Music as Embodied Action:
Interfacing autonomous systems and rhythmical expression

Jonathan M Bedworth

University of Wales College Newport

PhD Thesis

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed .... (candidate)

Date ....

STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated.

Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

Signed .... (candidate)

Date ....

STATEMENT 2

I hereby give consent for my thesis, if accepted, to be available for photocopying and for inter-library loan, and for the title and summary to be made available to outside organisations.

Signed .... (candidate)

Date ....

Contents

Acknowledgements

Undertaking this research has been in many ways a wonderfully rewarding experience. Much of this has been gained through the people that I have met as a result of research, many of which have all left their mark in terms of the many and diverse orientations that it has come to embody. I would like to thank Professor Roy Ascott for accepting me onto this research program, and both Roy and Mike Punt for their supervision, suggestions, and most importantly, their words of encouragement over this period. Their support has enabled me to take some intuitively felt ideas about music and explore these in a disciplined context of both practice and theory. It has consequently been the realisation of a rare opportunity. Furthermore, this research would simply not have been possible without financial support from UWCN, in the form of a three-year bursary.

In pursuing my music practice, I have had many collaborative experiences over this period which have served to enrich a critical understanding of my own practice. In particular, working with Ben Simmonds has resulted in many musical insights that have become central points for exploration in my thesis, many of which I feel would not have been as possible if pursued in isolation. The involvement of others within this collaborative environment has also on occasion brought similarly fresh perspective and technical skill to the creation of our music, in particular those from Marc Ziman and Mark Fanciullacci. Also, thanks to all those at Stompa Phunk Music in Brighton.

Academic collaboration and discussion with others have also shaped research ideas. In a significant way, important aspects of this thesis reflect my subsequent interpretation of the suggestions and orientations of others involved in different lines of research. This has included both Mike and Roy, and, in the research's early stages, Simon Waters. Simon helped deepen my understanding of certain musical discourses, then only implicit, within my own perspective and added a certain musical 'legitimacy' to my continued research. Discussions with Ezequiel Di Paolo at Sussex University have helped deepen my understanding of the significance that robotics research has within the context of my own research. Also, thanks to James Norwood, from STAR in Plymouth University, whose interest in theatre prompted some interesting dialogues about the nature of interactivity, and Drew Hemment for the great experience that was FutureSonic, and our collaboration at Consciousness Reframed 2. Working with Drew helped to ground my theorising of musical practices in contexts that were reflective of my own love of popular dance music. In this regard there are people who I have never met, like David Sudnow, Kodwo Eshun and John Miller Chernoff, who through their books, have opened up new musical worlds to me, or helped validate my own intutions.

There are also many people I could mention, outside of the immediate research context, who for more general reasons have supported my research, like my parents, Lou Mason, Gill Hunt and James Higham. Finally, thank you Pilar Canas for your continued support and friendship over much of this period, and for your own particular insight.

Summary

This thesis concerns a particular relationship between music practice, computer technology and the importance of rhythm as a vehicle of musical expression. The intention is to explore new technology to allow for computer-mediated improvisation of rhythmic forms that are derived from a consideration of West African drumming. In developing the thesis an analysis of personal practice is used to reveal the role of music technology and the musical aims implicit behind its adoption. The exploration of rhythm is seen as important both compositionally and as a means of mediating collaborative musical expression, and can be understood as the exploration of a particular form of complexity. In considering its importance, the idea of music as 'embodied action' is discussed and music is considered as a form of knowledge and communication equal to spoken language but different from it. These considerations form the background for a discussion of the musical potential that may lie within certain key developments in artificial life, situated robotics, and the computer modelling of perception. These technologies are looked at for their ability to recognise rhythmic complexity and to be able to suggest subtle adaptations of complex rhythmic forms. A proposal of an 'adaptive rhythm synthesis' is put forward. In its consideration, the rhythmic structures and improvisational styles found in West African music are seen to pose particular challenges for computer modelling and a range of possible solutions is explored. A consideration is also given to the nature of machine 'autonomy'. It is suggested that the progress may lie in some combination of these solutions. Finally, some thoughts about the relationship between art, music and science are discussed.

Introduction

This thesis concerns a particular relationship between music practice, computer technology and the importance of rhythm as a vehicle of musical expression. Its focus therefore is found within the relationship between these. The intention is to explore new technology for the exploration of rhythm, but which part of the compositional process is of interest? The music studio can be seen as a kind of ecology. The individuals within it, the technology used, and resultant music itself, are part of a highly interdependent process that is difficult to analyse into separate parts. It becomes important to explore the quality of experience within the studio and through this, reveal the implicit aims of practice and its relationship to the role of technology.

The studio itself can be seen as a musical instrument, and working within it, we become immersed in a network of processes supported and extended by technology. The technology therefore plays an 'active' role in the suggestion of new musical forms and their realisation. A central piece of technology is the computer and a significant part of the compositional process is realised through virtual musical reality, enabling the exploration of hybrid musics.

Within this environment, rhythm becomes seen as a means both to contextualise contrasting musical elements into hybrid musical forms, and as a means of social negotiation of collaborative musical expression. In part due to its hybrid nature, the music is not based on any existing shared compositional model and is open to a number of simultaneous interpretations. It can be seen as a particular form of complexity. The music as composed emerges through a negotiation of this complexity and involves a significant degree of improvisation. It is important to be able to 'compose in the moment'.

The composition of music is therefore considered as a form of situated communicative activity occurring within the collaborative environment of the studio. The expression of music comes to be seen as a form of 'embodied action' experienced as much through the body as through the ear. It is a form of knowledge at least equal to that of language and, in some sense, a form of communication that is experienced 'directly' in a manner different from spoken language.

West African drumming seems a good model to consider as an example of a shared negotiation of social and musical complexity. This music is simultaneously an expression of individuality and sociality. A significant vehicle for this expression occurs through the interplay of rhythm. This interplay and the subtle improvisation inherent in this music are already hinted at within personal practice, although not fully realised. This model can also be applied to interactive environments and the negotiation of social complexity brought about by the computer.

In the present context, computer technology is therefore considered in relation to its ability to support the evolution and adaptation of musical forms that owe a significant influence to these forms of interplay and improvisation. The emphasis is not on embodiment through the interface, for where *is* the interface between us and our technology? Instead, the computer-mediated generation of virtual rhythmic environments becomes another aspect of the immersive quality of the studio. The computer is in no way more musically aware or 'embodied', but instead produces new forms of adaptive behaviour that increase our own sense of embodiment and spontaneity within the compositional process, through the behaviour of the sounds themselves.

These considerations form the background for a consideration of the musical potential that may lie within artificial life and situated robotics in relation to the challenges posed by artificially creating certain formal elements of African rhythmic form and improvisational techniques. The intention is to synthesize new forms of machine behaviour that in some way reflect the behaviour, as expressed in sound, of an African drum ensemble. Specifically, these technologies are looked at for their ability to recognise rhythmic complexity and to be able to suggest subtle adaptations of complex rhythmic forms. In short, the question concerns how truly autonomous can the computer become in supporting our own embodied musical expression?

The contribution to knowledge is contained in a set of some speculative suggestions for the design of future interactive environments that are considered in relation to the kind of rhythmic, and improvisatory, interplay found in West African drumming. Future developments are seen as arising from some combination of these technologies, but at this stage it has been impossible to exactly say how.

The presentation of this thesis is comprised of three interrelated parts. A significant element consists of the results of a body of practice. This is presented in the format of a compact disk of original musical compositions[1] stretching over the period of this research. However, all of this is representative of a continuing musical collaboration, particularly with my cousin, Ben Simmonds, so I do not claim overall authorship. It is suggested that understanding part of the thesis will be derived from listening to these pieces in chronological order, reflecting the development of a set of ideas in sound.

The second element consists of a linked narrative. This serves to highlight and elaborate on research aspects that are only implicit in the actual music. It is hoped that this will then serve to contextualise an evaluation of the music, for music appreciation is a highly subjective activity.

The third element is a collection of papers that have been published over the period of this research. It is included in recognition of the way in which the focus of thesis has emerged over the research period. The papers form a less important part of the submission, but can be read in order for the reader to gain some appreciation of the evolution of ideas within the research process. They can therefore be read separately as a record of the emergence of a set of ideas.[2]

The work is presented in the following chapters.

Chapter 1. *Methodological Considerations* discusses issues that have arisen in the construction and application of a methodology for this enquiry. Methodological issues within this research have involved the design of technological systems for art practice, emergent research contexts, the role of practice and interdisciplinarity.

Chapter 2. *Musical Progress and Technology Design* is concerned with some general orientating issues regarding the relationship between technology and human expression that serve to orient the reader to my general underlying position regarding the role of technology within music practice. Some specific issues regarding technology in music practice are also considered. Technology in all its forms is seen as grounded in, and an extension of, human intention and ideas of human machine symbiosis are explored particularly in terms of the computer's ability to facilitate the development and exploration of virtual worlds.

Chapter 3. *The Music Studio* discusses the music studio. The idea of the studio as an ecology is discussed, and then aspects of this musical ecology are highlighted within the studio environment, and their musical significance is discussed. Practice within the studio has begun to reveal intriguing aspects of the nature of rhythm and these are contextualised in terms of wider understandings of music. The role of improvisation within the studio environment is also considered.

Chapter 4. *Rhythmical Complexity and Embodiment* elaborates on some of the issues discussed in the previous chapter, which relate to ideas of musical complexity and embodied music practice. Also within this chapter a model of formal aspects of African rhythm is presented as an example of musical complexity. A couple of examples of its existing influence within the interactive arts are also considered.

Chapter 5. *The Challenge of Adaptive Rhythm Synthesis* represents a synthesis of some of the ideas presented in the previous chapters. This chapter considers some research within neuroscience, cognition and robotics research that may, when applied to music technology, help to facilitate the evolution of novel machine-mediated polyrhythmic forms. In conclusion, some thought is given to the relationship between art, science and technology.

As a final note, throughout the text that follows I consciously use the idea of human 'expression' in place of the word 'creativity'. By expression I concur with David Rothenberg's notion that it is "the process by which a human idea is made into something else."[3] This serves to avoid the thorny issue of what counts as creativity and whether machines could be considered as 'creative'. The term 'expression' also serves to highlight that a significant point of music is as a communicative act and in this sense it is doubtful whether machines have a desire to express anything.

1. Methodological Considerations

This section discusses some methodological issues that have arisen during the formulation of this thesis. As well as an understanding of the 'problem', the kinds of methodologies considered for its investigation have evolved during the course of this research. In some important sense there has been a methodology in finding a methodology.[4]

The issue of methodology is one that concerns much doctoral Art and Design research[5] because the area itself is a relatively new one. Darren Newbury's discussion of this subject leads him to suggest that:

> "Art and design research is at a formative stage. It is possible to argue that the field lacks maturity in research terms, and has yet to develop a distinctive culture of research. Researchers in the field are only just beginning to develop a language of research with which to talk between themselves and, importantly, to those in other academic disciplines about the work they do."[6]

What follows is a discussion of some of the factors involved in the creation of just such a 'language of research' to pursue the aims presented in this thesis. These cover a range of issues that have arisen relating to an evolving research context, the need for innovative design, practice as a method of enquiry, interdisciplinary concerns, and the role of subjectivity in the research process. Each of these will now be discussed in the following sections.

1.1. Documenting an Emergent Context

As suggested by the opening remarks of this chapter, in seeking to define the very nature of the research focus, the very context of the research has evolved over time. This appears to be a common feature of Art and Design research as such research often seems to involve a process where the context itself is changing.[7] The development of both theory and methodology begin to take on the appearance of something far more evolutionary, as if one were witnessing a kind of unfolding narrative involving unexpected character developments and plot twists.[8] Descriptive categorisations of experience are transformed as part of this process.

The nature of this process contrasts to one where research is considered as a series of discreetly compartmentalised phases consisting of an initial literature survey, subsequent formulation of a hypothesis and methodology, followed by the testing of this hypothesis. The latter approach places an emphasis on the formation of categories that become fixed early on in the form of a hypothesis. Instead, it can be argued that the language of theory should not be forced to fit such initially preconceived frameworks, for this acts to constrain what may emerge from the process of research.

An inspiration for a more evolutionary methodological orientation was found in the social research methodology of Barney Glaser's *grounded theory.*[9] While its explicit method is not followed here, it serves as recognition of how hypothesis can emerge through the process of research. This kind of approach has value for art and design researchers. Justin Marshall, researching design at University of Wales Institute at Cardiff, has suggested that:

> "This method strikes me as appropriate because theory emerges from the data (theory emerges through practice of analysis), i.e. the method is not designed to test a preconceived theory but to develop a hypothesis."[10]

Approaches to grounded theory recognise how theory emerges through the process of research. For Strauss and Corbin, it is:

> "... inductively derived from the study of the phenomenon it represents. That is, discovered, developed, and provisionally verified through systematic data collection and analysis of data pertaining to that phenomenon. Therefore, data collection, analysis, and theory should stand in reciprocal relationship with each other. One does not begin with a theory, then prove it. Rather, one begins with an area of study and what is relevant to that area is allowed to emerge."[11]

Part of the problem in documenting this research has been in being able to sufficiently describe and categorise its relevant aspects so as to enable the construction of a linked narrative that complements the submission of music. In an important sense, much of the evolving understanding has fed directly into music practice and compositional strategies and writing the linked narrative has meant unravelling the changing influence of theory that has implicitly acted within the context of practice over time. Part of the solution has been to provide, in the appendixes, copies of various papers that I have published over the period of researching this thesis, that act as snapshots of my thinking over this time (see *Appendix 1 – Published Papers*).

1.2. Innovative System Design

The objective of this research has always been related to the design of a technology for music practice. The initial approach taken was understood primarily as an exercise in system design, which promoted an interest in engineering methodologies.[12] The research process became seemingly synonymous with one involving the systematising of a 'solution' to a design 'problem'. The result would be a constructed or programmed artefact that would then serve as an 'existence proof'[13] for the feasibility of the approach. This was to consist roughly of the following phases:

1. *Analyse the existing 'system'.* The system at this early stage was considered to consist of a user engaged with the computer in the pursuit of 'musical aims'.

2. *Identify system 'shortcomings'.* A major 'shortcoming' of this 'system' was a perceived 'distance' between musical intention and the actual result realised through the computer. An understanding of this seemed to revolve around the current relationship between the user and computer in terms of the physical interface between the two, and the kinds of musical responses that the computer was able to make in relation to the intentions of its user.

3. *Propose avenues for 'improvement'.* The assumption here was twofold: Firstly, the physical separation between user and computer could be addressed by a consideration of new interface technologies. Secondly, the computer's responsiveness and adaptability to musical gestures could be enhanced by an exploration of highly interactive generative techniques for computer music composition.

4. *Construct 'experiments'.* A series of musical experiments were to be constructed consisting of an interface apparatus whose input and output was to be mapped to and from generative and adaptive computational processes.

5. *Evaluate results and suggest further work.* These experiments were to be evaluated in terms of their impact on practice, whether they facilitated closer interaction between musical intention and the machine behaviour. The criteria for such evaluation are difficult to express objectively, and therefore were most likely to be described in terms of what 'felt right', was 'musically rewarding', and so forth.

The initial attempt at seeking to approach the problem in this way is probably a reflection of my own background in commercial software design, where factors such as the nature of the user, the role of the computer, and the actual task to be engineered in software are generally more clearly defined. Examples of this include the design of databases and graphical front ends for business applications. This methodological orientation assumed that, in a similar way, relevant aspects of the musical problem could be largely specified formally at the outset. It was assumed that the 'real research' then lay in development and testing.

This approach turned out to be inadequate for the eventual direction of this enquiry. While more straightforward software design problems may invite such structured methods, seeking to apply it to the design of 'artistic systems' presents an interesting challenge. The problem is far from being as clearly defined as it is for commercial software design.

The problem can be understood as one of *innovative*, as opposed to *routine* design. Jim Thorpe suggests that while routine design "lies closer to deduction with calculated reason", innovative design "invokes the magic of inventing the design problem to be solved by the designers".[14] This invites consideration of alternative methodologies. Thorpe suggests:

> "Design activity concerned with a known problem for which known ways of proceeding exist invites a different view of methodology from design undertaken in response to a need which is felt but is not fully articulated and for which in consequence issues about ways of proceeding have not yet arisen."[15]

In the present context, as the designer, I am faced with trying to combine musical intuitions, aesthetic concerns and practical knowledge with a sufficient understanding of how to gain enough experience in the relevant technical issues to be able to judge which appear most promising.[16] Navigating through this may involve collaborations with engineers[17] and computer programmers or the designer themselves becoming better able to engineer the materials or program computers. The computer becomes a new material for artistic exploration through speculative programming.[18]

Important within this approach is the use of metaphor. Metaphor serves to promote novel understandings as we see one thing to be *like* another.[19] By seeing one thing in terms of something else, we map the understanding we have onto the new situation and see it in a fresh way. This can result in new insights that enable us to focus on different aspects of a situation or thing.

For Thorpe methodologies are needed that are able "to create enough metaphor to glue together organising thought with design activity," rather than focusing on the modelling of systematic knowledge, for designers are "magicians who progress from fiction to faction." Such a process requires a more open-ended discourse that "does not move too fast towards definition."

> "In the activity of designing [designers] move from the status of specialists in skill and generalised knowledge of design problems, to that of bricoleur, bodging their way through towards condensing action and method into artefact, and finally into skilled action and expanded experience."[20]

In contrast to methods that focus too much on formal understanding Thorpe suggests designers find ones that consider "how to work in the gap between intention and action."[21] The art making process contains elements that can be considered 'non-formal', and these should therefore come to constitute valid aspects within research strategies for art and design. For Carole Gray and Ian Pirie

> "Intuition, innovation, subjectivity, risk, experiment and practice is embedded in the process of 'creation'. Human responses to these 'creations' (be they works of art or products designed for specific functions), are also governed by equally complex systems. 'Taste', for example, is affected by many factors. It has a historical past with association, and memories of people, places, events and objects and can also have a

present and future with associated self-reference to portray personal values and aspirations.

The holistic complexity of many of the areas of 'artistic' research practice in Art and Design, sometimes regarded as 'chaotic', cannot and does not conform to conventional measurable systems. Research of this nature is extremely difficult to carry out and evaluate if it tries to precisely emulate research models developed by scientific disciplines."[22]

In the context of the present research, the scope of my enquiry has expanded beyond the initial idea aimed at solving a problem, to one that involves a significant aspect of *problem creation*.

1.3. Theory and Practice

The motivation for this research was in exploring implications arising from personal practice in the hope of designing a piece of technology to further its aims. In first seeking to design software, to the wider realisations of the embodied and communicative value of music as a form of knowledge, a strong element of practical exploration has always been the aim and vehicle of this expression. In some sense there has been always been a perceived "need to discover or verify something through activity."[23] What has changed is the type and role of practice, which has invited consideration of several kinds of methodological relationship between theory and practice.[24]

Practice is seen as "a form of knowledge in action,"[25] a knowledge of *how* to do things and not necessarily *about* them, a significant aspect of which consists of *tacit* knowledge.[26] Within an academic context the role of such practice may in some way be seen as subordinate to that of theory. The current 'problem' of art and design methodology may relate to inherent historical bias against practice within academic traditions that have tended to favour theory as a more legitimate kind of knowledge. Scholastic 'rigour' is associated with notions of 'objectivity' and 'truth',[27] reflective of a philosophical orientation, which we may trace from Plato through Descartes up to modern positivism, which equates 'truth' with detached objective descriptions of the world. Here, as philosopher of technology Don Ihde suggests, "[t]rue knowledge is knowledge of the forms, or ideas which are supposed to be free of all taint of embodiment."[28]

Such a tradition poses an interesting challenge for the supposed academic legitimacy of art and design research. For Plato theory is the highest level of such knowledge, and art it's lowest. For philosopher of science Paul Feyerabend:

> "According to Plato, theoreticians find truth and artisans create useful objects. A carpenter who tries to make a good chair takes his cue from a theoretical entity, the ideal chair... A painter... [c]oncentrating on the material chair (which is already a bad copy of what a good chair should be)... imitates the way in which it appears when

viewed from a certain direction. His product is not only useless...it is also deceptive... clever painters... *intentionally replace reality by a chimera*."[29]

James Wood discusses how historically within art and design separate theoretical and practical traditions have "left us with two incommensurate ideas of knowledge", these being 'truth oriented' and 'task oriented', the former being explanatory and the later about 'situated actions and judgements'.[30] Similarly, within computer systems design Karamjit Gill refers to the 'rationality of the rule' reflective of an historical trend where design is separated from doing. Importantly, knowledge that cannot be systematised into rules, such as tacit knowledge, is abandoned resulting in "systems which map only part ... of the reality."[31]

Given this historical bias it is important to actively question these assumptions and ask, does practice and our supporting reflections on it invalidate the claim to knowledge equal to that of theory? According to philosopher of science Paul Feyerabend

"The distinction between theories that are related to truth and observations or skills that are not – and the corresponding dichotomies of real/apparent, objective/subjective, knowledge/opinion – became important ingredients of Western thought.[32]

This viewpoint arguably leads to problems in science.[33] Through Art and design research we can reconsider these dichotomies and reconfirm the interdependence of theory and practice.[34]

An important consideration is found through a reconsideration of the relationship between perception and conception. Instead of viewing conception as detached 'mental' processes following on from, and separate to, supposedly more physically embodied processes of perception, these processes can be seen to arise together through a reciprocal relationship.

William Clancey discusses how the way we perceive, act and conceive within a situation are deeply interwoven in a mutual relationship and how we understand and represent the world is a reflection of this.[35] In his argument he refers to Donald Schön. Schön's 'reflective practitioner' recognises that

"He shapes the situation, but in conversation with it, so that his own methods and appreciations are also shaped by the situation. The phenomena that he seeks to understand are partly of his own making: he is in the situation that he seeks to understand."[36]

Metaphor stimulates both practice and our wider conceptions of that practice. In seeing one thing to be *like* another our perspective on both is changed. Clancey illustrates this sense by discussing the significance of Schön's observations of a group of artists seeking to invent a synthetic paintbrush. In pursuit of this, through seeking to understand how an existing paintbrush worked they were able to reconceive of the paintbrush as a kind of pump. They were then able to look again at the process of painting and this in turn changed their ideas of what a pump was. This cross over of metaphor changed conceptions of both painting and pumps. Furthermore, none of the definitions or data was fixed in this relationship and this process occurred during "the concrete, sensory experience of using the brushes and feeling how the brushes worked with paint."[37] For Clancey, this is an example of the power of metaphorical thinking.

> "In perceiving and saying that one thing, the paintbrush, is an example of something else, a pump, we change both how we view paintbrushes and how we view pumps. Thus, the metaphorical conception is *generative* of both perceptual features and descriptions. ... The new way of seeing and the tentative way of talking arose together, but the painters don't yet have a descriptive model to explain this relation."[38]

The language we use becomes more than a descriptive tool. In his consideration of innovative design, Jim Thorpe suggests that theory forms an essential part of the practice of design, allowing us to "connect up words and action anew."[39] We fashion language in a 'language of struggle' to enable us to regain the kind of precision and the clarity appropriate to carrying out our craft work."[40] Therefore, as Clancey suggests elsewhere, the dualism of theory/practice is a false one:

> "The interplay by which practice (what people do) and theory (descriptions of behavior and the world) shape each other is dialectic. What people do and produce is not dictated by the theory. The value of a theory, by this view, is not simply in how it corresponds to past practice, but in how well it serves to guide future practice."[41]

Music practice serves to challenge and shape categories of experience that become new sources for theoretical contemplation. Theoretical insights then become hypotheses for certain musical explorations, the results of which guide further theoretical reflection in what can be considered to be a mutually evolving relationship. Indeed, as IRCAM researcher Andrew Gerzso suggests, a strategy for developing new music technologies should include "the incorporation of the elements of the musical vocabulary as they emerge in musical practice."[42] In this I am truly a participant-observer within my own research practice.[43]

1.4. Interdisciplinarity

The theoretical ground covered in my research covers some diverse disciplines, considering several large and interrelated questions. A seemingly necessary interest is focused on a complex of scientific, technical and musical issues and this makes the nature of this research highly interdisciplinary, perhaps even transdisciplinary as elements associated with each discipline come to form the substance of a new field of enquiry.[44]

A persistent theme has been that, in widely different disciplines, researchers seem to be asking the same kinds of fundamental questions. In carrying out my research it has therefore been extremely difficult to know which discipline best reflects the essential essence of what I am seeking to express through my research. The overall sense is that it has been necessary to become simultaneously aware of unifying perspectives within a multiplicity of differing subjects, while not delving too deeply into any single one.

Such an approach may leave what is discussed here open to criticisms of insufficient depth in any one field. However, to focus on one of these elements in isolation would mean losing the necessary richness that is derived from the interaction of these diverse elements, a richness that is considered essential in attempting to illuminate where the central area of concern actually lies. This is because, ultimately, the essential thesis is balanced, somewhat precariously, between their differing influences. Therefore a central challenge of this research has been to provide a coherent account of how these diverse elements relate, as well as a methodological means to explore, integrate and focus these diverse elements.

A consideration that arises from this concerns the potential readership of this work. The language used in this research is derived from a number of disciplines. A particular interest has become centred around relationships between science and music. A problem when elaborating on key points is then one of sufficiently grounding understanding of the musical and scientific language used so that the readership understands its significance. When such diverse terminology is used there is some inevitable simplification, and some of the finer points get lost.

Artists may encounter a lot of scientific discourse, particularly when they are concerned with artificial life and adaptive systems. Terminology can be referred to without question, but within science it can have very precise, even mathematical definitions, as, for example, do the words 'emergence', 'self-organisation', and 'complexity'.[45] In order to be able to say anything at all, to progress one's own perspective, it is arguably necessary to adopt less precise definitions. These looser metaphors can be useful as catalysts for artistic imagination. Sometimes however, a deeper consideration, or an attempt at a more precise definition, can be similarly fruitful. Such scientific terminology may be more contentious within the field from which it arises than it may appear to those on the 'outside', so to speak. The exact meaning of terms may be less universally accepted than commonly used scientific concepts like, say, the word 'gravity'. Here a consideration of the subtleties of such scientific debates can actually enrich artistic understanding. It becomes a matter of some subjective balance as to which approach - specific and detailed or more metaphorical - is adopted in elaborating one's own viewpoint.[46]

I would also like to mention the dangers of uncritically adopting scientific metaphors, for they can reflect 'a hidden metaphysics'.[47] A particular concern is when biological metaphors are used uncritically, for they may reflect implicit social ideologies[48] or simplistic interpretations of biological process, a current example of the latter seemingly being that of the *meme.*[49]

Through a consideration of these various concerns this research has become focused on issues within *both* science and art. Being engaged in art does not mean that one is doing something that is opposed to science. Instead, Art may explore 'scientific reality' on its own terms.[50] Therefore it is simplistic to refer to the idea of a monolithic 'scientific method' and set this in opposition to art and music. This point is well made by Darren Newbury in discussing art and design research:

> "The notion of 'scientific method' has become something of a straw man in debates about art and design research. The artist's engagement with complexity and freedom of thought and action are counterposed to the scientist's control and reductionist modes of thinking ... the notion that only research utilising the 'scientific method' can be worthy of a PhD is something of an extreme point of view. And indeed the notion of a pure scientific approach is probably not adequate for dealing with research in science either. Researchers in art and design that seek to define their own research practice and philosophy in opposition to positivism and 'the scientific method' are in

> danger of attributing a fixity to existing research methodologies that is neither credible nor useful. The notion of the scientific method is in most cases simply a shorthand way of dealing with a range of criteria that can be applied to research ... some of which may be entirely appropriate to particular research that is carried out in art and design."[51]

My research has not sought to use scientific or quasi-scientific approaches that attempt to 'reduce' what is observed to measurable quantities. But debates within science have directly informed and enriched its progress. Furthermore, it is arguably seeking to be about *both* art and science.

1.5. Subjectivity in the Research Process

The research reported here represents a highly subjective synthesis of others' viewpoints, underpinned by insights gained from personal practice. As an observer I am an integral part of the process. Within science and art in the twentieth century there has been growing acceptance that the observer in part creates what is observed through the act of observing. We no longer can be said to stand in some privileged position that is apart from the phenomena we observe. Here the 'Newtonian' universe becomes one of several possible perspectives as this subjective 'position' of the observer allows for multiple perspectives, an idea expressed simultaneously within cubism, quantum physics and relativity theory.[52]

I would like to conclude this chapter with a final thought on actively acknowledging, and expressing, the personal orientation of the researcher within the text. Paul Robertson notes how emotional factors, which serve as inspiration for the scientist, are removed from scientific papers and reports of its methodology. This use of 'objective' language serves to help us describe and define but removes us from what we observe. In contrast to dualistic viewpoints prevalent within our own systems of thought, ancient esoteric systems of knowledge, like the Greek triadic system, contained a third aspect.

> "It is one of the fundamentals of such esoteric systems of knowledge that they contain three such forces of energy. There is a fundamental difference here with our conventional science that always tends towards a duality of thought. For example, Western science tends to recognise action and reaction as cause and effect but is less likely to recognise the third, subtler, possibly emotional force in any objective measurement. This third force often seems to assume the character of a change of perception or change in attitude of the observer."[53]

The dualism of objective/subjective is more apparent than real and how we view a system is a reflection of our orientation towards it. In recognition of this basic position, within the text I often use the first person, 'I', to denote when the viewpoint expressed is my own, and 'we' to indicate the involvement of others, which can on occasion mean an explicit attempt at including the reader of this work. I hope that this is an acceptable format, for our subjective involvement is part of the 'facts' we seek.

2. Musical Progress and Technology Design

A consideration of technology forms a central and recurring aspect of this research. This chapter therefore considers some issues relating to technology that serve to contextualise the subsequent discussion. Significantly, an idea of what technology is and does has expanded through this research process. This has been a reflection of a focus that has evolved from a primary concern with system design, to one involving a consideration of how and why the computer plays a role in a wider musical environment.

Importantly, I have been led to consider how much my initial intention was a result of a particular unquestioned viewpoint on technology, this being that any musical progress within the studio is necessarily tied up with specific technical innovation. At the outset, it is worth bearing in mind that in seeking musical development through technological progress I may be influenced, perhaps unconsciously, by 'extra musical concerns', reflective of wider political and economic forces that serve to deflect from musical exploration into a concern for technology 'for its own sake'.

For technology is seductive. As Lewis Mumford discussed in his later writings, we can forget our intentions as we seek new technology. For him, the qualities of human intentions "often disappeared at the very moment the technical processes themselves were being simplified and perfected."[54] There is also the issue of desiring to legitimise one's own music through the adoption of new technology, particularly when this is new cutting edge technology, a consideration of which has formed a significant part of this research.[55] By my being involved in a music practice that is already embedded within the development of computing technologies, it can seem as if musical progress is synonymous with such technical progress. It is therefore perhaps important to be aware of wider political and economic factors that may have undue influence in these considerations.[56]

As computer musician Barry Truax suggests, it is important to focus less on new tools and more on how tools lead to new forms of creativity and ideas.[57] It is significant here that my research has led me to consider the role and embodied functions of rhythm that are not in themselves technological. This is reflective of an increasing concern to balance technical concerns against a deepening sense of music's purpose. For Truax

> "It is clear that technology by itself doesn't necessarily precipitate a paradigm shift. New ideas lead to new technology, but new technology doesn't always lead to new ideas... The paradigm shift involves the musical process, not the artifact or tool."[58]

To counteract such effects, a consideration of personal practice has increasingly served to focus my attention on specific features of what are large and diverse areas of 'computer music',[59] artificial life and robotics research. This focus on the primary role of my own practice in shaping technical considerations presents the problem of trying to elaborate on a model of one's own working practices and musical purposes, for they do not seem to conform exactly to any one existing model. Both theory and practice[60] have helped in defining this, to the extent of helping to shape a set of possible technological developments that form part of the conclusion, while also indicating that a significant aspect in further realisation of musical aims may lie outside of specific technological agendas.

Finding this balance of theory and practice appears to be reflective of a process common to the process of technological innovation within electroacoustic[61] music generally, as musician and researcher Agostino Di Scipio suggests:

> "For the composer, to gain control over the materials and forms of his/her art is to develop suitable generative and manipulative techniques (praxis), as well as to reason about the pertinence and coherence of those techniques (theory). The technical process in his/her design is ultimately a process of capturing knowledge into workable tools and strategies. It entails a careful consideration of one's own working environment and its technical processes and technological instruments, that reflects knowledge level creative strategies."[62]

It is my intention to provide just such an account of my own working practices and environment in the next chapter. First however I want to elaborate on my particular interpretation of the nature and creative role of technology.[63]

2.1. Technology as a Revealer

For Di Scipio technology can become an 'exploratory means of knowledge' within music practice, part of the creative process of questioning or transforming knowledge embodied within existing technology. It is primarily as such an exploratory means that I see the role of technology, for through seeking to define its roles within practice, we learn more about the musical aims implicit in such a consideration. Questioning the technology of the studio helps to *reveal* musical purposes. In showing us something beyond itself, something that was previously obscured, technology is therefore a way of *releasement* towards those purposes,[64] a form of transcendence.[65]

Therefore, the aim of my research is not to model a pre-understood system of my existing working practices within technology, for the very process of practice based research has helped reveal it, not systematise it. Nor is it an exercise in music cognition. Therefore, although this research concerns rhythm, there is little explicit reference to the literature on rhythm perception and cognition. However, some insights from those fields have been useful, particularly when they have resulted in computer models that appear to produce interesting machine behaviours that could be put to creative use.

It is also worth noting that in exploring one's own music practice, the technology developed does, in some way, reflect the cognitive processes of the composer, by becoming an externalisation of aspects of their compositional strategy. For, as Otto Laske suggests, in general "the representations (the artist) works with mediate a flexible boundary between his/her inner and outer world."[66] Elsewhere, Laske proposes that the computer programs developed to accomplish specific musical tasks can be viewed as "descriptive theories of the activity they support."[67] In this way the discipline of attempting to embody creative intentions within technology may in turn help to tell us more about the underlying psychological processes involved, while their technical realisation is not an actual representation of such processes. More may in fact be learned when such explicit strategies are not followed. For example, it has been noted that more progress was made in the development of artificial flight when explicit attempts to copy bird flight were dropped in favour of understanding the principles of aerodynamics. However these developments led to a more rigorous understanding of aerodynamics which then resulted in a better understanding of how birds fly.[68] Technology may therefore reveal aspects implicit in our concerns when we adopt a strategy that seemingly does not explicitly and directly address them.

2.2. The Computer as Human Extension

Within the music studio, technology is seen as an extension and not as a replacement for, or equal of, the musicians. I choose to see technology in all its forms, as ultimately enabling an extension of ourselves. It is also not necessary to suggest that we have only now reached a point where our technology is in some way fundamentally changing us.[69] All technology is transformative. As we use it we are also transformed by it, as suggested by David Rothenberg's 'philosophy as human extension'. He asks

> "...what is it precisely that is extended? Not simply an internal human idea, but an idea to act, a thought that engages the world, making the possible actual. The more we understand the tool, the more ways we conceive of how it may be put into practice. Our desires and intentions to act upon the world are themselves altered through the tools that we create to realize them. This is the essence of the philosophy of technology as human extension."[70]

What technology can do, as Rothenberg suggests, is to *intensify* human purpose. But within any practice the role of a technology is not simply a means to an end, and purposes are transformed as "*more* than the precise intention comes to fruition through the machine."[71] For, in extending us outward into the world it both "modifies our notions of what is possible and desirable" and "changes what it is possible to experience."[72] Furthermore, through using different kinds of machines we also come to see the world and ourselves as like them in some way.[73] One possible consequence is that as we become more adept at systematising understandings of ourselves and the world, "so does the imagined prowess of the machine."[74] As Rothenberg asserts, "The 'first cause' of the machine is always the human wish for the solution of a mechanical problem."[75] This is worth considering when we are faced with the seeming 'intelligence' of new technology, and forget that it was us who created it in the first place.

These concerns are particularly important to bear in mind in relation to the computer. There are some who see this device as having such prowess that it will exceed our abilities to the extent that we become redundant.[76] However, many of the machines we have already surpass us. Rothenberg asks, " Why should we worry about whether machines will someday surpass us? Lifting machines already have."[77] In considering the role of artificial intelligence (and artificial life), these at best represent what Massimo Negrotti terms an 'alternative intelligence', or by implication 'alternative life', that is different in kind from our own but with which we can achieve new insights.[78] As Massimo Negrotti has said "The great task facing AI should be that of compensating humans where they are lacking."[79] The desire is therefore that, by giving such machines more of an 'active' role in our musical environment, our abilities are transcended rather than replaced.

