Ubiquitous Music: Concepts and Metaphors

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Abstract. *Ubiquitous Music is a new area of research that encompasses ubiquitous computing, mobile and networked music, eco-composition and cooperative composition. This article examines both the metaphors for interaction and the musical activities that can be supported by ubiquitous music systems. Music making is characterized as an activity involving pragmatic-epistemic actions constrained by natural and social affordances. Music composition – a predominantly epistemic activity – results from the interactions between the musician's personal environment and the ecological niche where the activity takes place. Thus, the interaction metaphors encompass agents, tools, environment, and activities, providing a conceptual and methodological framework for musical and computational developments in ubiquitous music research. An example of a ubiquitous music work is included: Green Canopy, On the Road.*

1. Introduction

Ubiquitous music systems can be defined as musical computing environments that support multiple users, devices, sound sources and activities in an integrated way. Regarding technology, at the least, ubiquitous music systems should support: mobility, social interaction, device independence, and context awareness.

Our work stands at the intersection of mobile and networked music with ubiquitous computing technology and concepts [Weiser 1991], involving open, participative, non-trivial musical practices. Previous work on interactive installations, performance art, eco-composition, and cooperative composition partially fit within the concept of ubiquitous music. Although this term has recently appeared in the literature [Holmquist 2005; Holmquist and Tanaka 2005], there has not been any attempt to define a workable methodology that contemplates both the musical and computational issues raised by these practices. In order to establish a suitable theoretical framework for experimentation and artistic development, we will address both the categories of musical activities that can be supported by ubiquitous music systems, and the metaphors for interaction that can be applied to their design.

2. Ubiquitous Music: Activities

As composers, music practitioners, and system designers, we believe that ubiquitous music systems design should be guided by the requirements of music making. So, before tackling specific methodological issues we need to answer a basic question: What is music making? Or more specifically, what does music-making involve in the context of ubiquitous systems?

2.1. Activity and Affordances

For Leont'ev (1978), activity is at the center of human life: as soon as an activity is completed it is replaced by another activity. He suggests that activity has a circular structure: "initial afferent and effector processes regulating contacts with the objective environment, then correction and enrichment by means of reverse connections of the original afferent image" [Leont'ev 1978: 53]. This circular connection between physical and perceptual processes is a key characteristic of Gibsonian approaches [Chemero and Turvey 2007; Gibson 1966]. Thus, a research agenda that brings together Activity Theory and Ecological Psychology provides a firm ground for the study of human activity [Baerentsen and Trettvik 2002].

Our perception of the environment is shaped by the constant interactions with the objects and beings that surround us. These interactions are constrained by the possible actions that can be exerted upon the objects, that is, by their natural affordances [Gibson 1979: 127]. The permanent cycle "action / perception / attunement / new action" is at the core of the process of adaptation to a new environment. Or, more accurately stated, the mutual adjustment between environment and individual can be observed through the set of affordances that emerge from this process. So affordances can be defined either as being properties of the environment that are actualized by the agents' actions, or as relational properties of agent-environment systems [Chemero and Turvey 2007].

The basis for the perception of affordances is the temporally extended perceptual activity [Baerentsen and Trettvik 2002]. Affordances exist at the moment the organism interacts with the environment through structured actions. Perceptual activity, i.e. the efferent commands to muscles to establish contact with objects, and the influence of the perceived objects on the activity, via afferent feedback, inform the organism about the changes in the environment. Thus, affordances and activity are inextricably interrelated. More specifically, affordances are features of activity systems that include the physical environment and the organism's phylogenetic characteristics transmitted through the generations as species-specific adaptations to the ecological niches.

At a finer level of description, Leont'ev (1978) establishes a distinction between actions and activities. "When a concrete process is taking place before us, external or internal, from the point of view of its relation to motive, it appears as human activity, but when it is subordinated to purpose, it appears as an action or cumulation of a chain of actions" [Leont'ev 1978: 64]. Within the realm of physical/digital systems, Kirsh and Maglio (1994) propose two types of actions: epistemic and pragmatic. From their perspective, pragmatic actions serve a single function: to change the world. On the other hand, epistemic actions simplify the problem-solving task by uncovering hidden information and bringing the agent closer to its goal.

From an Activity Theory perspective [Leont'ev 1978: 68], internal activity that serves a cognitive motive is carried out through external actions or motor operations.

