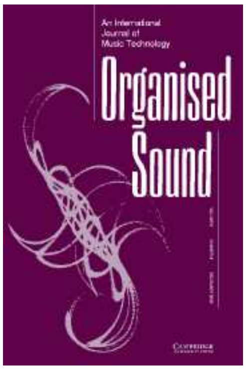

'Sound is the interface': from interactive to ecosystemic signal processing

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‘Sound is the interface’: from *interactive* to *ecosystemic* signal processing

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This paper takes a systemic perspective on interactive signal processing and introduces the author’s *Audible Eco-Systemic Interface* (AESI) project. It starts with a discussion of the paradigm of ‘interaction’ in existing computer music and live electronics approaches, and develops following bio-cybernetic principles such as ‘system / ambience coupling’, ‘noise’, and ‘self-organisation’. Central to the paper is an understanding of ‘interaction’ as a network of interdependencies among system components, and as a means for dynamical behaviour to emerge upon the contact of an autonomous system (e.g. a DSP unit) with the external environment (room or else hosting the performance). The author describes the design philosophy in his current work with the AESI (whose DSP component was implemented as a signal patch in KYMA5.2), touching on compositional implications (not only live electronics situations, but also sound installations).

1. INTRODUCTION

Talk of ‘interactivity’ in today’s Western world is common, ubiquitous, and often meaningless. The history of the ‘interactive arts’ and their paradigms is documented in an overwhelming body of literature – a survey is Dinkla (1994). ‘Interactive music’ is certainly an integral part of that picture. The goal of the present paper, however, is not to overview existing ‘interactive music systems’, but to discuss the paradigm of ‘interaction’ inherent to most efforts in this area, and particularly in the design of signal processing interfaces. The paper describes personal work that may represent an alternative strategy.

I start by asking: What kind of systems are ‘interactive’ computer music systems? What paradigm of interaction do they implement and make socially available? I try to answer by adopting a system-theory view, more precisely a *radical constructivistic* view (von Glasersfeld 1999, Riegler 2000) as found in the cybernetics of living systems (Maturana and Varela 1980) as well as social systems and ecosystems (Morin 1977). I think it is technically possible and musically desirable to achieve a broader understanding, if not a reformulation, of what is meant by ‘interaction’. As a practical example, I will later illustrate the design philosophy in my own *Audible Eco-Systemic Interface* project.

2. WHAT KIND OF SYSTEMS ARE ‘INTERACTIVE MUSIC SYSTEMS’?

Interactive music systems are dedicated computational tools capable of reacting in real time (i.e. in a time shorter than it takes to perceive two events – command and execution, cause and effect – as *subsequent*, anyway of the order of milliseconds; see Fraisse 1967: 111–12) upon changes in their ‘external conditions’. Minimal external conditions typically include initial input data and run-time control data. In most existing approaches, such data are set, changed and adjusted by some agent – a performer, or group of performers (which could include the composer, too, either working in the studio or improvising on stage). Control devices, with their mechanical and/or visual interfaces, are operated to determine these data. In short, *the agent’s operations, as reflected in the control data, implement the system external conditions and all changes therein*.

The main purpose of control data is to determine a system’s changes of internal state. This is done indirectly, by updating the parameters in either digital signal processing techniques or program routines operating at a more abstract, symbolic level. Changes of internal state are heard as changes in the musical output.

By operating the available control devices, the agent in effect ‘plays’ the system as if it were a new kind of music instrument. A variety of known interactive performance situations is described in available publications, ranging from the ‘solo instrument’ set-up, to the ‘duo’ and larger ‘ensembles’ where several performers and/or computer systems are interconnected and play together (Rowe 1993). However, in my opinion, whether the ‘instrument’ metaphor is entirely useful when discussing interactive music systems, remains debatable. For example, the utilisation of interactive interfaces in *studio* work (in the production of ‘tape’ music, not performance-oriented) raises specific issues, and is of high compositional relevance, although it has been less often discussed and too often taken for granted (a preliminary, ground-breaking discussion was sketched, a. o., in Truax 1978).