To acknowledge this transformative effect of all technology is not, however, to say that computers do not extend us in some new and interesting ways. Within the music studio the computer extends both conceptual and physical aspects of music making, becoming a kind of musical instrument, but also a means of representing, understanding and revealing music in new ways. As Di Scipio suggests

> "The introduction of computer-based tools and digital devices, being more than a mere enlargement of the technical resources, represents the emergence of new conceptual tools and a profound reworking of the composer's conception of the materials and forms of his/her art."[80]

A significant aspect of this arises from the computer's seeming ability to become many things. As suggested some years ago by Alan Kay, the 'protean' nature of the computer means that it can act as both a machine and a language becoming a 'metamedium'.

> "It is a medium that can dynamically simulate the details of any other medium, including media that cannot exist physically. It is not a tool, although it can act like many tools. It is the first metamedium, and as such it has degrees of freedom for representation and expression never before encountered and as yet barely investigated."[81]

It is therefore simultaneously possible of extending us in a variety of ways. We are therefore presented with many avenues to approach its future development. As Rothenberg says, the computer "appears as a tool both abstract and material, humanly driven and independent. It challenges any attempt to pigeon-hole it in any one place."[82] In its multiple role it is both intrinsically revealing, and yet frustrating, for "the attainment of any ends upon generic machines only occurs when a great distance is crossed from us to them."[83] We simultaneously have extended creative reach and yet increased musical distance as new musical possibilities are simultaneously revealed to us, yet we are sometimes too 'far away' to realise them. However the computer may also "create new unsolved dilemmas by changing our notions of what may be done to solve a problem."[84] Therefore the distance is in some important way partly an outcome of what the creative reach has revealed is possible yet not yet attainable and not just a product of an inadequate physical interface.[85]

2.3. A Phenomenology of Human Machine Relations

The kinds of experience we have with most other technologies can be contrasted with our experience of using the computer. In understanding just what kinds of experience these may be Don Ihde's 'phenomenology of human-machine relations' forms a useful perspective.[86] He also provides us with some useful diagrams that I will also use in elaborating aspects of his arguments.[87] For Ihde, the experiences we have with machines are diverse and not reducible to a single primitive 'set'. Ihde also notes the transformative effects of technology, our "relations with machines [being] non-neutral in the sense that they, by their very use, imply reflexive results for ourselves."[88] Therefore, we not only have a situation where the human perceives and acts in the world

$$human \rightarrow world$$

but an equally important *reflexive relation.*

$$\begin{array}{c} human \rightarrow world \\ \Leftarrow \end{array}$$

where the $\Leftarrow$ is a reflection from the world by which we understand ourselves.

I want to focus on three of Ihde's relations: *embodied*, *hermeneutic* and *alterity* relations.[89] With an *embodied* relation, we experience the world *through* our tools.

$$(human - machine) \rightarrow world$$

Here the machine is 'between' person and what is experienced and in some way the technology is 'transparent'. One of his examples is that we experience the blackboard through the chalk. For Ihde "The instrument allows me to be embodied at a distance, to get at the thing through the instrument."[90] The person does "experience something other than the machine being used and at the same time my experiencing is extended through the machine for that intentional fulfilment."[91]

Hermeneutic relations give us information *about* the world. Here the "machine is something like a text. I may read an author, but the author is only indirectly present in the text."[92]

$$human \rightarrow (machine - world)$$

Such instruments include gauges and thermostats. Our relation to knowing the world can, of course, also be unmediated and checked directly (as one can use a thermometer or finger to test the temperature of water), but:

> "In some cases instruments probe into areas previously unknown where such checking is not at all possible, and in this case we have a genuine hermeneutic situation in which it is the hermeneut who enters the cavern to hear the saying of the oracle and we are left to his interpretation. Thus, those instruments which probe the ultramicroscopic worlds of the atom leave room for doubt as to what previously is 'on the other side' of the machine."[93]

Interestingly Ihde observes how machine mediated experience and those of real life intermingle. "The world becomes a spectacle and the experiences I have in the movies become cross-sorted with those in 'real' life."[94]

In discussing Ihde's work, Ivan Hybs suggests these two relations work together simultaneously. With binoculars, for example, we both act through them, and they give us information about the world, altering our perception of it.[95] When these relations break down the technology gets in the way of our interaction with the world. For example, if a car breaks down, one is no longer experiencing the world through it; it is instead thematised and becomes an object, the 'other'. These are experiences *of* machines, not experiences *through* them.[96] The machine gets in the way of our relation with the world. These are *alterity* relations.

$$human \rightarrow machine - (- world)$$

The world can come to take on machine-like characteristics as we instead relate to the machine and not through it. With the computer particularly, this can encourage us to attribute to the computer anthropomorphic qualities, as it appears to attain a separate existence from us. The computer appears *autonomous*, having a will or life of its own and, as Hybs suggests, in these situations, we interpret alterity in a variety of ways, as disobedience, collaboration, or complete independence. This illusion results partly because its inner complexity and programming is hidden from us.[97]

Hybs contrasts the computer's suggested role as a 'prosthesis of the mind' with earlier prosthesis of limbs and senses.[98] He questions how truly embodied our relations with computers can be, given that there is a need for an interface, the technology is so complex, and computers have to be programmed. Because breakdowns in embodiment relations are so prevalent with computers, hermeneutic relations are also affected. The computer is not like other tools in letting us directly mediate with the world. Therefore the computer-as-tool metaphor is misleading for "it contradicts our practice with other tools that directly mediate our experience of the world."[99] However, another field of possibilities is opened up through computer-mediated exploration of *virtual* worlds.

2.4. Exploring Simulated Worlds

Hybs suggests that instead of engaging with the world through computer technology, we instead engage with a virtual world, aspects of which may have arisen from a *representation* of an aspect of the world. This makes the computer fundamentally different from other tools and instruments. Hence embodied relations constitute

$$(human - machine) \to virtual\ world$$

and hermeneutic relations

$$human \to (machine - virtual\ world)$$

The relation between the virtual world and the real world is expressed as one of *simulation*.

$$world \to simulation \to virtual\ world$$

It is interesting therefore to consider this connection between the real and simulated. Jean Baudrillard wrote that the link between the two had been broken.

> "Abstraction today is no longer that of the map, the double, the mirror or the concept. Simulation is no longer that of a territory, a referential being, or a substance. It is the generation of models of a real without origin or reality: a hyperreal. The territory no longer precedes the map, nor survives it. Henceforth, it is the map that precedes the territory – PRECESSION OF SIMULACRA – it is the map that engenders the territory ... It is the real, and not the map ..."[100]

This virtual world does not exist tangibly anywhere. As Rothenberg suggests, it is neither wholly within the machine, for we need to invoke it, nor our minds, because we need the computer to create it. Therefore it "exists within the relation between the machine and the user."[101]

These simulated worlds become new territories. As Steven Levy suggests "the map is not the territory, but a map *is* a territory."[102] Simulations let us model aspects of reality, and then abstract them into what Baudrillard calls the hyperreal. For composer Mark Trayle, such models "help create an 'allegorical knowledge' of the processes at hand, providing imagery that might further intuition and lead to understanding."[103] The computer becomes a kind of 'what-if' device[104] that stimulates our imagination. For Mazzioli

> "Computer sciences allow the creation, via computers, of metaphors of the real in order to improve the way in which it can be measured, represented or reinvented, but the part of the real that is observed becomes part of an artificial world... the user ... is immersed in a *fantastic form of reality* ... which is paradoxically present, yet extraneous to daily existence ... What could only be imagined before can now be perceived on a monitor due to the extraordinary capacity of a computer to process ideas."[105]

Mazzioli therefore suggests that communication between people and machines is "thus to a certain extent *stimulated*, and is quite different from a typically human linguistic relationship."[106] Furthermore, we come to appreciate the 'real' world in a new way, as suggested by Trayle. For Rothenberg "the otherworldly promise of a universe accessible only by computer leads the virtual voyageur back on a course to a nature more alive than ever before." This "describes a kind of interactive computing far removed from the way in which we usually use tools, as implements to help us complete specific and bounded action."[107] It is these ideas of enhanced communication and exploration through virtual worlds that will serve as a background to my considerations of machine mediated rhythm.

2.5. Human Machine Symbiosis

An important concept is the idea of *human machine symbiosis*. For Karamjit Gill this idea "emphasises the collaboration between human capabilities and machine capabilities" rather than their separation.[108] It is an approach that sets out to challenge the "myth that computerisation, automation and use of robotics devices will automatically free human beings from soul destroying backbreaking tasks and leave them free to engage in more creative work."[109] In our networked age symbiosis also goes beyond the single user and the machine to encompass "symbiotic relationships between the network of users and the network of machines". The design of such technology therefore becomes "both a technical process and a social process."[110] For Kevin Kelly human-machine symbiosis, "the joining of two worlds", was first suggested by invention of the servomechanism. In its simultaneous amplification of human steering movement combined with its feedback to the human on the rudder's position, the ship's pilot "merges into the servomechanism. He gets power, it gets existence. Together they steer."[111]

A related idea is that of *distributed cognition* between minds, bodies and artefacts. Salomon describes how our individual and distributed cognitions enter into a reciprocal interaction. They "interact with one another in a spiral-like fashion whereby individual's inputs, through their collaborative activities, affect the nature of the joint, distributed system, which, in turn affects their cognitions such that their subsequent participation is altered, resulting in subsequent altered joint performances and products."[112] Our technology and the environment generally serve to facilitate certain kinds of extensions to both our thinking and acting. The distributed nature of our activity is something recognised within a variety of fields including cognitive science[113] and human computer interaction.[114] Human consciousness may itself be in some way distributed.[115]

Within such an environment we engage in a kind of dialogue with the machine's behaviour, and it is from this that surprising insights can arise.[116] The relation of technology and music practice is much more complex than a simple causal one involving a one to one relation between the emergence of new musical forms through the deliberate application of new technology. Technology does not simply act as a means to an end.

With this in mind, an aim of this research is to seek new forms of human machine *dialogue*, while recognising the place of this within the fundamental social environment of our music studio. This becomes a fundamental orientation of this research and serves to mediate considerations of what appear to be two opposing viewpoints regarding the role of technology in shaping human intentions. These viewpoints may be broadly characterised as, on the one hand, those which see change and progress as being predominantly the direct result of technological change, and on the other, those which suggest that wider social and economic forces primarily shape the development and use of technology.[117]

In some way both are true, but the idea of dialogue serves to indicate that different users can have different dialogues with the same technology. The piano, for example, has helped give us music by Mozart and Thelonius Monk. It may be true, as computer musician Stephen Travis Pope has said, that "there are many areas where the composer who uses modern software and hardware tools will feel the influence of the task or user models implicit in the design of those tools."[118] However, through a dialogue with the machine the composer is not confined to producing music reflective of those models. Indeed working against such implicit models and their apparent limitations may help reveal one's own aims, as, through a perceived contrast that arises between intentions and the machine's behaviour, considering the 'gap' between helps define one's own purposes.

3. The Music Studio

This chapter presents a discussion of the aims and nature of our music studios. By 'our' I mean to suggest that a central and pervasive aspect of practice within it has been one of collaboration.[119] By 'studios' I am highlighting the fact that, over the period of this research, the 'studio' has consisted of a number of permutations of different instruments and physical locations. Through this discussion I intend to focus on a particular aspect of practice, the exploration of rhythm, and to make the computer's current role within this more explicit.

The intention is to indicate that this technology could be extended to aid in particular kinds of experiments in rhythm, reflective of something that is currently suggested, but not fully realised, within our practice. However, technology that works within and enriches one environment of practice may be found lacking in another. My judgements about music technology here are necessarily subjective. I think such a viewpoint accords well with much current thinking within cognitive science. For as Varela, Thompson and Rosch suggest, "the individuation of objects, properties, and events appears to vary according to the task at hand."[120] It is therefore impossible to talk meaningfully about technology without reference to the context of practice of which it is a part, and acknowledge the necessary and intrinsic subjectivity that this implies.

Through this chapter I hope to elaborate on my working practices and identify a 'gap' that appears to exist between musical intentions and the current studio environment, particularly in relation to the computer. For David Rothenberg

> "Radical transformation inspired by a technology must come from an unfulfilled pattern in the interaction between the technique and its context, which is made visible by the conception of something new."[121]

The following discussion represents an attempt to isolate just such an 'unfulfilled pattern' within our own practice and to hint at the conception of something new, something which will be subsequently explored in the following chapters. Therefore, what I attempt to do here in the following sections is to elaborate some important aspects of our working practices and musical aims. An account is presented that is partly personal, in that it emerges out of my experience, or more correctly, emerges out of the experience of our collaborations and reflects my interpretation of it. Yet also it is interpersonal, in that I seek to relate personal observations to a wider set of observations and discourses that contextualise my own observations and aid the reader's interpretation of my own experience. In this way it is hoped that that you, the reader, can relate your experience to my own.

Within the music studio, collaboration is embedded within a context that is both social and technological. Therefore, as Agostino Di Scipio suggests, "electroacoustic music poses problems of anthropology to the musicologist."[122] He suggests that we need to develop an 'ethnomusicological awareness' for situations where we are attempting to observe music practices for which we do not have a theory.[123] In the present context the discipline of ethnomusicology[124] turns out to be a useful orientation, because it acknowledges the differing mutual relations that exist between musical instruments, embodied social practices and actual music forms. An important aspect also is that, through such research, collaborative musical activity is found to be the norm rather than the exception.

The music that emerges within our environment does not seem the result of autonomous musical processes arising from the result of self contained musical laws.[125] Here ethnomusicological perspectives act as productive contrasts to a tradition of Western musicology and music analysis that has preferred instead to focus predominantly on music's abstract structural properties, to the neglect of its embodied functions.[126] In this way, ethnomusicology serves to challenge a prevalent strand of western thinking where observable patterns are abstracted away from the context of their production.[127]

In seeking understandings of both musical forms, and their wider purposes, the practitioners of ethnomusicology explicitly acknowledge the role of situated, social activity, distributed cognition, and by acknowledging the effects of instruments on musical form, human machine symbiosis.[128] Through this kind of perspective I have come to see our studio as reflecting some of the characteristics of complex natural ecological systems, a *musical ecology*. Therefore, to contextualise the subsequent discussion of my own musical products, aims, and practices I will first elaborate on this comparison between ecology and music studio.

3.1. Ecological Thinking

For William Clancey, the term 'ecology' concerns "the complex relations between an entity and its environment."[129] This idea may seem far removed from the seemingly isolated technological components of the music studio. However, using this metaphor serves to highlight that some of the relationships within our studio - an arrangement of individuals, technology and the wider contexts of practices and purposes of which it is a part – *behave like* those of a natural system. There is a particular kind of complex interplay between the actual musical forms, the behaviour of technology, and human intentions.

Ecological thinking becomes seemingly more applicable as Clancey's discussion is part of a wider one that concerns the nature of situated behaviour in which he discusses the implications for representing knowledge within the computer and developing autonomous artificial systems. It therefore seems appropriate that I consider it in terms of our own technically mediated environment.

Clancey's discussion provides us with some terminology to describe the interactive processes of the studio. In analysing a system it is seemingly composed of separate parts. However, in the way the system actually operates, these parts are interrelated in a number of ways. Parts can be *codependent*, which Clancey defines as "a mutually sustained relation that makes the parts what they are", and also *dialectic*, where "each aspect is the developmental context for the other."[130] Another important concept is that of *coevolution*, where a system's interdependent aspects evolve in relation to each other. Clancey therefore suggests that the ecological approach represents a 'philosophy of change'.[131] While an analytical viewpoint may freeze a system in time and isolate its parts, an ecological viewpoint fundamentally recognises that the behaviour of a system through time is a highly interrelated and evolving process.

This orientation presents a challenge when seeking to isolate and analyse fundamental aspects of the dynamics of the music studio. In the present context, elements of the situation we may wish to isolate may include the actual musical forms, our perception of the behaviour of the technology, or the quality of experience that we feel when working within the technology. However, what is considered as an observable, isolated 'property' of such a system actually forms part of a "mutual, ongoing development between the parts."[132] Therefore the roles and properties of parts of the studio environment, which includes the individuals involved, "are developed and defined with respect to each other." Observed properties do not reside exclusively within separate parts, as traits of those parts, but instead "are relational and dynamically constrained."[133] An illustrative example of this overall approach is ecological psychology.[134] Here, according to Irwin Altman and Barbara Rogoff

> "Persons, processes, and contexts mutually define one another and serve as aspects of the whole, not as separate elements. These aspects do not combine to yield the whole; they are the whole and are defined by and define one another."[135]

We can also define our studio environment as being an example of a *complex system*. A defining feature of such a system is that, as Vince Darley explains, "some of its global behaviours, which are the result of interactions between a large number of relatively simple parts, cannot be predicted simply from the rules of those underlying interactions."[136] Music emerges from this complex interplay. We may therefore describe it to be a kind of *emergent phenomenon*, which Darley defines as "a large scale, group behaviour of a system, which doesn't seem to have any clear explanation in terms of the system's constituent parts."[137]

I have subsequently found this idea of emergence to have an another unexpected significance. Technical terminology may lead one to assume that these are new concepts, but as Varela, Thompson, and Rosch point out, there is a long history of the idea of emergence. They suggest

> "Early Buddhism developed the idea of an emergent... this development was of central importance to the analysis of the arising of experience without a self. This suggests that our current formulations of emergence are not simply logical tricks soon to be replaced by some other way of conceptualizing phenomena, rather, our modern forms may be the rediscovery of a basic aspect of human experience."[138]

The intention has so far been to describe a framework for understanding my overall conception of the studio environment. One of the important outcomes arising from this perspective is that these understandings have implications for the parts of the musical process that we may choose to embody within technology, and how we go about doing it. It may not be enough to analyse the resultant compositions for their formal structural elements, as in the manner of a music score, and then program a computer with rules derived from this analysis, for, as musicologist Joseph Kerman suggests

> "by removing the bare score from its context in order to examine it as an autonomous system, the analyst removes the organism from the ecology that sustains it."[139]

For similar reasons, neither can the potentials of the technology be understood from outside the context of which they are an integral part. This is important to point out as the same technology can mean entirely different things for different users, and consequently create different perceptions of opportunities and limitations.

I will illustrate this point with an example. Within our studio we use something called MIDI (Musical Instrument Digital Interface),[140] a digital communications protocol that enables different digital devices and instruments to be connected together, enabling them to 'communicate' with each other. In this way a kind of network of instruments can be built, the output from one feeding into the input of another. It also forms a significant basis for how we structure and manipulate our compositions. It is possible to record when a sound is played, and also certain characteristics of how it is played. In this way MIDI represents a significant element in how we organise the studio and how we represent music in technology.

However, MIDI is open to a lot of criticism. Its basic way of representing music is in some ways like that of a music score, favouring pitch and duration information over expressive timbral transformations of sound. It represents music in the manner of discrete pitch values and duration information, though certain kind of continuous timbral transformations can also be represented by a series of 'continuous controllers'. Other problems occur when too much information is communicated at once, resulting in timing delays in the playback of music. It becomes limiting for expressive use when subtleties in performance are required, like that of a musical instrument or vocal performance.[141] It is also not a true network as communication through it is only one way.[142] These are all valid criticisms and, for some compositional goals, the intrinsic limitations of MIDI are a problem requiring new technological interventions. However, the point I am making here is these criticisms do not seem to apply presently to the situation within our studio because *we do not tend to use it* in the manner in which the criticism is framed.

Both the musical forms created, and the behaviour of the technology are involved in any interpretation. So are the aims of practitioners. The discussion presented in the next section is an attempt to discuss these aspects, concerned with both the sound of the music's structure, and apparent strengths and deficiencies of the technology. This is done through a consideration of the wider situation and aims of our practice, where a significant element is the quality of experience. Ultimately the meaning of the music, and the perceived capability of the technology are *emergent* properties arising from the quality of one's situated practice, but the description of my own situation that I now attempt may illuminate some useful concerns for others. Through this discussion I also aim at some initial suggestions for a desired kind of technology within our practice. I start with a consideration of the studio as a whole.

3.2. The Studio as Musical Instrument

An important overall idea concerning my experience of the studio is that, as a whole, it can feel and act like a musical instrument, as Brian Eno has suggested,[143] albeit a large and distributed one. The essential quality experienced is that a musical energy is distributed, amplified and transformed as we work through it. Robin Maconie defines an instrument as a kind of transducer, "a device that converts one kind of energy, the physical input of a performer, into another form of energy, which is radiated chiefly as sound."[144] Similarly, Paul Robertson suggests it is "no more than a device for amplifying vibration."[145] Importantly, this 'energy' is derived ultimately from the person who plays it. Therefore, as Robertson explains:

> "Although certain fine instruments are obviously extremely fine bio-feedback systems, and seem to liberate a performer's best potential, it remains true that all the energies that come out as sound are directly the result of the performer's own energies"[146]

The studio-as-instrument extends the idea of a single player of an acoustic instrument to a one of a larger sense of immersion in a network of processes. In the hands of some practitioners this studio instrument almost seems to feel 'alive'. Dub reggae producer Lee

'Scratch' Perry, in describing his relationship to the studio environment, gives a good sense of this:

> "The studio must be like a living thing. The machine must be live and intelligent. Then I put my mind into the machine by sending it through the controls and the knobs or into the jack panel. The jack panel is the brain itself, so you've got to patch up the brain and make the brain a living man, but the brain can take what you're sending into it and live."[147]

While we are the ultimate generators of this musical energy, the musical instrument amplifies and reinforces that energy with an energy 'of its own', a truly symbiotic relationship. As an extension of ourselves, a musical instrument feeds energy back into the musical situation. Through the mixing desk Perry is able to feed multiple tracks of recorded sound[148] through a variety of analogue effects that further process it in interesting and unpredictable ways. As Kodwo Eshun explains, with Perry's music, "listening becomes a field trip through a found environment."[149]

Human expression is transformed into something often intriguing as Perry's studio amplifies and transforms human intention. The machine's behaviour actively suggests courses of action, but in a sense that does not lead to anthropomorphic comparisons. If anything, Perry begins to feel more like the machine![150]

There is a sense of *dialogue*. Eshun's discussion of Perry's environment is one example of his elaboration of human machine coevolution through rhythm. Here the machine is always credited with having some kind of active role as "new soundworlds begin as accidents discovered by machines."[151] Through limitation and error, "the machine forces music into inhuman directions, and compels the human towards inflexible, impalpable parameters." [152]

What is interesting is that Perry, while not claiming his studio was in any sense truly alive, *feels* the studio to possess a kind of autonomy whilst still being dependent on human input for its 'life'. Far from becoming disembodied through such technology, for Eshun the "machines don't distance you from your emotions... quite the opposite. Sound machines make you feel *more* intensely, along a broader band of emotional spectra than ever before in the 20th century."[153]

An important aspect of the journey through this found environment of Perry's music is its rhythmic interplay. Tracks are unexpectedly muted, and fed from the mixing desks through networks of effects, an example of what Eshun terms an 'electronic ecology', a term derived from Kevin Kelly's observation that "one machine's input is another machine's output."[154] Particularly, the use of multiple delays and reverb[155] result in combinations of multiple echoes and reverberations, the interactions of which begin to feel like the interplay of simultaneous rhythms working with and against each other. With Perry's music:

> "As soon as you have echo, listening has to completely change. Your ear has to chase the sound. Instead of the beat being this one event in time, it becomes this series of retreating echoes, like a tail of sound... Where rhythm should be there is space, and vice versa. [The music] pivots around an absent beat.... confounds the process of pattern cognition by leaving the expected beat implied... Echo turns the beat from a localized impact into an environment with your inside."[156]

Eshun's description of the experience of Perry's music is suggestive of an aspect of my desire for embodied involvement within our studio environment, as a vibrant, interactive musical process generated by both human and machine. The sense is that embodiment occurs through *immersion* within the sonic realisation of a network of processes, and becomes less focused on consideration of physical interfaces between users and technology.[157]

This line of thinking is, however, not reflective of a desire to simply recreate Perry's studio. While Perry's studio is an analogue environment where music is mediated through networks of hardware, within our studio significant aspects of such an environment have become represented in the computer in one form or another. This reflects a situation where, as David Toop suggests, the recording studio "has become increasingly virtual."[158] The virtualisation of the studio provides further avenues for the creation of new musical worlds through symbiosis. This virtualisation is both creatively suggestive and frustrating.

3.3. The Computer Studio

Within our music practice the desktop computer has become a focus for our collective musical activity. While the music studio environment has undergone changes, the computer has remained its central organising technology, mediating a diverse range of musical practices. However our musical technologies can be considered passive and musically 'simple' by certain standards. There are no algorithmic composition[159] or artificial intelligence techniques[160] employed. Instead this form of 'computer music' has been based primarily around the interrelated roles of the sequencer, sampler and drum machine. Significant aspects of this process emerge in interaction with the computer's role as a 'sequencer' of the musical materials. Various external samplers, synthesizers and digital effects become linked to the sequencer and, through various activities, the overall shape of the music is constructed.

Within this environment, it is not simply a case that the computer performs one clearly defined role. This is suggestive of Terry Winograd's assertion that "Computers are not primarily used for solving well-structured problems ... but instead are components in complex systems."[161] The music emerges out of a set of processes, the nature of which can fluctuate within the continuum between lone composition and group improvisation. Unravelling the relationship between the computer and our music practice reveals contexts that concern both composition and improvisation, shared spontaneous collaboration, and isolated refinement.[162] The important point is that these are qualitatively different aspects of musical experience.

3.4. The Sequencer

Within the studio, a central role, or more correctly, a series of roles, is played by the sequencer.[163] This piece of software has facilitated approaches to creating music that can be considered as a blend of both composition and improvisation. By composition I mean that formal elements of the music can be shaped and arranged in a way that is detached from its actual 'performance', facilitating more reflective and measured ways of working. By improvisation, I mean that one can spontaneously change and play with and against the music, adding to and changing it, as the computer is playing it back.

The way the sequencer represents elements of the music is an important consideration. Our compositions are visually represented on the computer screen as a number of distinct 'tracks', each corresponding to a different 'instrument'. As visually displayed, these tracks have a linear form, and as the music is played the music progresses from left to right across the screen, a moving cursor indicating at which position the music is currently located.[164] In this way there is a certain similarity to a multitrack tape recording enabling the recording and selective playback of separate instruments on each of its tracks. Like such a tape recorder, it is possible to 'forward' and 'rewind' to different places and to 'mute' certain tracks thereby disabling their playback within the overall 'mix'. It is also possible to isolate sections of tracks for separate playback.

These tracks consist predominantly of either digital samples, or placements for MIDI data used to trigger sounds and certain other behaviours of any suitably equipped MIDI instruments, for example synthesizers and drum machines, connected to the computer. This also includes any digital sound card within the computer itself. This makes the computer a representation for music, a means of acting on this representation and another 'instrument'. In the manner of a music score, the placing of these MIDI and sample elements visually on the screen corresponds with their placement in 'time' within the music's overall structure. The sequencer can also 'perform' its own score, a group of virtual 'musicians' reproducing what has been previously recorded. The playback of these tracks is synchronised by a single, underlying tempo, which is in a way analogous to how a conductor ensures that all elements of the orchestra remain in time. Also, the only relationship *between* the tracks is their temporal synchronisation.

Music can be played in 'live' via these external MIDI instruments, or 'written' on the screen using the keyboard and mouse, and subsequently visually edited via the mouse and keyboard. This editing process allows for operations that are analogous to a word processor where "music is built up from the parts like a construction set ... worked on like a novel, with sounds moved around erased and replaced".[165] Therefore, an aspect of working with the sequencer is in some way like writing a music score whose individual elements can be added, moved and edited, but the resolution of its representation system is such that each of its musical elements can be minutely shifted and edited. Here, the sequencer has proved to be extremely useful in a variety of situations as a malleable music representation, providing a high degree of access and visibility to the details many aspects of music structure.

The sequencer allows for a limited form of 'interactive composition.'[166] The user can interactively add, remove and adapt aspects of the music as it is playing, almost 'playing along' with the music in a process that is likened to a kind of improvisation. Elements of this improvisation can then be isolated, reflected upon, and further composed as these "direct expressions become fragments to be studied, edited, and recombined into new musical wholes."[167]

3.5. Rhythmic Complexity Revealed

Despite its simplicity and limitations, the sequencer has helped us open up an exploration of some aspects of musical complexity, which has as one of its important aspects a kind of rhythmic complexity. This reflects a fundamental influence of various forms of dance music on our practice. As Andrew Goodwin suggests

> "...music made by machines, or to sound like machines, has not taken pop's trajectory into electronic or art music, but has instead become the chief source of its dance music... pop musicians and audiences have grown increasingly accustomed to making an association between synthetic/automated music and the communal (dance floor) connection to nature (via the body). We have grown used to connecting machines with funkiness."[168]

The promise of a rhythmically rich complexity has been found through interacting with the sequencer's 'looping' facility. I do not wish to indicate that the sequencer is particularly sophisticated in this regard. However, it has served as a useful vehicle for an exploration of various aspects of music.[169] Sections of the music can be isolated, and looped, and by muting different tracks, different combinations of its elements can be highlighted. In this way the music's possibilities can be explored and refined in a way that invites comparison with an earlier technique where analogue tape could be cut up and sections looped and recombined. In this way, looping techniques can reveal a microcosm of sound to the listener by helping to open-up awareness of sonic complexity within the sound. However, in contrast to manual tape splicing, the process of looping using the sequencer becomes far more interactive and immediate.

The music's tonal and rhythmic complexity is in part derived from the use of digital samples. The sequencer can be used to trigger external digital samplers, but can also be used to represent and manipulate samples 'within itself'.[170] Used in this way, this 'precomposed' musical material can be further cut up, altered and re-combined.

Shaping the interplay of these samples, and contextualising them within one's own compositions, becomes a catalyst for the musical imagination. Even the scratches and imperfections on vinyl records become sources of inspiration.[171] These samples also become suggestive of the musical worlds from which they originally emerged and their associations thus extend beyond their formal relationships within the music's structure. As Kodwo Eshun suggests "each component excites another in an adventure of concepts.[172] Samples are 'signs', signifiers of musical worlds, and through incorporating these within our music we come to learn something of the nature of the musical process implicit within them.

Sample based music is therefore, as David Toop suggests, a kind of "music which absorbs into itself the music which surrounds it."[173] Such absorption can result in what electroacoustic composer Simon Waters refers to as 'complex hybridisation'[174] as the entire world's recorded music can potentially become a source of ideas in sound. This juxtaposition of samples can create an intriguing sonic complexity, full of implied rhythms and harmonies, suggesting an expansion of musical vocabulary, which Jon Hassell terms a 'new tonality'. According to Toop

> "At the heart of our emergent sense of beauty in the present is a new tonality, which Jon [Hassell] sees as a development of samples being detuned and overlaid, particularly in hip-hop, to create dense, strange harmonic dissonances. To people who don't insist that music must be Eurocentrically in tune, these are very pleasurable, but to those whose first and formative listening experiences are hip-hop, this new tonality is normal."[175]

These innovations create shifting relationships of sounds and rhythms that produce sensations of a sonic dynamism that is only implied by formal analysis. In contrast to attempting to seek some final musical resolution of these dissonances, one is instead seeking a musical expression that reflects an exploration of a continuing and shifting balance between this rhythmic-harmonic interplay. Through surveying such musical 'terrain' I have increasingly realised how melody, harmony and rhythm are highly inter-related aspects of this balance. Rhythm is not just something on which melodies and harmonies are constructed but becomes the essential vehicle for expressing one's understanding of the timbral implications within the samples. It is a dynamic element where implied melodies can emerge through shifting conjunctions arising out of different rhythmic relationships. The music becomes a kind of 'surface' simultaneously suggestive of a number of possibilities felt subjectively, but latent within the sound.

In considering the overall evolution of this musical form, looping suggests a circularity of musical form rather than linearity. Consequently, how the elements change their relationships to each other over time is subject to a different organising principle. The music's sense of being coherent arises from the changing temporal relationships of its elements, rather than by reference to an absolute, quantifiable system of tuning. We may see such music as repeatedly 'revolving' around some implied central point. The sense of music's development becomes cyclic, working against the linear (left to right) model of music implicit in the sequencer's representation of music, but nonetheless supported by it.

Despite its technical simplicity, novel explorations of some of the microdynamics of rhythm become possible through the sequencer, and a range of associated software that can be used to isolate and recombine rhythmic elements from samples.[176] Eshun terms this 'breakbeat science' and compares it to a form of scientific enquiry whose aim is to intensify sensation through rhythm. Sampled rhythmic fragments are cut up and isolated as "rhythmic DNA" to be recombined into strange new wholes as the breakbeat is "assembled from molecular components of rhythm."[177] In describing this deconstruction and reconstruction of these rhythms he refers to a process of 'Escherizing' the break, making reference to the impossible dimensions contained within the drawings of M. C. Escher. He cites Escher

> "I can conceive of the series of images on a plane division and the sequence of sounds of a musical composition as different steps of just one staircase."[178]

Escher's drawings appear that they could *almost* exist but are quite impossible. They are 'real' enough to intrigue, containing familiar objects, yet entirely virtual for these objects exist in impossible combinations and perspectives. In a similar way these new rhythmic combinations could not exist outside the computer, but they retain a connection to it, through the body. Eshun discusses how this music's relationship to dance results in a kind of re-education of the body as such music compels into new behaviours reflective of these rhythmic forms. His discussion is a great illustration of the suggestive power of virtual environments. Conceiving of rhythm in this way has proved to be an interesting compositional perspective.[179]

Douglas Hofstadter, in *Gödel, Escher and Bach* also discusses Escher's work in relation to looping and recursion.[180] Such circular musical form suggests a musical development that is 'vertical', rather than 'horizontal', an idea expressed by jazz theorist George Russell. For Russell, "Music is architecture. I build structures. Buildings go up – they're vertical forms. My focus is on the vertical evolution of a form, not necessarily on the horizontal linear exposition of that form."[181] The music is not constructed in the manner of a logical, syntactical operation - a series of discrete 'statements' to be contrasted and combined.[182] Instead it becomes an evolution of permutations that can result in interesting and surprising conjunctions. This kind of organisation invites comparisons with Russell's description of the African drumchoir:

> "In the African drumchoir, one drummer is the rhythmic gravity while the others gradually layer on sophisticated rhythms on top of this tonal centre. The whole isn't really evolving in horizontal way; its evolving in complexity and density. It's vertical energy getting higher and higher, compounding."[183]

In discussing the aesthetics of popular music Simon Frith notes how one of the most important aspects of 20th century popular music in the West has been the mutual influence of Western and Afro-American musical forms. Here a fundamentally different sense of musical development arises, which contrasts to that of much European art music. He cites the work of Andrew Chester in suggesting that the former's focus on rhythmic interplay expresses what Chester terms a complex 'intentionality', while the latter's concern with linear development expresses a complex 'extensionality'. In the extensional form, according to Chester "theme and variations, counterpoint, tonality (as used in classical composition)[184] are all devices that build diachronically and synchronically outwards from the basic musical atoms. The complex is created by combination of the simple, which remains discrete and unchanging in the complex unity". In contrast, with the intentional form, "the basic musical units (played/sung notes) are not combined through space and time as simple elements into complex structures. The simple entity is that constituted by the parameters of melody, harmony and beat, while the complex is built up by *modulations* of the basic notes, and by *inflexion* of the basic beat."[185]

Working interactively with the sequencer, with looped sections of varying lengths, can begin to feel like 'clay spun on a potter's wheel'. More pointedly it can almost feel like *several* different sized pots simultaneously spun on *several* wheels, a perception that is suggestive of an inherent circularity that lies at the very heart of the approach I seek.[186] Just like the process of shaping a clay pot is a process of gradual refinement, a partnership of human expression and the material properties of the clay, so evolving musical forms becomes partly a matter of subtly shifting elements of its microstructure, testing its possibilities. However, what is also important is creating moments of dramatic contrast between these elements in order to render a different, and possibly surprising, reinterpretation of the terrain.

Overall, significant aspects of this process evoke a metaphor of craft. Musical materials throw up new possibilities as we manipulate them, which may in turn guide further creative decisions, much in the same way as a fine woodcarver incorporates knots, bark and other features of base materials into the final design. The computer becomes a kind of 'canvas'[187] or 'medium' on which we can undertake what Malcolm McCullough calls 'digital craft'.[188] In an important sense, within our studio, we engage in a kind of virtual craft on a simulated medium.

3.6. The Role of Improvisation

While the sequencer provides visual bar lines and subdivisions, in some ways akin to a music score, how I try to evolve music with it has more in common with playing by ear, than formally manipulating a score's syntax by sight.[189] Indeed the score-like representation system often only serves as a guide as musical elements are subtly moved around until they 'feel right'. What becomes more important is focusing on the qualities of sound as continually experienced, than on the visual bar marker's suggestion of rigid quantization.[190] Therefore, as we focus on the microstructure of the music, our approach has something important in common with oral, rather than literate modes of music construction.