Similarly, the actions and operations that realize external activity may constitute internal – cognitive-physiological – processes, but they always keep their integrity as actions or operations. Therefore, a separation between cognitive and motor actions is unwarranted; thus, we could think of psycho-motor actions as part of a feedback process that involves both epistemic and pragmatic activities.

Generally, we could say that the organism-environment system is just a collection of affordances. Because these affordances are dependent upon the agent's personal history of interactions, we have to restrict our definition of ecological niches to the specific relationship agent-environment, that is, to the personal environment [Keller and Berger 2001] or the personal sense [Leont'ev 1978].

2.2. Social Affordances and Musical Activities

The unit of analysis in studying human mediated activity is an activity system, a community of actors who have a common purpose [Miettinen 1997]. Social mediatedness is characterized by constraints mediating the interaction between the individuals within the activity system. The focus of study moves away from isolated subjects to encompass the interaction between the individual, the artifacts and the other individuals in a dynamic changing environment. Thus, the collective activity system connects the psychological, the cultural and the ecological niches where activity takes place.

All organisms exert pressures on their habitats modifying the environment to suit their needs. In the case of the human species, these processes guide the development of tools within the context of cultural societal praxis. In other words, cultural activities involve interactions with artificial habitats and with other organisms and these interactions are constrained by canonical or social affordances [Costall 1995]. This specific type of affordances regulates community exchanges and fosters the development of physical tools to fulfill specific societal needs.

As Christopher Small (1998) suggested, musical practices are only part of a unified system of social interactions. If music is understood as social activity, the tools and concepts developed in Activity Theory can be applied to musical research. From this epistemological perspective, we can analyze musical activities as comprising systems of epistemic-pragmatic actions with specific goals. In turn, these goals will guide the implementation requirements of systems that support musical activities.

Acoustic musical instruments are just one example of tools that emerged out of a process shaped both by the environmental and societal pressures. Musical instruments co-evolved with musical practices on the one hand constraining the ability of musicians to establish new forms of sonic organization, and, on the other, providing opportunities for novel forms of music making. For instance, orchestral acoustic instruments – through their specific set of affordances – came to be suited for music thought for a single player per instrument, playing inside a concert hall.

But social affordances not only influence the development of tools, they also provide a context for the application of conceptual frameworks. Compositional paradigms are just one form of social affordance. They serve as an interface between the sonic potentialities of objects (natural affordances) and the common musical knowledge shared by the members of a society (just for the record, this knowledge also belongs to the realm of social affordances). Thus, compositional systems that are well-adapted to the available physical tools and that fulfill the current societal needs are the ones that survive social and environmental pressures.

2.3. Compositional Activities

Composition requires the exploration of numerous possible outcomes, involving tasks such as categorization, organization and planning, among others. More precisely, we could say that composition involves pragmatic-epistemic actions with the goal of internalizing micro, meso and macro imagery. From an eco-compositional perspective [Keller and Capasso 2006], the three space-time competencies required by compositional activities can be defined in the following terms:

a. Micro space-time imagery: involves the prediction of processes applied upon structural and transformational invariants.

- Structural invariants: describe the sonic qualities of events within a static spatial configuration.
- Transformational invariants: inform about sonic qualities of events within dynamic spatial configurations.

b. Meso space-time imagery: establishes the outcome of processes at a meso-time level, i.e., taking into account variables such as phase, density and distribution of meso-time processes.

c. Macro space-time imagery: involves the prediction of perceptual relationships among sonic events and across multiple time levels.

Micro space-time imagery encompasses the behavior of sound sources such as musical instruments, resonant objects, synthesis algorithms, etc. On the transformational side, it demands the prediction of outcomes resulting from DSP processing, spatialization and other types of manipulations of sonic material. Macro space-time imagery – comprising the perceptual relationships among sonic events across multiple temporal levels – is constrained by short-term and long-term human memory limitations and by selective attention processes.

Given that the personal environment results from the history of interactions between the individual and the ecological niches where the activities take place and that this process is constrained by the social affordances, the composer cannot predict whether his imagery will match the listener's. Nevertheless, two tentative strategies may be used to partially close the gap between the composer's and the listeners' imagery: 1) to implement artificial eco-niches that are as much removed from any pre-existing niche as possible; 2) to exploit natural affordances that are common to most human environments. Eco-composition usually takes the second approach.