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Of special interest for the present paper are real-time digital signal processing (DSP) interfaces designed and dealt with by composers in creative ways, because the interactions mediated by such interfaces often have direct influence on the structure and the internal development of the output sound. The interface design becomes then the very object of composition (Hamman 1999), and the array of DSP algorithms, and the methods by which they communicate among themselves, should be seen as the material implementation of a compositional process or concept. This approach, by which one invents and works out interdependencies among real-time control variables, already reflects a paradigm shift from *interactive composing* (as in the pioneering work of Joel Chadabe and other composers, in the 1970s) to *composing interactions*. In my view, the shift is especially relevant when composed interactions are audibly experienced as a music of *sound* (timbre composition), more than a music of *notes* (as is often the case with interactive music systems, especially when instrumentalists are involved).

Some interesting research work in physical modelling (e.g. Smith and Smith 2002) shows that even the design of mechanical control devices for computer-operated sound synthesis, far from being a mere question of exerting proper controls over a *separate* sound generating process, can indeed become a direct determinant of the timbral quality of the output. This is especially the case when complex textural sonorities are considered (in Smith and Smith 2002, the sound of the cicadas).

3. WHERE AND WHEN IS 'INTERACTION'?

Notwithstanding the sheer variety of devices and computer protocols currently available, most interactive music systems – including developments over the Internet – share a basic design, namely a linear communication flow: information supplied by an agent is sent to and processed by some computer algorithms, and that determines the output (see figure 1).

This design implicitly assumes a recursive element, namely a loop between the output sound and the agent-performer: the agent determines the computer's changes of internal state, and the latter, as heard by the agent, may affect his or her next action (which in turn may affect the computer internal state in some way, etc.; see figure 2). This recursive element is a source of creative developments, yet it remains purely optional (dashed arrow in figure 2), as the basic communication flow is a linear one. The perfomer is first the initiator agent of the computer's reaction, and only secondly, and indeed optionally, might become the very *locus* of feedback, injecting some noise into the overall system loop.

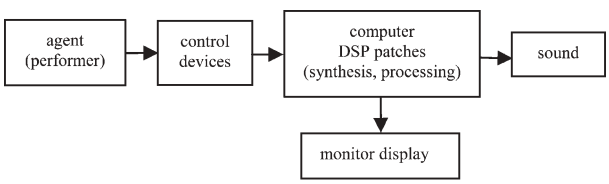

Figure 1. Basic design in interactive music systems.

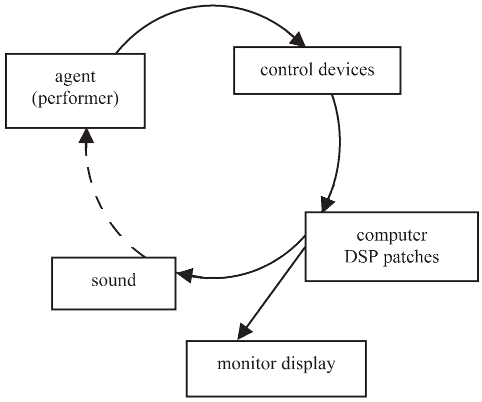

Figure 2. Implicit feedback loop in interactive system design.

Here, 'interaction' means that the computer's internal state depends on the performer's action, and that the latter may itself be influenced by the computer output. One could introduce complex transfer functions in the mapping of information from one domain to another, from control data to signal processing parameters (similar to many musical instruments with their complex mapping of gesture into sound), but that is not essential to the underlying ontology: *agent acts, computer re-acts*. For the proper reaction to take place, in principle there should be no noise in the external conditions, no unwanted or unforeseen actions on the agent's part.

On a closer look, the role of the agent-performer appears itself ambivalent (no criticism implied), in that it is the only signifier of the system's external conditions and, at the same time, it represents an internal component of the overall meta-system including *man, machine and environment*. Indeed, in this common notion of interaction, the agent is indeed the *interface* between the computer and the environment, and, at the same time, it is the only source of energy and change.

Today, most efforts in interactive computer music can be referred to this notion, which also returns in live electronics music (relevant exceptions are noted later, others exist that will go unmentioned here). Even in recent surveys (Battier 1999, Schnell and Battier 2002), a linear design ontology is taken as if it were the only one we may think of when speaking of such things as 'live electronics' and 'interactive music'.

In a broader perspective, in this standard approach, *the sound-generating system is not itself able to directly cause any change or adjustment in the 'external conditions' set to its own process*, i.e. it has no active part in determining the control data needed for its changes of internal state to take place. The only source of dynamical behaviour lies in the perfomer's ears and mind.