One of the problems to have emerged is that working with the sequencer can lead to music that is in some ways lifeless. Brian Eno comments that computer mixing "creates a cautious, perfectionistic way of working",[191] while David Rothenberg suggests that sequencers can become the "masters of empty minimalism".[192] The music can become over-crafted, as most of the terrain of musical potential has had to be entirely realised through intense operations. This can involve using the mouse to make hundreds of small iterative adjustments to an individual element's length and placement in time. The sequencer tempts endless refinements, as music is chopped, isolated and looped and this can result in either dead sounding music or, paradoxically, music that becomes too chaotic because what is suggested becomes impossible to explore coherently.[193] Evolving a musical idea can become a fragmented process and one feels 'thrown' by an inability to express effectively an intention within the creative 'flow' of events. The desire here is to stimulate the musical dialogue *between* user and computer.

Another problem emerges out of the first. When working collaboratively, inherent subjective interpretations of the simultaneous musical possibilities arise. This means that *collectively* negotiating the evolution of musical forms becomes an important process. We seem to hear different music in the sounds coming from the machines. Part of the process is therefore a social process mediated through the computer, a negotiation through which is in part represented in the resultant musical forms. But the labour intensive process of crafting can also become an intense, antisocial activity that can intervene severely in productive collaboration. My experience of working musically with computers seems to work best when it is part of an overall process of such collaboration, even if aspects of that experience may involve isolated work. The critical involvement of others grounds the musical process in a wider environment of purposes and intentions. In contrast, the experience of using a computer in musical isolation has often resulted in a situation where the computer seems to 'suck out' musical energy[194] and encourage overly perfectionist ways of working.[195] The desire here is to stimulate human musical dialogue *through* the computer.

An important consideration is that of the *process* of composing music using the sequencer. It is the quality of the engagement with musical materials as we are shaping them that can bring energy to both collaborative and individual compositional activities. The overall aim is to become very much more involved in the 'musical present' and to be able to carry out musical adaptations as they are suggested, both sonically and socially, *in* that moment. The sense of immersion and embodiment within the subtleties of a dynamic process has aspects in common with the experience of listening to 'minimalist' or 'process' music[196] while offering a potential for participatory experience that can feel like improvising jazz. Minimalist composer Terry Riley highlights this heightened sense of making music in the moment:

> "The ritual spontaneity of Riley's music derives from the fact that most of my musical experience has been in the jazz hall, or places where musicians are actually on top of the notes they're playing, every note is danger. I think that the music has to have danger, you have to be right on the precipice to really be interested, not gliding along playing something you know. If you never get on the brink you're never going to learn what excitement you can rise to."[197]

In this regard a great influence on my musical thinking has arisen from my interest in the so-called 'jazz fusion' of Miles Davis and Herbie Hancock that emerged in a period from the late 1960s to mid 1970s. Listening can feel like being immersed in a rainforest of sound, full of rhythmic interplay, diverse instrumental sounds and strange electronically treated noises, as various intriguing permutations of the basic arrangement are explored over extended periods of time, remaining constantly vital and alive.[198] Eshun suggests that

> "Electronic Jazz's rapid transitions from extreme turbulence to prolonged static lulls suggest that it exists at the dissipative edge of ordered chaos, making audible the chaotic order being discovered by Benoit Mandelbrot."[199]

Significantly, while a lot of this music can emerge through significant elements of improvisation, these musicians were also exploring the use of early analogue drum machines, sequencers and tape looping and splicing. Improvisation is mediated through technology and a rich and dynamic interplay emerges.

For these reasons being able to increase opportunities for improvisation through the computer has always been a guiding feature of this research. Currently, many aspects are improvised in real time to the extent that they are played in (mainly through keyboards) and immediately become represented elements within the sequencer. However, an intention has increasingly been to improvise more spontaneously with rhythms as they are represented in the sequencer, instead of performing hundreds of minute adjustments to get them to be where you *feel* they should be.

In light of these considerations, when it comes to thinking about the role of the computer in facilitating improvisation, I have found that the most interesting practitioners in the field have, by and large, had an interest or background in jazz and social music making. For example, members of the *Hub*, a "computer network band", recognise music as a social process. For one of its members, Mark Trayle, interest in this arose from the process music of the 1960s, which he suggests was concerned with "the idea of creating a closed system and listening to its behavior." Trayle has subsequently sought to open up this system by seeking to incorporate distributed group improvisation within this process.

> "When the system is opened up to inputs from performers and other processes, a more free-wheeling kind of behaviour can be heard. The rigid temporal and harmonic conventions of 'minimalism' are bypassed, while the focus of attention (and the locus of musical form) is maintained through the system's behavior."[200]

For *Hub* members, the computer becomes supportive of social action, and musical cognition is distributed through their systems and players. The technology supports and augments their interactions as, suggests another *Hub* member John Bischoff, the musicians "enter programs" and form "extensions of the network."[201] In contrast to a system that is used to support lone composers, the computer becomes a way of facilitating embodied social processes. Musicians are not replaced or isolated by this technology but augmented in their relation to one another through it.[202]

Other practitioners of interest include David Wessel and George Lewis who both have a background in jazz. For Wessel the computer has a role in a musical discourse that is also a social discourse of mutually influencing participants.[203] He describes an approach attempting to enhance musical communication through the computer, so that "a new form of musical discourse might emerge." The computer becomes an 'intimacy amplifier' in that "it could pay detailed attention to the performers and provide a flexible representation of the materials at hand and their musical context."[204] Elsewhere, Wessel and Michael Lee describe their emphasis "on the machine adapting to the specified gestures of the performer rather than on the traditional situation of the performer adapting to the instrument."[205] An intention here is to promote a computer instrument that is adaptive to the musician's personal style, itself reflective of a sensibility rooted in jazz.

George Lewis's explorations of computer mediated jazz improvisation lead him to some interesting speculations regarding the nature of interactivity. The following is an interesting perspective on the problem of interactive music. Evoking an explicitly biological metaphor, he suggests

> "A real 'interactive' entity, a mammal for instance, exhibits complex behaviour that cannot be simply tied to a set of controlling 'triggers'. Moreover, the structures present at the animal's inputs (senses) are processed in quite a complex, multi-dimensional fashion. Often the animal's output (behaviour) is not immediately traceable to any particular input event. The number of triggers needed to fully control every sonic movement of an 'interactive' composition of the complexity of a housefly would already be quite high; perhaps hundreds of triggers would be needed, far too many to be manipulated at once by anyone."[206]

3.7. Freedom and Control in the Artistic Process

For me, understanding the idea of both composition and improvisation revolves around a consideration of the negotiation between freedom and control, voluntary and involuntary action, predicted and unpredicted outcomes, and increasingly, social and individual action. This negotiation between points of control and 'non-control' is something that for 1960s experimental musician Earle Brown was a defining feature of art.

> "What interests me is to find the degree of conditioning (of conception, of notation, of realization) which will balance the work between the points of control and non-control... There is no final solution to this paradox... which is why art is."[207]

Therefore, in using the computer, a fine balance is sought between processes that can be specified and those that are open to 'chance'. Most importantly its behaviour has to remain musically meaningful. This balance therefore is not equated with control versus *randomness*. The kinds of systems that appear interesting are those that enable its players significantly to shape processes to fit expressive intentions, while recognising the machine's 'active' role in this. In evaluating the capabilities of rhythm technology certain features of human rhythm production are considered important, in particular, a sense of fluid and dynamic movement that in some way parallels the musical sensitivity and spontaneous improvisations that a jazz drummer is capable of producing. Such improvisations may consist of subtle variations on existing rhythmic musical forms, and also dramatic interventions that cut into the rhythmic structure. The subtle timing inherent in this can be construed as an important aspect of music's, 'swing', 'groove' or 'funk', and not as mere random deviation from rigid formalism.[208] It is instead a consciously aimed at part of the expressive power of the music, as some in the field of computer music have begun to realise.[209]

In exploring musical and social balance, an interest has emerged concerning *how rhythm works* to enable us to contextualise these musical juxtapositions, and our own different interpretations of the musical possibilities latent within them. Furthermore, the importance of musical process, with its implicit social and psychological dimensions, has also led to a consideration of *why rhythm works.*[210] The process is as important as the actual sounds of the music. Peter Michael Hamel, discusses "the gaining of self-experience through group improvisation" providing an opportunity for "collective experience-patterns such as arise from exercises in group dynamics and sensitivity training."[211] The ethnomusicologist John Blacking suggested that "the chief function of music is to promote soundly organised humanity by enhancing human consciousness."[212] It is interesting to speculate that seeking to enhance the quality of interactively transforming rhythmic patterns within the compositional process may reflect an attempt to promote a particular kind of heightened consciousness.[213]

The discussion in this chapter has attempted to highlight certain important characteristics of music practice and give a sense of the kinds of musical form, technology and kinds of participation that appear important within it. Rhythm forms a significant focus, and issues become centred around the possibilities for interactively adaptive rhythm. Motivations for this appear to be concerned with enhancing the present studio environment with opportunities for fluid rhythmic transformations that reflect both compositional concerns and an interest in the spontaneity of social music making. An initial consideration was given to the kinds of approaches within computer music that appear interesting in this regard.

In the next chapter I expand some of these ideas through an investigation of a number of wider issues that include those of musical embodiment, music's social function, and a consideration of models of musical complexity that have, in particular, been inspired from a consideration of West African musical forms.

4. Rhythmical Complexity and Embodiment

The last chapter represented an elaboration of some insights gained from practice that has served to focus an interest on furthering computer-mediated explorations of rhythmic complexity. In this chapter I want to explore more fully some ideas relating to musical complexity, particularly those inspired by the theories and practices of West African social and artistic systems.

In discussing this however, I hope to avoid an accusation of what Edward Said has referred to as 'orientalism' in the context of the West's interpretations of the cultures of the East.[214] I do not seek to suggest that we become more 'African' in some general and ill-defined way, and in so doing simplify, trivialise or romanticise what are, in reality, a diverse set of cultures of which I know relatively little. Instead I wish to explore how some elements of West Africa's musical environments, which by necessary implication include their social ones, may in some way help us to approach specific concerns of our own present cultural and technological situation. This chapter therefore represents a wider contextualisation of the more personal observations elaborated on in the previous chapter.

A significant orientation for my understanding of West African music has been found through reading John Miller Chernoff's superb *African Rhythm and African Sensibility*. This is an ethnomusicological account of West African drumming in which Chernoff himself becomes a participant observer as he learns the art of drumming. This book has subsequently become a great inspiration in both the following discussion, and within my music practice.[215] It has prompted a consideration of several aspects of West African music, particularly its underlying rhythmic form and style of improvisation. With its emphasis on the integration of music and social activity, it also forms a particularly good example of what Hamel referred to as an exercise in 'group dynamics and sensitivity training',[216] a form of embodied social activity. The essential idea is that through rhythm we are able in some sense to negotiate the complexities of our individual and social environment 'directly' and 'through the body'. Rhythm is therefore at once both musical and social. In exploring its dynamics, the computer may allow us to virtualise and extend rhythmic behaviour becoming, as Mark Trayle suggested, an example of 'allegorical knowledge' that 'might further intuition and lead to understanding.'

I begin this chapter with a consideration of 'musical complexity' and the role of the computer. This is followed with a discussion of the idea of 'music as embodied action' and continues with a consideration of the role of rhythm in the negotiation of individual and social action. As an example of musical complexity I then present a detailed discussion of some formal characteristics of West African drumming, inspired in large part by Chernoff's complete and detailed account. However, as I hope is clear by now this is not an exercise in reducing this music to its rhythms, of creating a decontextualised abstraction that then serves to 'stand' for the music. It is a only a model of a socially situated negotiation of complexity. But this model may have useful applications for our computer-mediated interactive and online experiences, which I illustrate, in the conclusion to this chapter, with a couple of examples.

4.1. Models of Complexity

In 1992 Barry Truax published an article *Musical Creativity and Complexity at the Threshold of the 21st Century* that represents an application of ecological viewpoints to musical issues, with a number of interesting implications. He discusses new models for sound and composition that he terms 'models of complexity', characterised by three interrelated factors. Firstly, non-linearity becomes "a legitimate and ordering factor in the system",[217] reflective of developments in the biological and physical sciences. Secondly, suggesting a need for a "new acoustics of complexity",[218] he acknowledges that the properties of sound as perceived cannot be separated and understood in isolation. An example he gives is the quality of 'loudness', which is not a separate property, but a subjective perception that arises out of the interaction of other aspects of sound. Such artificial separations have helped focus understanding on abstract pitch relationships, promoting "the concept of music as abstract". Thirdly, new 'ecological' models of musical systems will supplant hierarchical top down systems, as reflected for example in the organisation of the Western orchestra. Such modes of organisation will be replaced by, what he terms, 'organic' systems that include within them their environmental context, containing "interacting levels, with messages and feedback between them, self-organization and massive parallelism."[219]

An exploration of a closed tonal system becomes replaced with one that is more embedded within the world with its 'physical attributes', 'social situations', and 'psychological realities'. Social and cultural contexts become an acknowledged part of the compositional process and complexity arises both from internal musical structure and its relation to these external factors, the artist/composer seeking to link 'artefact to context', rather than trying precisely to control the system.

Truax contrasts what he terms the 'literate composer' with a 'post literate complexity'. The former emerged in the 19th century, focusing on composition through abstractions of music's text like qualities and "persists today, at least psychologically."[220] With its associations with 'reading music', this literate approach divorces music from its aural roots.

> "Post literate complexity may involve a serious re-evaluation of what musical complexity refers to, in what sense leading edge music is complex... A new complexity ... may involve both a reassessment of the sophistication of what literate culture regards as 'simple' oral culture, as well as the exploration of new expressions of musical complexity."[221]

Within this 'post literate complexity', there is the emergence of what he terms a 'neo orality',[222] reflective of the complexity and musical orientation of oral cultures. Thus

> "... a return to the complexity found in oral culture where sound reflects a constantly changing present – a 'becoming' – where repetition means re-enacting the structures of sound combined with other sense modalities."[223]

The computer mediates one of the principle aspects of our exploration of these new models of complexity. It plays a central role in the modelling, exploration and control of complex systems. The computer becomes a 'partner' extending our view of music.[224] While critical of western music representation and the 'literate composer', Truax does not suggest the abandonment of representation. The computer is a representation medium so within this new complexity what will emerge will not necessarily reflect an abandonment of representation, but representation ceases to be music's 'sole representative'.[225] Hence we have a neo-orality, and not a return to full orality, but a computer mediated one. In this regard Truax envisages that there will be many forms of such representation.

4.2. Music as Embodied Action

This section is concerned with a consideration of the idea of music as 'embodied action', a term that was originally inspired from Varela, Thompson and Rosch's discussion of cognition,[226] but subsequently developed within a more specifically musical context. A central point of departure for them "is the study of how the perceiver can guide his actions in his local situation"[227] This orientation comes to form an essential aspect of the *why* of rhythm.

As John Shepherd suggests, "music is cultural text", not a symptom or reflection of the social, but part of the very dynamics that make up social action, playing a part in its very creation.[228] Shepherd's central idea here is that "social or cultural elements are contained within or passed through its sonic components."[229] Music's sounds and practices form a parallel form of knowledge, enacted through the body, even though the sounds themselves do not appear to refer to anything explicit in the manner of spoken language.

For Shepherd it is more a question of how the 'logics' of the artistic process resonate with those of other social processes, an idea that has particularly been taken up in ethnomusicology. In this way music has a 'relative autonomy'. For Shepherd:

> "Sociality is manifest in structured relationships between people and the worlds they create, and in the structures of the symbolic and cultural forms which arise through and give expression to such relationships."[230]

The idea of relative autonomy gives us a perspective from which to see how music can communicate cross-culturally. He cites Catherine Ellis who suggests that music can bridge thought processes, becoming a communication channel between cultures, such that "a person is no longer a member solely of one culture."[231] Therefore for Shepherd, music allows us to escape the "prison house of language". To fully appreciate music is to be actively engaged in its interpretation, music being a framework that allows people to map meaning through social negotiation. In this way music communicates difference and mediates between individual and society.

Musical perception and conception arise together, a process of both what we hear and how we hear it. It is worth making a note here about the codification of music, as expressed through formal notations (and also musical instruments). These can emerge as particular perceptions within the continuum of sound become discrete conceptions of music's important features. These symbols then come to 'stand for' this conception of music.[232] The more abstract the notation, the more it can be operated on independently of its context, and also serve to create the *perception* of 'wrong notes'.[233]

Beyond agreement and negotiation within social groups, Shepherd discusses how music can communicate culturally. This suggests to him that in some way music is able to directly 'instruct' in the manner of other symbolic media. Here "music can act as a medium for learning and for the expansion of individual and cultural horizons."[234] In this way music has some power to communicate "*directly* and *concretely*" to the individual through sound. However, its power over other symbolic media derives from a process that is *felt* through the body as much as heard. This can indirectly have an effect on higher-level cognition. In this way music becomes an embodied version of the 'teaching machine' suggested by Marvin Minsky,[235] or what Kodwo Eshun has referred to as a 'subjectivity engine'. This instructive power of music is a two way process as an individual's inner life, expressed as music, is communicated out to the social world. Consequently, for Shepherd

> "The specific power of music lies... in its ability to both evoke and to structure symbolically the fundamental immediacy of people's relationships to themselves and the world, and to do this in a manner that is itself direct and concrete."[236]

4.3. The Negotiation of Difference

One of Shepherd's concluding thoughts concerns the importance of shared music making, noting that within modern society music "has tended to speak with 'one voice'."[237] He contrasts this with modes of music making in other cultures where "the logics of a society's relationships are not mediated through the being of any one individual." Furthermore, the social mediation apparent in these "emphasizes the importance of individual autonomy and creativity to the social process."[238] He describes how the ethnomusicologist Feld describes the Kaluli people as displaying a kind of 'anarchistic synchrony' promoting a kind of interaction that 'maximises social participation and maximises autonomy of self.'[239]

Shepherd suggests this means that individual expression need not be seen as in opposition to sociality.

Music therefore is essentially a social and not an abstract process, at least equal to that of language, although it may impact on more abstract forms of thinking. In further appreciating music's fundamental role as a communication medium we may see it as capable of representing the emergence of multiple perspectives and narratives, while providing embodied responses to the fracturing of discourse, conditions reflected in the term *postmodernism*.[240] A significant aspect of the 'problem' of postmodernism seems to be essentially a problem born out of excessive focus on language and abstraction to the neglect of other ways of being.

As already suggested by John Shepherd music performs a crucial role in the negotiation and incorporation of difference, both musical and social. Instead of seeking to find a single unifying resolution, the music's energy comes out of an interplay of its contrasting aspects. This is something already implicit within our own music making, discussed in the previous chapter. In this way, insights from music practice have already served to focus an interest on forms of organisation and structure in music that contain within them a significant element of West African influence, in the form of loops and the microdynamics of rhythmic interplay.

It is also worth bearing in mind that elements of this music have become familiar to Western culture generally in the form of musical hybrids, which have emerged particularly through 'popular' music, as was discussed in the previous chapter. In the case of the latter, a significant musical influence has been emerging from certain transatlantic hybridisations that Erik Davis calls the 'Black Electronic',[241] and Eshun, 'Atlantic Futurism'.[242] This music is in some ways 'in' many of us already.

Chernoff claims that the African sensibility is "profoundly pluralistic."[243] Its musical expression represents "a method of actively tolerating, interpreting, and even using the multiple and fragmented aspects of everyday events to build a richer and more diversified personal experience."[244] For Chernoff, the many ways that rhythms can be interpreted and contextualised parallels that of how we "approach or interpret a situation or a conversation. And there is always an in-between, always a place to add another beat."[245]

In the preceding discussion I have attempted to present some ideas regarding *why* rhythm works. The next section forms a discussion of *how* certain formal, rhythmic elements work within the music. The intention is to arrive at a model that captures an essential understanding of how rhythm works formally, and how improvisation works within this framework.

4.4. Aspects of West African Rhythm

The majority of the focus in this section is on West African drumming's formal aspects. Therefore it only reflects a partial insight into the rich situated phenomena that is reflected through the actual practice of this music. In any full understanding of West African music it is important to acknowledge its fundamental embodiment within its social environment. As Chernoff says:

> "... African music is not abstracted from its social setting as an 'art form' but rather is directly integrated into social activities ... the 'aesthetic effect' of the music would appear in the particular way the music 'functions' to involve people in a specific social event."[246]

The musical elements are interwoven with social expression and "the power of music is a social fact."[247] Furthermore, the actual music is not just rhythmic, but melodic also, for the drums can be struck in different ways so as to give different sounds.[248] Many of these melodic characteristics derive from the tonal characteristics of the local African languages, where pitch is an important component.[249] Therefore "the drums actually speak the language of the tribe"[250] and rhythm, melody and improvisation are constrained by fundamental correspondence with language.[251] Consequently

> "Westerners listening to African drumming should try to hear all the properties of tones – pitch, duration, intensity, and timbre – even while they focus on rhythmic relationships."[252]

In short, the music is substantially more than its rhythms and is not entirely reducible to any kind of abstract system.

With these considerations in mind I want to concentrate here on an aspect of how the rhythms 'behave'. This primarily concerns the nature of rhythmic interplay, and of how improvisation works, within this framework. These elements in themselves give an interesting perspective on 'oral' complexity within music. This understanding should provide a framework for considering some issues that emerge when attempting to simulate some kind of abstraction of it in the computer. For my present purposes, Chernoff's account is so complete that I draw extensively from it in the subsequent discussion.

African culture possesses what Kirk Degiorgio refers to as an Advanced Rhythmic Technology.[253] A defining feature of the majority of its music is the complexity of its rhythms[254] and a kind of holistic complexity emerges through interactions of simpler repeating parts. Chernoff cites A. M. Jones:

> "Rhythm is to the African what harmony is to the Europeans, and it is in the complex interweaving of contrasting rhythmic patterns that he finds his greatest aesthetic satisfaction."[255]

A good place to start is to contrast the basic organisation with certain Western concepts of rhythm and metre. The most common approach to rhythm in the West has been to confine the music to a single unambiguous metre. This basic segmentation is reflected in the bar lines and time signatures of traditional scores, and for that matter, in the sequencer's representational system. This framework serves as the basic 'scaffolding' on which to hang melodic and harmonic movement.

> "A Western rhythm marks time at an even pace with a recurrent main beat, generally with a major pulse every two, three, or four beats. What is most noticeable about the rhythm is that it serves to link the different notes to each other. We say, for instance, that a piece of music has a certain rhythm, and as we count out the beats, we will notice certain things. First, most of the instruments play their notes at the same time, and second, if we have a sequence of notes that runs into a phrase or a melody, the whole thing will start when we count 'One'."[256]

It becomes a basic feature allowing for a particular social organisation of musicians. That every musician counts from the same starting points allows for the organisation of large orchestras and enables conductors to ensure that all the musicians in the orchestra keep to the basic 'time' of the piece. The complexity of polyphonic music requires that different melodic lines need to be synchronised and notation serves to inform musicians of their temporal location within the music. The vertical bar lines enable this to become more accurate.[257]

All the musicians remain synchronised by reference to an underlying pulse, as reflected in the single 'metre' or 'time signature' of the music. This results in a situation where, as Chernoff says, "rhythm is something we *follow*" and it is concretely expressed in the sounds, being "largely determined in reference to the melody or even actually defined as an aspect of the melody."[258]

Rhythm is secondary to harmony and melody in this kind of Western music. In contrast, while tonal relationships are important in West African music a kind of dynamic rhythmical tension is created because "*there are always at least two rhythms going on.*"[259] At a fundamental level if one were to try and represent this music, a notation system would be needed that allowed for different instruments to have different metres.

In contrast to a group of Western musicians finding their place by reference to 'counting in' based on this single metre, West African musicians "do not find their entrances by counting from a main beat, but rather, they must find their entrances in relation to other instruments."[260] As Chernoff suggests this means for the listener used to finding the single 'metre' of the music, the music is seemingly more complex because there are in fact multiple 'metres', hence the description that this music is 'polymetric', or 'polyrhythmic'. In the type of Western music we have been discussing there, is in a sense, only one 'time' expressed through the single metre. In contrast:

> "...there is more than one 'time' in the music. We tend to think of 'time' as a single, objective phenomenon, moving quite steadily (as our philosophical heritage tells us) toward some distant moment (as our religious heritage tells us). Our music, of course, is above all a way of ordering sound through time, and Western music imposes a rather strict order to time."[261]

At a basic level then, simple metres in combination give West African music a significant aspect of its complexity, these rhythms being composed of simple duple and triple metres (like 2/4, 3/4 etc.) rather than a single more complex one (such as 5/4, 7/4 etc). These simple metres are important because this music is for dance, even if it is a mental one. The conflict of these patterns forms *cross-rhythms*, and it is this 'clash and conflict of rhythms' that is a defining feature of West African music[262]

> "The diverse rhythms establish themselves in intricate and changing relationships to each other analogously to the way that tones establish harmony in Western music. The effect of polymetric music is as if the different rhythms were competing for our attention. No sooner do we grasp one rhythm than we lose track of it and hear another... The Western conception of a main beat or pulse seems to disappear..."[263]

In order for the separate players to keep a sense of their own rhythm within this space of competing rhythms, the drummers and dancers practise what Robert F. Thompson has referred to as 'apart-playing', focusing on their own rhythm and not listening too closely to the others.[264] Erik Davis describes this as:

> "...maintaining a definite distance between their beats and those of the other drummers, a 'space of difference' which refuses to collapse or fuse into a unified rhythmic 'point'"[265]

To be able to do this, we need to understand that while there is a competing interplay of rhythms, underlying this is an implied 'beat' or 'pulse' that unifies these,[266] and the musicians play 'around' this, playing only some of what they actually hear. This implied beat *unifies* the music although it is not always reinforced with actual sounds. Therefore an understanding of this music is gained if we are "able to maintain, in our minds or our bodies, an *additional* rhythm to the ones we hear."[267] Perceiving this 'additional rhythm' enables steady, coherent listening, 'apart-playing' and for that matter, dancing, providing "a way of being steady within a context of multiple rhythms".[268] Richard Waterman refers to the idea of 'metronome sense':

> "From the point of view of the listener, it entails habits of conceiving any music as structured along a theoretical framework of beats regularly spaced in time and of co-operating in terms of an overt or inhibited motor behavior with the pulses of this rhythmic pattern whether or not the beats are expressed in actual melodic or percussive tones. Essentially, this simply means that African music, with few exceptions, is to be regarded as music for the dance, although, the 'dance' involved may be entirely a mental one."[269]

Therefore, those involved as players, dancers and listeners, become "*actively engaged* in making sense of the music... The full drum ensemble is an accompaniment, a music-to-find-the-beat-by"[270] and the musicians, knowing this, can elaborate their rhythms around this instead of needing concretely to express this underlying rhythm in sound. Waterman also suggests the idea of a 'subjective beat' and contrasts this with the European tradition:

> "The assumption by an African musician that his audience is supplying these fundamental beats permits him to elaborate his rhythms with these as a base, whereas the European tradition requires such close attention to their concrete expression that rhythmic elaboration is limited for the most part to mere ornament."[271]

Therefore, as Chernoff suggests, musicians and dancers perceive the relationships *between* the rhythms rather than on following 'stressed beat'. This they do by being able to "*listen to at least two rhythms at once.*"[272] This subjective element of these additional rhythms has further implications for attempting to notate such music, because a crucial part of what coheres the music is not actually expressed, only implied, in its sounds.[273] Instead 'one rhythm defines another' in the 'mind' of the listener and your own rhythms can only be played in relation to others' in the ensemble, as these others rhythms help define your own sense of the beat. Separating out and isolating these elements means that each element can seem almost random.

> "One drum played alone gives the impression of a rhythm tripping along clumsily or senselessly accented; however, a second rhythm can make sense of the first."[274]

Fluid musical movement is created as these stable rhythms' accents and emphases define each other, in a manner which struck me to be in some ways like the visual effect of using a kaleidoscope. The "*basic organization of the rhythms is the essential composition*, what an African might call the *beat* of the music."[275] The dynamic power of the music results from a "*a tension in time*" that is heightened as the musicians, instead of following the beat, seek to 'push' it, driving it forward to "make it more dynamic".[276] This in some way is what I understand to be the music's 'groove', something that finds its way into Western dance music such as funk. It is this driving energy that compels your body to move.

How the rhythms cross and cut each other can "make time seem to speed up or slow down, as if the rhythms, which are founded on recurrence, were somehow knocking on their own foundation."[277] Important here is the role of repetition, for instead of being associated with monotony, "repetition of a rhythm often serves to clarify its meaning. When rhythms change too abruptly, the music can lose some of its meaning"[278] This idea of meaning is also related to its correspondence with language.

The relationship these rhythms can have to each other has characteristics of a *conversation*. This is based around *call and response*, a defining feature of many African and some Afro American art forms. For Chernoff

> "In African music, the chorus or response is a rhythmic phrase which recurs regularly; the rhythms of a lead singer or musician vary and are cast against the steady repetition of the response. In essence, if rhythmic complexity is the African alternative to harmonic complexity, the repetition of responsive rhythms is the African alternative to the development of a melodic line"[279]

The evolution of the music revolves around the relationship between repetition and change.

> "[Repetition] is necessary to bring out fully the rhythmic tension that characterizes a particular beat, and in this sense, repetition is the key factor which focuses the organization of the rhythm in an ensemble. The repetition of a well chosen rhythm continually reaffirms the power of the music by locking that rhythm, and the people listening or dancing to it, into a dynamic and open structure."[280]

Because of the conflict of the cross-rhythms cutting across and responding to each other, by repetition the power of the music is 'magnified', the drummer using repetition to reveal the depth of the musical structure. The drummer can 'cut across' and focus other rhythms by varying his own, but because the rhythms define each other, the limits of this improvisation are defined by these rhythmic relationships. Those who step too far out from these relationships destroys the basic implied beat that is a result of their interplay, risk overemphasising their own beat and destroying the fine balance between all the parts. In improvising within the ensemble the drummer should therefore be aware of what everyone else is doing, their 'freedom' being limited by the organisation of all the parts (and the relation to spoken language). Importantly the drummer, whose rhythms are being focused by other rhythms, and who in turn focuses theirs, must not stray too far from his basic rhythm for it destroys the delicate balance at work in the subtle interplay. There needs to be a continued separation of the rhythms for each helps define the others. In order to do this restraint is necessary, for "a good drummer restrains himself from emphasizing his rhythm in order that he may be heard better."[281] Therefore, a good drummer is concerned as much with what he chooses to leave out as what is actually played.

Improvisation is not entirely free, as respected forms of music have grown up over a long tradition. Novel interpretations are most often associated with how the existing rhythms are organised. But the subtle improvisation within these constraints does mean that these forms remain continuously vital. The master drummer serves to highlight aspects of the rhythmic interplay, and the music's relationship to the social situation, fulfilling "a complex social role" by attempting to "integrate the social situation *into* this music". Different social situations therefore generate differences in the music and therefore musical sensitivity "extends from a general sense of the occasion to the very rhythms that the musicians play."[282] Also through call-and-response the master drummer engages in a dialogue with the other participants, reflecting different rhythmic takes on the repeated 'emphatic statement' of the chorus.[283]

It is important to mention this idea of novelty within these frameworks. New styles can emerge, but they come from simple modifications of existing structures, such as through the replacement of a single note. Particularly inappropriate is 'random expression'. Instead "expression is subordinated to a respect for formal relationships, and technique is subordinated to a communicative clarity."[284] Therefore "truly original style consists in *subtle perfection of strictly respected form.*"[285] Importantly, a sense of 'balance through dialogue' is needed to avoid 'overstatement and isolation'.

Through an awareness of the total context for the music, the master drummer therefore "organizes and focuses the expression of the power of both social and musical relationships."[286] Here the subtle *timing* of interventions and changes is of the utmost importance. Instead of a series of rapid changes to demonstrate technical virtuosity, lead drummers 'take their time':

> "Once into a style ... the lead drummer will continue to play that style for a long time. It is the duration of time that a drummer plays a particular rhythm, *the amount of repetition and the way the rhythms change*, to which the drummers pay attention, and not so much any particular rhythmic invention. The aesthetic decision which constitutes excellence will be the *timing* of the change and choice of a new pattern."[287]

A change of the lead drummer's style within the flow of music can have the effect of 'refocusing' our perception of all the other rhythms, precipitating a subtle perceptual shift in what we hear. By emphasising different aspects of the overall rhythmic 'surface' new relationships can be highlighted within the existing structure even though the other drums continue to play the same thing. Chernoff explains

> "With the dynamic potential of the beat as a foundation, the changes put pressure on the existing rhythms, and those rhythms become transformed in the sense that the musician, as we might say, 'renders his interpretation' of the beat; the new style will cut the music differently and maintain the tension from a different rhythmic perspective, often introducing new tension to support or go against the perspective which a spectator, or a dancer, had been trying to maintain."[288]

Above all, the 'smoothness and fluidity' of these changes is paramount to enable the music to remain coherent, danceable and socially relevant. How and when the master drummer chooses to refocus the music demonstrates his awareness of the music's social situation, introducing a "dramatic *gesture* that will play upon the minds and bodies of his fellow performers and his audience."[289]

An important quality of the music is that it remains open to a variety of rhythmic interpretations. Reminiscent of Pamela Jennings discussion of Eco's 'Open Work' in relation to narrative, the open structure of the music allows for players, dancers[290] and listeners to contribute to the overall shape of the music. Thus the music can be considered "*an arrangement of gaps where one may add a rhythm, rather than a dense pattern of sound.*"[291] What is not played, the silence between notes, is as important to the music's form as what is actually played. This serves to highlight the inherent conflict of rhythms.

Finding one's place within the musical situation becomes a balance of freedom and control, individuality and social belonging. The drummers, in finding a place to add their own beat, must balance their accent "on the edge of disorder and confusion" and find "'additional rhythm which complements and mediates those other rhythms."[292] It is therefore a musical form of being able to distinguish yourself while still being collectively related. For Robert Thompson "Multiple meter is … a communal examination of percussive individuality."[293]

Finally, I want to consider another form of collective transformation that can occur. When dramatic changes in the music do occur, everyone usually re-orientates themselves and collectively shifts their rhythms.[294] Interestingly, Chernoff compares this to the music of James Brown, music that is popular in West Africa because of its correspondence with West African forms, where all the instruments shift together to go to the 'bridge' and then shift back again. Ultimately, a fine balance exists within this music, with a sensibility that values "a particular *balance* of inherent tendencies" in a series of dialectical relationships:

> "the specialization of cross-rhythmic apart-playing should evoke the mediated appreciation of wholeness; the overlapping of call-and-response yields intriguing accents; the traditionally established rhythmic organization reinforces the situational commentary of the songs; the continuing dynamic tension of conflicting rhythms is varied through the appropriate timing of dramatic gestures which change the tension; the concentration on precision and control stabilizes the expansion of feeling."[295]

4.5. African Models for the Interactive Arts

This section contains a couple of examples of approaches within the interactive arts that are inspired by certain aspects of some African art forms. The first is Pamela Jennings' discussion of new narrative structures for the interactive arts inspired by African oral literature, and the second, Erik Davis' suggestion of a 'polyrhythmic' cyberspace as metaphor for our negotiation through the diversities of the online world. Significantly, these writers have also referred to a negotiation through balance of differing tendencies.

Pamela Jennings' discussion represents a reflection of her belief that our (Western) culture is moving away from "linear modes of organising knowledge".[296] She cites Brian Eno's comment that "the problem with computers is that there is not enough Africa in them"[297]. For Jennings, this taps "the surface of what I believe are rather poignant connections between the linear and nonlinear synapses of the computer as a medium of the mind and body."[298] For her, prevailent conceptions of narrative in the West, which appear historically rooted in Ancient Greece, contrast with African 'circular' conceptions of time. These two reflect "opposing metaphors: the unidirectional line and the iterative circle."[299] Dramatic progression and final resolution, the climax of the Western narrative, is replaced with a 'multiple climaxes' and rhythmic interplay of narrative elements, these elements acting as "individual agents that can communicate despite their placement within a story."[300] The storyteller and audience interact in a kind of feedback loop.

> "The oral narrator manipulates the audience's sensations by controlling the pattern of narrative beats ... By intricate variation of these rhythmic patterns, a good narrator will create a complete aesthetic experience for the audience."[301]

The narrator alters this narrative flow in response to the audience, a process of call and response where oral presentation moves from the literal "into a realm of circular mind-mapping."[302] While each performance is reflective of the basic narrative, its performance is always unique becoming open to a field of simultaneous evolving interpretations, which Jennings relates to Umberto Eco's idea of the 'Open Work'.[303] She explored some of these implications in a discussion of her own work.