3. Ubiquitous Music: Metaphors for Interaction

So far, we have characterized music making as a human activity involving pragmatic-epistemic actions which are constrained by natural and social affordances. We have also conceptualized music composition as a predominantly epistemic activity that results from the interactions between the musician's personal environment and the ecological niche where the activity takes place. This section will address how musical interaction metaphors impact the design of ubiquitous music systems.

A classic interface metaphor, the WIMP model uses elements such as menus, dialog boxes and scrollbars to act as mediators between users' actions and the objects being manipulated [Beaudouin-Lafon 2000]. The advantages of the WIMP model are its low cost and wide availability. Most interactive music systems support WIMP actions. And many standard audio procedures such as editing and mixing are usually done through mouse actions. Nevertheless, the WIMP metaphor presents several limitations:

- Users have a limited sense of engagement because their actions are achieved through the mediation of intermediate software objects [Beaudouin-Lafon 2000];
- PCs, monitors and QWERTY keyboards are usually associated with office work [Zicarelli 1991];
- Actions done with the mouse (without haptic feedback) are not an option to users with visual disabilities; and
- The standard mouse only gives access to simultaneous control of two continuous parameters.

As Beaudouin-Lafon pointed out (2004), WIMP interfaces have already reached their limits. These limits are particularly acute in the context of pervasive computing: the amount of information each individual user deals with has grown exponentially; the distribution of this information needs to be deployed over multiple computers and devices, including mainframes, desktop computers, laptops, PDAs, mobile phones and custom hardware; and the range of computer users has expanded drastically, incorporating novices to what was previously regarded as the exclusive realm of experts (music making is a particularly good example). So let us discuss metaphors better suited for musical interaction in the context of ubiquitous musical activities.

3.1. The Instrumental Metaphor

In contrast with other areas of computer science, most research in computer music systems has adopted the musical instrument as the ideal metaphor of interaction [Wandeley and Orio 2002; Wessel and Wright 2002]. For music performance done in real-time, this type of metaphor is the one that has the longest cumulative knowledge. Performance activities demand low-latency, immediate sonic outcome, making the "one-gesture-to-one-acoustic-result" [Wessel and Wright 2002] the ideal benchmark for implementation and testing. On the other hand, creative, exploratory activities such as the compositional activities discussed in section 2.3, are not readily supported by this paradigm.

Interfaces developed following the instrumental metaphor foster musical activities tailored after the performance of acoustic instruments. Within this context, Wanderley and Orio (2002) define a musical performance as the continuous changes of sound parameters exerted by a controller. Regarding the physical/digital mapping, music system designers should account for the perceived relationship between gestures and changes in the performance parameters and the level at which these features can be controlled. The accuracy, resolution, and range of perceived features should be determined, the focus being what the user perceives rather than the actual values of the control parameters.

The performance of a musical instrument requires very precise timing. Wanderley and Orio (2002) propose that musical tasks should strive to attain temporal precision so that musicians have complete temporal control of the performance parameters.

Transposing this guideline to multiple-user task management means prioritizing real-time strategies for synchronous control of multiple parameters on multiple devices.

The instrumental approach introduces a difficult problem for ubiquitous music systems. As Barbosa (2006) has pointed out, latency in large network systems will remain in the perceivable range for the next few years. Therefore, music systems need to take this limitation into account in order to reduce the effects of network time delays. In contrast with the instrumental paradigm, Barbosa suggests conducting the general direction of musical behavior instead of producing sonic events by direct manipulation of physical controllers.

Ubiquitous music systems place further demands on the interface which cannot be fulfilled by the instrumental paradigm. A good example is the adoption of mobile devices as musical interfaces. Multiple users need to have access to the state of the system and the location where the action takes place. This demands context awareness mechanisms and location-specific configuration of parameters. Depending on the context, devices may provide sensor or actuator capabilities to the system. Thus, the instrument metaphor is necessarily broken. In the context of ubiquitous systems, a device is not a passive object that a musician can play. It is an agent in a dynamical system that adapts itself to the musical activity, to the local environment and to the other agents that interact with it.

3.2. The Cup Metaphor

A promising paradigm for ubiquitous music interfaces has already appeared in the context of multimedia performance and installation works. Several works make use of space as an unbounded, unobtrusive interface that may be freely explored by the participants. Dannenberg and co-authors (2003: 1) use an interesting metaphor to describe this situation: “the space within an empty cup is what makes the cup useful and necessary”. Thus, we could gather all these works under a common denominator: the cup metaphor.