Observe, too, that interaction is normally referred to the *man/machine* interrelationship, never to the mechanisms themselves implemented within the computer: the array of generative and transformative DSP methods in interactive music systems usually consists of separate processes and functions working independent of one another. User interfaces do not normally allow to create a communication between DSP processes, but only to independently handle their parameters in the form of separate run-time variables. The agent selects the particular function(s) and process(es) active at any given time, and the output sample streams of active processes are linearly summed together. No mutual influence is exerted among them, no interdependency among sonic processes is implemented.[1] As an example, the sudden occurrence of, say, too dense a mass of notes – or sound grains or other atom units – would not automatically determine, say, a decrease in amplitude (a perceptually correlate dimension of density). In general, adjustments in the interference among sonically relevant parameters are left to the agent. I think these interrelationships may, instead, be the object of design, and hence worked out creatively as a substantial part of the compositional process.

4. FROM *INTERACTIVE COMPOSING* TO *COMPOSING INTERACTIONS*

The very process of 'interaction' is today rarely understood and implemented for what it seems to be in living organisms (either human or not, e.g. animal, or social), namely a *by-product of lower-level interdependencies among system components*.

In a different approach, a principal aim would be to create a *dynamical system* exhibiting an adaptive behaviour to the surrounding external conditions, and capable to interfere with the external conditions themselves. Not only would it be able to detect changes in the external world and 'hear' what happens out there (an 'observing' system, capable of tracking down relevant sonic features in the external world, not demanding this from a separate agent-performer),[2] it would also be able to become a *self-observing* system, that is, to determine its own internal states based on the available information on the external conditions – including the traces of its own existence left in the surroundings. A kind *self-organisation* is thus achieved (von Foerster 1960). Here, 'interaction' is a structural element for something like a 'system' to emerge (Greek *sys-thema* = a gathering of connected components, like a community of agents, or any other complex structure as a result of *syn-thesis*, i.e. com-position). System interactions, then, would be only *indirectly* implemented, the by-product of carefully planned-out interdependencies among system components (see also Lewis 1999), and would allow in their turn to establish the overall system dynamics, upon contact with the external conditions.

This is a substantial move from interactive music composing to composing musical interactions, and perhaps more precisely it should be described as *a shift from creating wanted sounds via interactive means, towards creating wanted interactions having audible traces*. In the latter case, one designs, implements and maintains a network of connected components whose emergent behaviour in sound one calls *music*.

5. AMBIENCE AND NOISE

When a system enters a non-destructive interaction with the surrounding environment (the system's houseplace, literally its οικος), it is called an *eco-system* (*oiko-sys-thema*). In which case, though 'external', the environment is indeed an integral, uneliminable component. Eco-systems are systems whose structure and development cannot exist (let alone be observed or modelled) except in its permanent contact with a medium. They are *autonomous* (i.e., literally, self-regulating) as their process reflects their own peculiar internal structure. Yet they cannot be isolated from the external world, and cannot achieve their own autonomous function except in close conjunction with a source of information (or energy). To isolate them from the medium is to kill them.

The role of *noise* is crucial here. Noise is the medium itself where a sound-generating system is situated, strictly speaking, its *ambience*. In addition, noise is the energy supply by which a self-organising system can maintain itself and develop. Paradoxical as it may appear, no autonomous system exists if no direct access to the external is available to it (in other words: no *context*, no *text*). Indeed, a complex dialectic takes place here between 'autonomy' and 'eteronomy' in all living systems, either human or social (a dialectic

[1]Computer systems capable of 'listening' to instrumentalists, 'making decisions' based on what they listen to, are no exception, as the computer's decision-making usually depends on a predetermined, sonically abstract knowledge-base representation. A survey on 'machine listening' is in Rowe (2001). The typical example is 'score following', where run-time control variables are updated based on the successful or unsuccessful matching of an instrumental performance against a stored event list (score representation).

[2]A similar approach was pionieered by Gordon Mumma in his 1967 composition, *Hornpipe*.

that may eventually bring the reader to issues of a socio-political nature).

In effect, as was made clear by Heinz von Foerster (1960), self-referantial attributes – like 'self-observing' or 'self-organising' – are meaningless unless we also account for the relationship to the ambience, and to the noise that the ambience provides a system with. Noise is a *necessary* element, crucial for a coherent, but flexible and dynamical behaviour to emerge. (In the linear communication flow of most interactive systems, noise remains something to be filtered out in order to minimise odd reactions on the computer's part – and still *therefore* it is, even here, the only source of creative behaviour).