Erik Davis suggests the idea of a 'polyrhythmic cyberspace'.[304] This model is derived from the new kinds of "acoustic spaces" of contemporary popular and avant-garde music. In contrast to visual analogies for cyberspace, Davis draws our attention to "the space we hear: multi-dimensional, resonant, invisibly tactile", "a psychological, social and perceptual mode that eroded visual space's logical clarity and Cartesian subjectivity, returning us electronically to a kind of premodern experience."[305] In his discussion of the 'Black Electronic', he points to the significance of "the remarkable acoustic spaces that emerge when the rhythmic sensibility found in traditional West African drumming encounter those electronic instruments, at once 'musical' and 'technological', that record, reproduce, and manipulate sound."

Therefore Davis, also inspired by Chernoff's account of West African music, suggests that the structural aspects of West African polyrhythm are "an excellent and overlooked model for the kind of distributed, multi-centered, hybrid consciousness associated with the networked mind." West African drumming becomes "an excellent analog model" for distributed technological networks, an understanding of multiplicity and "the emergent properties of complex systems" for which he finds inspiration from African influences on cybernetics.[306]

The next chapter builds on the ideas of rhythmic complexity discussed in this chapter, in order to evaluate a range of developments in artificial life, robotics and the computer modelling of perception.

5. The Challenge of Adaptive Rhythm Synthesis

In this chapter I present a discussion of some issues involved in considering the development of computer systems able to represent and adapt virtualised forms of West African inspired rhythmic expression. It is hoped that this will enable further explorations into the dynamics of its polyrhythmic interplay. This represents the most speculative aspect of the arguments presented and there are many ideas implicit within it that have not been fully worked out. In considering this I would agree with Agostino Di Scipio, who suggested that for Gyorgy Lukács "the material of art is the *still-to-be-reached*, the *not-yet* of the artist's knowledge."[307] In a significant way the following discussion reflects an attempt to express a vision of future rhythm technology that is in many ways felt implicitly but difficult to express. Significant aspects of this are being explored through studies in perception and the design of artificial adaptive systems. This chapter represents an account of some of these developments.

Through this discussion, I hope to show some general tendencies that may provide certain avenues of approach to the issue of machine rhythm. I do not claim credit for any of the individual developments and insights discussed here. However, what is interesting is that, collectively, these developments do reflect a trend in current thinking which is seeking to address the issue of time as an active and fundamental aspect of all sorts of human, animal and physical systems. I suggest that it is from some form of *combination* of these aspects that the requirements for a truly adaptive rhythm machine is emerging, and which will facilitate new types of computer mediated rhythmic complexity. In this way it is hoped that the reader will be able to relate aspects of these developments to specific features of West African music's structural characteristics. In order for the reader to get a general feel of the rationale, I also suggest that they read the final published paper in the Appendix.[308]

Developing any kind of fluid rhythmic movement using the computer is itself a newly emerging area. As computer musician Roger Dannenberg said in 1996

> "A natural area for further work [within computer music] is in drumming. In popular, jazz, and ethnic music, drumming appears to operate within highly constrained worlds

> consisting of idiomatic rhythms and phrases. This is not to say that drumming is easy or that it is easy to automate, but this seems like a natural area of research... We need the experience of building a dozen or so 'artificial drummer' systems in different styles to really get at the issues. This area is ripe for machine learning techniques."[309]

While insights from such a pursuit will undoubtedly produce interesting approaches, in the virtual world of the computer we do not have to seek to make a machine that is an automated drummer. Also, as Kodwo Eshun suggests, the term 'drum machine' is a limiting term. As Eshun suggests

> "There are no drum machines, only rhythm synthesizers programming new intensities from white noise, frequencies, waveforms, altering sampled drum sounds into unrecognizable pitches. The drum machine has *never* sounded like drums because it *isn't* percussion: it's electronic current, synthetic percussion, syncussion ... "[310]

I have therefore tentatively called the general approach advocated here one of *adaptive rhythm synthesis*. The desire is to develop a system that is highly *adaptive* to improvised changes in the environment of its use, in the manner that somewhat reflects a jazz drummer, able to provide structured transformations of related rhythmical elements in 'real time'. I use the term *rhythm synthesis* in explicit recognition of Eshun's point. In the creation of entirely virtualised rhythmic forms, new possibilities comparable to Eshun's 'Escherizing the break' may become possible. It is impossible to speculate what the music will actually become, as possible "new soundworlds begin as accidents"[311] discovered by these new machines.

This chapter begins with a consideration of some implications for computer representation of polyrhythmic music that displays subtle improvisations. The kind of technology that is suggested is sketched out and some recent developments in the field of rhythm perception, adaptive behaviour and object recognition are briefly discussed. An important notion is in the consideration of metre as a kind of dynamical system. Finally, in the light of such interdisciplinary concerns some reflections are made on the relationship between art, music and science.

5.1. Implications for Computer Representation

In considering the overall shape and purpose of West African music, clearly some of the balance and purpose of the music is beyond the machine, embedded within a social sensitivity of which, to my knowledge, no machine is yet capable.[312] Any attempt at representation of this system within the computer is bound to reflect a limited aspect of its overall richness as a meaningful social activity.

Simulating some of its formal aspects may however promote novel musical explorations in the structured relationships that emerge between rhythms. And, by representing some basic 'rules' apparent in their interaction, allow us to improvise more freely within this complex interplay.

Furthermore, it is suggested that this may become an interesting scientific exercise because the formal characteristics derived from the interplay of rhythms serve as good candidates in the scientific exploration of complex systems and the perception of complex objects.

The representation of timing is a particularly difficult issue in computer music. As Peter Desain and Henkjan Honing have suggested

> "Timing turns out to be one of the most complex and pluriform aspects of music to capture in a representation."[313]

In relation to the computer, the terminology usually referred to in the situation when the computer is responding immediately to the situation is that of 'real time'. As McCullough defines it, when discussing the display of visual information, 'real time' normally refers to "the condition in which data are delivered quickly enough to prevent any perception of discontinuity or lag". This becomes "especially important for continuous operations, where the response to a *stream* of input must be dynamically calculated and displayed at least as quickly as it is anticipated."[314] As Simon Emmerson notes 'real time' does not necessarily mean 'live' and one can get reduced to following the computer 'in real time'.[315] Real time becomes computer time.

Attempts at enabling the computer to be able to pick up and synchronise with the underlying pulse of the music are referred to as 'beat tracking'[316] or 'beat induction'.[317] In this way, the computer is programmed to be able to pick up and synchronise with the music's underlying metric pulse - even live music - and therefore able to vary its tempo in response to tempo changes made by the musicians. Attempts at this represent a substantial improvement on the musicians having to follow the tempo set by the computer. Consequently, a potential with these systems is that the musician does not have to follow the 'real time' operation of the computer, but can instead use the computer in the musical exploration of the nuances of live improvised performance.

My aims here though are different. Most attempts at getting the computer to follow the beat appear aimed at getting a computer to track and synchronise with an underlying pulse that is made manifest by the presence of actual sounds that serve to reinforce it. This is of course reflective of a Western musical system that expresses rhythm in this concrete way, as suggested by Chernoff in the previous chapter.

There has been a history of interest in rhythm, and its perception, within music perception and cognition research. However, when thinking about the usefulness of many existing computer models for rhythm, most of the models developed seemed concerned with issues derived from conservative views of Western art music. Niall Griffith and Peter Todd, in an introduction to their recent book *Musical Networks*, acknowledge that such models borrow heavily from Western music analysis. This consequently grounds them in terminology that "diminishes other possible arrangements between, for instance, rhythm and tonality."[318] They also suggest

> "In moving to embrace other, non-western systems of tonality, models ... will encounter the largely unexplored relationships between tonality and other musical dimensions, such as rhythm and phrasing. The significance of these relationships has often been sidelined by forms of musical analysis that tend to emphasize the separation of tonal from rhythmic structure."[319]

Within Chernoff's model of rhythm there is no underlying beat expressed in sound for the machine to explicitly refer to and track. Instead this emerges through the subjective interpretation of the listener, Waterman's 'subjective beat'. The question becomes whether a machine can develop a sense of this 'subjective beat', or 'metronome sense'. Furthermore, the aim in the present context is not so much to follow a beat as to use the computer to synthesize new interesting rhythmic relationships that can emerge from its 'interpretation' of the polyrhythmic interplay emerging from several competing rhythmic centres.

The second consideration concerns the computer's ability to provide subtle and coherent improvisations around these basic forms. As we have already seen rhythmic improvisation is a subtle affair where timing is of the essence. It is significantly more than random variation and involves a considerable ability to work with complex musical 'laws'. How effectively autonomous can a machine be in this?

5.2. Evolving Polyrhythmic Forms

The modelling of polyrhythmic events poses interesting questions for computer modelling, specifically in the computer's ability to represent the relationships that emerge through interactions of competing rhythmic pulses. The emergent nature of such rhythmic organisation makes these models good candidates for a kind of *Artificial Life*.

One of the field's originators, Christopher Langton, defines Artificial Life (ALife) as:

> "... a field of study devoted to understanding life by attempting to abstract the fundamental dynamical principles underlying biological phenomena, and recreating these dynamics in other physical media - such as computers - making them accessible to new kinds of experimental manipulation and testing."[320]

Within this area the idea of *Synthesis* represents an important methodology within research on ALife and situated robotics. New forms of machine behaviour can be synthesized, forming hypotheses of how something might work, and then compared to the behaviour of existing systems. This is in contrast to *analysis* of existing systems into discrete elements that are then modelled in some system. Bonabeau and Theraulaz suggest that this is a good way of studying complex systems, such as living systems, for discovering the principles of life are hard to come by with a top down analysis. Instead, by starting from the bottom up as it were, it is possible to synthesize increasingly complex behaviours from simple interacting 'objects' that may capture some important aspects of the dynamics of life.[321] For Christopher Langton, therefore, ALife's 'key' concept is *emergent behaviour*.[322] These life-like mechanisms can then provide for understandings of life, new kinds of artificial systems, and be an inspiration for a variety of practices.

Interactions with simulations of living systems become models for art, though whether these can then actually said to *be alive* is questionable.[323] Potentials are offered for new types of interactive experience. For Kenneth Rinaldo

> "With artificial life programming techniques, for the first time interactivity may indeed come into its full splendor, as the computer and its attendant machine will be able to evolve relationships with each viewer individually and the (inter) part of interactivity will really acknowledge the viewer/participant. This may finally be a cybernetic ballet of experience, with the computer/machine and viewer/participant involved in a grand dance of one sensing and responding to the other." (Rinaldo, 1998)

It is interesting to consider a technology that helps us to actively learn about polyrhythmic forms through highly interactive explorations that enable us to evolve and improvise with these basic forms. Operations that currently have to be explicitly programmed and handcrafted may be replaced with more fluid and contextual adaptations. The desire is therefore to extend the sequencer in such a way as to explore this vertical, rhythmic terrain.

The embodiment of musical processes is revealed as immanent in nature as biologically inspired algorithms 'grow' music that in some way mirrors our own, so that, for example, Stephanie Mason and Michael Saffle see musical structure emerge from algorithms that can model the growth of plants.[324] In his discussion of digital craft Malcolm McCullough suggests that with such growth algorithms

> "Form may evolve in uninterrupted time, or in artificial intervals (as in game cycles), or as a frame of the design process (e.g., version history)...for although craft depends on the impetus of the craftsman, elements of the work may have dynamism of their own, like material spinning on a lathe."[325]

It can therefore represents a kind of human machine evolution of rhythm where we learn about the dynamics implicit behind its structures as they evolve in time, rather than through static snapshots of waveforms and patterns of MIDI notes. An interesting idea is that expressed by cybernetician William Ross Ashby in his consideration of how species coevolve in symbiotic relationship, each becoming dependent on the other. For Ashby, genes do "not specify in detail how a kitten shall catch a mouse, but provides a learning mechanism and a tendency to play, so that it is the mouse which teaches the kitten the finer points of how to catch mice."[326]

The desire is to use ALife inspired techniques as a means of evolving and adapting parallel rhythmic forms, while allowing for a constant interactive shaping of this evolution. The emphasis therefore is not so much on deriving novelty from their initial generation, but in their subsequent adaptive potential. A desired aspect of the rhythmic character of the music comes to represent a collection of such interactive adaptations to these forms as they have occurred over time. These rhythmic developments therefore represent a trace of this process but one that is constantly shaped.

An artificial life technique that interested me early on in my research was William Latham's technique he described as *evolutionism*. This technique was based on Richard Dawkins computer program *Biomorphs*.[327] Here, a few simple rules can be used to describe visual forms. These forms can then be evolved from the successive application of simple rules that transform differing aspects of these forms. This is a gradual iterative process. For Dawkins these rules are analogous to the way that 'genes' control the evolution of organisms and give rise to the diversity of forms in life. After each iteration of the program, several different forms emerge from the application of these simple rules and the user can choose the one they like the most. In effect several possibilities can be 'bred' from these 'genes'. Here the computer and user together create a succession of new forms.

Using his adaptation of this technique, Latham constructs an imaginary world. For Latham the artist using this technique "first creates the systems of the virtual world, applying whichever physical and biological rules he chooses: light colour, gravity, growth and evolution. The artist then becomes a gardener within this world he has created; he selects and breeds sculptural forms as a plant breeder produces flowers."[328] For Latham the computer gave him "freedom to explore forms which previously had not been accessible to me, as they had been beyond my imagination." Importantly Latham considers that the total artwork is the trace left by successive breeding and selecting, reflecting his navigation through a field of computer mediated possibilities. As he says "My work of art was now the whole evolutionary tree of sculpture."[329]

Latham's approach is interesting because it resonates with the idea of evolving a range of simultaneous possibilities from loops from which the user can then choose those that are most 'useful'. However, a different sense is also required for we are concerned here with generating different kinds of rhythmic behaviour in time, rather than just a series of static variations.

Hub member Tim Perkis suggests something closer to what I have in mind. He discusses a way of working that he refers to as *emergent*. The musical result is neither an entirely crafted expression nor the result of the behaviour of a complex system where music is merely the 'trace' of this behaviour. Instead music results from an enhanced, dynamic form of representation, in successive and iterative interaction with human intention, through a process analogous to the successive shaping of looped elements. For Perkis, increased understandings of complex systems and the generation of models inspired by biological models close the gap between these two, resulting in a way of working that "has more in common with conversation than with a traditional human/tool relation"[330]

> " If the crafted-object way of working has meant *getting what you want* (and specifying that in great detail); and the experimental way of working has meant *wanting what you get* (being interested in whatever arises from ill-understood systems of interaction), the emergent ways of working based on evolutionary paradigms means *getting what you didn't know you wanted.*"[331]

This approach represents a highly directed form of artificial evolution. Within the flow of the music, an interplay of human intention and sensibility is mediated through the computer in the breeding of new musical forms.

5.2.1. *Metre as a Dynamical System*

To be able to create a highly directed form of evolution for the development of rhythm poses further challenges. The computer must not just suggest *what* happens next, but *when* it happens. The former is usually called sequence processing, and the latter can be referred to as temporal processing. As Large and Kolen suggest

> "a sequence processing system must collect, organize, and use knowledge of sequential structure. On the other hand, a temporal processing system must predict when future events are likely to occur ('When next?') by exploiting knowledge of temporal structure."[332]

In creating a system that can deal with the 'when next' of an event, we can understand and model polyrhythm as a kind of interplay of dynamic systems. Many natural phenomena can be described as some kind of dynamical system, as patterns that emerge through time.[333] This essentially is the essence of the word *dynamics*, a system that changes or 'behaves' through time.[334] Within the computer such dynamic systems can be modelled whose aspects are "evolving simultaneously and continuously in real time."[335] The systems' aspects interact with each other and how each of them changes depends on the state of the others. Therefore, a system is "interactive and self contained." An example of such a system is the solar system where the positions of the planets influence one another due to the effects of gravitation. However, the computer enables the modelling of systems with much more dynamism and complexity than the simple orbits of planets.

Michael Wheeler describes a dynamical system as "any system for which we have a rigorous analysis of the way it evolves over time."[336] The dynamical approach gives us a particular language to describe a system's behaviour, as

> "a *system* is a set of changing aspects of the world. The overall *state* of the system at a given time is just the way these aspects happen to be at that time. The *behavior* of the system is the change over time in its overall state. The totality of overall states the system might be in makes up its *state set*, commonly referred to as its *state space*. Thus the behavior of the system can be thought of as a sequence of points in its state space."[337]

The numerical space of the overall state of the system is referred to as a *state* or *phase space*. This phase space has *n* dimensions where *n* corresponds to the number of changing system aspects. We can for example visualise a system with 3 aspects as being mapped out in three-dimensional space. How the system actually evolves in this space becomes its *trajectory* (or curve) through this phase space. By varying parameters different trajectories become possible. Thus we get a spatial or geometric understanding of a system's behaviour over time: "behaviors are thought of in terms of locations, paths, and landscapes in the phase space of the system."[338]

The current state of the system determines its future state. The system's future development is therefore a function of its present state.[339] Factors that affect the system, such as the gravitational constant, are called *parameters*. Although such constants remain the same over time, hence constant, parameters may change in value over time, and these affect the evolution of the system.

Michael Wheeler discusses several features of dynamical systems that are important to consider. An *attractor* is a term used to describe how patterns can emerge in such a system. It can be thought of as "a state of the system to which trajectories passing nearby tend to converge."[340] A particular kind of behaviour emerges from what are called *periodic* attractors. In this way the behaviour of the system can settle into a pattern where the behaviour of the system is seen to *oscillate* around this attractor. There may be several attractors existing in the state space. *Coupling* can occur between two dynamical systems such that "at any particular moment, the state of either system fixes the dynamics of the other system."[341] In this way one dynamical system may be said to *perturb* the other. At some points, a change in parameter values may result in a qualitative change to the system's trajectory through its phase space, making the system become *structurally unstable* resulting in a *bifurcation* which leads the system into another trajectory. This may result in the system settling around another attractor or, indeed, complete instability.

Dynamical systems can be used to represent the behaviour of systems in real time. Trajectories can be plotted as a series of discrete points in time. The resultant trajectories reflect the ordering of these points in real time rather than just an ordering of points.

> "Thus the notion of time in which the system operates is also one to which a substantial notion of 'length' can be applied, in other words, it comes to possess some of the same key mathematical properties as *real* time."[342]

The usefulness of this approach is that models of real world events unfold in time and "*timing* is essential"

Erik Davis presents an interesting and evocative metaphor for understanding the interplay at work in such music.

> "Establishing an analogy with nonlinear dynamics, we could say that the lead drummer must maintain an open field of competing rhythmic attractors. The game is to push the beats to the edge of bifurcation without allowing them to settle into a singular basin of attraction. For listeners that means remaining constantly open to productive chaos: to the disorienting surprise of beats struck earlier than expected, or

to the little voids that open up when beats are unpredictably dropped out – an experience Chernoff brilliantly likens to missing a step on a staircase."[343]

Studies in the perception of metre in music and language suggest that metre can be understood as a stable attractor within a dynamical system. Various models using particular kinds of neural networks[344] called 'oscillatory' neural networks have been used to suggest, as for example do Robert Port, Keichi Tajima, and Fred Cummins, the idea of "meter as an abstract dynamical system on the state space of two or more oscillators." [345] These networks are said to *entrain* to the metre of language or music. A particularly interesting approach is that of Petri Toiviainen whose model attempts to deal with the fluctuations in timing of real time performance.[346]

It is an appealing prospect to be able to improvise with virtualised rhythms made up competing dynamical systems. As McCullough suggests in relation to digital craft

"By altering the settings of a dynamic system (e.g., the coefficients of a system of differential equations), one can improvise within the context of a simulation."[347]

Within the fields of robotics and cognitive science these metaphors are becoming actualised within technology that works, and to varying degrees improvises, within an environment. Therefore, here I want to consider certain developments in the field.

5.2.2. Adaptive Behaviour

The field of adaptive behaviour[348] is concerned with the development of devices and software simulations that can operate within changing and unforeseen environments.[349] In this pursuit various models from nature are used as inspiration for machine behaviour. This general approach is taken to be indicative of a general desire to increase a machine's ability to improvise spontaneously within its surroundings.

As an aspect of this research situated robotics[350] represents a renewed focus on the design of artificial systems, often referred to as 'agents', that interact with the environment, where the environment is considered to form an equal and reciprocal part of the relation.[351] This general approach may be considered to have emerged partly as a result of problems encountered in the design of an earlier generation of artificial systems. These earlier systems attempted to navigate through an environment by representing and manipulating an internal model of that environment. The important point is that these models only formally corresponded with abstracted facts about that world. Here the environment was something to be represented and modelled within the machine. How the machine consequently behaved was therefore a result of internal manipulations of this model. In consequence, these devices were fundamentally disembodied from their environment, in a way that any abstraction removes structure from its context. A problem of relevance was that these earlier attempts were 'brittle' in the sense that they could not cope well with more complex or dynamic environments. In short, they could not improvise particularly well.[352]

An important goal of situated robotics is to develop "fast, reactive behavior."[353] To this end, there is generally an explicit attempt to acknowledge the embodiment of mutual interacting relationships of an organism's mind, body and its environment.[354] Consequently, approaches to situated robots seem primarily concerned with synthesizing new kinds of useful behaviour. As Horst Hendriks-Jansen suggests

> "[Situated robots] are models of behaviour, not attempts to model the mind or brain. There is no presumption that the computational devices used to implement the behaviour bear any resemblance to mechanisms inside the creature whose behaviour is being modelled."[355]

The focus becomes shifted to engineering observable *activity*, rather than hidden knowledge structures corresponding to facts about its world. Knowledge is not equated with our own verbal descriptions of it.[356] Representations are consequently different in kind from those consisting of facts about the world.[357] Representations *support* activity and consequently, as Clancey explains, the task is to design "*interactions* rather than structures in memory" and the problem one of constructing "an *interactive system-in-its-environment*."[358] The characteristics of the environment form an extension to internal representation, while the representation extends the agent's ability to interact with that environment. The environment itself facilitates activity.

An important idea is the idea of *coupling*. The robot is in constant interaction with its environment through a tight loop of acting and sensing.[359] Therefore the focus of concern is not "'What knowledge structures should be placed in the head of the robot?' but rather 'What sensory-state coupling is desired, and what machine specification brings this about?'"[360] Behaviour emerges from multiple distributed interactions and for many actions there need be no central controller in overall charge of co-ordinating these interactions. Indeed, as Andy Clark points out "centralized control via detailed inner models or specifications seems, in general, to be inimical to fluid, contextual adaptation."[361] In order to be able to facilitate smooth interactions, it is important to avoid a situation analogous to where a learner driver zigzags over the road in an attempt to over-compensate for changes in the system.[362]

In Rodney Brooks' 'subsumption' architecture, interactions that produce simple behaviours can be layered in a hierarchy, and through combinations of these simpler behaviours, more complex behaviours can emerge.[363] Maja Mataric's wall following robot is an illustration of this type of approach. Basic behaviours, such as 'homing' and 'wall following'[364] consist of "well-defined control laws that achieve and maintain a particular goal." For Mataric

> "Behaviors are directly tied to the dynamics of interaction with the world: they are designed so as to rely on and exploit these dynamics. Thus, the specifics of a wall-following behavior may vary greatly across different robots and environments. It is in this sense that embodiment is crucial; the detailed specifics of a behavior cannot be derived, tested, or verified outside of its environment of application."[365]

Mataric also describes how groups of robots can be designed to interact with each other and 'flocking' type behaviour can emerge.[366] This behaviour is not centrally controlled but emerges from a situation that is "firmly grounded in the immediate, local, physical interactions between the agents."[367]

An important aspect of much behaviour is the role of *timing*. Consider walking for example. This involves the co-ordinated rhythmic synchronisation of leg movements. In exploring this work has being carried out in emulating insect locomotion in simulated and real environments.[368] Rhythmic, synchronised leg movements arise from the simple dynamics involved. Importantly neural network representations are used that are simulated dynamical systems.[369] It's interesting to consider less that it moves 'like an insect'; more that the simple dynamics involved create the patterned movement we recognise as insect-like.

5.2.3. A Note on Machine Autonomy

It is a useful exercise to seek to clarify what kinds of machine behaviour can be considered as truly 'autonomous'. The word 'autonomy' conjures up many meanings but a deeper consideration of its meaning serves to suggest particular kinds of approach to the possibilities for a musical autonomous machine. An important consideration is in the machine's ability to extend our ability to improvise within complex environments of interacting musical elements. In considering what autonomy could mean in this context I have been greatly helped by Tim Smithers' attempt to clarify its meaning.[370] The approach that he takes is in seeking to tie machine autonomy more closely to definitions found in other disciplines such as philosophy and the law, which suggest the idea of self-determination.

Smithers looks at the etymology of the word 'autonomous' and compares it with other similar words that are often confused with autonomy. An *automatic* or 'self-moving' system[371] is therefore "a system that can produce movement (of some kind) on its own." An example is the clock. Also included is 'self acting', allowing us to include certain kinds of software like operating systems and word processors.

The second term discussed is cybernetics, invented by Nobert Wiener (Wiener, 1948). The word *cybernetic* is derived from the Greek *kybernan* (for steer) and *kybernetes* (for pilot or governor). Such systems are therefore "self-regulating systems, systems that are not just able to move or to act by themselves but are also able to regulate and control their movements or actions so as to maintain their effectiveness in the face of disturbances and perturbations, according to some predefined control law or rule of regulation." Examples here include thermostatically controlled devices like ventilators, refrigerators, and factory automation systems. The term 'automatic' is often used to cover both of these. The idea here is that order or organisation is *imposed* by some kind of controller.

In relation to this, Smithers considers ideas of *self-organisation*. Instead of a control law being specified from outside, order is "an inherent property of the system". Here order or organisation is sometimes referred to as an *emergent* property of the system.

The word *autonomous* is again different, derived from the Greek *autonomos* (auto, or self, and nomos, or rule or law). Used by Greeks to describe a city-state where citizens made their own laws rather obeyed laws made by others. So "a system is an autonomous system when it regulates its behaviour according to rules or laws that it has constructed for itself." In contrast to cybernetic systems autonomous systems are *self-law making.*[372]

As Smithers points out, most situated robots are not truly autonomous for their 'laws of interaction' are predesigned. This limits their ability to improvise within environments, because it is impossible for the designer to foresee all outcomes. Furthermore "This problem becomes quickly more and more difficult as environments have more degrees and amounts of normal variation, dynamic change, and unpredictability." The problems to be solved are essentially synonymous with how biological organisms engage in their world.[373] It is interesting to consider to what extent a machine is able to infer its own laws about the rhythms that it represents and adapts.

5.2.4. Feature Binding

Waterman's 'metronome sense' suggests that complex rhythms emerge out of an interplay of multiple metres where the sense of the 'beat' of music becomes 'subjective' in the sense it is *inferred* from the events in time that surround it. An insight into understanding this problem may be derived from a consideration of how the mind is able to cohere a perception of a complex object. A visual object may consist of a series of separate features – for example, intersecting lines, shapes and colours - from which the object itself can be said to emerge through our active perception and assimilation of its features.

This idea is based around that of *feature binding*, the perception of a complex object from its simpler parts.[374] In the visual system it is hypothesised that a hierarchy of localised feature detectors serve to discern features of the visual scene such as lines, colours and movement. Higher-level detectors serve to combine these in detecting more complex aspects of an object. The simple detectors serve to 'inform' these higher detectors but the process is highly interactive as higher levels act to constrain interpretation. Recognition of a complex object arises out of co-ordination between the perceptions of its features.

Even if the perception is of a static object, feature binding seems to be an intrinsically temporal process. When we perceive an object in space and a musical object in time we may be doing basically the same thing – repeatedly sampling our environment through time. In discussing the nature of aesthetic perception, Jason Brown suggests that although we may consider that the object is fixed and the music is ever changing, our minds handle it in the same way. Thus our perception of spatial and temporal events involves significant similarity.[375]

How this process actually occurs may arise out of a highly synchronised process, as suggested by various studies and computational models. For example, using models of oscillatory neural networks, Roman Borisyuk explores a hypothesis that within the brain 'higher' brain areas modulate the oscillation of 'lower' perception in the formation of coherent object perception.[376] In his model, what appears to happen is that individual perceptions of lower level features are cohered by processes of modulating waveforms. This results in these separate areas, each displaying unrelated rhythmic behaviour, becoming synchronised. Perceptions of simpler features therefore shape higher-level perceptions, but these higher-level perceptions can in turn bias the perception of simpler features. It is a highly interactive process that is suggestive of how perception and conception arise together. Aspects of Borisyuk's model appear to bear some resemblance to a technique that has already been applied to create 'emergent form' in musical synthesis, John Chowning's frequency modulation (FM) synthesis.[377]

A perceived rhythmic complexity therefore can be said to emerge from the co-ordination of these dynamic systems.[378] The important point is that what is analogous to the 'subjective beat' in the mind of the perceiver may relate in some way to a, possibly more embodied, version of such an approach. Musically, the exciting thing is that computer models of dynamical systems are being developed to investigate the phenomenon.

5.3. Tools for Art, Tools for Science

The previous discussion involved an explicit attempt to investigate various scientific developments that may aid the exploration of rhythmic complexity. They have served to inform and enrich a viewpoint that is still in its early stages. Through my discussion I hope to have made it clear that, in some important way, this research has concerned both science and art in a fundamental way. Conversely, it is possible to suggest that the study of complexity brings science "closer than ever to Art."[379] This section discusses some ideas that have arisen out of the research process regarding the nature and values of enquiry that is both science and art.

It has been noted how, historically, scientific, musical and artistic systems have displayed close affinities and simultaneous change.[380] It is interesting therefore to consider to what extent art and music may serve to actually *stimulate* scientific and engineering research. The composer and music researcher Jean Claude Risset believes that

> "... art's concerns, demands, theory and practice can stimulate science, and the artistic exploration of new media helps the scientific understanding of phenomenal reality."[381]

Risset discusses how musicians' questions and demands have been "quite challenging and inspirational to science and technology", and how many mathematical concepts "were used implicitly in music before being defined in mathematics." Technology developed for musical ends can pre-empt science, as Risset suggests. He notes how Pythagoras's use of arithmetic to describe musical vibrating strings "was physics in the making" and how the organ was "the first information machine", which used a method of generating sound that predated its mathematical formulation by centuries.[382] Risset suggests that music has already provided interesting challenges for computing, where it has "often led the way for significant advances in computer science and technology."[383] Descriptions of mechanical organs from the 17th century contain within them the "notion of a stored program".[384] More recently, musical technologies have been developed that deal with virtual reality and real time computer control.

Both science and art originated in rituals of everyday living, according to art historian and philosopher Ernst Fischer.[385] But the rationalism inherent in Newtonian science subsequently brought about a break in this relationship. For Charles Garoian and John Mathews, performance artist and physicist respectively, a situation resulted where

> "What was once the unified domain of ancient shamans, involving rituals performed to mediate between human life and the uncertainties of the world, has, in the modern world, been divided and isolated into separate academic disciplines whose scholars stand vigilant to protect the boundaries of their expertise and knowledge."[386]

However the activities of music, art and science all serve to "expand our cultural vocabulary." Similarly, the biologist Mae Wan Ho has suggested that they both involve "actualization of patterns or forms, and the communion of shared experience through a universal ground."[387] Garoian and John Mathews therefore speculate that the removal of these boundaries will result in the opening up of new areas of investigation, a "new Renaissance".[388]

A question concerns the method one chooses to explore the world. I have discussed the role of music practice as a method of knowledge, and of the inherent 'subjectivity' and tacit knowledge that this implies. However, such tacit dimensions are also part of science, as for example suggested by Malcolm McCullough's discussion of Michael Polanyi's study of scientific learning. In this regard

> "His main argument concerns the subjective act of affirming objective scientific methods. Whatever it is that drives a researcher to pursue particular sorts of findings is inarticulable and personal."[389]

It is recognised that emotional, visual and visceral impulses serve to stimulate the process of scientific discovery,[390] so it is reasonable to include the aural. Scientific insight appears to involve an element of 'poetic intuition'[391] and involve elements of 'passion' and the 'irrational'.[392] In discussing the relationship between scientific discovery and musical creativity Tang elaborates on how the composer Stravinsky used "rule-governed, objective manipulating and ordering of musical materials."[393] This is reflective of a discussion that suggests both science and art contain creative generative processes and ruled governed organisation of materials. Scientific rules serve to "channel criticism and facilitate evaluation of subjectively formulated hypothesis."[394] In engaging with their materials both artists and scientists therefore display rational, emotional and tacit characteristics that figure in the heart of their method.[395] Perhaps, as physicist Jacques Mandelbrojt has suggested, both scientists and artists engage in what he calls 'creation-discovery'.[396]

The musical worlds I have discussed represent prime examples of truly complex systems. As Heinz Pagels suggests, while on the surface complex systems may appear qualitatively different, underlying mechanisms may show surprising similarities. Therefore

> "As our understanding of complexity develops, laws of complex systems may be found that apply to a variety of systems irrespective of what discipline they are found in."[397]

I have seemingly come to investigate complexity through music. I want to consider this in terms of mathematics, which I have never found an easy subject. This I have come to understand as largely due to an abstract terminology that has prevented a fuller appreciation of mathematics, in a way that perhaps relates to a similar alienation from common music notation. Jocelyn Godwin has suggested that music is a form of mathematics whose concern is with the quality rather than the quantity of number. For Godwin it means that musicians can directly perceive mathematical realities without the mediation of abstract symbols. An important idea is that music can play a *speculative* role, enabling us to play with models expressed in sound that become a form of speculative enquiry. In urging a rediscovery of the power of speculative music she says:

> "Music exists in order to give human beings knowledge about the universe, of a kind that is inaccessible through other channels. The composer reveals knowledge of emotional states, which enrich and educate the listener. The speculative musician discovers universal principles as surely as the mathematician or the philosopher, though since he does not use the medium of words or of pictures, his knowledge is undervalued today, and his discoveries may seem like coincidences or curiosities."[398]

Stravinsky, when asked by Robert Craft about the relationship of musical form and maths, replied that it was something akin to mathematical thinking

> "... the way composers think, the way I think, is, it seems to me, not very different from mathematical thinking. I was aware of the similarity of these two models while I was still a student; and, incidentally, mathematics was the subject that most interested me in school."[399]

John Shepherd recognises something similar when he suggests that, through its "relative autonomy", musical behaviour may appear to not resonate with any other social processes, only to be *subsequently* recognised. Consequently

> "It therefore remains possible for people both to create and to know about aspects of their world which may not be accessible to them initially through any other medium other than music."[400]

Through an investigation of music, I have come to appreciate the power of mathematics, particularly through an appreciation of dynamical systems. Notation still forms a barrier, but the computer's visual representations of these phenomena become very instructive. Music has therefore become a bridge enabling an appreciation of worlds formally closed to me.

In discussing music and science, Robin Maconie suggests that we need to recognise the deep interrelationship between music and science, for

> "... the two worlds of art and science are not mutually exclusive but deeply interrelated and therefore that the concerns of music and science throughout history have shared common objectives that can be articulated in a common language"[401]

For Maconie, "by understanding music's place in human development, we enlarge our view of science."[402] As Maconie suggests, we should recognise the neglect of "aural modes of reasoning" and the consequent favouring of visual metaphors and ways of verifying the world.

I hope that my thesis in part is a demonstration of the potential power of this. Through music research an appreciation has emerged of the mutual role that both science and art can have in the exploration of emerging areas, a balance that I have tried to reflect in my considerations.

Conclusion

The essence of this thesis is an attempt to consider technology in relation to models of West African rhythm and improvisation. This has served to focus attention on specific developments in artificial life, adaptive systems research, and the computational modelling of perception. These contain within them some important perspectives on the possibility of subtle machine improvisation and suggest future avenues for the representation of complex musical knowledge. What has also been of great interest is how such developments in technology, and the intellectual thought of which they are an expression, seem to increasingly acknowledge the importance of the dynamics of time in understanding behaviour.

An example is musical metre. It was particularly interesting that some researchers in rhythm perception were conceiving of metre as a dynamic, rather than static, phenomenon. By dynamic I mean to suggest that, even though it appears as stable, this stability is something that emerges from a process that is inherently one of continual balance. Similarly, the perception of visual objects appears to be an inherently dynamic process, promoting a consideration that the perception of music and that of visual objects are in some ways similar.

Another important aspect concerns the role of the environment. There is increasing acknowledgement that in order for artificial systems, such as situated robots, to be able to sufficiently adapt and improvise within their environment, that actual environment must be explicitly included as part of the dynamics of the interaction. Consequently, seemingly complex, and often rhythmical, behaviour emerges through the robot's constant interactions. The work of situated roboticists is concerned in the main with such interaction within physical environments, but these insights could equally serve in relation to the negotiation of musical worlds where the changing tensions of polyrhythm are conceived of as a highly structured, but dynamic terrain. An important insight from this research is that rhythmic behaviour is considered an important aspect in the synchronisation of behaviour and communication generally.

