mindstorms NXT programming for young children. During the teaching of robot programming to the children, video recordings of their behavior and of their interaction with the robots were made. We wanted to study the interaction of the children with robots and their reactions in artistic environments. Our students Julia Wewers and Henrik Niemann analyzed the video material in order to discover some significant behavioral units. The outcome was that the real and interesting interactions between robots and children and the children itself took place only when they were not observed. This indicates that indirect observation should be used in further studies.

In addition to these studies, robot programming is used as a way to introduce students of the liberal arts to computing in media art and cognitive modeling. There are different

platforms and curricula for AI courses (Dodds et al. 2006) but only a few ideas outside the
engineering domain have been tried in education (e. g. Artbotics (Yang et al. 2007, Martin et
al. 2007), the Robot Design Studio (Turbak/Berg 2002) and the Roberta project (Petersen et
al. 2007)). We started a course on "Musical Robotics" in 2006. In 2007 and 2008 we integrated
robot programming in our courses "Science of Music", "Embodiment I", and "Embodiment
II". Our robotics-inspired approach to music research is now part of the curricula for our
new Bachelor and Master studies which began in 2007. In 2007 one Master thesis and in 2008
two PhD theses were completed on the topics of robotics, music, and media art since the
introduction of robotics, human-robot interaction and embodied cognitive science into
musicology. Currently we are transferring the algorithms of the first LEGO Mindstorms
NXT project to the more complex Khepera III robot platform.

11. Conclusion

In order to develop a new approach to the scientific study of the musical mind, cognitive
musicology has to be complemented by research on human-computer and human-robot
interaction. Within the computational approach to mind, interactionism or embodied
cognitive science using robots for modeling cognitive and behavioral processes provides an
adequate framework for modeling internal processes underlying artistic and aesthetic
experiences. The computational framework provided by cognitive science corresponds to
the fourth stage in traditional psychological research methodology enabling theory-building
and is based on model and recursion theory. The approach of cognitive science to the mind
via computational modeling related to psychology may be conceived of as an empirical
research strategy resulting from of these theories. This traditional approach of cognitive
science focusing mainly on individual internal processing has to be supplemented by a
computational approach to the mind taken into account intermental functioning embedded
in social environments based on processes of social interaction and the use of cognitive
artifacts. Therefore, cognitive musicology has to be supplemented by research on human-
computer interaction, especially by research on human-robot interaction, or more generally
by research on the interaction of humans with algorithmic agents. For us, new media art
environments seem to be the most appropriate place to extend the classical laboratory
situation to the study of the relation between intermental and intramental processes in a
natural and social environment. We argue that in order to cope with the resulting new
research questions, an integrated approach has to be developed. We are trying to develop
such an approach using computational modeling of intermental and intramental processing
in connection with traditional empirical approaches to data acquisition and analysis from
sociology and psychology. Structured observation of human-robot interaction within new
media environments seems at present to be the best starting point for prospects of empirical
research to achieve an integrated research method, because concerning the accepted
methodological standard set by representational measurement theory for psychology and
sociology, it can be viewed as measurement. Furthermore, using human observers as
measurement devices instead of technical measurement instruments takes into account the
complexity of the "stimuli" and "situation" under study.
LEGO Mindstorms robots and structured observation were used in our exploratory studies
in order to gain first insights into problems and pitfalls of approaches combining
computational modeling from cognitive science and classical empirical research from the

social and psychological sciences in order to study intermental and intramental processing in natural social settings such as artistic human-robot interaction in new media art environments. We hope that our approach might contribute to research on human-computer and human-robot interaction and expect that the development of an integrated methodology might especially contribute to the methodological discussions in the young field of human-robot interaction (Gold et al. 2007).

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