6. THE *AUDIBLE ECO-SYSTEMIC INTERFACE* PROJECT

To deal with these matters in actual compositional work, I think the agent-perfomer should firstly be dropped, and the DSP routines implemented in such a way as to function only based on purely acoustical information including, in particular, the ambience noise. The ambience is the real – not virtual! – space hosting the performance.

Accordingly, I will from now on refer to 'interaction' as not meaning the *man/machine* interrelationship, but the *machine/ambience* interrelationship, and always keeping in mind the triangular, ecosystemic connection, *man/ambience/machine*, that can be thus established (figure 3). Direct *man/machine* interactions (via control devices) are optional to an ecosystemic design (dashed arrow in figure 3), as they are replaced with a permanent indirect interrelationship mediated by the ambience (dashed lines in figure 3).

Also, I will from now on assume all information exchanges – from and to the ambience, from and to the computer, from and to a possibly included agent-performer – to be of a purely sonic nature. I am interested in the interdependencies, connections and disconnections that can be *listened to* across the micro-, meso- and macro-temporal unfolding of sound, as hey are brought forth by micro-time processes (granular rate, or even sample rate). This comes from my own previous compositional efforts in what has been termed *micro-sound*, some of which are described in Di Scipio (1994a) and Roads (2001a: 322). In Di Scipio (1997), 'interactive micro-time sonic design' was discussed.

I started the *Audible Eco-Systemic Interface* (AESI) project three years ago in order to explore the actual implementation (not a formalised model, nor a purely sensuous-aesthetical illustration) of *sonorous niches*, either sounding natural or artificial to the ear. The task is not to evoke existing environmental phenomena, but to create small audible ecosystems that can be coherent in their internal structure and temporal unfolding, and that can develop in close relationship to the space hosting the music and the audience. So far, I developed the project to the point where I could compose two short live electronics solos (mentioned later, but not described in their musical characteristics). A most appropriate public presentation of works thus composed will eventually be that of a large-scale sound installation.

The basic idea reflects a self-feeding loop design (figure 4). A chain of causes and effects is established, ideally without any human intervention but the practical instalment and set-up of everything needed for the performance to take place (loudspeakers, electret condenser microphones, a programmable DSP-based workstation, and a mixer console).

A compact description of the overall process is as follows. (i) The computer emits some initial sound (either synthetic or sampled), heard through the loudspeakers; (ii) this is also fed back to the computer by two or more microphones scattered around the room (their placement is crucial); (iii) the computer analyses the microphone signals and extracts information on relevant sonic features; (iv) the extracted data is used to generate low-rate control signals and drive the audio signal processing parameters (DSP modules I often use here include granulators and sample playback modules); submitted to audio signal processing is the computer-generated sound itself that was initially emitted; (v) meanwhile, the microphone signals are matched against the original synthetic or sampled signal, and the difference-signal is calculated (the

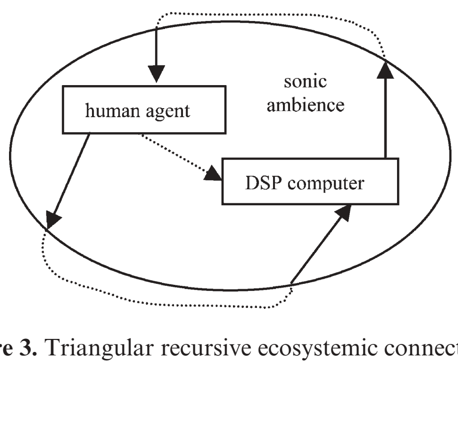

Figure 3. Triangular recursive ecosystemic connection.

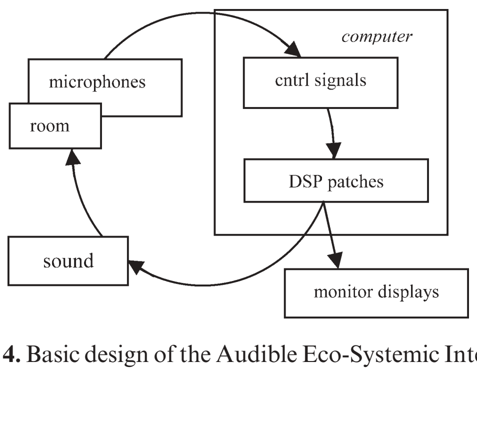

Figure 4. Basic design of the Audible Eco-Systemic Interface.

difference numerical values between original and ambience sound signal, reflecting the room resonances added); (vi) the difference signal is used to adapt a number of signal processing parameters to the room characteristics (the adaptation process takes a variable time-span to complete; see below for a discussion of the system *sensitivity to external conditions*).