The challenge now is in how to combine these insights into the creation of workable 'semi-autonomous' musical devices. An important consideration was in defining what actually counted as 'autonomy'. The use of the term 'autonomy' was not meant to suggest that the machine could become an artificial musician. It is us who are embodied and distributed within the environment of the music studio, and not the machine. However, musical structures emerge in our environment, for which the machine could be equipped with an ability to make its own laws regarding the relationships implicit within them. In this way they can serve as extensions to our own understanding by making explicit the implicit rhythmical relationships in the music. They may also become a tool for rhythmic improvisation, to the extent that they are able to suggest interesting structural transformations and facilitate the possibility of adaptations that may be made simultaneously *between* the components of rhythm. In this way such devices may act as teaching machines, enabling us to learn some important lessons about rhythm through our interacting with their behaviour.

The kind of musical instrument desired is that suggested by Erik Davis' metaphorical understanding of West African drumming, to create "an open field of competing rhythmic attractors", where we, as its players, become master drummers rendering various interpretations of these dynamics, and in turn altering those dynamics. Computer technology can therefore serve to extend the musical environment, not replicate or understand it, but still be a collaborator of sorts, becoming an amplifier and transformer of expressive musical intentions. Disembodiment is not necessarily the result of inadequate computer interfaces but possibly emerges out of our own orientation towards it. An important idea is that through human-machine dialogue (and symbiosis) the technology and its supposed limits permit differing interpretations as its behaviour meets with the differing intentions of its users. In the present context, the potential of the computer has come to be seen as offering the potential for new forms of immersive embodied experience within virtual musical worlds of our own making. It is argued that rhythmic exploration through such worlds becomes a powerful means of sonic and social negotiation.

Exploring this thesis has also helped reveal a range of deeper issues that inform its conclusion. Music is not just an abstract set of relationships in sound to be transplanted to the medium of the machine. In considering what part of the musical process may be extended with technology, it has also become necessary to consider deep issues regarding the *why* and *how* of music. This has resulted in an enhanced understanding of the functions of music and the nature of technology. This can be contrasted with an initial intention that was concerned just to design music technology.

One of the significant catalysts for this expansion of perspective has been music practice itself. Practice more than anything else has helped ground a consideration of all these discourses within a context that is personally meaningful. It forms a valid and powerful means of enquiry equal, and complementary, to that of theoretical reflection. As suggested by John Shepherd, music is itself a form of knowledge that does not merely reflect social conditions, but plays an active part in their creation. This is my understanding of music as embodied action, an understanding not only concerned with how music is a sensual art involving the interaction of bodies, but that it is a knowledge creation and communication process. The computer may be help to intensify aspects of these processes by allowing us to virtualise and play with aspects of reality

This understanding of the social power of music has in turn posed interesting questions in regard to its relationship to science as a mode of human discovery. A tentative proposal is that it is possible to explore musical ideas that can become the genesis for scientific hypotheses. This is illustrated with a suggestion that the exploration of rhythmic complexity forms part of a wider interest in complexity in general. In this way an exploration of rhythmic complexity through the medium of music practice may form a speculative contribution to what Heinz Pagels calls 'the sciences of complexity'. It is just that the method chosen has been a different one.

What I have tried to represent in this discussion, and in the music I have included as part of the submission, can only partially reflect what has been a rich exploration of music, science and technology. The experience of this research has served to significantly progress understanding of my own music practice and led to many divergent and intriguing insights.

Notes

---

[1] Although the incorporation of digital samples have also served as inspiration for certain compositions.
[2] The methodological reasons for doing this are discussed more fully in Section *1.1. Documenting an Emergent Context.*
[3] (Rothenberg, 1994), p. 16. When I use the word creative in the present context I am implicitly referring to the sense of a transformation of something human.
[4] This was a suggestion by Mike Punt.

[5] For a recent bibliography of issues in art and design research methodology see http://www.biad.uce.ac.uk/research/guides/case_studies/bibA_D.html. and http://www.stare.com/beryl/learnma2.html

[6] (Newbury, 1996a).
[7] (Gray and Pirie, 1995).
[8] This is highlighted by Gray and Pirie's discussion of Anne Douglas' doctorate on sculpture.

"She soon discovered the limitations in this structuralist approach (i.e. the data was selected, and could only deal with stable, unchanging contexts- what structuralists describe as "synchronic"), realising that practice-led research requires "diachronic" data - which has evolved through time, is unstable and changing." (Gray and Pirie, 1995, p. 8).
[9] See for example (Glaser and Strauss, 1967); (Strauss and Corbin, 1990); (Glaser, 1992), also (Pandit, 1996).
[10] Posting to the CTI Art and Design newsgroup, 8 Jan 1998.
[11] (Strauss and Corbin, 1990) p. 23, cited in (Pandit, 1996).
[12] Thanks to Mike Punt for clarifying this idea.
[13] This term is somewhat borrowed from a particular kind of mathematical proof that demonstrates that something with certain properties exists because one can show an example of it. For example, the number 2 is an existence proof for there being at least one even prime number. In the present context such a 'proof' is in fact highly subjective.
[14] (Thorpe, 1995), p. 260.
[15] (Thorpe, 1995), p. 259. See also (Chandrasekaran, 1988).
[16] Quite how hard it is to seek to translate one's musical intention into computer technology is well illustrated by Daniel Oppenheim. In introducing a discussion of his computer-based DMIX compositional environment he reflects:

> "Any discussion of creativity, the creative process, the effects of technology on our creativity, or how technology can be adapted to better support creativity, is problematic at best. It is hard, if not impossible, to define what creativity is – so how can we design technology to support it? And when we consider systems for supporting music composition, we are faced with other questions that are no less problematic, such as: What is music? What is a musical idea? ... It is difficult to design a general system for dealing with music without a clear, formal understanding of both the musical domain and the creative process of composition.
>
> "We are faced with a fundamental dichotomy. On the one hand is the artist's natural creativity as initially manifested in a set of musical concepts and ideas. On the other hand is the computing environment in which the artist must work in order to realise his

ideas. This computing environment, by its very nature, imposes a formal framework within which the artist must work. At some stage, the musical ideas must be expressed in terms of numeric parameters that are manipulated by the computer program. This causes two problems: first, the ideas will become distorted in the process of transforming them into the formalised parameters. Thus, in a way the composer is no longer working with his original ideas. Second, a composer may find it disrupting to shift from thinking in his own musical terms to working within the rigid framework required by the computer application. At best, this would only slow down the creative process; more likely, it would introduce negative effects on the composer's creativity ... there is not obvious translation of any natural musical idea into any single formal system. Problems arise when we try and force musical concepts into a formal framework in which they really do not belong." (Oppenheim, 1996, pp. 117-118)

For Oppenheim, the computer's compositional limitations are not understood enough, while the computer gives the illusion that is has few limitations. Therefore "the (naïve) composer may try to implement ideas that, in a given system, are hard to materialize." (Oppenheim, 1996, p. 118). Oppenheim suggests that rather than design whole integrated systems we focus instead on 'simple-to-use components'. It is my intention here to focus on a single aspect of our own compositional process in order to seek to provide the basis for creating just such a simple component. A consideration of this is balanced with a desire to continue to support familiar and productive aspects of existing processes. A consideration of any new approach is balanced with that of its applicability to our existing working practices and musical purposes. Therefore it is important to recognise at the outset that certain approaches adopted by other people, while interesting, reflect different working practices in the pursuit of different forms of music for different audiences.

[17] For example, a panel discussion entitled 'Do Engineers and Artists Make Good Love Objects?' was held at the recent Creativity and Cognition conference (Loughborough University in 1999) concerning how engineers and artists can collaborate (Bacon; Rieser; Fleuriot; Heard, and Easy, 1999).

[18] Programming is itself a creative activity. Craig Hickman suggests that artists should program, rather than to use off-the-shelf programs because they can make important contributions to new kinds of software. Commenting on the software industry's 'profound lack of imagination' he believes "[t]here must be many applications for computers waiting to be discovered by someone with imagination to look for them." (Hickman, 1991, p. 50) He gives an example of a fractal graphics program developed between artists and a mathematics professor that would not have been possible without the artists' knowledge of computer programming. He says:

"Artists have always been explorers and innovators, and one of the primary areas for such innovation by contemporary artists has been in developing new connections between media. Some entirely new media have come out of such explorations ... Since the 1960s, media have been a primary focus of artists ... this attention has expanded their roles from simple vehicles of ideas to *objects* of communication ... This is why artists should learn to program. If artists are going to work with media as subject matter, create new media and realign relationships between traditional media, they probably will do so, in large part, through programming because it offers artists the flexibility they need. Most software today was modelled on some existing medium or application; what artists must do is expand upon what already exists. To do so they have to be able to create their own software." (Hickman, 1991, pp. 49-50)

Encouraging this kind of interaction at the level of programming may also help dispel some of the mystique that seems to surround the computer, for "[i]t is much easier to mythologize technology while dreaming about it, not trying it out." (Rothenberg, 1994, pp. 155-156)

[19] George Lakoff and Mark Johnson discuss metaphorical power and its deep embodiment within language (e.g. Lakoff and Johnson, 1981; Lakoff and Johnson, 1998).

Metaphor has an important role in many disciplines. Within art Heinrich Bluecher "identifies the type of thinking used for all art production as metaphorical, as a tool of the human mind." (Alcopley, 1994, p. 184, see also Bluecher, 1968). Donald Schön discusses the use of generative metaphors within art practice (e.g. Schön, 1979). Within science, Max Black has advocated that scientific understanding starts with metaphor (Black, 1962). Scientific words can be grounded in non-scientific concepts (for example gravity and gravitas). For discussions on the relationship between metaphor and science see also (MacCormac, 1976) and (Hesse, 1980). Therefore considerations of the computer are deeply in embedded in metaphor. For discussion of its influence within discourses within general computing and artificial intelligence (e.g. Johnson, 1992, Harvey, 1996), and various discussion in (Haken, Karlquist, and Svedin, 1993).

[20] (Thorpe, 1995), p. 261.

[21] (Thorpe, 1995), p. 261.

[22] (Gray and Pirie, 1995).

[23] (Waters, 1997), p. 20. As electroacoustic composer Simon Waters suggests, cultural pluralism and the emergence of hybrid musics are leading to a breakdown of the influence of traditional institutional validations of music. He notes

> "a shifting of the balance between composer and listener, investing the latter with an authority to decide something's value or meaning which until recently was the preserve of the composer ... Authorship (compositional autonomy) can be deconstructed as another kind of institutional power. Comfortable ideas about a 'canon' of objectively 'Great Art' or 'Great Music' which is timeless and international are also undermined, as attention is drawn to the historically contingent, ideological nature of the way in which such a 'consensus' emerges. But without these comfortable certainties it becomes increasingly difficult to find general criteria for criticism, evaluation or legitimation of the arts (or anything else, for these upheavals are as prevalent in scientific as in artistic thought). Perhaps one of the few remaining legitimate criteria for a composer may be the need to discover or verify something through activity." (Waters, 1997, pp. 19-20)

[24] Christopher Frayling suggests three kinds of relationship: research *into* art and design, research *through* art and design, and research *for* art and design (Frayling, 1993). Research *into* art and design concerns the various theoretical issues that surround it and could include psychological, sociological and historical issues of art and design practice, for example. Research *through* art and design is where the art and design practice itself forms a methodology of enquiry. Research *for* art and design relates to "where the end product is an artefact – where the thinking is, so to speak, embodied in the artefact, where the goal is not primarily communicable knowledge in the sense of verbal communication, but in the sense of visual or iconic or imagistic communication" (Frayling, 1993, cited in Newbury,

1996b, p. 216). Frayling expresses reservations about the point of doing research for art and design within an academic context, where the "... primary goal is the art itself, and not knowledge or understanding." (Newbury, 1996b, p. 216) These approaches invite different methodologies.

The research presented here contains elements of all three types. A methodology has therefore resulted which concerns the interplay between all three of Frayling's classifications. Darren Newbury, in discussing the usefulness of Frayling's categorisations for art and design research, presents two case studies of doctoral research that draws on knowledge and methodologies associated with all three (Newbury, 1996b). Darren Newbury suggests that a useful strategy within art and design research would be to explore this interplay between intuitive and systematic processes (Newbury, 1996b)

[25] Théberge, 1997, p. 4. This is a reference to idea of activity as discussed by Pierre Bourdieu in *The Logic of Practice* (Bourdieu, 1990).
[26] Michael Polanyi refers to this idea of tacit knowledge (e.g. Polanyi, 1967). Elsewhere he writes:

> "Musicians regard it as a glaringly obvious fact that the sounding of a note can be done in different ways, depending on the 'touch' of the pianist. To acquire the right touch is the endeavour of every learner, and the mature artist counts its possession among his chief accomplishments... Yet when the process of sounding a note is analyzed, it appears difficult to account for the existence of touch." (Polanyi, 1958, p. 50, cited in McCullough, 1996, p. 5)

[27] See for example (Wood, 1996).
[28] (Ihde, 1979).
[29] (Feyerabend, 1996, p. 24).
[30] (Wood, 1996, see also Thorpe, 1995).
[31] (Gill, 1996b, p. 118, 119).
[32] (Feyerabend, 1996), p. 23.
[33] Paul Feyerabend suggests that this view within much of science, that theory is superior to practice, results in major failures due to this disconnection between theoreticians and artisans, although historically this was not necessarily a view shared by all scientists. An example of such a scientist is Francis Bacon (Rothenberg, 1994, p. 70).
[34] An interesting example of knowledge arising through interplay of theory and practice is the discovery of geometry, discussed by the philosopher Edmund Husserl. For Plato, in line with his view of the superiority of the abstract Ideal, the perfect circle was superior to the constructed one. However, Husserl asks how we first learned geometry and suggests that it emerged through practical knowledge. Increasingly precise measuring techniques meant constructed shapes could increasingly approach imagined 'perfect' ones (Husserl, 1970, especially 'The Origin of Geometry', pp. 353-378, also discussed in Rothenberg, 1994). Euclidean geometry is therefore more like a form of technical praxis than an independent phenomenon in itself. As David Rothenberg explains

> "we imagine that it describes a regularity inherent in the world itself. But what is explained is the universe of planned human objects. Euclid explains laws abstracted from a built place enforced out of right angles. We then have a theory that explains how we build things, and we analyze, imagining that it applies to all of nature, or all of

experience...so what we build in its apparent independence, returns to deeply affect the way we see the world." (Rothenberg, 1994, p. 34)

[35] In his book *Situated Cognition: On Human Knowledge and Computer Representations* Clancey uses this essential idea to reflect on a wide range of topics to do with cognition and the representation of knowledge within computer and robotic systems (Clancey, 1997b). His orientation has served to inform significant aspects of my own within this thesis.
[36] (Schön, 1987), p. 73, cited in (Clancey, 1997b), p. 201.
[37] (Schön, 1979), cited in (Clancey, 1997b), p. 207.
[38] (Clancey, 1997b), p. 209.
[39] Thorpe suggests, "When we talk about what action to take we may well be doing theory. The word 'theory' originally referred to the process of contemplation, beholding or speculation. So that theory was primarily an activity and meant any disciplined enquiry springing from reflection." (Thorpe, 1995, p. 261) Similarly, for David Rothenberg, language can allow us to "to play, to test, to reach towards the change in our context before we actually build it." (Rothenberg, 1994), p. 197. According to Rothenberg this was the strength of language for Heidegger.
[40] (Thorpe, 1995), p. 263.
[41] (Clancey, 1997a).
[42] (Gerzso, 1992), p. 78.
[43] The researcher is part of the very context of the research and should not be removed in an attempt to gain some 'objectivist' credo by assuming that one is engaged in a detached description of some independently existing reality.
[44] This is reflective of a suggestion made by Roy Ascott in relation to the field of art and consciousness research (Personal recollection from the Closing Plenary session, Consciousness Reframed 3, University of Wales College Newport, August 2000).
[45] Heinz Pagels presents a lengthy discussion of various mathematical definitions of complexity in his book *The Dreams of Reason: The Computer and the Rise of the Sciences of Complexity* (Pagels, 1988). Similarly precise definitions exist for emergence and self-organisation (e.g. Baas and Emmeche, 1997; Baas, 1994)
[46] In considering the relationship between definition and metaphor in science Dik Gregory refers to how definitions can be considered as 'fossilised metaphors' (Gregory, 1993). The idea of a definition is itself a metaphor. Definitions arise from our attempt to solidify metaphors to allow us to act, for "in order to do anything there comes a time when we have to stop asking for clarifications, make some assumptions, and begin. As soon as we make and use these assumptions we create 'facts' and 'definitions'" (Gregory, 1993, p. 66). He suggests therefore that certain 'ontological and epistemological questions' arise from such a perspective. Is knowledge of the world a result of the questions we ask of it, and if so, is it therefore a relationship *between* us and the world that is reflected in shared scientific ideas through subjective agreement amongst scientists? He therefore asks, "Do we discover the world, or do we distinguish it?" (Ibid.)
[47] Gerald Johnson suggests this in his discussion of computer jargon (Johnson, 1992, p. 267). He discusses Colin Turbayne's claim that there are at least three stages in the life of a metaphor.

> "At first the crossing of sorts is simply inappropriate, startles those who hear it, and may even elicit disapproval. With time it gains acceptance, is recognized to express something essential about the original referent, and enjoys a heyday. These first two

periods, however, are brief in comparison to the long period that follows. In this third period ... metaphors lose the startling quality of their original fusion of meanings. They often become embedded in the language, often cease to exist as metaphors, and begin to lead fairly 'literal' lives (e.g., the roots of many of our 'literal' English words point to colorful metaphorical origins). Too often, however, the 'conventional sort' gives way to 'sort-trespassing', an insidious process in which metaphors are taken too literally. To take metaphor literally in this sense is to transfer too many attributes, or the wrong attributes, from the metaphor to the referent." (Johnson, 1992, p. 266, see also Turbayne, 1962)

Consequently, for Turbayne, "sounds are nothing but vibrations, and the human body is nothing but a machine" (Turbayne, 1962, p. 26, cited in Johnson, 1992, p. 266). Therefore "[w]e do not so much use such metaphors but we are used by them." (Johnson, 1992, p. 267, see also Turbayne, 1962, p. 22)

48 Emily Martin discusses how the scientific language of sexual reproduction is inaccurately based on cultural stereotypes about male and female gender roles and suggests a need to 'wake up sleeping metaphors in science' (Martin, 1991, p. 501). Arguing how in the nineteenth century there was a strong mutual influence between social and natural sciences, she says

"the social ideas of Malthus about how to avoid the natural increase of the poor inspired Darwin's *Origin of Species*. Once the *Origin* stood as a description of the natural world, complete with competition and market struggles, it could be reimported into social science as social Darwinism, in order to justify the social order of the time." (Martin, 1991, p. 500)

She cites David Harvey as suggesting that such models may serve as an "implanting of social imagery on representations of nature so as to lay a firm basis for reimporting exactly that same imagery as natural explanations of social phenomena." (David Harvey, cited in Martin, 1991, p. 500).

Similarly Evelyn Keller uses the example of evolutionary theory to argue how language within science permits 'tacit incorporation of ideology into scientific theory" yet hides these influences from those involved.

"The net effect is to insulate the theoretical structure from substantive critical revision... The result ... is to effectively exclude from the domain of theory those biological phenomena that do not fit (or even worse, threaten to undermine) the ideological commitments that are unspoken yet *in* language, built into science by the language we use in both constructing and applying our theories." (Keller, 1991, pp. 99-100, see also other discussions in Sheehan and Sosna, 1991).

49 The idea of a meme comes from Richard Dawkins' concept of some kind of mental gene that propagates itself through culture in way that is analogous to how genes perpetuate themselves, as units of cultural and biological evolution respectively (Dawkins, 1976, see also Hofstadter, 1985). Artists have taken up this meme metaphor, it being a central theme of the 1996 Ars Electronica conference. However, within scientific discourse accounts which attempt to reduce cultural evolution to such Darwinist principles may be questionable (Fetzer, 1996, see also Goodwin, 1994). The terminology may be too general to take

account of important distinctions that exist between the various phenomena to which it has been applied (Boyd, 1993, p. 117). It also seems appropriate to ask what this scientific notion brings to an understanding of art that earlier acknowledgements of the dynamics of the spread of human ideas do not? Consider Ernst Gombrich's notion of 'schemata' (Gombrich, 1960). These schemata consist of conventions for representation by artists – a visual language - that affect not just stylistic aspects of representation but also ways of thinking and perceiving. He cites the example of Dürer's 1515 drawing of a rhinoceros that had, incorrectly, included armour plating. It was only 300 years later, in 1790, that a drawing by James Bruce corrected these errors – the incorrect visual convention had a profound and lasting influence.

[50] For example, George Gessert argues that there was a 'genetic art' long before the advent of genetic engineering. "We do not have to look to the future to see genetic art. It is already abundant. Domesticated ornamental plants, pets, sporting animals and consciousness-altering drug plants constitute a vast unacknowledged genetic folk art, or primitive genetic art, that has a history stretching back thousands of years." (Gessert, 1993, p. 205)

[51] (Newbury, 1997). Here it is perhaps useful to consider that there is not one 'scientific method' but several. For philosopher of science Paul Feyerabend, "... it makes sense to speak of scientific styles and fashions giving rise to a great variety of products. It turns out that science is indeed composed of divergent procedures and correspondingly divergent results ... *science does not contain one style of research, it contains many.*" From this " ... *scientists have developed different views about the world that surrounds us.*" (Feyerabend, 1996, p. 26). For an accessible discussion of the nature of science see Alan Chalmers' *What Is This Thing Called Science?* (Chalmers, 1982). Chalmers questions the idea that there is something that can be generally characterised as science. He questions the presumption that "...there is a single category 'science' [that] implies that various areas of knowledge, physics, biology, history, sociology and so on, either come under that category or do not." Instead we can analyse and criticise an area of knowledge 'for what it is'. This means

> "...we can investigate what its aims are, which may be different from what its aims are commonly thought to be or are presented as, and we can investigate the means used to accomplish those aims and the degree of success achieved... We can attempt to criticize any area of knowledge by criticizing its aims, by criticizing the appropriateness of its methods used for attaining those aims, by confronting it with an alternative and superior means of attaining the same aims and so on. From this point of view we do not need a general category 'science' with respect to which some area of knowledge can be acclaimed as science or denigrated as non-science." (Chalmers, 1982, p. 166).

[52] Reflected in physics with Heisenberg's uncertainty principle. These parallel interests in art and science are discussed by, for example, Garoian and Mathews, 1996; Miller, 1995; and Soto, 1994.

[53] (Robertson, 1996), p. 19. Wilden has discussed this 'either-or' perspective and instead suggests a 'both-and' orientation. (Wilden, 1987). Dualisms emerge from a particular way of observing a system. In this regard it is also worth considering the idea of *complementarity* as introduced into quantum physics by Neils Bohr which stresses the fundamental unity of things despite their apparent opposition. Rudy Rucker gives several illustrative examples. For example, a line is both continuous and made up of an infinite

number of points. Rucker quotes Bohr as saying "A great truth is a statement whose opposite is also a great truth." (Rucker, 1987, p.7).

[54] (Mumford, 1959), p. 534, cited in (Rothenberg, 1994), p. 101. David Rothenberg also notes: "Machines that extend cognitive dexterity independently of our guiding movements reinforce just those aspects of our thought which can be precisely codified into terms which a machine may understand. Digital computers begin with the simplest binary kind of mathematics, easiest to store and transmit, and may be used to model all kinds of complex processes through an intricate set of repetitive procedures. *The more we extend ourselves through use of these devices, the more we tend to ignore qualities which cannot be represented within their constraints.*" (Rothenberg, 1994, p. 38) Also for Massimo Negrotti "people learn to think like computers rather than computers learning to think like people." (Negrotti, 1990, p. 80, cited in Mazzioli, 1992, p. 225)

[55] This is discussed for example by Mike Vaughan. He suggests:

> "Any discussion of the significance of the studio environment must address the question of whether the evolution of the studio is a result of the necessities of compositional thought or whether it is a result of a political desire to possess, and justify by use, the latest and most advanced means of production as an end in itself." (Vaughan, 1994, p. 119)

For computer musician Mark Trayle, "in high musical academia algorithmic composition and related AI research is often a symptom of terminal modernism. It's a way to legitimize a work, to prove that it has "form", whether that form is perceivable or not. It also serves as a score (reams of code), which is another grand method of legitimizing the piece by proving its complexity." (Personal communication with Mark Trayle, 29th June 1997)

[56] This is noted by several practitioners and theorists. Composer Tim Perkis notes how "The modern electronic musician is in a relatively 'high-capitalization' business. Whereas traditionally a musician would buy an expensive instrument once early in his career, the electronic musician is typically constantly buying and selling equipment, and wishing for more. The traditional musician is a poor consumer: a reed player may buy some reeds occasionally, but his life is focussed on a practice which has nothing to do with buying and selling; he is engaged in an essentially spiritual discipline of perfecting his art. But the electronic musician is always adjusting to new equipment, and needing more to keep up with current developments. This is an essential re-definition of what it means to be a musician." For Perkis "artists who embrace complex technologies have largely abandoned their critical function and have been co-opted, becoming unwitting (or witting) servants of other social and commercial projects that have little to do with art. As a result in music, there has been a shift in emphasis away from the development of a personal spiritual power, and away from the inherently social aspect of music making." (Perkis, 1993)

In discussing the relationship between popular music and consumer technology, Paul Théberge argues that the desire to use digital technology is deeply involved with ideas of technological progress and commercial pressures. Musicians become 'consumers of technology': "In the past, the evolution of musical instrument design was a relatively slow process. Today, in the fast paced electronics and computer industries technological obsolescence is both the rule and the rationale for increased consumption. Certainly, musicians are not completely ignorant of this problem. There appears to be a growing awareness among many musicians that their artistic practice has become deeply implicated with a particular version of the notion of technological 'progress' and that along with this ideology comes a number of disturbing musical, economic, and political dilemmas. These dilemmas are particularly acute in popular music ... An understanding of the various issues relating to music and technical innovation cannot be separated from a broader analysis of contemporary social and economic relations." (Théberge, 1997, pp. 4-5. See also Truax, 1996).

[57] (Truax, 1996), p. 28.

[58] Ibid. Also for David Rothenberg "A new technology never teaches creativity... Where will we get it from? Only from a careful consideration of measuring our intentions against the capabilities offered by the machines, recognizing how they influence us, not quickly succumbing to what is easiest to realize with the technology." (Rothenberg, 1994, pp. 45-46)

[59] Music using computers is often referred to as *computer music*. However, what musical processes and products does the term imply? For Chris Brown "computer music is not a single type of music, but a musical instrument technology that applies to many kinds of musics." (Brown in Brown; Bischoff, and Perkis, 1996, p. 28).

It can potentially be construed as representing a very broad area. A broad, inclusive definition is given by John Pierce:

> "To me, it is anything that has to do with the digital generation of musical sound – commercial or academic. This includes sound synthesis, sound analysis, digital instruments, and compositions realized by digital means ... If we accept as part of computer music any activity that involves music or musical sounds and computer sound generation or sound analysis, we must accept as computer music levels of technology and taste that range from inexpensive music software devised to entertain amateur hackers to collections of hardware that enable a lone composer to compete with or surpass an orchestra in providing background music for movies and TV programs ... Shouldn't anything, musically good or bad, that involves computers qualify as a part of *computer music*?" (Pierce, 1996, pp. 50-51)

Taxonomies of computer music reflect the different concerns of practitioners. See various examples in (Pope 1996). These not only include research and activity from scientific concerns (such as the physics of sound and music perception and cognition), but also broader aesthetic and cultural issues, as well as classifying the compositional activities involved in creating music using computers. They are useful in indicating the current orientations of its practitioners. As Pope says, "a taxonomy always represents a relatively subjective weighting of the sub-fields at one point in time." (Pope, 1996, p. 137). Barry Truax believes the term 'computer music' is "a term that is likely to fade away as the distinction becomes less and less meaningful" (Truax, 1996, p. 27).

[60] This relationship poses certain methodological issues that are discussed in section *1.3. Theory and Practice*.

[61] Computer music can be considered as a subset of this larger field of modern music practice which includes within it various other techniques of creating electronic music.

[62] (Di Scipio, 1995b), p. 373.

[63] My definition of technology includes systems of representation, like music notation and to some extent music itself. This is because, as David Rothenberg suggests, while some

expressive elements of such languages do not fit into this definition, "communicative language and mathematics ... may be considered technologies to the extent that they are constructed instruments that help realize our aims." (Rothenberg, 1994, p. 30). Implicit in my definition is also the role of technique, and technical know-how, for these mediate our use and interpretation of technology. In this regard MacKenzie and Wajcman propose three definitions of technology, which progressively include more aspects of these contextualising factors. Technology as physical artefact alone is the first. Their second definition also includes the human activities of which the artefacts are a part, for "a computer without programs and programmers is simply a useless collection of bits of metal, plastic and silicon" (MacKenzie and Wajcman, 1985 p. 3, cited in Longhurst, 1995, p. 81). The third definition also includes knowledge and 'know how'. In his discussion of popular music and technology, Paul Théberge's definition of technology also includes technique so as to acknowledge the role of "training and discipline of labor and the organization of means." (Théberge, 1997, p. 257)

I contrast this with Don Ihde's definition (Ihde, 1979) which rules out technique. This is not a criticism, as his definition is serving different purposes and is useful for defining the material aspect of technology. Here technology

a) must have some concrete component/material element;

b) must enter into some set of praxes (uses) which humans may make of these components;

c) there exists a relation between the technologies and the humans who use, design, make, or modify the technologies in question (they mediate between the user and the world).

[64] The kind of sense that I am trying to develop here is related somewhat to Martin Heidegger's idea that technology is a 'mode of revealing' and as releasement (*Gelassenheit*) (Heidegger, 1977). For Heidegger the concept of releasement is "an active yet accepting process that allows an individual tool to let its user flow into the world, becoming a part of nature through active engagement, *not* severed contemplation of the awesome and frightful ... successful technologies offer 'releasement *toward things*.'"(Rothenberg, 1994, p. 196, quote from 'Memorial Address for Conradin Kreuzer' in Heidegger, 1966, p. 54). Rothenberg's interpretation of this is that this can be a releasement *with* technology that he suggests is different from the orthodox view that implies releasement *from* technology (see Rothenberg, 1994, notes, p. 239).

[65] This line of thinking seems evident in some of the theoretical writings of Roy Ascott. In particular his *Seeing Double: spiritism, cyberception and the technology of transcendence* makes interesting comparisons between the interconnected and immersive world of contemporary cyberspace and the spiritual world of the South American shamans (Ascott, 1998)

[66] (Laske, 1991), p. 266, cited in (Di Scipio, 1995b), p. 371.

[67] (Laske, 1993), p. 209.

[68] See (Yazdani and Whitby, 1987); and (Whitby, 1988), especially pp11-23 and Ch. 2.

[69] As Rothenberg comments, "Technology changes something about our essence as it changes itself. This does not mean it is necessary to speak about human life before technology and then after technology, or to force the equivalent by picking some arbitrary line where technology influences enough to have a last a fundamental impact. On the

contrary, we find it as a factor in all conceptions of humanity reaching outward in and to the world." (Rothenberg, 1994, pp. 24-25)
[70] Ibid. p. 14.
[71] Ibid. p. 52.
[72] Ibid. p. xiv, p. 9.
[73] For Rothenberg "We see the progression of technical metaphor as the universe and its subset of inhabitants are successively seen through history to be *like* different types of machines – wheels, clocks, engines, arrays of digital on/off memory chips." (Ibid. p. 3) Cybernetic systems (see e.g. Wiener, 1948), capable of self-regulating behaviour through a feedback loop of sensing and acting, enable us to conceive of the transforming effects of technology as we at once realize and transform our intentions (Ibid. p. 128). Therefore "*these embodied machines are extensions of the very idea they give rise to...* self-regulation is a human idea, and we extend it through the things we build... The engine suggests feedback, and new machines extend feedback into new situations. The ensuing world view suggests a theory of technology which also inhabits the cycle" (ibid. p. 130-131).
[74] Ibid. p. 135.
[75] Ibid. p. 132.
[76] An extreme example of this line of thinking is expressed by Hans Moravec in *Mind Children*. For him the essence of himself is "...the pattern and process going on in his head and body, not the machinery supporting that process...the rest is mere jelly" (Moravec, 1988, p. 4, cited from Pryor, 1991). A future is imagined in which humans are seemingly removed from the future development of technology they helped create, as we are superseded and computers become our 'descendents'. In a similar vein the computer is capable of containing the essential essence of a human being to the extent that the physicist Frank Tipler believes that we can download ourselves into computers to be one day resurrected (see Gardner, 1996). However, in Rothenberg's view these would still form extensions to human desires. Jaron Lanier suggests that these desires form new incarnations of age-old approaches to the very human fear of death. He suggests

> "In the late twentieth century a bizarre and inverted form of death-denial has been gaining ground. It is the ironic grandchild of an earlier generation of rational thought that sought to quell all such sentimentality. In this new fantasy, technology will conquer death" (Lanier, 1997, p. 184).

[77] (Rothenberg, 1994), p. 149.
[78] (Negrotti, 1991b). Thanks to David Smith for pointing me in this direction. The idea of 'alternative intelligence' is also discussed further in a paper included in the Appendix (*The Turing Test is Dead*).
[79] (Negrotti, 1991a), p. 7.
[80] (Di Scipio, 1994), p. 135.
[81] (Kay, 1984), cited in (Laurel, 1991), p32, and (McCullough, 1996), p. 232.
[82] (Rothenberg, 1994), p. 134.
[83] Ibid. p. 158.
[84] Ibid. p. 48.
[85] In considering this distance and Heidegger's idea of releasement (at least in Rothenberg's interpretation, see note 64), in an important sense, technology exists to be transcended, and the duality of creative reach and musical distance are fundamentally interlinked aspects of our interaction through technology to something that is beyond it. New possibilities are revealed through the computer, but we are prevented from moving

forward directly to explore these within the same technological framework. As the video artist Bill Viola suggests, at a given time in history "all technologies are 'advanced' technologies", therefore "all technology is equal and all technology ultimately exists to be transcended." He does not relate this transcendence to the evolution of new technology, "but in terms of the self – the individual who is using and interacting with that technology." This forms part of the tension between what it reveals and what it seems to obscure, between creative reach and distance.

> "I've always felt that every technology I've used – from a pencil to a computer editing system – has been in the way of the creative process. The technology is simultaneously the obstacle and the path to realizing the impetus that drives one to express oneself." (Bill Viola, video artist in Viola; Machover, and Sellars, 1992, p. 3)

Therefore, one is not so much solving a problem as creating a field of possibilities with new technology. It is the sense of gap between what is revealed and where we stand in relation to it that feeds into the paradoxical sense of creative reach within our environment.
[86] Rothenberg also seeks to categorise the ways that technology extends us, providing useful perspectives on the ambiguous range of influences that the computer seems to be having within our studio environment. The technology acts both as a *physical* extension and extension of *thought*, and within these broad categorisations Rothenberg discerns some finer distinctions. (Rothenberg, 1994, see particularly Chapter 2) The computer represents a blurring of all these categorisations and "this where technology is going – combining its features to elude demarcation." (Rothenberg, 1994, p. 43).

Physical extensions extend our bodies. Here it can be a *direct* extension of limbs, like hammers and levers. Other *non-direct* physical extensions require us to drive them, such as cranes. There are also seemingly *independent* physical extensions that "operate independently of our physical actions, embodying human alteration of the environment. These are the mechanized systems, which, if simply set in motion, do the job" which can also include simple technologies such as roads, telephone networks and houses. (Rothenberg, 1994, p. 30.) Interestingly, this third type are considered to be "the ones most likely to conceal their human roots" because they are seen to be least like extensions.

Thought extensions "radically change the way we think and organize, without implying immediate physical effects" (Rothenberg, 1994, p. 30). *Perception* can be extended by enhancements to existing senses and includes telescopes, microscopes and telephones. Our senses become transformed by this augmentation. *Conception* becomes enhanced, even created, by codification of forms of reasoning such as language and music notation. Finally, *memory* is extended by "devices that hold information *without* abstraction, in images retained to be sensed by sight and sound" (Rothenberg, 1994, p. 30) such as photographs and sound recording. However, in reality, abstraction remains on a more subtle level and therefore it is hard to separate conceptual from memory extensions.[86]

From all these categorisations Rothenberg suggests that certain dichotomies appear to arise. In considering whether something extends *action or thought*, thought extensions cease to be wholly conceptual when they lead to attempts to change the external world. Here "they inspire and combine with techniques of the [physical] kind" (Rothenberg, 1994, p. 44). In considering whether technology is *means or a construction*, some direct technologies do not change the nature of our interaction with the world. A magnifying glass does not really alter what it is to see. But other technologies do require "an alteration of basic intentions. An abacus or calculator requires new ways of thinking about number to input to the machine. The way we conceive of number is immediately changed" (Rothenberg, 1994, p. 44).