A good example of this approach is The Urban Corridor, an interactive multimedia installation premiered in 2001 at the CU Art Galleries, Boulder [Keller et al. 2001; Keller et al. 2002]. The installation space was constructed as a corridor featuring lights, motion sensors, two slide projectors, a video projector, and a multichannel sound system.

The visual and sonic elements in The Urban Corridor consist of two layers of material: active and passive [Keller et al. 2002]. Active elements or events are triggered by the presence of the public and passive elements, or the environment, provide a constant background that reinforces the sensation of a surrounding urban landscape.

The active layer is controlled by means of four motion sensors placed at each section of the corridor to detect the presence of people. When a sensor detects motion, it sends a command to a radio frequency receiver plugged into the power line. This receiver routes the signal through the line to an interface that decodes it as a serial message.

At the heart of the system, the control software triggers both sonic and visual events. Sound events are stored as audio tracks and are played back by two CD-ROM drives. Visual events are produced by two slide projectors and three sets of lights. When motion is detected in region one, an ON command is sent to address A1, corresponding to the projector placed at the entrance of the corridor. In turn, a two-way interface translates the serial message and routes it to the power line. The projector is plugged into a module which is set to address A1. When the module receives the ON command, it turns the slide projector on.

The Urban Corridor provides a detailed example of one of the first installations to make use of the cup metaphor. The system reacts to the presence and the actions of the participants without requiring any musical expertise. Given the visual and tactile elements, the global multi-sensory experience encourages multiple forms of interaction. Accumulation of sonic material, prompted by the actions of the visitors, determines the dynamic of the piece. And by sharing the same space, participants not only relate to the artwork, they also share a common playground.

3.3. The Ecological Metaphor

Generally speaking, ecological models represent forms of interaction between agents and objects which occur along three dimensions: time, energy and space. Each axis is determined by *n* dimensions that do not necessarily represent linear or continuous mappings. Time, the first dimension, is mapped onto finite segments called events. These events are shaped by patterns of interaction between agents and objects. The processes that shape these patterns take place at three temporal levels simultaneously: micro, meso and macro [Keller 1999].

The temporal evolution of a sound event is defined by dynamic interactions between two processes: excitation and damping. This process establishes temporal constraints on the parameter range of the excitation pattern. In other words, every event starts from zero energy and builds up at an ecologically-bound rate, until the energy input stops. At this point, the damping process kicks in reducing the energy level until zero is reached. Thus, the excitation and damping processes shape the event's energy profile. By means of a single control parameter, this algorithmic structure generates ecologically constrained meso-patterns.

The sound event is effected by the dissipation of energy by an agent on an object through their natural affordances. Each event constitutes a unique instance, temporally finite and spatially localized. As long as the events can be perceptually recognized as the result of a specific interaction between an agent and an object, they are classified as belonging to a single sound class. Complementarily, a stable form of interaction between the agent and the object is usually described as a sound source. Thus, a sound class is a collection of events that share the same source.

The second dimension of ecological models – energy – is the result of complex interactions between excitation and damping processes. These processes determine how energy gets into the resonant system and how it is dissipated. The type of excitation, the state of the object, and the forms of interaction among excitation and resonance systems give shape to events. Generally, correlations and constraints on variable ranges within finite time segments approximate the behavior of real-world sound producing processes. In ecological parlance, these constraints are encapsulated in a single concept: natural affordance.

The usual representation of the third dimension of ecological models – space – consists of three axes: azimuth, elevation and distance. Nevertheless, if events are to abide by ecological rules, arbitrary mappings of temporal patterns are not possible. The sonic field is the spatio-temporal distribution of sound events produced by actions constrained by natural affordances within a spatial and temporal horizon. The limitations are not only determined by physics but by the available modes of interaction between agents and objects within the specific ecological niche. In other words, the behavior of agents and objects is constrained by their natural affordances producing events which are limited to a spatio-temporal horizon.