All AESI run-time variables are therefore in a constant flux of change depending on the resonances in the room as they are elicited first by the sound initally emitted and, henceforth, by all of the sonorities that are created in the feed-back loop process. The room resonances affect the parameters in the DSP methods implemented, and the DSP output affects the total sound in the room, generating new sonic material as a function of the resonances themselves. With the language of bio-cybernetics, this is a *recursive coupling* (von Foerster 1960). An ecosystem is created by the recursive coupling of an autonomous system with its ambience, i.e. with its medium of existence. In our case, the 'autonomous system' is the array of DSP methods (a complicated signal patch that I designed in Kyma), and the 'medium' or 'ambience' is the real performance space.

Observe that, due to the built-in recursion, all real-time functions operated in the AESI (either at the level of audio or control signals) become *iterated functions*. Were these functions to include nonlinear maps of data, the recursion would cause them to be *nonlinear iterated functions*, which happens to be a peculiar model of complex dynamical systems. Indeed, in principle, the overall AESI process could be modelled in mathematical terms, as found in the theory of chaotic systems (e.g. Collet and Eckmann 1980). But perhaps more significant to the present discussion is the notion that the recursion is structural to the overall design, not optional: once started, the process develops independently of human agents, nurturing itself with the noise provided by its permanent interaction with the ambience. (Clearly, performers could eventually enter the process cycle and contribute to the overall system dynamics.)

7. NETWORK OF TIME VARIABLES

In the AESI design, the main role of feedback is to create control signals, as the system loop is *not* in the audio domain, but in the sub-audio (low, inaudible frequency). This process is heard as patterns of variation in the sound texture, and eventually as the rhythm or pace of an overriding musical flow.

Each control signal in the computer DSP patch has its own sample rate (control rate), equal to the integration time of the feature-extraction method by which it is created. As an example, with amplitude followers, the time-window of the sample averaging process becomes *de facto* the sample rate of the generated control signals.

Control signals are also submitted to a variety of time maps, such as multiple time-dilations (delays of the order of seconds to minutes), time-reverse of control samples, etc. Indeed, the implementation of the DSP component of the AESI project was largely a matter of *control-signal processing* (as opposed to the more normal audio signal processing). I think this area – the real-time *synthesis and processing of control signals* – is rich in musical implications hitherto unexplored in the digital domain (perhaps more explored in the analogue, e.g. the voltage control technology of the 1970s). It raises technical and musical-psychoacoustical questions worthy of further investigation.

All these time-related variables sum up to constitute a network of temporal coordinates of different magnitudes (= several time scales). This allows the overall system loop to bring forth a variety of behaviours in sound, from more textural to gestural or rhythmical, from very dense to sparser. Time variables also affect the relative promptness with which the signal processing methods react to the ambience resonances. Their individual magnitude cannot be established in abstract, and must be carefully and empirically tested on the particular sound material introduced into the system loop. This is because the micro-time characteristics of the input sound in the end contributes to the overall system dynamics (in this sense, all signal processing in the AESI is *sound-specific*, as discussed later). Overall, the network of time variables also contributes to a phenomenon peculiar to ecosystems, namely the fact that important long-term consequences could follow from events that at first may seem marginal.

8. ECOSYSTEMIC DYNAMICS

8.1. Run-time variables

In the AESI run-time process, *variables* are control signals created by processing sonic data extracted from the ambience. Psychoacoustically relevant features taken into account include

- *amplitude*,
- *density of events* (rate of onset transients),
- *brilliance* (or other spectral properties), and
- *transient delay between room microphones* (to detect different 'early reflections' in different places of the room, and tracking other spatial cues, e.g. the occurrence of the perceptual precedence effect in the room).

Pitch and frequency-related data could be exploited, too (with frequency trackers), although I personally tend not to rely on pitched material too much. (In my electroacoustic music, pitch is more often a resultant or by-product of micro-compositional processes, than a determinant factor in the musical flow.)