Whether we perceive of a technology as *driven or embodied* is especially interesting when considering 'autonomous' technology. Independent physical extensions like roads and houses become embodied in the 'natural' world, becoming embodied within it as they transform it. But how do extensions of thought become independently embodied? How do they become "able to enact thought processes without constant prodding"? (Rothenberg, 1994, p. 45) With the computer, "It is not appropriate here to ask if it can think *for* us. The question is whether any conceivable structure can embody the way we think, making the operation of our mind somehow tangible in our conceptual surroundings, independent of any particular intended thought process" (Rothenberg, 1994, p. 45). Only the parts of our minds that we are able to systematise into mechanical form get embodied within the computer and "It is when we mistake the part for the whole that our intentions are unexpectedly altered" (Rothenberg, 1994, pp. 45-46).

[87] See *Technics and Praxis* (Ihde, 1979), and *Technology and the Lifeworld* (Ihde, 1990). Some of my interpretation is also derived from (Hybs, 1996). Thanks to Mike Punt for suggesting this line of thought.

[88] (Ihde, 1979), p. 4.

[89] Idhe also talks about *background* relations. This is expressed as

$$human \rightarrow \begin{pmatrix} machine \\ world \end{pmatrix}$$

There is a 'technosphere' surrounding us. With certain machines, like central heating "I neither relate through these machines, nor explicitly, except momentarily, to them. Yet at the same time I live in there midst, often not noticing their surrounding presence". In regard to such technology "we may said to be 'inside' the machine" (Ihde, 1979, p. 14).

[90] Ibid. p. 19. Similarly, for Martin Heidegger the more familiar we become with a tool (what he more generally calls 'equipment'), the more intuitive our relation to it, the more it 'feels a part of us'. It is 'ready-to-hand' (*zuhanden*). He gives the example of a hammer. We become involved in the act of hammering and do not focus on the hammer.

> "The less we just stare at the hammer-thing, and the more we seize hold of it and use it, the more primordial does our relationship to it become, and the more unveiledly is it encountered as that which it is – as equipment. The hammering itself uncovers the specific 'manipulability' of the hammer." (Heidegger, 1962, p. 96, cited in Wheeler, 1996, p. 226)

By being absorbed in the situation in this way "flexible common-sense know-how operates without thoughts-that or thoughts-about, and an awareness of objects and thematic self-awareness are not present." (Wheeler, 1996, p. 227). See (Wheeler, 1996) for a useful discussion of how Heidegger's philosophy relates to approaches to situated robotics.

[91] (Ihde, 1979), p. 8.

[92] Ibid. p. 12.

[93] Ibid.
[94] Ibid. p. 11.
[95] (Hybs, 1996), p. 216.
[96] In Heidegger's terminology the equipment becomes *un-ready-to-hand* as we no longer act through the equipment. "Resolving the situation will require deliberate action and/or deliberate reasoning (explicit planning)" (Wheeler, 1996, p. 228). There are times, however, when this separation is desirable, when for example, we want to observe and analyse objects. In this way the equipment can become *present-at-hand* (vorhanden).
[97] It is interesting to consider that a pianola is never considered autonomous because we are aware of its inner workings. We can look inside this instrument and clearly see how it works.
[98] See (Morgantini, 1989).
[99] (Hybs, 1996), p. 220.
[100] (Baudrillard, 1983), cited in (Kelly, 1994), pp. 308-309.
[101] (Rothenberg, 1994), p. 154.
[102] (Levy, 1993), cited in (Kelly, 1994), p. 309.
[103] (Trayle, 1991), p. 51. See also Richard Wright (1990), Computer Graphics as Allegorical Knowledge: Electronic Imagery in the Sciences, *Leonardo* Supplemental Issue *Digital Image-Digital Cinema*, p. 70.
[104] Thanks to Mike Punt for suggesting this term.
[105] (Mazzioli, 1992), p. 228.
[106] What I have suggested above forms part of a wider discussion where Mazzioli discusses the relation between evolution of forms and techniques of communication, techniques enabling socio-technical systems "to process strategic forms of manipulation of complexity" (Mazzioli, 1992, p. 223). For him an intensification of human machine relations opens up new modes of communication.
[107] (Rothenberg, 1994), p. 157.
[108] (Gill, 1996b), p. 117.
[109] Ibid. p. 111.
[110] Ibid. p. 110. The idea of human machine symbiosis has a broad relevance for human relations with technological systems, including Human Computer Interaction (Gill, 1996a) forming an aspect of *human-centred computing.* For Karamjit Gill, symbiosis is rooted in the diversity of cultures and the interdependence between individuals and society. According to Gill

> "It therefore seeks a symbiosis of relationships between the human and machine, between the social and the technical, between the objective and subjective dimensions of knowledge, between the technical possibility and social desirability of technology and systems design. This notion of symbiosis therefore challenges the very notion of the 'ideal of certainty', 'rational method', and the 'one best way' so rooted in the dominant science and technology of today, and in the scientific method of designing social, economic and technological systems. It also challenges the notions of the separation between the individual and community, private and public, reason and emotion, function and the social, work and living, and technology and society. (Gill, 1996b, p. 117)

[111] (Kelly, 1994), p. 152.
[112] (Salomon, 1993), p. 122, cited in (Kaptelinin, 1996b), p. 17.
[113] See for example (Hutchins, 1995), (Clark, 1997).

[114] Victor Kaptelinin's concept of a *functional organ* prompts new considerations of issues in human computer interaction (HCI) and the nature of the interface between the computer and its users. The concept arises from *Activity Theory* which emerged from Russian psychology (see for example Vygotsky, 1978). For Kaptelinin:

> "The main idea behind Activity Theory is that psychological analysis should focus on the goal-oriented human *activity*, which mediates the interaction between the individual and the world. Activity includes both external and internal [mental] components, which are organized into an integral whole and can transform each other." (Kaptelinin, 1996b, p. 21)

Artefacts form a crucial role in mediating human thought and activity, with consciousness understood as not located solely within the brain, but 'distributed' within the broader environment.

> "The boundaries of the individual embrace various types of resources integrated into the structure of activity, both internal and external. According to this perspective, individuals are distributed by definition, and there is no need to introduce an abstraction of the individual being confined to the boundaries of his/her skin." (Kaptelinin, 1996b, p. 24).

Thus Activity Theory "extends the concept of consciousness past an idealistic, mentalistic construct in which only cognitive resources and attention `inside the head' are at issue, to a situated phenomenon in which one's material and social context are crucial" (Nardi, 1996b, p.13).

A functional organ corresponds to a combination of internal and external components that are combined to achieve a specific goal (Kaptelinin, 1996a, p. 49, see also Kaptelinin, 1996b, pp. 20-23). Applying the functional organ concept to HCI results in less focus on the interaction and 'information exchange' between an individual and computer, and more on the wider context in which this takes place, a context which includes the wider goals of users and their interactions, an *open system of user-and-computer-in-an-environment.* For Kaptelinin computers are a special kind of functional organ mediating our relations with the world and several different types are possible because the computer can perform several roles. A particularly interesting one concerns the augmentation of creativity. For Kaptelinin, "artifacts can greatly support creative thinking, for instance by providing an external representation of the problem which makes it easier to develop a holistic internal representation" (Kaptelinin, 1996b, p. 23). One function concerns "an extension of the internal plane of actions." (Kaptelinin, 1996a, p. 51) Here computers allow for the ability to simulate and play with aspects of reality before actually acting on that reality.

For a range of papers on theoretical and practical applications within human-computer interaction research see (Nardi, 1996a). For a review of this book see SIGCHI bulletin Vol.29 No.2, April 1997 review by Mary Brenner and Shilpa Shukla, see http://www.acm.org/sigchi/bulletin/1997.2/book-review.html

[115] See for example (Núñez, 1997).

[116] An example of the striking nature of this surprise is in the discovery of fractals Benoit Mandelbrot (Mandelbrot, 1982), as discussed by Roger Penrose in *The Emperor's New Mind.* Penrose describes how "Its wonderfully elaborate structure was not the invention of

any person, nor was it the design of a team of mathematicians. Benoit Mandelbrot himself had no real conception of the fantastic elaboration inherent in it... When his first computer pictures began to emerge, he was under the impression that the fuzzy structures that he was seeing were the result of a computer malfunction. Only later did he become convinced that they were really there in the set itself." (Penrose, 1989, p. 95, cited in Emmer, 1994, p. 238)

[117] These viewpoints are usually called *technological determinism* and *social construction*. Technological determinism concerns the view that technology causes social change, and the related concept of *technological autonomy* suggests that technology evolves according to its own criteria, as "an entity separate from humanity ... that will most fulfill human purpose when it is allowed to pursue its own inner logic." (Rothenberg, 1994, p. xiv). Such a view appears to suggest that we are able to view the evolution of technology as if observing the behaviour of a natural system outside the control of ourselves. In contrast arguments that suggest there is a *social construction* of technology point to the shaping role played by wider economic, political and social forces on technological invention, and adoption (for a discussion of these issues see for example MacKenzie and Wajcman, 1985; Bijker, Hughes, and Pinch, 1989; Bijker and Law, 1992; Marx and Smith, 1994; Bijker, 1997; Law and Hassard, 1999).

[118] (Pope, 1991).

[119] Principally, though not exclusively with my cousin, Ben Simmonds.

[120] (Varela, Thompson, and Rosch, 1991), p. 148. This observation they acknowledge is based on arguments developed in (Winograd and Flores, 1987).

[121] (Rothenberg, 1994), p. 23.

[122] Where anthropology can be understood as the study of differing cultures' systems of practice, beliefs and customs.

[123] (Di Scipio, 1995b), p. 372.

[124] Understood as the relation of musical systems and practice to culture (e.g. Nettl, 1983; Blacking, 1973).

[125] The idea of music's autonomy is understood as "the notion that music shapes itself in accordance with self-contained, abstract principles that are unrelated to the outside world." (Leppert and McClary, 1987, p. xii). For further discussion on this see various chapters in Leppert and McClary and (Kerman, 1985).

[126] An approach which arguably reached its zenith with Heinrich Schenker's method of score analysis (e.g. Schenker, 1979). For a discussion of some of the issues concerning musicology and music analysis see (Kerman, 1985). This emphasis can be traced to a consequent neglect of embodied practices of music, like performance, in favour of its abstract symbolic qualities. Therefore it is reflective of a general mind body split in Western modes of discourse (e.g. Covach, 1994; Cusick, 1994). For Suzanne Cusick

> "Music, an art which self-evidently does not exist until bodies make it and/or receive it, is thought about as if it were a *mind-mind* game. Thus, when we think analytically about music, what we ordinarily do is describe practices of the mind (the composer's choices) for the sake of informing the practices of other minds (who will assign meaning to the resulting sounds)... We end by ignoring the fact that these practices of the mind are nonpractices without the bodily practices they call for - about which it has become unthinkable to think." (Cusick, 1994).

[127] For some, the essence of things is within their formal structure. For example Steven Holtzman suggests that all languages, even subtle ones like "poetry, painting, sculpture,

and music" can be studied in terms of their formal structure (Holtzman, 1994, p. 51). An example of this emphasis on language structure is Noam Chomsky's cognitive theory of language (Chomsky, 1957). Here language is both a competence (system of rules) and performance (the enactment of speaking). However, Chomsky's focus was on language competence resulting in an abstraction *away* from its actual performance. Scott Kelso notes how such viewpoints focused the field of cognitive science on mentalistic formal structures and, combined with the computer metaphor, "pushed to the extreme by program theorists who see the brain as the programmer and body as mere slave." (Kelso, 1995, p. 34). For a consideration of Chomsky in relation to musical concerns see (Laske, 1993). The psychologist Jean Piaget points out that

> "The discovery of structure may, either immediately or at a much later stage, give rise to formalization. Such formalization is however the creature of the theoretician, whereas structure itself exists apart from him." (Piaget, 1970, p. 5, cited in McCullough, 1996, p. 95)

It is instructive that Holtzman's line of thought leads him to some rather bizarre conclusions regarding the future of computers in music, suggesting that computers will pursue their own 'creative objectives'.

> "Computers, writing music understood only by other computers, may even develop a disdain for human listeners and their inability to hear or understand their rich languages of expression." (Holtzman, 1994)

[128] See for example, the work of John Baily who has discusses how the spatial properties of instruments may influence shape of music played on them (Baily, 1977; Baily, 1985, Baily, 1992).
[129] As defined in *Webster's New World Dictionary of American Language* (cited in Clancey, 1996, p. 225). Most of my understanding of the ecological approach is derived from Clancey's discussion.
[130] Ibid. p. 226.
[131] The interested reader may be interested in Henri Bergson's philosophical writings (e.g. Bergson, 1998).
[132] (Clancey, 1997b), p. 225.
[133] Ibid. p. 226.
[134] A field associated with the work of J. J. Gibson (e.g. Gibson, 1979).
[135] (Altman and Rogoff, 1987), p. 32, cited in (Clancey, 1997b), p. 177. Applying an ecological perspective becomes an acknowledgement that, as an observer, I am also part of these processes, as reflected in, for example, my shifting attitudes to their very nature over the course of this research (a methodological issue which is discussed in Section *1.1. Documenting an Emergent Context.*). What I may choose to separate out and discuss from this analysis reflects my own biases as I am situated within the very context I seek to understand. In some sense an observed aspect emerges out of an active attempt at separation and analysis, and is not an intrinsic part of the system as it operates.

A methodology that is useful for studying how people and contexts form a dialectic relation is that of a *transactional perspective*. According to Clancey, this methodological approach has been applied to "fields as diverse as anthropology and physics." (Clancey, 1997b, p. 177). Aspects of this approach are implicit within my own approach to investigating the studio environment. Irwin Altman and Barbara Rogoff summarise the approach as it is applied to ecological psychology:

> "Transactional approaches treat 'events' as the fundamental unit of study. Events are composed of psychological, temporal, and environmental aspects and therefore require methodologies that tap these facets of the unity... The researcher must always treat the process as embedded in a context, and no context can be assumed to be widely generalizable... The location, attitudes and behaviour of the observer are aspects of the phenomenon..." (Altman and Rogoff, 1987, p. 34, cited in Clancey, 1997b, pp. 176-177)

[136] (Darley, 1994), p. 411.
[137] Ibid.
[138] (Varela, Thompson and Rosch, 1991), p. 120.
[139] (Kerman, 1985), p. 72, cited in (Shepherd, 1992).
[140] For a discussion of MIDI see e.g. (Rumsey and Watkinson, 1995).
[141] See e.g. (Moore, 1988).
[142] Partly because of this limitation, a proposed true network alternative has been developed called ZIPI (e.g. Wright, 1994; McMillen, 1994; McMillen; Simon, and Wright, 1994).
[143] e.g. (Eno, 1983).
[144] (Maconie, 1997), p167.
[145] (Robertson, 1996), p. 33.
[146] Ibid. pp. 33-34.
[147] Cited in (Toop 1995). See also (Eshun 1998), p. 62, and (Davis, 1996).
[148] Perry's basic method therefore revolves around the multitrack recorder, where separate tracks can be recorded, both together and separately, and mixed. But this basic arrangement is substantially enhanced and distributed through Perry's studio environment. For a discussion of multitrack recording see for example (Milano, 1988).
[149] (Eshun, 1998), p. 66.
[150] Eshun quotes Perry as saying, "You are listenin' to a machine. I imitate human being [sic], I'm a machine being. I don't work with human beings." (Ibid. p. 63).
[151] Ibid. p. 19.
[152] Ibid. p. 20
[153] Ibid. p. 2.
[154] (Kelly, 1994), p. 176, cited in (Eshun, 1998), p. 6.
[155] The delay effect allows for a sound to be repeated and, possibly fade out gradually. A reverb unit allows for the simulation of the natural acoustics of sound that occur in closed environments as the sound reverberates within this space.
[156] (Eshun, 1998), p. 64. References to Lee Perry's recorded music can also be found in Eshun.
[157] An initial approach within this research concerned the direct comparison of the computer with a physical instrument like the piano. Consequently this provided a focus that was based around its physical interface. It was felt that in some important way the person was literally disembodied through the computer's inadequate interface. The idea was to integrate gesture and computer to create a 'virtual instrument', inspired by the work of several researchers. These included research into ideas of 'Virtual Musical Instruments' (e.g. Mulder, 1994; Beck, 1996), 'HyperInstruments' (e.g. Machover and Chung, 1989; Machover, 1992), the 'live electronic art' at STEIM in Holland (Ryan, 1991) and approaches

based on physical models of acoustic instruments (e.g. de Bruin and van Walstijn, 1995, p. 148). Mapping between performance gesture and the computer's musical output is not a trivial problem (e.g. Ryan, 1991; Emmerson, 1994; Pressing, 1990).

This orientation was based on my experience of playing the piano. In acquiring a sufficiently fluid technique playing it becomes a natural extension of ourselves, a situation that David Sudnow describes as 'singing' with his hands. For him

> "the keyboard is a setting of places, with measurable dimensions. The hand is an 'organ' with measurable dimensions. The knowing relationships obtaining between them, the way the hand finds itself correspondingly configurated to fit dimensions of this keyboard, involves a mobile hand engaged in a course of action." (Sudnow, 1978, p. 58)

Sudnow emphasises the physicality of playing the piano, the role of body posture and the hands' engagement with the 'terrain' of the keyboard, such that "to hear the sounds...was to be behaving in particular ways." (Sudnow, 1978, p. 43).

[158] (Toop, 1995), p124.

[159] The area of computer based algorithmic composition concerns the application of compositional formalisms to the computer. A *compositional formalism* can be defined as "any systematic ordering, or way of organizing, creating, or analyzing compositional systems (or processes or designs)" and *algorithm* as specifying "actions on symbolic states" (Loy, 1989, p. 293). The algorithm could consist of a set of rules or sequence of actions in order to complete a task. See Loy for a more complete description and examples (and also Harley, 1995; Richard, 1996). All manner of models can be used as a basis for such composition on computer including models of existing compositional formalisms (e.g. Cope, 1991; Cope, 1996), probabilistic mathematics (e.g. Xenakis, 1974), fractal mathematics (e.g. Leach and Fitch, 1995), models of biological growth and evolution (e.g. Prusinkiewicz, 1986; Mason and Saffle, 1994; Martin, 1996) and nonlinear dynamical systems (e.g. Pressing, 1988; Di Scipio and Prignano, 1996). This approach is reflective of a recognition of the deep relationships between music and mathematics and can be linked with models of human creativity (Jacob, 1996).

It is also worth pointing out that algorithmic composition is applied to a variety of different compositional approaches. For example, Iverson and Hartley "take it that the goals of algorithmic composition are to produce 'musical' compositions with the minimum amount of human interaction." (Iverson and Hartley, 1990). Bruce Jacob uses genetic algorithms in the context of an 'assisted composition', for generating ideas to be scored performance by acoustic instruments (Jacob, 1995).

For others it serves as models of existing compositional approaches. Computer music pioneers Lejaren Hiller and Leonard Isaacson "desired to simulate the composing process itself with computers, rather than use computers as an aid to composition." (Loy, 1989, p 309)

It also can be applied in forms of interactive composition, so that algorithmic routines extend the composer's own interactive explorations of the musical space opened up by the use of such algorithms (see for example Harley, 1995). For example Di Scipio and Prignano's Functional Iteration Synthesis "provides an *indeterministic* model of sonic material: the composer must learn his/her strategy by interacting with a source of structured information, at the level of the microstructure of music - within and through the sound." (Di Scipio and Prignano, 1996, p. 42).

[160] This approach is uses both symbolic and connectionist (neural network) models of mental processes in generating music and exploring musical processes (for an overview see for example (Balaban, 1996). It can be used as a method of research into music cognition, symbolic approaches which include (Balaban; Ebcioglu, and Laske, 1992); (Schwanauer and Levitt, 1993); (Cambouropoulos; Nelson; Smaill, and Wiggins, 1996). Certain connectionist approaches will be discussed later in relation to rhythm.

And also it can be used as a means of generating novel compositions and in this way it is a form of algorithmic composition (e.g. Cope, 1996, Farrett, 1996). These aims of understanding and composition may, of course, be interrelated.

[161] (Winograd, 1979), cited in (Vaggione, 1996). See also (Winograd and Flores, 1987).

[162] Terry Riley talks about something he calls 'self-interpretative improvisation':

> "In the last ten years I have given up the traditional rôle of the composer in favour of self-interpretative improvisation. Since my ideas derive neither directly from the Eastern nor from the Western tradition, I have devoted myself a great deal of energy to the composition of formal elements on which the improvisation can be based." (Hamel, 1976, p. 144, cited from programme booklet of the Meta-Music Festival, Berlin, 1974)

[163] For Andrew Goodwin

> "[Sequencers] automate the process of music making, allowing drum patterns, keyboard bass-lines, arpeggios, melodies, and so forth to be entered in 'real time' (a musician actually hits pads, electronic drum surfaces, or a synthesizer keyboard) in which the music is entered simply as information (with values such as the quarter note, for instance, or perhaps numerically constituted). The machine can then play the music back. It can also be manipulated by changing tempo, accuracy ('quantizing'), sequence, and sometimes timbre." (Goodwin, 1992, p. 78, cited from Longhurst, 1995, p. 84).

Drum machines can be considered as like sequencers in that they allow for the construction of rhythms using both sampled and synthesized percussive sounds. Furthermore, sequencers now increasingly allow for the storage and manipulation of samples.

[164] An initial research interest concerned the sequencer's visual representation. Here associating graphical elements with musical ones may be a useful aid in interacting with real time programs (e.g. Roger Dannenberg in Pope, 1993, see also Freed, 1995). Further investigations were made into the possibilities of visualising music through the application of scientific visualisation techniques (e.g. Domik, 1993, p. 153, Braham, 1995, p. 20). The idea is based around synaesthetic experiences (Cytowic, 1989; Cytowic, 1993). This was in an explicit recognition that there has been a long history in recognising a link between sound and colour by artists and composers (e.g. Hamel, 1976, esp. p. 123, Kandinsky, 1947; Kandinsky, 1912; Schoenberg, 1984; Webern, 1963; Scriabin, 1991; Peacock, 1985; Malouf, 1985). Consequently the computer may further this exploration in mapping from

one sense modality to another (e.g. Lücke, 1997, Prusinkiewicz, 1985, Lesbros, 1996, Haus and Morini, 1992). See (Harris, 1994) for a bibliography of some recent approaches.
[165] (Rothenberg, 1996), p. 43.
[166] The use of this term is different from its more normal usage. Such systems are a good deal more active than what I describe here, where compositional formalisms, algorithmic generators of musical material, can be constructed within the computer the output of which is subsequently altered (e.g. Chadabe, 1984; Roads, 1986; Rowe, 1993; Nelson, 1996, Helmuth, 1996). With increasing computer power it has become more possible to conduct this in 'real time', it becoming possible to improvise aspects of the composition through modifications of the computer's sonic output. An example of a popular general-purpose software environment for the construction of such systems is the Max programming language (e.g. Puckette, 1991, Scholz, 1991, Todoroff, 1995, Winkler, 1998). Also various comments on Max's strengths and weaknesses can be found in (Pope, 1993)
[167] (Rothenberg, 1996), p. 40.
[168] (Goodwin, 1992), p. 263. I am however wary of suggesting that what we do in our studio is exclusively 'popular' music. The distinction between 'popular' music and 'serious' or 'art' music is difficult to maintain as an absolute boundary between the two. For John Blacking

> "Many, if not all, of music's essential processes may be found in the constitution of the human body and in terms of interaction of human bodies in society. Thus all music is structurally, as well as functionally, folk music." (Blacking, 1973, pp. x-xi)

[169] All the pieces of music on the accompanying CD have been written using the sequencer and it is hoped that the reader can see how the development of the music reflects a growing exploration of rhythm.

The hint of interesting rhythms initially emerged by accident. For example, track 1 (*DJ*) contains a lot accidentally produced jazz-like breaks, programmed into the drum machine. The use of digital delay and track muting in Track 2 resulted in interesting conjunctions of musical elements (e.g. at 3.45 mins) and the hint of multiple tempos (e.g. starting at 3.48 mins). Later tracks represent a more systematic attempt to play with rhythm, starting with track 3 and 4 (*Venetian Blind*) that was based on a sample that contained an interesting syncopation. On track 3, more conscious effort was made in exploring this syncopation by the addition of a 4/4 stick drum sound whose last beat in the bar is slightly early (starting at 0.14 mins). At 2.44 an attempt is made to break down the rhythm by stripping away elements a recombining them. Finally, the last section (3.52) contains an early attempt at using additional single drum sounds played periodically to cut into the looped rhythm.

Track 6 (*The End of a Very Long Day*) was a further exploration of rhythmic dynamics that really pushed the capability of the sequencer. A lot of interesting musical ideas were discovered by accident but proved very hard to adequately explore using looping and cutting and pasting alone. By shifting the loop positions slightly, a different, and sometimes surprising, syncopated feel can be created. One of these occurs between 3.44 mins and 4.58, and another (almost reggae like) feel is created at 6.04 mins.
[170] Newer types of sequencer become virtual studios in that they allow for the addition of effects loops and sample manipulation entirely within the computer. Examples include Steinberg's Virtual Studio Technology found on their *Cubase* program (see http://www.steinberg.net) and Sound Technology's *Emagic Logic Audio* program (see http://www.soundtech.co.uk/emagic/index.htm).

[171] Simon Waters discusses the wider role and purpose of surface noise and imperfection within various forms of electroacoustic music. (Waters, 1994, esp. pp. 22-24.)
[172] (Eshun, 1998), p. 131.
[173] (Toop, 1995), p. 261.
[174] (Waters, 1997), p. 17.
[175] (Toop, 1995), p. 167.
[176] I am thinking here particularly of Steinberg's *Recycle!* program that enables various operations for cutting up and changing the rhythmic feel of loops. For information go to http://www.steinberg.net. This program suggests how the sample can be cut up based on its rhythmic dynamics. Therefore this becomes educational as the rhythmic feel of the sound is revealed and transformed with the help of this program.
[177] (Eshun, 1998), p.12.
[178] (Escher, 1989), p. 121, cited in (Eshun, 1998), p. 75.
[179] Eshun's analogy served as an inspiration for the composition of Track 3, *Venetian Blind.*
[180] (Hofstadter, 1979).
[181] Russell quoted in (Eshun, 1998), p. 5. For a flavour of George Russell's theory of music see also (Russell, 1953). Here he discusses the 'modal' organisation of harmony, which contrasts with that of tonality.
[182] Robin Maconie attempts to show that "there are statements in music and that they can be subject to a form of logical manipulation (Maconie, 1997, p. 190). He notes how in the eighteenth century the development of First Movement, or Sonata, Form, a form which become a 'determining' feature of the 'absolute' classical music reflected in "sonatas, string quartets, concertos and symphonies", "pioneered a new form of abstract logic." He continues

> "[This form] consists essentially of an exposition, a development and a recapitulation. The exposition is concerned with statements of a principal and optional secondary (opposing or complementary) theme. The exposition begins in the tonic key but evolves away from it towards a related key, usually the dominant. The arrival at a new key, representing a change from the initial terms of reference, is summarized by an optional codetta. There follows a development section, in which the themes are anatomized, transposed and combined in various ways. The recapitulation is a restatement of the themes of the exposition, this time incorporating modifications arrived at during the development, and beginning and ending in the tonic key, with an optional coda summarizing the final point of arrival. In effect, first-movement form subjects one or more initial propositions to critical examination and draws out a variety of options for further development ... ending with a restatement of the initial propositions in a manner conveying a higher sense of their potential for meaning." (Ibid. p. 191. He discusses what this meaning could be on p. 194)

[183] Russell quoted in (Eshun, 1998), p. 5.
[184] For Mark Delaere

> "[Tonal music is] characterised by the presence of a central tone, to which all other tones are subordinated in a fixed hierarchy. The fact that this tonic is also known as the 'ground-note' demonstrates that the principle of gravity plays a certain role. In the hermeneutics of tonality, every other tone (than the tonic) is considered to be an overtone of the tonic. Given that this tonic remains the lowest note (ground-note), all the other tones gravitate 'in a natural way' towards this fundamental tone, depending

on their localization in the overtone spectrum (decisive for the strength of the gravity pull). The 'weightiest' interval is the fifth (the first non-identical overtone) and the tonal theoreticians have based the mechanism of functionality upon it. According to this school of thought music possesses only three functions: in addition to the tonic (the hierarchical middle point) the dominant and subdominant (a fifth higher and a fifth lower than the tonic respectively) govern all music. Every chord can be reduced to one of these three principle functions (or to one of their subordinate substitutes) by establishing the chord's root, to which all notes in the chord gravitate 'in a natural way'." (Delaere, 1990, pp. 17-18)

[185] See (Chester, 1970) and (Frith, 1987, p. 145).
[186] For David Rothenberg, "the turning wheel graphically illustrates technique altering intent. Once we can make fairly symmetrical containers, we quickly think of new applications for such forms." (Rothenberg, 1994, p. 114). In this regard cybernetics is a model that "encompasses roundness within its very construction, conceptually far deeper than symmetrical gears or wheels of any physical kind" (Rothenberg, 1994, p. 129)
[187] (Rothenberg, 1996).
[188] (McCullough, 1996).
[189] For a discussion on 'playing by ear' see (Lilliestam, 1996).
[190] The sequencer allows elements to be quantized, as in made to fall on, or nearer, 'exact' measures of musical time.
[191] quoted in (Toop, 1995), p. 128
[192] (Rothenberg, 1996), p. 41.
[193] This problem was especially evident when creating Track 5/6, *The End of a Very Long Day*.
[194] The chess player Gary Kasparov comments on his experience of playing chess with IBM's Deep Blue:

> "When playing a human being there is energy going between us. Today I was puzzled because I felt no opponent, no energy – kind of like a black hole, into which my energy could disappear. But I discovered a new source of energy, *from the audience to me*, and I thank you very much for this enormous energy supply." (Quoted in *New York Times Magazine*, 14 January 1990, p. 65, cited here from Rothenberg, 1994, p. 148)

[195] This effect within my own practice was particularly noticeable when creating Track 5 and 6 (see *Appendix 2 – Track Listing*)`. The experience was both one of the most interesting, yet frustrating experiences as I was unable to fully realise many of the transformations desired through the sequencer, resulting in periods of both incoherence and excessive repetition. Significantly, much of the work on this was carried out in isolation and much of the collaborative energy was missing.
[196] According to Hamel, "The chief characteristic of *minimal music* is the repetition of short motifs which alter almost imperceptibly and are varied only minimally. Music is transported into a state of constant regeneration ...Everything proceeds as though the principle of repetition had no other purpose than to hypnotise the listener. At a first hearing, such music sounds 'primitive' and monotonous; yet as soon as one gets the feel of it a deep self-experience becomes possible... Not least significant precursors of these endless repetitions, periodic formulae and prolonged sounds are Indian music, African rhythmic figures and gamelan music." (Hamel, 1976, p. 143)
[197] Cited in (Nyman, 1974).

[198] Some favourites include the expansive sound of Hancock's *Rain Dance* on 1973's *Sextant* (Hancock, 1998), Davis' *Black Satin* from 1972's *On The Corner* (Davis, 2000) and half hour long live version of *Ife* on 1973's *Miles Davis in Concert* where the music loops around the repetition of the bass guitar (Davis, 1997).
[199] (Eshun, 1998), p. 11. See also (Mandelbrot, 1982).
[200] (Trayle, 1991), p. 52. I also discuss aspects of one of Mark Trayle's systems in an early paper (See 'Computer Music and Human Expression').
[201] John Bischoff in (Brown, Bischoff and Perkis, 1996, p. 30).
[202] See also (Perkis, 1993). Mazzioli discusses the idea of new 'tripolar' forms of communication brought about by computers, "which in *triangular fashion* tie the participants to linguistic action specified by a person-to-machine-to-person model of relations which is taking its place beside, or perhaps replacing the traditional dual person-to-person structure." (Mazzioli, 1992, p. 229. See also (Silvia; Gaggiolo; Martini, and Morando, 1993).
[203] (Wessel, 1991b), p. 82.
[204] (Wessel, 1991a), p. 344.
[205] (Lee and Wessel, 1992), p. 277.
[206] Cited in (Pope, 1993). See also his *Singing the Alternative Interactivity Blues* (Lewis, 1997).
[207] quoted in (Nyman, 1974).
[208] 'Groove', or 'funk', is rather difficult to describe in an academic context, for it is something that you feel rather than explain. However, the idea of groove is described rather poetically by Kodwo Eshun. He describes 'groove' as "when overlapping patterns of rhythm interlock, when beats syncromesh until they generate an automation effect, an inexorable effortless sensation which pushes you along from behind until you're funky like a train." (Eshun, 1998, p. 82). Elsewhere he describes funk as "the feet that move, the hips which swivel in time, the head which nods, the nerves which pulse: all the body counts. To get funked up is to acclimatize yourself to the endless complexification of these states, to be sensualized by all the processes that process you." (Eshun, 1998, p. 152)
[209] I am thinking here particularly of Jeff Bilmes' representation system for expressive timing (e.g. Bilmes, 1992; Bilmes, 1993; Iyer; Bilmes; Wright, and Wessel, 1997).
[210] A significant catalyst in this regard was my tutor Mike Punt, when I was discussing playing the piano, asking me 'What is that doing?' This helped result in a reappraisal of the purpose of music and technology's relation to these highlighted concerns.
[211] (Hamel, 1976), p. 29, 28.
[212] (Blacking, 1973), p. 101, cited in (Shepherd, 1992), p. 138.
[213] This is something that is suggested by Eshun. In fact this sense runs throughout his whole discussion. It is also expressed elsewhere. For Michael Tucker, discussing the role of the 'shamanic spirit' in Western 20th century music, music can be seen as "an exalted state of consciousness". He makes some particularly interesting comparisons to jazz which, for Tucker "has always spoken of the essential, shape-shifting spiritual quest of humanity." (Tucker, 1996, p. 84) He cites Martin Luther King:

> "Jazz speaks of life ... When life itself offers no order or meaning, the musician creates an order and meaning from the sounds of the earth which flow through his instrument." (Cited in Tucker, 1996, p. 84)

Peter Michael Hamel's *Through Music to the Self* is an excellent resource in this respect (Hamel, 1976). For Hamel different forms of music express different states of consciousness. For example he discusses music's effects through tone colours and rhythms in relation to Jean Gebster's 'modes of consciousness'. Here I just focus on these in relation to rhythmic forms associated with *magical*, *mythical* and *mental* consciousness.

Music associated with *Magical* consciousness includes the music of the shamans (e.g. Tucker, 1996), Gamelan orchestras (e.g. Brinner, 1995), and Mongolian chanting and is "closely bound up with dance and movement, and nearly always fulfil an initiatory function" (Hamel, 1976, p. 11). Rhythm "is built up out of continuous patterns, indefinitely repeated. These drum-rolls and sequences of beats bring the shaman to the 'centre of the world', enable him – in the shamanic ceremonies of the tundra – to fly or to capture the spirits, or help him to concentrate on making contact with the spirit-world. The drumbeat is modelled on the rhythms (perhaps unconsciously perceived) of the heartbeat or of walking (duple time) or of breathing (triple time) each being repeated, as in nature, *ad infinitum*." (Ibid. p. 90) 'Magical cultures' make "quite different associations with the drum and the cymbal from those usual in the West." (Ibid. p. 77) Jeffrey Biddeau describes to the author how for shamans "All the gods ... have their own special drum signals, which are almost indistinguishable to the untrained ear. The differences consist of minute rhythmic hesitations, short gaps and pauses between the beats and the minutest gradations of volume. These acoustic signs are detected not by the head – i.e., in the intellect – but with the belly, or rather in the human centre of consciousness." (Cited in Hamel, 1976, p. 77) For Hamel, jazz taps into this 'magical consciousness'.

Mythical consciousness includes Greek *musike*, plainsong, Gregorian chanting, raga improvisations, containing elements "common to Eastern and to early Western traditions. Here speech and music are still closely associated" (Ibid. p. 12). Rhythmic patterns here "are *cyclic* ones – patterns which, after going round in a circle, return to the point of departure, as described in the case of the Indian *talas*. The beat itself becomes very sophisticated, and the variations are so arranged as to be subtle metric subdivisions of the beat itself; or else a variation may be used on another beat, but in such a way that they both converge on a single point. This dynamic of rhythmic polarity is felt or experienced by the heart or emotions, as in all Indian or Persian mythical music. (Hamel, 1976, p. 90)

Mental consciousness is associated with developments in Western music from the 15th century onwards reflected in the rise of polyphony, analogous to the development of perspective "with its three-dimensional view of the objective world." The composition of this music "demanded techniques of construction, organisation and notation" giving rise to such things as the closed rational system of tonality and equal temperament. " (Ibid. p. 12) Rhythmic form here is 'rationally devised' and not therefore, "in the proper sense of the term, a rhythmic form at all, but a metric, mathematical one. The fascinating, but still consciously-devised structures of a work by Johann Sebastian Bach, right through to the minutely interlocking rhythms of the music of Anton von Webern or Pierre Boulez are similarly a purely intellectual component of their composition." (Hamel, 1976, pp. 90-91)

[214] Edward Said's book *Orientalism* was principally concerned with the influence of historical colonial relations between East (the Orient) and West. (Said, 1979).