4. Green Canopy

Green Canopy is a series of sculptural sound installations involving elements and sound inspired and collected in the North-Western Amazonian rainforest (Green Canopy: The Tree, Green Canopy: The Forest, Green Canopy: The Bud) [Keller et al. 2005, 2006]. The sculptural elements of the work are built entirely from recycled materials, including PVC pipes, carpet padding and crocheted plastic bags. Green Canopy has been featured in exhibits at Sculpture Space (Utica, NY, 2005), the 6th Kingston Sculpture Biennial (Kingston, NY, 2005), Hamilton College (Clinton, NY, 2006), LMAKprojects (Williamsburg, NY, 2006), the Islip Art Museum (East Islip, NY, 2006), MACO (Mexico City, 2006), and the Preview Berlin Art Fair (Berlin, June 2006).

All previous versions of Green Canopy enforced a dynamic group interaction. In the case of The Tree people would walk toward or away from the sculpture, experiencing vertical and horizontal phase relationships among sound sources (Figure 1). The Forest made use of a sonic environment that surrounded all participants sharing the common space (Figure 2). The Bud only allowed for a limited number of people to stand close to the sculpture, thus demanding alternation between groups to listen to the work.

Figure 1. Green Canopy: The Tree

Figure 2. Green Canopy: The Forest

Green Canopy, On The Road is the latest implementation within this series. In this version we further expand an issue previously explored in Green Canopy: The Bud: portability. On the Road opens up its sonic material to exploration by extending a concept borrowed from HCI techniques: the music probe [Gaver et al. 1999]. Music probes are devices designed to let users establish their personal experience of a musical work. While serving as a framework for art experimentation, they provide data for developers to refine their decisions on architecture and interface design. The probe works as a sensor / transducer system, allowing the collection of data at the site of interaction. Channels of interaction include sound and movement. Two variables that influence the usability of the system within the context of compositional activities are studied: the ability to manipulate the temporal relationship among sound events and the perceptual limits on the number and characteristics of the samples used. On the Road uses the music probe infrastructure to give users the ability to mix their own version of the work. Because the probe has been implemented for a portable device, listeners can carry the work with them. Thus the type of experience provided by this version of Green Canopy is mostly individual and self-contained.

5. Final Discussion

Ubiquitous Music, an emergent research field that integrates computer music and ubiquitous computing, presents exciting new challenges and possibilities for music making. This paper has focused on key issues for ubiquitous music system design, providing a conceptual and methodological framework for future developments. In line with broad approaches to Human-Computer Interaction [Bevan 1995], we have not dealt with specific system details and have avoided techniques that restrict the applicability of the proposed framework. As research moves on, user demands will dictate the needs for development within narrower contexts.

Adamczyk and collaborators (2007) ask “how might public presentation and communication of highly situated HCI new media projects be made compelling to new audiences?”. Ubiquitous music systems may provide part of the answer. By embedding musical tools in everyday consumer devices, non-musicians are given a chance to participate in a growing community of music practitioners. Placing music-making as an extension of everyday activities reduces the cognitive cost of several years of training with non-intuitive interfaces and the highly specialized knowledge of the common practice musical syntax.

By applying the metaphors described in this paper, under a broad HCI perspective, we pave the way to a wide range of possibilities regarding the use of multiple devices as musical interfaces, from the control of notes and continuous sound parameters (within the instrumental paradigm) to the emergent properties of social collective actions in artistic spaces (within the cup paradigm). We believe that in these various contexts (particularly when actions are not explicit and are based on mundane, everyday activity), the user gains intuitive control over relevant musical parameters. Thus, we may empower both musicians and non-musicians to express themselves in collective, open-ended music making.

The ability to adapt to context through awareness of environmental variables – a key requirement of ubiquitous systems – changes the basic design philosophy. New media audiences should not have to deal with generic musical instruments that need to be mastered in order to make sound. Participants of ubiquitous new media works only need to be concerned with the creative aspects of the artistic experience: exploration and experimentation of forms and content. It is the system – and not the user – the one that should adapt its behavior to each specific context.

From an eco-compositional perspective, acknowledging the existence of natural and social affordances has a clear corollary: we cannot separate agents from objects, tools from activities, and actions from locations. What we construct, as musicians, are ecological niches or habitats where musical activities can exist. Depending on the characteristics of these eco-niches, including the agents (users), tools (systems), environment (location, space), and activities (performance, composition), we define a specific set of forms of interaction (affordances). As music systems developers we design interfaces that support interaction and co-adaptation between agents and environment, the sonic result being just a by-product of this process.

Sound Examples: Green Canopy, On the Road – fragment.

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