Based on empirical experience, I think it is good idea to create several control signals out of a single feature-extraction process. Imagine, in a simplest example, the occurrence of comparatively 'dark' spectra in the ambience sound causing (i) an amplitude *decrease* in lower frequency bands and (ii), at the same time, by complementing the numerical value for that variable, a *shortening* of grain durations (shorter grain durations having the effect of a high-pass filter).

8.2. Functions

The DSP component of the AESI includes the following *functions* (or automated controls) described here in their systemic meaning:

- *Compensation*, e.g. decrease amplitude of the input material, when the sonic density in the ambience gets larger. Let's call *memWriteLevel* the system variable that scales the amplitude of input samples before they are written into an internal memory buffer (granulators will later read samples off this buffer). At time t it is calculated as:

$$memWriteLevel_t = 1 - [(dens1_t + dens2_t)/2]^2$$

where *dens1* and *dens2* are the current local maxima (calculated by some other process not described here) of the sound coming over microphones 1 and 2. Thus calculated, *memWriteLevel* is the squared inverse of the room sound max amplitude. By scaling down the new input sound materials, in effect it counterbalances the amplitude of the room sounds when the latter increases. Thus, an equilibrium point is eventually reached, as in a short turn of time the attenuation of new input material will determine a softer total sound in the room.

Another example of compensation is: shorten the grain durations (or other musical atom unit) as the input signal gets louder. Shorter grains will less often overlap among them, resulting in a decrease of the total amplitude.

- *Following*, i.e. run after, and finally match the value of a given variable (as set by some other process), with some delay. This is like the *hysteresis* found in many biological and electromechanical systems.
- *Redundancy*, i.e. support a given predominant feature, e.g. automatically increase the density of generated grains as the external amplitude gets larger. This will increase the perceived intensity (or 'volume') of the total sound, without necessarily boosting the actual signal level.
- *Concurrency*, i.e. support a sonic feature contrasting or even competing with the predominant one, e.g. boost comparatively high frequencies when low frequencies predominate in the room.

As should be clear, the purpose of system functions is to create a network of constraints among run-time variables, and to regulate such constraints depending on both *external* (room resonances) and *internal* conditions (features of the computer-generated sound itself, before it is output). In this way, the DSP routines interact among them, creating a feedback that is heard as patterns of variations in some perceptually relevant dimension of the output sound. These patterns, in turn, influence the continuing *machine/ambience* exchanges, thus affecting the system development in the long run.

8.3. Sensitivity to external conditions

All system functions implemented in the AESI computer component have a variable, automatically regulated *sensitivity to external conditions*. In other words, their response or reaction to the external conditions is not fixed, as it varies in direct proportion to the rate of events (density) and to the absolute local maximum amplitude in the external sound. This is implemented simply by boosting or scaling down all control signals in direct proportion to those external variables: the more responsive the room is to the particular computer-generated material, the quicker and quantitatively more substantial becomes the effect of control signals on DSP parameters.

Clearly, the ambience noise may happen to include random events completely independent of the musical process. The AESI process would not be much affected by, say, a separate cough in the audience. But it would certainly become sensitive to very frequent coughs. In an ecosystemic view, this is coherent and acceptable. A single cough doesn't make for a significant characteristic of the external world, but many do! (We human listeners would behave in a very similar way.)

8.4. Competing orientation criteria

By influencing the *machine/ambience* interaction, functions contribute in the long-run to orient the overall system development, ultimately building-up what could be heard as an overriding musical process. On this aspect, we should consider at least two very general criteria:

- *Omeostasis*, the centripetal tendency to keep to a stable or recurrent behaviour. This marks the system's sonic 'identity' to an external ear.[3]

[3]Listeners are a very special kind of *external* observer or hearer, because their mere physical presence in the room acts as an element of acoustical absorption. Hence they are rather an *internal* component of the ecosystemic dynamics. As is well-known, audience-less rehearsals are far from replicating the real performance context, and even a relatively small audience can deeply modify the room response. In the AESI project, this is not considered a problem, nor an element irrelevant to the music: changes in the ambience will reveal peculiar changes in the overall ecosystemic dynamics, and therefore in the audible results themselves.

- *Omeoresis*, the opposite, centrifugal tendency to meander, following a more varied, random path. This marks the system's ambiguity to an external ear.

A rich and varied system behaviour, making for a desirable performance, is a resultant of the competition of these two. And still, these orientation criteria are patterns arising from the lower-level process operated by the above-mentioned system functions, and not explicitly implemented as such.