[215] An example of how theory and practice inform my research is that through reading this book I decided to join a group and take up African drumming myself.

[216] (Hamel, 1976), p. 29, p. 28.

[217] (Truax, 1992), p. 29)

[218] Ibid. p. 31.

[219] Ibid. p. 30.

[220] Ibid. p. 35. Though this literate approach may be considered dominant, it is worth noting that not all 19th century composers fit so easily into its model. A particular favourite example of mine is the piano music of Chopin. Fiona Richards discusses Chopin's 'composing in performance', and points out that "the initial impulse took place at the keyboard, and even in public. In other words, much of his piano music had improvisatory origins." (Richards, 1997), pp. 84-85. She points out that this was not uncommon for composers at that time (early 19th century).
[221] (Truax, 1992), p. 37.
[222] This he relates to Ong's 'secondary orality' (Ong, 1982).
[223] (Truax, 1992), p. 38.
[224] Ibid. p. 38. The computer's role in allowing us to explore complex systems is also discussed by Heinz Pagels in *The Dreams of Reason: The Computer and the Rise of the Sciences of Complexity*. Pagels points to how the computer has enabled the modelling of physical and biological systems, a recurrent theme being "the discovery of new general principles inspired by biological systems." (Pagels, 1988, p. 49) This is seen as due to the computer's ability to process humanly impossible numerical calculations and "computationally model and simulate complex systems" (Pagels, 1988, p. 43). This has therefore enabled many disciplines to approach problems that were intractable before. Importantly these have included a class of more complex (nonlinear) equations previously impossible to calculate due to the sheer number of calculations required. See (DeLanda, 1995) for a discussion of some of the artistic potentials within this. Within mathematics Borel notes there are emerging some "important, reciprocal, and fascinating interactions between computer science and pure mathematics." (Borel, 1983, p. 14)
[225] (Truax, 1992), p. 36.
[226] In their book *The Embodied Mind* (Varela and others, 1991).
[227] Ibid. p. 173.
[228] In support of this idea he quotes cultural theorist Raymond Williams

> "We have got into the habit, since we realized how deeply works or values could be determined by the whole situation in which they are expressed, of asking about these relationships in a standard form: 'what is the relation of this art to this society?' But 'society', in this question, is a specious whole. If the art is part of the society, there is no solid whole, outside it, to which, by the form of our question, we concede priority." (Williams, 1965, p. 61, cited in Shepherd, 1992, p. 134)

[229] (Shepherd, 1992), p. 129.
[230] Ibid. p. 134.
[231] (Ellis, 1985), p. 15, cited in (Shepherd, 1992), p. 139.
[232] This understanding of the basic mutuality of perception and conception has been derived mainly from Clancey's discussion (Clancey, 1997b).
[233] For a discussion of some of these issues see e.g. (Sinding-Larsen, 1991). In his discussion of 'fields of complexity' he notes how, as a notation develops each symbol comes to represent decreasingly musically rich information, becoming more independent of context. This however means they can be combined in new ways giving rise to different forms of musical complexity. Complexity can be increasingly explored independently of sound resulting in what he terms a 'synthetic complexity'. (Sinding-Larsen, 1991, p. 114).
[234] Ibid. p. 147.
[235] (Minsky, 1981).
[236] (Shepherd, 1992), p. 150.

[237] Ibid.
[238] (Shepherd, 1992), p. 152.
[239] (Feld, 1988), p. 83-84, cited in (Shepherd, 1992), p. 152.
[240] For discussion of postmodernism see e.g. (Lyotard, 1984), (Harvey, 1990), (Jameson, 1991).
[241] (Davis, 1996). After what Paul Gilroy called the 'Black Atlantic'. See Paul Gilroy 'The Black Atlantic as a Counterculture of Modernity' (Gilroy, 1993). For Davis the 'Black Electronic' represents technologically mediated musical fusions that acknowledge "not just Afro-American culture, but the hybrid cultures of the Caribbean and British Isles."
[242] Eshun presents an elaboration of its various forms, and the aims of its practitioners. Included is an extensive discography (Eshun, 1998).
[243] (Chernoff, 1979), p. 155.
[244] Ibid. p. 156.
[245] Ibid. p. 158.
[246] Ibid. p. 93.
[247] Ibid. p. 87.
[248] For a discussion of these variations see Ibid. pp. 78-79.
[249] Specifically, in some languages the relative pitch within and between words contributes to, and differentiates, their actual meaning. Here the term 'tonal' is being used in a way that is distinct from its use in music.
[250] Ibid. p. 73.
[251] Kofi Agawu (Agawu, 1995) argues that drumming is only one kind of rhythmic expression, and that African music can be better understood through the tonal and rhythmic aspects of language.
[252] (Chernoff, 1979), p. 80.
[253] See (Eshun, 1998), p. 5. In which he includes "the classical musics of the Ghanaian drumchoir, Balinese gamelan orchestras, Indian and Jajouka master musicians..."
[254] Chernoff suggests there are good reasons for thinking of an overall 'African style' of music. In noting the crossovers and essentially unifying characteristics of music of African descent which exists in varying forms in the Caribbean, the United States and South America he says: "That there exists a basis for thinking about an 'African' musical style seems obvious and is unquestioned by those most directly involved... What so many people accept is that there is an essential African style which can be perceived in the different musics of African people." (Chernoff, 1979, pp. 29-30)
[255] (Jones, 1954), p. 26, cited in (Chernoff, 1979), p. 40.
[256] (Chernoff, 1979), p. 41.
[257] See also (Sinding-Larsen, 1991).
[258] (Chernoff, 1979), p. 42.
[259] Ibid.
[260] Ibid. p. 45.
[261] Ibid. p. 95.
[262] See also (Jones, 1954), p. 27, cited in (Chernoff, 1979), p. 47.
[263] (Chernoff, 1979), p. 46.
[264] See (Thompson, 1966), cited in (Chernoff, 1979), p. 47.
[265] (Davis, 1996).
[266] But Chernoff notes that this is not emphasised on the first beat as in much 'traditional' Western music. Instead the second and third beat is stressed in preference to the first and third, this being related to the idea of the 'off-beat' (stressing), something which is also referred to as 'syncopation' in jazz, for example.

[267] (Chernoff, 1979), p. 49.
[268] Ibid.
[269] (Waterman, 1952), p. 211, cited in (Chernoff, 1979), pp. 49-50.
[270] (Chernoff, 1979), p. 50.)
[271] (Waterman, 1952), pp. 211-212, cited in (Chernoff, 1979), p. 50.
[272] (Chernoff, 1979), p. 51.
[273] Ibid p. 201, note 19.
[274] Ibid. p. 52.
[275] Ibid. p. 53.
[276] Ibid. p. 95.
[277] Ibid, pp. 97-98.
[278] Ibid. pp. 80-81.
[279] Ibid. p. 55.
[280] Ibid. pp. 111-112.
[281] Ibid. pp. 59-60.
[282] Ibid. pp. 67, 68.
[283] Ibid. p. 56.
[284] Ibid. p. 122.
[285] Ibid. p. 112.
[286] Ibid. p. 113.
[287] Ibid. p. 100.
[288] Ibid. pp. 100-101.
[289] Ibid. p. 113.
[290] Chernoff later notes that "dancing gives the rhythms a visible and physical form" (Chernoff, 1979, p. 143) and that "the confidence of a foot is the placing of communicative certainty into a context of rhythmic ambiguity." (Chernoff, 1979, p. 144) Therefore dancers can also add an additional rhythm to those already there as "He tunes his ear to hidden rhythms and he dances to the gaps in the music." (Chernoff, 1979, p. 144). Drummers and dancers rhythms serve to "vitalize each other" (Chernoff, 1979, p. 145).
[291] Ibid. p. 113.
[292] Ibid. p. 114, p, 125.
[293] (Thompson, 1966), p. 91, cited in (Chernoff, 1979), p. 125.
[294] (Chernoff, 1979), p. 114.
[295] Ibid. p. 123.
[296] (Jennings, 1996), p. 346.
[297] Eno quoted in Kevin Kelly, 'Gossip is Philosophy', Wired 3.05 (May 1995), p. 148, cited in (Jennings, 1996), p. 346.
[298] (Jennings, 1996), p. 346.
[299] Ibid. p. 346.
[300] Ibid.
[301] Ibid. p. 347.
[302] Ibid.
[303] For Eco "all forms of communication, interpretation and understanding are by their nature tentative and hazardous acts of inference" The 'Open Work' is "the work of movement. There is no single prescribed point of view, and there is the possibility of numerous different personal interpretations... The open work does not narrate; rather it offers the participant an infinite potential for exchange rich in unforeseen discoveries." (Jennings, 1996, p. 347).
[304] (Davis, 1996).

[305] Which Davis defines as musical and sociological environments that Marshall McCluhan referred to as 'acoustic space'.
[306] For this idea he is inspired by Ron Eglash's work, *African Influences in Cybernetics* (Eglash, 1995)
[307] According to Agostino Di Scipio (Di Scipio, 1995b, p. 376)
[308] See the paper 'Give us the Funk...': Machine Autonomy Meets Rhythmic Sensibility
[309] (Dannenberg, 1996), p. 54-55.
[310] (Eshun, 1998), p. 78.
[311] (Eshun, 1998), p. 19.
[312] For example in discussing whether a computer can 'understand and produce art' Roberto Maiocchi suggests

> "... both to understand and produce aesthetic objects one has to take into account the cultural environment in which the artwork is produced and how the artist is influenced by it, the intended meaning of the piece of art, and the definition of new forms of aesthetics." (Maiocchi, 1991, p. 201).

For a discussion of this in relation to Harold Cohen's Aaron see also (Clancey, 1997b), Ch. 1.
[313] (Desain and Honing, 1991), p. 143.
[314] (McCullough, 1996), p. 134.
[315] (Emmerson, 1994). Emmerson notes that "The term 'live electronic music' faded slowly but steadily from the vocabulary between about 1975 and 1985, giving way to the (albeit correct) term 'real-time'. But language cannot so simply obscure a fundamental misunderstanding that has come with this change. The human performer has somehow been subsumed into the computer itself, as into the terminology that goes with it." (Emmerson, 1994, p. 95)

With such an approach, "Live performance as we known it can logically cease. From muzak which can be generated in real-time from synthetic and sampled sounds complete with algorithmic control of 'expressive timing', to perfect recreations of historical performances through computer analysis of earlier recordings, to a virtual reality in which I can be soloist." However he notes optimistically that "just as drum machines did not replace drummers, humans will not write themselves out of the script quite so easily." (Ibid. pp. 95-96)
[316] See for example (Large, 1995), (Allen and Dannenberg, 1990).
[317] See for example (Desain and Honing, 1994a), (Desain and Honing, 1994b).
[318] (Griffith and Todd, 1999), p. xiv.
[319] Ibid. p. viii.
[320] (Langton, 1992a), p. xiv.
[321] (Bonabeau and Theraulaz, 1995), pp. 303-304.
[322] (Langton, 1989), page 2.
[323] Christopher Langton suggests it is possible to create 'life-as-it-could-be' using the techniques of ALife (Langton, 1989, p. 1). This is because, for Langton, ALife is concerned with life as "a property of the *organization* of matter, rather than a property of the matter which is so organized." Therefore, instead of being concerned with life's material basis, as has biology, it is concerned with its formal basis (Ibid. p. 2.).

Among those artists using artificial life Kenneth Rinaldo (Rinaldo, 1998) suggests there are now "hard A-Life and soft A-Life" artists. The former believe "they are really creating life", while the latter believe they are just creating simulations. It is worth bearing in mind that the majority of artistic explorations in ALife have been based around computer simulations. In this way these are just ungrounded symbol systems as Stevan Harnad suggests. He says such models "can capture the formal properties of life, perhaps predict and explain it completely, but it can no more *be* alive than a virtual forest fire can be hot. In itself, a computational model is just an ungrounded symbol system; no matter how closely it matches the properties of what is being modeled, it matches them only formally, with the mediation of an interpretation" (Harnad, 1995, p. 293)

Believing that their simulations are in some way actually alive creates an odd perception as to their intentionality, as suggested by Rinaldo

> "One difficulty with artificial life artworks is that the system may not seem to be responsive to the changing environment, as the work demonstrates its own internal desires. This can make the work seem unresponsive or uncaring. Natural living systems manifest their complexity through their interconnected relationship to an ever-changing environment. Still, it illustrates a cultural moment in which the computer may not need to be concerned with the participant/viewer."

It is an odd concept that a model could be concerned with anything. However, there are other possibilities for ALife, as discussed by Eric Olson. He contrasts computational models considered alive ('virtual' strong ALife), with simulations ('weak' ALife) and building living systems out of inorganic matter ('robotic' strong ALife). For Olson, many who support strong ALife "have not thought clearly about the ontological nature of those computer-generated entities they claim are alive" and some basic questions about these virtual creatures are not asked. He goes on

> "Extremely basic questions about these putative creatures are not answered: Where are they, and what is their size and shape? Are they literally inside the computer? Or are they located in space and time at all? What are they made of? What is their relation to the hardware of the computer? What happens to them when the program stops running, or when the computer is shut off? How many of them are there? Are they material objects, made of matter? Events or processes going on somewhere? Abstract universals that do not participate in causal relations? Or none of these? Until we can answer at least some of these questions, we literally do not know what we are talking about when we ask whether alife creatures are alive." (Olson, 1997, p. 30)

However, Olson considers the possibility that in some ways the physical behaviour of the computer could be alive in some way. Therefore

> "None of this ... impugns the claim that computer-generated organisms are physical objects inside the computer: that certain copper and silicon atoms found there becomes caught up in complex, self-organizing electrical activities in a way analogous to that in which certain carbon, hydrogen, and other atoms sometimes become caught up in complex, self-organizing biochemical events. Just as those carbon and hydrogen atoms thereby come to make up snakes and snails and you and me, perhaps those copper and silicon atoms thereby come to make up artificial

organisms. This, I claim, is the only coherent account of strong alife." (Olson, 1997, p. 38)

[324] (Mason and Saffle, 1994). This example involves the computational simulation of the generation of various biological forms using Lindenmeyer Systems (L-Systems), a formal grammar that can be used to model growth processes, useful for looking at "...systems that grow, develop, and differentiate like real organisms, but which are not, themselves, real organisms" (Langton, 1992b, p. 13, see also Prusinkiewicz, 1995)

As early as 1986 Przemyslaw Prusinkiewicz used L-Systems to generate music (Prusinkiewicz, 1986). Stephanie Mason and Michael Saffle generated 'melodies and rhythmic patterns' using L-Systems. Interestingly, melodic phrases were duplicated which were "...associated with hundreds of pre-existing works by classical and popular Western composers" like, for example, Bach. From this "...the possible link between the perception of musical beauty and the fractal or quasi-fractal character of music associated with L-system curves" is discussed. Earlier, the similarities between fractal structures and much music prompts Michael McNabb to speculate: "The fact that fractal properties are common to music across such a wide range of cultures and times at least suggests that there is physiologically-based common ground for musical aesthetics." (McNabb, 1986, p. 153)

[325] (McCullough, 1996), 230-231.

[326] Cited in (Kelly, 1994), p. 95.

[327] Discussed in his book *The Blind Watchmaker* (Dawkins, 1986).

[328] (Todd and Latham, 1992), p. 12.

[329] Latham cited in (Kelly, 1994), pp. 353, 351.

[330] (Brown, Bischoff and Perkis, 1996), p. 31.

[331] Ibid.

[332] (Large and Kolen, 1994).

[333] My principle sources for an understanding of dynamical systems is found from (van Gelder and Port, 1995), and (Wheeler, 1996).

[334] (Norton, 1995), p. 45.

[335] (van Gelder and Port, 1995), p. 7.

[336] (Wheeler, 1996), p. 222.

[337] (van Gelder and Port, 1995), p. 6.

[338] (van Gelder and Port, 1995), p. 14.

[339] As van Gelder and Port point out, this is an example of a *state-determined* system (Ashby, 1952).

[340] (Wheeler, 1996), p. 223.

[341] Ibid.

[342] (van Gelder and Port, 1995), p.10.

[343] (Davis, 1996).

[344] A neural network can be considered as a highly abstracted model of how neurons in the brain learn, represent and transmit information. For an introduction see e.g. (Jain, Mao, and Mohiuddin, 1996) and (Clark, 1997).

[345] (Port, Tajima, and Cummins, 1998). See also (Large, 1995), (Large and Kolen, 1994), (Large, 1996), (Gasser; Eck, and Port, 1999).

[346] (Toiviainen, 1997).

[347] (McCullough, 1996), p. 230-231.

[348] From this field has emerged its own journal *Adaptive Behavior* that reflects many differing approaches to the general problem of machine adaptivity.

[349] Computers are useful in exploring the space of possible behaviours before devices are actually built. Although the computer is associated with abstract symbolic logic and discrete binary operations this does not make it unhelpful in exploring embodiment. As Rodney Brooks says:

> "We are not saying that computers are not sufficiently powerful to simulate cognitive processes, just that we must be careful that we choose the right abstractions to simulate. Traditional AI chose the symbol level as a higher abstraction – many now feel this was the wrong level of attack. The situated robotics community must also be prepared to carefully think, and rethink, about its levels of abstraction." (Brooks, 1994, p. 23).

Similarly Clancey points out that it is not the binary representation system of the computer that is the problem, but that "the modelling methods used by cognitive sciences are inadequate – a shortcoming in the understanding of causal mechanism, not necessarily the computer hardware." (Clancey, 1997b, p. 234)

[350] Robotics can be defined as "the intelligent connection of perception to action". (Brady and Paul, 1984), cited in (Bryson, 1992), p. 79. The term 'situated robots' is used in the present context to refer to a range differing perspectives on the problem of designing interactive robotic systems, examples of which include Embodied Artificial Intelligence (e.g. Prem, 1997), Evolutionary Robotics (e.g. Harvey, Husbands, Cliff; Thompson, and Jakobi, 1997), Behaviour Based Robotics (e.g. Mataric, 1992) and Autonomous Agents (e.g. Steels, 1995; Maes, 1994a; Dellaert and Beer, 1996).

[351] Exploring the idea of an 'agent' in its environment did not start with Artificial Life and situated robotics. For example Phil Agre discusses how Artificial Intelligence grew out of cybernetics (e.g. Wiener, 1948, Ashby, 1952) and a consequent concern with the reciprocal role of agents' interactions with each other and their environment. (Agre, 1995, see also Edwards, 1996). Furthermore Agre points out that, in 1969, Artificial Intelligence researcher Herbert Simon, discussed an ant's complex interactions with its environment (Simon, 1969, p. 64). However, as Clancey points out, Simon's interpretation diminished the role of environment in favour of the ant's internal thought processes. (Clancey, 1997b, p. 106).

[352] For some examples of early robots see for example (Clark, 1997, Ch 1). In some fundamental way researchers in situated robots seem to be orientated to a different kind of philosophy than those involved in these earlier attempts, one that acknowledges the embodied, situated character of behaviour. For example Michael Wheeler discusses the relationships between situated robotics and the philosophy of Martin Heidegger (Wheeler, 1996). Researchers in this field also refer to the phenomenology of Merleau-Ponty (e.g. Loren and Dietrich, 1997). In contrast, it has been argued that an earlier generation of Artificial Intelligence researchers, in focusing on rational thought, reflected a philosophical heritage that favoured mind over body (e.g. Dreyfus and Dreyfus, 1991). For Michael Wheeler

> "Descartes's legacy was not merely to give a whole new (although now largely discredited) respectability to the thesis of mind-matter substance dualism. In effect, he helped to open up an *explanatory* divide between mind and world, according to which a fundamentally 'internal' subject relates to an 'external' world of objects via some interface." (Wheeler, 1996, p. 213)

[353] (Maes, 1994b).

[354] Itself reflective of a general trend in thought that extends through philosophy (e.g. Heidegger, 1962), phenomenology (e.g. Merleau-Ponty, 1962), developmental psychology (e.g. Thelen and Smith, 1994; Hendriks-Jansen, 1996a) and cognitive science (e.g. Clark, 1997; Varela and others, 1991). The influences on my thinking derived from some of these individuals' ideas are discussed in my published papers (See *Appendix* 1 – Published Papers).
[355] (Hendriks-Jansen, 1996a), p. 291, see also (Hendriks-Jansen, 1996b).
[356] William Clancey makes the point that what this knowledge corresponds to is more like our verbal descriptions of it, rather than a reflection of how our brain actually represents and uses 'knowledge' about situated activities (Clancey, 1997b), see also (Clark, 1997).
[357] This I think is what Rodney Brooks was suggesting when he wrote *Intelligence Without Reason* (Brooks, 1991a) and *Intelligence Without Representation* (Brooks, 1991c).
[358] (Clancey, 1997b), p. 181, p. 175.
[359] This idea of promoting a close relationship between sensing and acting relates to the close reciprocal link observed in organism acting within and sensing its environment. For example Wheeler refers to the idea of a 'perception-action cycle'. (Wheeler, 1996) and Andy Clark discusses 'action loops' (Clark, 1997).
[360] (Clancey, 1997b), p. 175.
[361] (Clark, 1997), p. 43.
[362] As described by (Kelly, 1994), p. 158.
[363] See for example (Brooks, 1986), (Brooks, 1990), (Brooks, 1991a), (Brooks, 1991b), (Brooks, 1994).
[364] These terms constitute an observer's description of how these behaviours appear.
[365] (Mataric, 1997), p. 7.
[366] Reflective of the bird-like flocking type behaviour demonstrated in the simulated environment of Craig Reynolds *Boyds* (Reynolds, 1987).
[367] Ibid. p. 8.
[368] See for example the simulated examples in (Beer and Gallagher, 1992).
[369] So called 'dynamical neural networks'.
[370] (Smithers, 1997).
[371] Derived from the Greek *automatos* - auto (self) matos (movement).
[372] Here Smithers also talks about Humberto Maturana and Francisco Varela's ideas of *autopoietic* systems, from the Greek for 'self-producing', which is a kind of autonomy. See (Maturana and Varela, 1973), (Varela, 1979), (Maturana and Varela, 1980), and for a more accessible discussion (Maturana and Varela, 1992)). For Smithers,

> "Maturana and Varela's autopoietic theory of single cells defines the minimal living organisation as one that continuously produces the components that specify it, while at the same time realising the cell as a concrete unity in space and time, which is responsible for the production of these components. Thus, autopoiesis attempts to capture the essential process that generates the identity of living organisms, and thus serves as the basis for distinguishing them from non-living things." (Smithers, 1997)

Here the material processes, the physical stuff itself, do matter in this kind of autonomy, and this makes it different from simulated processes on computer. "In the case of single cells ... [this] involves a material process of matter and energy transport across the (self-produced) identity-environment boundary."
[373] He relates this to Maturana and Varela's idea of structural coupling between agent and environment.

"the internal organisation of the agent reflects the structure and organisation of the environment with which it interacts.... Designing and building autonomous agents thus becomes the problem of designing and building processes that can support and maintain this kind of identity formation through interaction: processes that, through interaction, are continuously forming the laws of interaction that can sustain and maintain the interaction needed to form them. In other words, we need interaction processes that can support the self-construction and maintenance of interaction processes through interaction, in essentially the same way that the material and energy interaction processes of single cells can be understood as being involved in the continual forming of the mechanisms that support this interaction. Such systems will thus be self-law making as well as self-regulating, in essentially the same way as we can understand biological systems and autonomous city states." (Smithers, 1997)

[374] See for example (Zeki, 1999).
[375] (Brown, 1999).
[376] (Borisyuk, Borisyuk, and Kazanovich, 1998). For a technical discussion of the dynamic behaviours possible with oscillatory neural networks see also (Borisyuk, Borisyuk, Khibnik, and Roose, 1995). This is a detailed mathematical paper, but the diagrammatic representations of the behaviour of these are very instructive.
[377] (Chowning, 1973).
[378] Rhythm perception can be construed as "a process employing oscillatory circuits in the brain that entrain to low-frequency periodicities in the neural firings evoked by an acoustic signal" (Gjerdingen, 1993)
[379] (Gray and Pirie, 1995). Carole Gray and Ian Pirie point to possible interesting convergences of science and art in relation to the exploration of these issues. It is also worth mentioning the possible relationships between art and mathematics. Some mathematicians have considered their subject to contain elements of art, though this is not to imply that they are the same. For example, G. H. Hardy said, "A mathematician, like a painter or a poet, is a maker of patterns" (Hardy, 1940, p. 84, cited in Emmer, 1994, p. 237).
[380] For example, Mark Delaere suggests that the musical system of tonality reflects a deterministic Newtonian universe from where it derived its 'truth value'. Music came to be validated through its formal structural correspondences to that prevalent scientific system. Both systems broke down in the early 20th century to be replaced with an acknowledgement of more indeterminate and subjective factors in the formulation of both musical and scientific laws (Delaere, 1990).
[381] (Risset, 1994), p. 260.
[382] (Risset, 1994), p. 257. With the organ, each pipe produces simple tones that can be added together in various combinations to produce more complex timbres. *Fourier* analysis and synthesis enables the description and creation of complex waveforms in terms of their constituent sine waves. As Risset points out, therefore organ makers implemented Fourier synthesis four centuries before Fourier. For Robin Maconie the organ is one of several musical technologies that served to enrich scientific and technical knowledge (see Maconie, 1997, ch. 14). In relating the organ's development with the growth in the size of churches and cathedrals in the middle ages, he suggests that:

"Gothic cathedrals in their day were temples of acoustic science, and the case for ever larger cathedrals was the same as for ever larger particle accelerators in the twentieth century: the bigger the scale, the larger the wave structure that can be studied, and the greater the detail of the wave structure of the universe that can thereby be revealed." (Maconie, 1997, p. 175)

Peter Michael Hamel has discussed more esoteric and bizarre links between physics and music.

> "Contemporary research has ventured into the field of 'occult' phenomena and revealed a scientific basis for many of our intuitive and mystic intimations. The natural phenomena of music have been once again recognised to be elements of the basic laws of physics. The *Harmony of the Spheres* is discussed in relation to Max Planck's law of quanta; the basic laws of acoustics find their equivalent in the ratios between the shells of the atomic nucleus. Observation of the radiation-spectrum shows that the radiation-quanta released when an electron jumps from an outer to an inner orbit possess a sequence of gradation similar to that of the note-intervals." (Hamel, 1976, p. 106)

Also there is the work of Wilfried Krüger "Self-taught in the fields of atomic physics and musical theory, Krüger has succeeded in constructing a picture of the musical *modus operandi* of the atomic nucleus. He returns constantly to the theme of the musical proportions governing intervals and notes, proportions which are to be found equally in the shells of the atomic nucleus." (Hamel, 1976, p. 106). His work makes it clear "how the esoteric knowledge and intuitions of the ancients can be tied in with today's scientific method." (Ibid. p. 107)

[383] (Risset, 1994), p. 258.

[384] Mechanical organs described in the 17th century by Kircher in *Musurgia Universalis* (1650) predate both technical and mathematical discoveries:
"In such devices, musical information was coded on a cylinder with appropriately placed pins, or in a punched paper tape: as early as the fourteenth century, the notion of a stored program was put to work in such devices. This way of storing music implicitly used Cartesian coordinates long before Descartes developed them." (Risset, 1994, p. 257).

[385] As suggested by Charles Garoian and John Mathews (Garoian and Mathews, 1996, p. 193, see also Fischer, 1959, p. 36).

[386] (Garoian and Mathews, 1996), p. 193.

[387] (Ho, 1991), p. 614. For the physicist Ilya Prigogine science is also a partly search for the transcendent common to many artistic activities. (Prigogine, 1996, p. 42).

[388] Ibid. The Renaissance involved a close interaction between artists and scientists (Miller, 1995), p. 36. It is notable that at the Fourth European Conference on Artificial Life, held in 1997, two of its keynote speakers were artists (Stelarc and Norman White). Sussex University's School of Cognitive and Computing Sciences has its own 'artist in residence', whose residents have included Stelarc and Paul Brown. Another example is that at Pennsylvania State University College of Engineering (Mathews, McCart, Klevans, Walker, Fisher. Kunz, and Brighton, 1990).

[389] (McCullough, 1996), p. 5, see also (Polanyi, 1958).

[390] Garoian and Mathews note

> "a general misunderstanding of the intellectual and emotional origins of what we term 'science'. In science, thought processes only become quantitative at their end – with the formation of a product. The scientist's internal language is often both visual and visceral: the first expression of an idea comes in the form of inchoate images that may

or may not reflect the order of things in the external world, but may become more organized and begin to 'feel right'. (Garoian and Mathews, 1996, p. 194)

Similarly, in his review of two recent books on phenomenology, John Dance suggests

> "it is notorious that scientists frequently cannot account rationally or systematically for the way they formulate hypothesis but rely on inspiration and guesswork." (Dance, 2000, p. 74).

[391] According to biologist Mae Wan Ho (Ho, 1991), p. 608. For Ho this recognition is reflective of the views of 19th century poet/scientist Goethe, "a romantic poet who understood science better than most scientists" who saw that the "process of creative scientific thought ... begins as a perceptive act akin to the artistic impulse." (see also Bortoft, 1986; Bortoft, 1996).
[392] Physicist Ilya Prigogine discusses the 'role played by passion and, more generally, irrational elements in processing knowledge' (Prigogine, 1996).
[393] (Tang, 1984), p. 265.
[394] Ibid. p. 261.
[395] For Alfred Copley, an artist or scientist may be 'Apollonian', lead by conscious thought and systematic practice, or a more intuitive 'Dionysian'. Both are necessary, the former solidifying what the latter bring into the world (Alcopley, 1994, p. 183).
[396] " ... art is not only a construction, a creation, it is also a discovery. Similarities between paintings from different epochs or places ... tend to demonstrate the discovery of similar archetypes, or at least are evidence of a common working of the human mind and hand." (Mandelbrojt, 1994, p. 185)
[397] (Pagels, 1988), p. 51. The basic similarities that may exist between differing patterns in nature and behaviour is also discussed by Scott Kelso (Kelso, 1995).
[398] (Godwin, 1992), p. 271.
[399] (Stravinsky and Craft, 1980), p. 34, cited in (Tang, 1984), p. 265.
[400] (Shepherd, 1992), p. 137.
[401] (Maconie, 1997), p. xi.
[402] Ibid. p. xiii.

Appendix 1 – Published Papers

Computer Music and Human Expression

Author: Jon Bedworth

Published: 1998

Publication: *Digital Creativity* 9(2), pp.115-120

Introduction

As an improvising musician interested in tools that enhance a live working through of some inner musical process, my interest in computer music stems from being informed by the computer as a tool I use in musical expression. So far the computer has played a fairly passive role. Fairly passive because I feel in some way that I have been informed by the computer, that it 'actively' inspires due to the nature of what it is.

Research at CAiiA allows me to reflect on the nature of the 'creative coupling' between people and machines (particularly computers). Attempts at finding ways to enhance this include gestural interfaces and 'visual music'. But beyond the interface, it seems important to ask some questions regarding the potentials of computer in relation to the music. What relationships can we have with such a machine? In helping me make musical choices, how autonomous can a computer be?

Computer Algorithms and Musical Systems

In combination with artists' free will "the creative act of self-expression directly through a computer program places in unique juxtaposition ... mutually contradictory philosophical extrema [of freedom and determinism]".[1] These concerns mirror those of experimental[2] and avant garde musical traditions, respectively. Compare Cage's 'sounds in themselves' with strict serial formalisms. Similarly algorithmic music can produce results having elements of unpredictability, but set within prior constraints of the system; the formal and explicit specification of its parameters and structure. In constructing computer music systems it is important to realise that the algorithm will be an abstraction of some finite musical system.

However, such algorithms may allow computers to become initiators and evolvers of ideas, creating "...complex relationships between programmed intention and actual result".[3] An example is the simulated biology and ecologies of Artificial Life, the latest quest to "...imitate nature [mimesis]... and to simulate the qualities of being human (anthropomorphism)"[4]. These twin drives "... blur the lines between animate and inanimate, between human and machine."

A-life potentially offers artists an interactivity that "... allows systems to react in ways not so explicitly defined."[5] An example is William Latham's technique *evolutionism*. Here the artist "...becomes a gardener within ...[a]... world he has created; he selects and breeds sculptural forms as a plant breeder produces flowers." The computer is "...a creative partner, almost a shadow of himself." [6]

Such techniques applied to music would seem to be a useful next step. There is popular interest in generative music software[7]which can generate endless non-repeating musical patterns from musical 'seeds', essentially a set of values which are assigned to the system's musical parameters. This approach can enhance accessibility to musical exploration but also takes some musical choices away from the user.

This implies computers can make those musical choices. Brian Eno desires "A thing that makes choices about its inputs and says to itself: this is good output, reinforce that, or replay it, or feed it back in. I would love to have this machine stand for me. I could program this box to be my particular taste and interest in things."[8]

Latham and Eno's remarks imply a particular attitude to technology. Elsewhere Latham is quoted as referring to a blurring of "... distinctions between human creativity and natural creativity and the generative power of computing."[9] What attitudes get reflected in the tools we use and the approach we adopt in using those tools? I would agree with Eno when he says machines "... do things I would not have thought of."[10] But the question becomes whether we wish to get the computer to 'produce art by itself' or to 'open up new possibilities for humans to produce art'. "It is a question of the relation of tools and techniques to human activity."[11]

Social Construction of Technology

Microsoft asks: 'Where do you want to go today?' A review of Steven Holtzman's 'Digital Mantra' refers to:

"[t]he belief that there are technological solutions to the problems of life, of living, of being human, through software or hardware extensions to our central nervous system. All of this is wrapped up in the entrepreneurial proselytizing of the "free market" embedded within a "post-modern" costuming of the American frontier myth in order to conquer the world market for computer-entertainment."[12]

Arguments for a 'Social Construction of Technology'[13] suggest social concerns shape scientific/ technological progress, contrasting a 'determinist' view which sees technology as a consequence of 'objective' approaches. Computers and their software exist in social context, are products in economic systems, which shape assumptions built into their structure. Hypertext reflects a particular view of representing knowledge. Art produced on it reflects this. Tools shape perceptions. But also perceptions shape tools. Any attempt at creating a computer music system falls within a particular paradigm which reflects views on how music is made.[14]

Consider also the view that mind is pre-eminent to body; the concepts of art are superior to their physical base. Cartesian Dualism: 'I think therefore I am'. This is not surprising in computer arts: Computers are themselves a physical embodiment of a Western rational thought process, of logic, of disembodied ideas. Simon Penny refers to beliefs in 'cyber-cultural circles' that "... the body is 'obsolete'." But lack of appreciation of bodily intelligence in computers results in loss of physical knowledge when tasks previously requiring it are computerised. The body is being 'de-skilled' and "... the process which links conceptualization to physical realization is [being] destroyed."[15]

The 'Social Construction of Music'

Music for me is a physically embodied activity, about communication through spontaneous improvisation, the musical instrument an amplifier of musical 'energy'[16]and I look for technology that supports this. Through improvising you may develop a shared musical language, aware of, expressive of, and responsive to the ever changing present; music as a purposive human activity between people embodied in an environment, its 'language', meaning, and affect, emerging through this interaction. To what extent can computers engage in this process?

Computers as Musical Surrogates

To ask such a question is to question the extent to which a computer is able to make responsive choices; to be self aware, and aware of the context of its behaviour. Such concerns can be addressed on a technical level (the capabilities of the computer and the relevance of the concept of information), but also in relation to a revealing of attitudes to ourselves as human beings, attitudes which can shape the development of technology

Believers in 'strong' Artificial Intelligence believed computers could be programmed to equal or exceed human intelligence. Thus in computer music we have Chomskian generative grammars for music similar to those for language, and programs that can write music like, for example Bach, because they are able to manipulate abstractions of the form of Bach's music.[17] Such views are amenable to computer representation. It is however, one thing to abstract a set of rules from an existing system, another to create a system capable of creating new rules, new music, in concert with humans.

Furthermore a certain view of intelligence is presupposed; one that promotes mind over body. For example, physicist Frank Tipler believes he can download his mind into a computer, favouring abstract qualities of mind over physical embodiment, the 'stuff' of mind and consciousness[18]. In a similar fashion, believers in 'strong' A-Life envisage that computers are capable of being alive[19]. But because we model abstractions of reality does that make them that reality? Can a computer be 'alive' because it has been programmed to display life like behaviour? If we define phenomena to fit methods of analysis should we be surprised if our observations fit our conjectures?