9. SOME OBSERVATIONS

In the real-time AESI process, interactions between computer and ambience appear as emergent properties of a self-organisational dynamics. They emerge not only from (i) the mapping of the control signals onto the parameter space of the DSP routines, and (ii) the network of time-variables (integration time in feature-extraction processes, time maps of control signals), but they also emerge from (iii) the particular sound materials introduced into the system loop. The systemic meaning of the input raw sound material is to elicit the room resonances (which will in turn be used to create the control signals driving the audio DSP routines, to which the sound material is itself submitted). But this means, too, that the overall emergent interactions also depend upon (iv) the specific room acoustics, i.e. upon the very material and geometrical characteristics of the room or court, or other place hosting the performance. In the AESI approach, *the overall musical performance stems from the meeting, or the clash, of a particular sound material with a particular venue* (room or other space).

In this perspective, it makes little sense to say that a room has or does not have *good* acoustics. No such value judgement is pertinent when the aim is to meet and welcome, into the music, the particular space hosting performers and listeners, although it's clear that some rooms will contribute more, and others will contribute less, depending on their material and geometrical design. The AESI run-time process unfolds as it 'learns' about the environment where it is set to work. The structural coupling between the DSP system and the external takes place in the medium of sound. In a way not at all metaphorical, *by way of doing something to the environment* (sending sounds to it, thus having it resonate to them), the AESI determines its own internal state as a function of previous ones. 'Learning by doing' clearly echoes a contructivistic view of cognition (a Piagetian perspective).

Because all exchanges between system components take place in the medium of sound, in the approach taken here, *sound is the interface*. All processes or equipment involved, including microphones and loudspeakers, are uniquely vehicles or transformers of *sonic* information.[4] As finally perceived by listeners, sound bears traces of the structural coupling it is born of. Therefore, I think we could speak of *audible interfaces*, meaning interfaces whose process – the continuing mediations between machine and environment, and eventually perfomers, too – is actually experienced as time-varying shapes of sound.

10. PRELIMINARY CONCLUSIONS

A thorough technical description of the AESI is out of the scope of the present paper. It would require details of the DSP methods, including at least the audio signal transformations (several granulation techniques, and automatically controlled sampling), feature-extraction algorithms (averaging processes, filter circuits, logical operations at signal level, etc.). And it would extend to the microphones' technical characteristics, their placement (relative distance and orientation), size and geometry of the room, placement of loudspeakers, etc. The purpose of the present paper is instead limited to introduce an ecosystemic perspective on interactive signal processing, and sketch the design philosophy behind my *Audible Eco-Systemic Interface* project.

In the above described approach, 'interaction' means 'interdependency among system components', and 'structural coupling' between an autonomous DSP component and the external world. The notion that a computer reacts to a performer's action is replaced with a permanent contact, in sound, between computer and the environment (room or else). The computer *acts upon* the environment, observes the latter's response, and adapts itself, re-orienting the sequence of its internal states based on the data collected. At all time except the very beginning, the data that constitutes the ambience to the system (noise in external conditions) is a result of previous interactions. Therefore, not in a merely metaphorical sense, the overall process develops based on its own history, i.e. on the sequence of past interactions. That's the way by which ecosystems are cognisant of their past and do exhibit a kind of *memory*.

Reflecting a radical constructivistic epistemology (as in the work of philosopher Ernst von Glasersfeld and bio-cyberneticians Humberto Maturana and Francisco Varela), the *Audible Eco-Systemic Interface* implements a 'structurally closed' yet 'organisationally open' process, to use terms borrowed from what was once called 'system-theory' (von Bertanlanffy

[4]In a similar vein, Lewis (1999: 104) writes: 'There is no built-in hierarchy of human leader/computer follower: no 'veto' buttons, pedals or cues. All communication between the system [he means the *computer*, which in the AESI approach is just a system component, though] and the improviser takes place sonically. [Such] a performance . . . is in a very real sense the result of a negotiation . . .' While in Lewis' approach a human 'improviser' is the only 'ambience' to the computer, in the AESI project that would represent just another element inhabiting the shared ambience.

1968). 'Closed' because no component can be removed or altered without causing a collapse of the overall system, or a substantial change of its behaviour. In this sense, 'closure' preserves the system identity, heard as the *timbre*, the specific sonic presence of the implemented ecosystem. 'Open' because the random configuration of system variables and the sequence of internal states are not pre-determined, and rather depend on a close and permanent contact with the ambience and all events happening therein. 'Openess' reflects the system's ability to creatively adapt to, and itself act upon, the ambience. This is heard as variations of the system timbral identity.

10.1. Addendum

A major source of inspiration behind these efforts was for me the observation of processes by which natural and social phenomena emerge from, and nurture themselves with, noise. Another was the hand-made algorithmic process by which Iannis Xenakis composed *Analogique A et B* (for 9 string instruments and tape, 1958–1959), an often-reputed marginal work of his, yet one that raised all-important general issues in composing. Last but not least, I should mention my own idiosyncratic conviction that, sound being the primary domain of experience in all electroacoustic musics, algorithmic composition (formalised approaches) and timbre composition (sonic design usually pursued in more qualitative, intuitive approaches) can merge and fuse together, yielding into a sonic art that both transcends and collapses the traditional dichotomy of *sound materials* and *musical form* – allowing *timbre* to be truly experienced as *form* (Di Scipio 1994b). That the latter notion – timbre as form – could materialise in live electronics situations, with compositional implications impossible in non-real-time media, has always been of profound interest to me (my first efforts in this regard include the 1993 work, *Texture-Multiple*, for small chamber ensemble and interactive signal processing, and the 1998 work, *5 difference-sensitive circular interactions*, for string quartet and interactive signal processing).

As we have seen, ecosystemic interactions are *context-specific* not only in the sense that they depend on the particular performance space, but also in the sense that they depend on the specific sound material being used. The micro-time characteristics of the latter may interact in constructive and destructive ways with the built-in network of time-variables and with the ambience. Ecosystemic interactions are *sound-specific*.

In real-time computer music applications, an example of sound-specific musical signal processing is the granular time-shift operated in Barry Truax's GSAMX program (Truax 1994). There, the duration of an input sound is stretched according to a *real: stretched* ratio that is directly proportional to the current amplitude of the input material. When the latter gets softer, the ratio gets smaller, and eventually silent segments (pauses) in the input material, detected as amplitude levels below some threshold, are not stretched at all, or they are made much shorter than real. The dependency thus created between amplitude and duration, at the level of signal processing, has direct compositional implications. Truax calls this an *automated control* (Truax 1994: 42).

The idea of the *Audible Eco-Systemic Interface* can be seen as a systemic generalisation of that notion of automated, sound-specific control, and materialises in DSP methods using an array of mutually connected sound variables of psychoacoustical relevance. Ultimately, the *Audible Eco-Systemic Interface* is the same as a *computer program* operating at a micro-time scale, with output data structured in a purely audible format (rather than printed, graphical, or anything else). In this sense, it represents a real-time algorithmic-composition approach, but one whose by-products are mainly heard as a timbral construction. The merging of *formalised* (algorithmic composition) and *sonic* (timbre composition) is made by means of ecosystemic principles.

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As already mentioned above, in passing, the current implementation of the DSP component of the AESI was made with SymbolicSound's KYMA5.2 (running on the CAPYBARA320 DSP engine). The first work I composed with it, the live electronics solo, *Audible EcoSystemics n.1 (Impulse Response Study)*, also requires two condenser microphones, and an audio track of short to shortest sound pulses as the raw sound material introduced into the system loop. I created the pulse material with the PULSARGENERATOR program (Roads 2001b), during a compositional residency at CCMIX (Centre Creation Musicale Iannis Xenakis, Paris, April 2002). *Audible EcoSystemics n.1* was premiered in Stoke-on-Trent (Keele University, October 2002), and was soon played again in Leicester (City Gallery & DeMontfort University, October 2002). In these UK concerts, Kurt Hebel took care of the set-up and supervised the overall performance. On the occasion of the Italian premiere, in Florence (Centro Tempo Reale, May 2003), I could more thoroughly work out the overall ecosystemic dynamics, with the assistance of Alvise Vidolin. Another performance took place in Coimbra, Portugal (Musica Viva festival, September 2003), with technical support by Carlos Alberto Augusto.

In a second live electronics solo, *Audible Eco-Systemics n.2 (Feedback Study)*, the only raw sound material is Larsen tones created live by carefully handling the gain of the two condenser microphones, using a (possibly analogue!) mixer console. At the

time of writing, this work is scheduled for premiere in Ghent (IPEM, October 2003).

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