There are limits to digital computing. Not every computation is best dealt with by Turing machines, the mathematical basis of such computers. A recent article discusses the "... many problems that a Turing machine simply cannot cope with at all." "[B]y modifying the physical basis of computing devices, novel machines become possible."[20] Computer art is not necessarily digital art. Should we let present technologies constrain artistic possibilities inherent in technology?

Computers and communication imply information. But it is questionable whether information exists independently 'out there'[21]. Information arises out of human perception of salient features of their environment and is communicated between individuals situated in that environment. Information exists in meaningful relation to context. The computer is not situated in and responsive to its environment the way organisms are. Outside of human context what are computers using information for?

Perhaps this is more a question of what we are wishing on computers. Hans Moravec has referred to[22] 'computers as becoming our descendants'. Here are two quotes from 'Digital Mantra'[23]:

"Computers will prodigiously compose, paint, write and sculpt all day every day...forever. Oblivious to the debates surrounding origination, authorship, intentionality, and meaning, computers will pursue their creative objectives."

"Computers, writing music understood only by other computers, may even develop a disdain for human listeners and their inability to hear or understand their rich languages of expression"

What creative objective are computers expressing? William Latham has said "If you've got a computer program which ... is producing things that are more interesting than a human can produce, then what's so great about human creativity?"[24] But 'passive' instruments - the piano, synthesizer, guitar - also produce interesting results. But they are not just 'interesting'. As opposed to reflective composing there is physical involvement and effect in the process of improvising. Is it reasonable to want and expect disembodied computers to act as autonomous musical surrogates?

Computers as Instruments

It is natural to want to use machines creatively reflecting a world dominated by them, to fashion instruments out of them, as earlier instruments were fashioned out of wood, metal, analogue electronics. I am thinking of the computer's ability to enhance the human functions of music. Can the computer act as an 'amplifier' of expression, a linker of energies? Two questions come to mind here. What qualities of music are we seeking to abstract and what will be our relationship to those abstractions?

The first question promotes issues regarding representation. Representation implies abstraction - the ability to express music in some language that is not music, in this case computer code. This is complicated when we consider that with digital sampling and signal processing, music increasingly becomes continuous sound manipulation, and less about the operation of harmonic rules upon discrete note values.

The second question relates to how we can categorise our relationship to machines in terms of their relation to the world we are perceiving. The application of gestural interfaces is an example of enhancing what Don Ihde[25] refers to as an *embodied* relationship 'through' machines. Here the intention is to become unaware of operating through a machine, like driving a car.

Attempts at visualising music on the other hand enhance what Ihde refers to as a *hermeneutic* relationship with machines. Here the machine tells us about the world, it becomes the 'other'. We have experience of the machine, and are involved with it.

We play music through instruments, the instruments also presenting visual and physical cues for the learner. Consider the guitar fretboard, for example.

A Future Direction

A-life's approach and methodology indicate useful future musical directions. A-life has been said to reflect the "...subjective and value laden assumptions of the researchers... disguised as axioms."[26] As a tool for art it is interesting precisely because it may do this. If science is social process, then, regardless of its objectivity, what tools can it give us? Its techniques, such as neural networks and cellular automata, stress emergent, bottom-up behaviour in contrast to AI's symbolic top-down approach. Furthermore some A-life practitioners take account of the situated, embodied nature of life; the interaction between the environment and the physical organism in perception, development and evolution. Its language reflects these concerns, for example, 'interactive emergence'[27], 'embodied action'[28], 'situated robotics'.

When thinking about the machine helping you discover your own musical expression I came across Mark Trayle's creation of a 'self-attenuating feedback loop- a closed system', a musical 'machine' using a network of analogue equipment.[29] Simple processes together produced, not easily predictable, complex results. By adding human control into this process (via various interfaces), "[r]ather than being scored, the detailed characteristics of musical events arose in real time from the interaction between network and performer." Such "...interplay within the network, and between the network, and between the network and the performer, began to take on the character of a small ecosystem. Interactive, flexible and nonhierarchical, it inspired the notion that networks can provide a rich metaphor for nature". Applying this to computer resulted in "[s]omething in between a musical instrument, a computer game and a written score, the network displayed a responsiveness and vitality missing from sequenced or taped computer music."

Notes

---

[1] Ken Musgrave, one of several panellists discussing the role of algorithms in art at SIGGRAPH'95 ('Algorithms and the Artist').

[2] Nyman, M. 1974. *Experimental Music: Cage and Beyond.* New York: Schirmer Books.

[3] Peter Beyls, See [2].

[4] Penny, S. 1995. 'The Pursuit of the Living Machine', *Scientific American*, Vol 273(3). Sept. p.172.

[5] See [5]

[6] Todd, S. and Latham, W. 1992. *Evolutionary Art and Computers.* San Diego, CA: Academic Press.

[7] An example is SSEYO's Koan Pro. http://www.SSEYO.com

[8] *Wired*, May 1995.

[9] http://www.nemeton.com/axis-mutatis/latham.html.

[10] *Wired* [9]

[11] These comments from personal communication with Ezequiel Di Paolo, COGS, Sussex University.

[12] Cited from Henry See's review of 'Digital Mantra' at http://macsee.citi.doc.ca/Papers/DMrevu.html

[13] For example Bijker, W. E. AND Law J. 1992. *Shaping Technology/Building Society.* Cambridge, MA: MIT Press.

[14] Gerzso, A. 1992. 'Paradigms and Computer Music', *Leonardo Music Journal*, Vol 2(1). pp 73-79.

[15] Simon Penny 1996 at Ars Electronica 1996.

[16] A "..musical instrument is no more than a device for amplifying vibration." Robertson, P. 1996. 'Music as Model of the Psyche', *Contemporary Music Review*, 4(1-2). pp. 11-37.

[17] *Requiem for the Soul*, New Scientist, 9 August, 1997.

[18] See Gardner, M. 1996. 'Computers Near the Threshold?', *Journal of Consciousness Studies*, 3(1) pp. 89-94. Re-introducing the body we see mind and computer as made of different stuff.

[19] Although the importance of the relationship of physical matter to life is recognised by others. See, for example, Moreno, A., Etxeberria, A., and Umerez, J. 1994. 'Universality Without Matter'. In Brooks, R. and Maes, P. eds. *Artificial Life IV*, Cambridge, MA: The MIT Press.

[20] *Computing the Uncomputable,* New Scientist, 17th May, 1997

[21] See, for example, Brier, S. 1992. 'Information and Consciousness: A Critique of the Mechanistic Concept of Information', http://www.db.dk/dbaa/sbr/vol1/v1-23sbr.htm

[22] Cited in [19]

[23] Cited in [13]

[24] See [10].

[25] Ihde, D. 1979. *Technics and Praxis (Boston Studies in the Philosophy of Science, Vol. 24)*. Dordrecht: Reidel.

[26] Penny, S. 1996. *The Darwin Machine: Artificial Life and Interactive Art.* http://www-art.cfa.cmu.edu/www-penny/texts/Darwin_Machine_.html

[27] Hendriks-Jansen, H. 1996. *Catching Ourselves in the Act: Situated Activity, Interactive Emergence, Evolution, and Human Thought*, Cambridge, MA: MIT Press.

[28] Varela, F., Thompson, E., and Rosch, E. 1991. *The Embodied Mind*, Cambridge, MA: MIT Press.

[29] Trayle, M. 1991. 'Nature, Networks, Chamber Music', *Leonardo Music Journal*, Vol 1(1). pp 51-53

Artificial Life, Embodiment and Computer Music

Authors: Jon Bedworth

Published: 1998

Publication: *Proceedings of the XII Colloquium on Musical Informatics*
Udine: AIMI

Abstract

In relation to musical activity, the computer can be seen to impact in three inter-related ways, these being: augmenting human creativity; understanding compositional processes; and creating artificial musicians. If a computer is to be creative it has to be able to not merely generate but also be able evaluate its productions. Composing with timbre highlights the importance of the phenomenal experience of sound in such an evaluation and ethnomusicological evidence points to alternative embodied and decentralised music making. The implications of these are discussed in relation to aspects of Artificial Life and 'embodied cognition', particularly in regard to the pursuit of artificial musicianship.

Introduction

Computers have opened up new sound worlds, and ways of working, both in composition and music understanding. We are able to model aspects of reality, and then conduct experiments that would not otherwise be possible. Thus the computer alters our perception of, and potential for action in, the world. As technology, the computer is both a result of social concerns and values, and a causal agent in our perceptions. We see and manipulate the world through technology[1]. A computer music system embodies an abstraction of a particular musical approach [2] and yet also transforms 'what can be considered music', the computer acting as "...a dynamic device that transforms the imagination" resulting in a 'circular, cybernetic relationship' [3]. Given that musical developments "...have paralleled important changes in social, cultural and intellectual life" [4], this paper considers some perspectives within the fields of Artificial Life (A-Life) and 'embodied cognition', which have musical implications. Such models and metaphors inspired by biology "... will have their greatest influence when they spread outside of the scientific community and into the general culture." [5]

For the purposes of discussion here, it seems important to first delineate three inter-related aspects of how the computer could be considered to be transforming musical practice. These are: (a) augmenting human creativity in assisting the exploration of new musical approaches; (b) understanding compositional processes and (c); creating 'artificial musicianship', involving emulating, equalling or even replacing human musical creativity.

(a.) *Augmenting human creative activity.* The computer may be perceived as an instrument [6], medium or tool, in relation to which it is important to consider the mapping of human input (gestural, haptic and so forth) to musical output [7]. Also it may act as a suggester of ideas and device for 'organising complexity'[8] within certain compositional approaches.[9]

(b.) *Understanding compositional processes.* Computer music pioneers Lejaren Hiller and Leonard Isaacson " ... desired to simulate the composing process itself with computers, rather than use computers as an aid to composition."[10] Subsequently computers have been applied to 'cognitive musicology'[11], which "...derives from reflections upon the structure of real-time processes made possible by, and monitored by, computers." Here "thinking is situated in some social and technological context ... A form of action, rather than a disembodied reflection."[12]

(c.) *Emulating, equalling or replacing human creativity.* One motivation is to give computers 'greater musicianship', "... making the program more aware of musical implications in the performances of its partners, and ... better able to perform itself more musically."[13] Here many problems are still not clearly articulated at the conceptual level, let alone the level of implementation.[14] Opinions about the computer's potential in this regard range from those who see such attempts to mimic human musicians as stage performers as 'misplaced'[15] to implications that computers could make music 'understood only by other computers'.[16] The latter echoes beliefs that computers could become sentient beings.[17]

In attempting to automate music making, it is useful to be aware of the social conditions that lead to such a desire. Music's social technology can pave the way for music's machine technology, where "...machine technology involves the processing of tools and machines, and social technology involves the skills and means of organizing people to get work done."[18] The 19th century sees a growing desire for automating music, and the "...abstraction of the performer from the performance takes place when a social technology allowing such abstraction prepares the way for machine technology.... Current aesthetic arguments which view technology in utopian terms reflect values by which man has abstracted from his productions"[19]

Musical Systems and Processes

In considering the 'abstraction of the performer from the performance', it is useful to discuss the relationship of musical systems to musical process and function. What is the relative importance given to music as the construction of objects and products on the one hand, and the type and quality of human engagement with the musical process, on the other? The rise of the classical composer 'genius'[20] and the development of more formalised music notation furthered the sense of an independently existing 'eternal' art object, that can be abstracted, recorded and analyzed. Computers, like previous technologies such as the phonograph[21], have further helped to freeze music in time.

Abstracting away musical forms from their origins in specific musical activities makes detached analysis of music's structure possible, aiding our understanding of musical forms. However, traditional musicology's primary focus has been on such musical texts to the virtual exclusion of performance[22]. Western tonal music, codified into written notation, can give the impression that we are dealing with a closed, entirely encodable system of finite harmonic relationships, transformable by clearly definable rules. Trevor Wishart believes the 'fundamental thesis' of the analytic system of notation is:

> "...that music is ultimately reducible to a small, finite number of elementary constituents with a finite number of 'parameters', out of which all sounds possibly required in musical praxis can be notated by the combination of these constituents."[23]

It can appear as if the music itself resides in the notation.

Such a view finds resonance with traditional Artificial Intelligence's view of cognition (excluding connectionist approaches) as the representation of explicit symbols and intelligent behaviour as the manipulation of those symbols; the so-called Physical Symbol System Hypothesis[24]. Symbols could be represented in the computer as data structures and intelligent behaviour by algorithms, which act on the data structures. Crucially, it assumes that such intelligence resides wholly within the mind, and therefore could equally reside in the computer. However, certain musical approaches question such a view. Here I refer to timbre composition and evidence from ethnomusicology.

Timbre Composition

Composing with timbre[25] has consequences for the nature of the distinction between the sound materials (data structures) and the rules for sound manipulation (the algorithm); i.e. between musical design and materials, between 'composing-the-sound' and 'composing-with-sounds'.[26] This challenges the distinction between computer as instrument (able to encode, process and transform sound) and as having the "... potential for designing the compositional process".[27] For example, Di Scipio and Prignano's Functional Iteration Synthesis "...provides an *indeterministic* model of sonic material: the composer must learn his/her strategy by interacting with a source of structured information, at the level of the microstructure of music - within and through the sound."[28] Such an approach implies, along with the application of intelligence, a response to the phenomenal, experienced aspects of sound.

That computer software can produce surprising results leads to speculation that the computer itself could be creative in this situation. However, it is important to distinguish the difference between the **generation** and **evaluation** of creative ideas. It is not enough to produce something novel and interesting. Matthew Elton says:

> "If we are aiming at for artificial creativity, then our main worry concerns not what the machine can produce, but the way in which it evaluates its productions"[29]

In evaluating its productions, is the computer capable of experiencing sound in the same phenomenological way as humans?

Will A-Life produce artificial entities capable of not just generating, but evaluating such musical productions? Christopher Langton, one of Alife's originators, has defined Artificial Life as:

> "... a field of study devoted to understanding life by attempting to abstract the fundamental dynamical principles underlying biological phenomena, and recreating these dynamics in other physical media - such as computers - making them accessible to new kinds of experimental manipulation and testing."[30]

And a variety of techniques and technologies used within A-Life research have been used as generators of musical ideas and compositions, arguably opening music up to 'new kinds of experimental manipulation and testing' using computers. These include fractal mathematics, cellular automata, genetic algorithms and dynamical systems, which seemingly provide fertile ground for musical explorations. In generating musical form, A-Life systems, in contrast to connectionist approaches, could attempt to 'develop their own principles of organization' and '... model multi-level order'[31]

Is such order emergent or is it imposed? Margaret Boden sees that

> "[t]he central concept of A-Life ... is self-organization [which] ... involves the emergence (and maintenance) of order, or complexity, out of an origin that is ordered to a lesser degree ... This development is 'spontaneous', or 'autonomous', following from the intrinsic character of the system itself (often, in interaction with the environment) instead of being imposed on the system by some external designer. In that sense, A-Life is opposed to classical AI, in which programmers impose order on general-purpose machines"[32]

Equipped with more realistic biological models, 'recreating these dynamics in other physical media' in the form of computer software, it would appear that we may be a step closer to an 'artificial musician' able to generate and evaluate its own productions. However, what is the status of such biologically inspired models? As Stevan Harnad argues that

> "Computational modeling ... can conquer the formal principles of life, perhaps predict and explain it completely, but it can no more be alive than a virtual forest fire can be hot. In itself, a computational model is just an ungrounded symbol system; no matter how closely it matches the properties of what is being modeled, it matches them only formally, with the mediation of an interpretation."[33]

Similarly, an 'epistemological danger' exists in "... the belief that a high-quality simulation can become a realization – that we can perfect our computer simulations of life to the point that they come alive."[34] The same could be said for the modelling of emotions and creativity. What would make the computer feel like it wanted to participate in the musical situation, to *be* musically aware rather than just be a model of musical awareness?

Ethnomusicology

What type of musical situation do I have in mind? Ethnomusicology reveals other models of musical participation, examples being the Venda[35] and Kaluli[36]. Understanding such musical practice may in turn have implications for our own, at least in reminding us what we may have lost. Such studies point to decentralised, distributed musical activity. Michael Chanan writes that "in surviving oral cultures... [t]here are no composers in such societies set apart from other musicians in a separate caste, and music is far from an exclusive activity of specialised performers... tribal community encourages and sustains a degree of musical ability in virtually all its members through the widespread use of informal music. Moreover music enters into the widest range of activities."[37] In such societies "The logics of a society's relationships are not mediated through the being of any one individual ... The musical mediation of the relations between the individual and society and these instances emphasise the importance of individual autonomy and creativity to the social process."[38]

And such participants have a knowledge of what has been termed by Roland Barthes as *musica practica*, who described it as "...a muscular music in which the part taken by the sense of hearing is only one of ratification, as though the body were hearing."[39] For Chanan

"... *musica practica* is nothing but the form that musical knowledge takes directly from musical practice. Theoretically filtered or not, fundamentally it has no need of theory or even notation. It is the musical equivalent of the way the baby learns to talk."[40] If music is viewed as physically situated, collective human activity, is it then just a case of encoding the particular music system's observed rules into a machine? Where does the musical knowledge reside?

Distributed. Embodied Cognition

An interesting perspective on this question emerges when we reconsider cognition as embodied and decentralised; when we view cognition as distributed between brain, body, and world.[41] Within such a viewpoint perspective structure does not lie in any one place, and is not entirely represented in any one thing (or mind), but emerges through complex interactions. Furthermore, in contrast to Cartesian mind-body distinctions which gave rise to an idea where "...the mind controls the body as a captain pilots a ship"[42] the phenomenologist Merleau-Ponty considered that it "...is not brains that think, it is bodies. The brain is one part of a larger system, the nervous system and ultimately the entire body."[43]

Such a view is finding technical application in the design of robots. The emerging field of Embodied Artificial Intelligence highlights the necessity "... to study intelligence as a bodily phenomenon",[44] in constructing autonomous robots. Furthermore, such robots "...react directly (bottom-up) to environmental cues rather than (top-down) to internal world-models or representations."[45] Here cognition "...is no longer viewed separately from its bodily substrate ... cognition is also the study of bodily action and perception in the system's environment and cannot be viewed separately from either of the three (body, action, environment)."[46]

In seeing cognition as embodied, we can consider artistic activity less as the conscious, top-down, application of symbolic rules, and more as embodied, situated human experience, form arising out of physical interaction with the environment. Analysis should consider how structure emerges through process, increased understandings of which will impact on our relationships to computer technology, and its interface.[47]

Decentralized Models

How might we consider the use of A-Life in relation to embodied musical experience? Otto Laske believes that in contrast to the narrow view of technology "...as tools for producing artifacts", it is "...ultimately a tool for self-knowledge deriving from forms of situated, technologically embedded cognition."[48] In his article *Learning about Life* Mitchel Resnick talks about how the "...growing interest in Artificial Life is part of a broader intellectual movement toward decentralized models and metaphors." He suggests that the methodology of Artificial Life can help people move away from a centralised mindset and "...develop intuitions about decentralized phenomena"[49] and he suggests providing "...opportunities to create, experiment, and play with decentralized systems."

Conclusion

The arguments above point to new techniques to augment musical creativity, and new considerations in attempting to understand the compositional process. However, attempts at developing computer based autonomous 'musicians' may be inappropriate given such considerations, reflecting both a questionable interpretation of the computer's capabilities, and its relationship to social action. In relation to the various aspects of musical process, it becomes important to question the appropriateness and feasibility of computer programming; to make judgements regarding those aspects that can be abstracted such that the computer performs an integrative, rather than distancing, role in the creative process. Most importantly, in defining our creative relation to the computer we should not limit ourselves "... to the categories and procedures represented in the computer, without realising what has been lost."[50] It is perhaps more useful to see the computer more as augmentation to compositional and improvisatory activity, "...as *habitats* rather than mere *tools*",[51] and as a medium for communication, than as a potentially autonomous 'musician', attempts at which may serve to further abstract ourselves from embodied social functions of music.

Reference

[1] For example, D. Ihde, *Technics and Praxis*, Reidel, 1979 and D. Rothenberg, *Hand's End: Technology and the Limits of Nature*, University of California Press, 1994.
[2] A. Gerzso, "Paradigms and Computer Music", *Leonardo Music Journal*, Vol. 2(1), pp73-79, 1992.
[3] D. Rothenberg, "Sudden Music: Improvising Across the Electronic Abyss", Vol. 13(2), pp23-46, 1996. p28
[4] J. Shepherd, "Music as Cultural Text", in J. Paynter, T. Howell, R. Orton, P. Seymour (eds.) *Companion To Contemporary Musical Thought, Vol. 1*, Routledge, 1992. p128
[5] M. Resnick, "Learning About Life", in C. G. Langton, (ed.), *Artificial Life: An Overview*, MIT Press, 1995, p230).
[6] J. Pressing, "Cybernetic Issues in Interactive Performance Systems", *Computer Music Journal*, Vol. 14(1), pp12-25, 1990.
[7] S. Emmerson, "'Live' versus 'Real-Time'", *Contemporary Music Review*, Vol. 10(2), pp95-101, 1994.
[8] B. Truax, "Computer Music Language Design and Composing Process", in S. Emmerson (ed.), *The Language of Electroacoustic Music*, MacMillan Press, 1986, p157
[9] D. G. Loy, "Composing with Computers – a Survey of Some Compositional Formalisms and Music Programming Languages", in M. Mathews & J. R. Pierce (eds.), *Current Directions in Computer Music Research*, MIT Press, 1989, p308. See also Iannis Xenakis, *Formalized Music: Thought and Mathematics in Composition*, Indiana University Press, 1971.
[10] *ibid*, Loy [9], p309. Also Lerajan Hiller & Leonard Isaacson, *Experimental Music*, McGraw-Hill, 1959.
[11] O. Laske, "A Search for a Theory of Musicality", *Languages of Design*, Vol. 1, pp209-228, 1993.
[12] O. Laske, "Knowledge Technology and the Arts: A Personal View", *Computers and Mathematics with Applications*, Vol. 32(1), pp85-88, 1996, p85.
[13] R. Rowe, "Incrementally Improving Interactive Music Systems", *Contemporary Music Review*, Vol. 13(2), pp47-62, 1996, p47.
[14] *ibid*, Rowe [13]
[15] *ibid*, Emmerson [7], p100
[16]] S. R. Holtzman, *Digital Mantras: The Languages of Abstract and Virtual Worlds*, MIT Press, 1994.
[17] H. Moravec, *Mind Children*, Harvard University Press, 1988.
[18] J. Frederickson, "Technology and Music Performance in the Age of Mechanical Reproduction", *International Review of the Aesthetics and Sociology of Music*, Vol. 20(2), pp193-220, 1989, p 194. This distinction derives from R. Peterson, *The Industrial Order and Social Policy*, Prentice Hall, 1973.
[19] *ibid,* Frederickson [18], p215.
[20] E. T. Harris, "Handel's Ghost: The Composer's Posthumous Reputation in the Eighteenth Century", in J. Paynter, T. Howell, R. Orton and P. Seymour (eds.), *Companion To Contemporary Musical Thought, Vol. 1.* Routledge, 1992.
[21] M. Chanan, *Repeated Takes: A Short History of Recording and its Effects on Music*, Verso, 1995.
[22] For example, S. G. Cusick, "Feminist Theory, Music Theory and the Mind/Body Problem", *Perspectives of New Music*, Vol. 32(1), pp8-27, 1994.
[23] T. Wishart, *On Sonic Art*, Imagineering Press, 1985.
[24] For example, A. Newell, "Physical Symbol Systems", *Cognitive Science*, Vol. 4, pp135-83, 1980.

[25] For example, Wishart [23] and A. Di Scipio, "Micro-Time Sonic Design and Timbre Formation, *Contemporary Music Review*, Vol. 10(2), pp135-148, 1994.
[26] A. Di Scipio, "Inseparable Models of Materials and of Musical Design in Electroacoustic and Computer Music", *Journal of New Music Research*, Vol. 24(1), 34-50, 1995.
[27] *ibid*, Truax [8], p156. See also B. Truax, *Acoustic Communication*, Ablex Publishing, 1984.
[28] A. Di Scipio & I. Prignano, "Synthesis by Functional Iterations: A Revitalization of NonStandard Synthesis", *Journal of New Music Research*, Vol. 25, pp31-46, 1996, p42.
[29] M. Elton, "Towards Artificial Creativity", *Languages of Design*, Vol. 2, pp207-222, 1994, p217.
[30] C. G. Langton, "Preface", in C. G. Langton, C. Taylor, J. Farmer, J. Rasmussen, S. (eds.) , *Artificial Life II*, Addison-Wesley. 1992, p xiv.
[31] M. A. Boden, "Introduction", in M. A. Boden (ed.), *The Philosophy of Artificial Life*, 1996], Oxford University Press, 1996, p4.
[32] *ibid,* Boden [31], p3
[33] S. Harnad, "Levels of Functional Equivalence in Reverse Bioengineering", in C. G. Langton, *Artificial Life: An Overview*, MIT Press, 1995, p293.
[34] H. H. Pattee, "Simulations, Realizations, Theories of Life", in M. A. Boden (ed.) *The Philosophy of Artificial Life*, Oxford University Press, 1996, p384.
[35] J. Blacking, *How Musical is Man?*, University of Washington Press, 1973.
[36] S. Feld, "Aesthetics as Iconicity of Style, or 'life-up-over-sounding: getting into the Kaluli groove", *Yearbook for Traditional Music*, Vol. 20, pp74-113.
[37] M. Chanan, *Musica Practica: The Social Practice of Western Music From Gregorian Chant to Postmodernism*, Verso, 1994, p24.
[38] *ibid*, Shepherd [4]
[39] cited in Chanan [37], pp27-28.
[40] *ibid*, Chanan [37], p28
[41] See, for example, F. Varela, E. Thompson, E. Rosch, *The Embodied Mind*, MIT Press, 1991. Also A. Clark, *Being There: Putting Brain, Body and World Together Again*, MIT Press, 1997.
[42] L. A. Loren & E. Dietrich, "Merleau-Ponty, Embodied Cognition, and the Problem of Intentionality", *Cybernetics and Systems,* Vol. 28(5), pp345-358, 1997.
[43] *ibid*, Loren & Dietrich [42]
[44] E. Prem, "Introduction to the Special Issues/Epistemological Aspects of Embodied Artificial Intelligence", *Cybernetics and* Systems, pp v- xi, 1997.
[45] *ibid*, Boden [31], p4.
[46] *ibid*, Prem [44], p vii.
[47] I. Hybs, "Beyond the Interface: A Phenomenological View of Computer Systems Design", *Leonardo*, Vol. 29(3), pp215-223, 1996.
[48] *Ibid*, Laske [12], p86.
[49] *ibid*, Resnick [5], p231.
[50] J. Lanier, "Agents of Alienation", *Journal of Consciousness Studies*, Vol. 2(1), 76-81, 1995.
[51] *Ibid*, Laske [12], p85.

The Turing Test is Dead

Authors: Jon Bedworth and James Norwood

Published: 1999

Publication: Proceedings of Creativity and Cognition

Abstract

Instead of continuing to judge the computer's capabilities directly against those of the human mind, the potentials of the computer as an 'alternative intelligence' (Negrotti) can be explored. Re-conceiving the nature of our interaction with the computer leads to a less impoverished appreciation of the human-computer as a creative assemblage.

Keywords
Interactivity, Creativity, AI, Alternative Intelligence

> "The taste of the apple ... lies in the contact of the fruit with the palate, not in the fruit itself; in a similar way ... poetry lies in the meeting of poem and reader, not in the lines of symbols printed on the pages of a book. What is essential is the aesthetic act, the thrill, the almost physical emotion that comes with each reading."[1]

INTRODUCTION

This paper is written in response to the authors' perception of the misconceptions and assumptions of many artists creating work involving Artificial Intelligence (AI). Broadly, this paper argues that it is inappropriate to attempt to locate creative potential exclusively within technology. Specifically, we argue that to pursue such a goal has a limiting effect on the perception of possible human involvement with this technology.

Until recently, AI's development largely carried with it an implicit definition of the nature of human intelligence, resulting in claims for truly autonomous computer intelligence. The Turing Test provides popular focus for this understanding, Turing having suggested an 'imitation game'. A human and a computer are interrogated, via text-based questioning, the computer considered as intelligent if the interrogator is unable to distinguish them apart [2]

How relevant is this to art? Technologies may mirror humanity, largely attempting to "... capture the principles governing one or another of our biological abilities and to embed them in different medium."[23] However, in utilising them, we engage with a complex of implicit assumptions about the artifact's nature and purpose. In adopting technology, artists are not immune to its implicit, and possibly inappropriate, categorisations and metaphors. When these enter the heart of artistic practice, wholesale, unreflective adoption can result in little more than advertisements for certain scientific viewpoints.

... LONG LIVE THE TURING TEST

The following examples show continued adherence to Turing Test-like evaluations of machine capability.

Creative Machines[4]

> "I think that to say that machines can't be creative is utter rubbish. I think that one way in which artists and scientists can work together is that artists could help to teach machines what, maybe, we appreciate in terms of art, possibly pictorial art, music and so on."[5]

This robotics researcher reflects a section of the scientific community that clearly believes that machines can be creative in their own right. Whilst this may be a worthy goal, the perceived success of this seems to depend on a particular definition of creativity, one that can be located within the machine. It is assumed that machines can potentially experience a world where human art becomes relevant to them, where they can come to 'appreciate' it.

However, what is it that makes humans want to produce and appreciate art and when is it judged to be a creative act?[6]

The Intelligent Pianola[7]

"Watch Out: This machine could steal your soul."[8]

David Cope's music generation program, Experiments in Musical Intelligence (EMI), generates music in the style of composers such as Mozart and Bach. EMI's notion of music consists of the manipulation of a fixed lexicon of musical symbols, by formalised grammatical rules. Such a view of representation finds accord with Newell and Simon's *Physical Symbol System Hypothesis*[9], itself criticised. However, it is still asked, "If creating sublime music is the highest of human achievements, how come a pile of computer code writes better music than most people?" This prospect alarms Douglas Hofstadter: "Does that mean…that the composer's soul is irrelevant to the music?"[10]

The worry expressed here is that the computer will write music so well that the value of human music is reduced. However, what is it that the computer is better at and does it matter to the human pursuit of music?

ALTERNATIVE INTELLIGENCE

The recognition of a machine's limits in understanding is evident with others in the AI community. Importantly, it is argued that the computer has no sense of meaning:

> "To a machine, the symbols it shunts around are syntactic patterns; it is only when a user interacts with a machine that the patterns are given some final symbolic value that finds existence as a semantic experience in the user."[11]

However, this should not negate the computer's value, and in this regard it may be fruitful for artists to consider Massimo Negrotti's proposal that the computer represents an *alternative intelligence*. Instead of perceiving AI as recreating humans, we should develop "intelligent devices whose complexity could be synergetically integrated with humans."[12]

Such devices would be comparable with the human mind but different from it in terms of both nature and power", the computer's novelty arising from "the wide range of possibilities which come from the great complexity of the interactions among [its] structures and processes."[13]

Human creativity arises out of the process of interacting with such devices. For Ernest Edmonds, this process "... can be more than simply capturing knowledge in a machine usable form. Creative insights, some of which may be represented in the system, may arise as a result of the interaction." For Edmonds, such a view "... vividly realizes the extension of the computing machine into the process of generating human knowledge."[14] We consider the computer as capable of expanding and modulating perspectives, providing a kind of prism. Rather than trying to represent the world 'in' the machine, what becomes the challenge is the type, extent and result of the interaction between the computer and its users(s).

COMPUTERS AS INSTRUMENTS

> "Although certain fine instruments are obviously extremely fine bio-feedback systems, and seem to liberate a performer's best potential, it remains true that all the energies that come out as sound are directly the result of the performer's own energies"[15]

Musical instruments are an embodiment of musical knowledge. However, a musical instrument also serves to amplify its player's expressions. The feedback from this can musically inform the player, 'filling-in' and suggesting further courses of action. There is some sense of dialogue between musician and instrument, just as 'poetry lies in the meeting of poem and reader'. The challenge lies in how to 'synergetically' integrate the computer's symbolic calculations with human expression. Here, nature provides the best model of true interactivity. Computer musician George Lewis provides an enlightened artistic understanding of the richness of such interaction:

> "A real 'interactive' entity, a mammal for instance, exhibits complex behaviour that cannot be simply tied to a set of controlling 'triggers'. Moreover, the structures present at the animal's inputs (senses) are processed in quite a complex, multi-dimensional

fashion. Often the animal's output (behaviour) is not immediately traceable to any particular input event. The number of triggers needed to fully control every sonic movement of an 'interactive' composition of the complexity of a housefly would already be quite high; perhaps hundreds of triggers would be needed, far too many to be manipulated at once by anyone."[16]

CONCLUSION

Beyond initial novelty, true interactivity will not be achieved alone through the development of more elaborate triggering devices and interfaces. The computer's role as 'interactive partner' has to be re-evaluated from a fresh perspective, one not so tied to being a mirror of ourselves. A challenge becomes that of what to represent in the computer. Is it necessary to embody a human understanding of art appreciation in a computer when it has not been necessary to imbue the paintbrush with such knowledge? In seeing the human-computer as a creative system in itself, answering this challenge will probably only develop through engagement with the computer over time, as practice impacts on received ideology.

Notes

---

[1] Borgés, J. L. Foreword to *Obra Poética*. From Borgés, *Selected Poems 1923-1967*, Penguin, London, 1985.
[2] Negrotti, M. Introduction: Artificial Intelligence: Its Future and its Cultural Roots. In Negrotti, M. *Understanding the Artificial*. Springer-Verlag, London, 1991a. See p. 57
[3] Turing, A. M. Computing Machinery and Intelligence, *Mind*, LIX, 236, 1950.
Negrotti, M. Alternative Intelligence. In Negrotti, M. *Understanding the Artificial*. Springer-Verlag, London, 1991, See p. 57
[4] A type of piano, which could mechanically play prewritten music usually encoded on punched rolls.
[5] Warwick, K. From transcript of 'Eye of the Storm: Artists in the Maelstrom of Science' (London, Feb 19-20, 1997). Panel on 'Artificial Consciousness'
http://www.artscat.demon.co.uk/cons3.htm
[6] Clancey discusses Harold Cohen's drawing program Aaron, attempting "... to tease apart the different relations Aaron and Cohen have to the resultant drawings and the community of artists." (Clancey, W. J. *Situated Cognition: On Human Knowledge and Computer Representation*, Cambridge University Press, Cambridge, 1997, Ch. 1. See p. 20.)
[7] A type of piano, which could mechanically play prewritten music usually encoded on punched rolls.
[8] The front cover of New Scientist (No. 2094, August 1997).

[9] "The Physical Symbol System Hypothesis. *A physical symbol system has the necessary and sufficient means for general intelligent action* ... By 'necessary', we mean that any system that exhibits general intelligence will prove upon analysis to be a physical symbol system. By 'sufficient' we mean that any physical symbol system of sufficient size can be organised to exhibit general intelligence." (Newell, A. and Simon, H. Computer Science as Empirical Enquiry: Symbols and Search. In Haugeland, J. C. *Mind Design: Philosophy, Psychology and Artificial Intelligence*, MIT Press, Cambridge, MA, 1981. See p. 41)
[10] Holmes, B. Requiem for the Soul. *New Scientist*, 2094, (August 1997), 23-27. See p. 23.
[11] Gregory, D. Distinguishing Gordon Pask's Cybernetics. *Systems Research*, *10*, 3, 59-71. 1993. See p. 63.
[12] Negrotti, M. Introduction: Artificial Intelligence: Its Future and its Cultural Roots. In Negrotti, M. *Understanding the Artificial*. Springer-Verlag, London, 1991b. p. 6.
[13] Negrotti, 1991a. (see note 2) p. 56.
[14] Edmonds, E. culture, knowledge and creativity – beyond computable numbers. *Languages of Design*, *1*, 253-261. 1993. See p. 260.
[15] Robertson, P. Music as a Model of the Human Psyche. *Contemporary Music Review. 14*, 1-2, 11-37. 1996. See pp. 33-34.
[16] Pope, S. T. Putting Max in Perspective. *Computer Music Journal*, *17*, 2, 1993.

'Give us the Funk...': Machine Autonomy Meets Rhythmic Sensibility

Authors: Jon Bedworth and Ben Simmonds

Published: 2000

Publication: Proceedings of Consciousness Reframed 3. Newport: UWCN

Abstract

We discuss a future role for artificially intelligent devices within music, a perception arising from a shared music practice increasingly concerned with rhythm. Adopting these technologies does not mean promoting autonomous artificial musicianship, which may further remove the musician from the process of creating music. Instead, interacting with these technologies can enhance our sense of musical participation. Far from challenging the role and agency of the artist, such machines can provide new opportunities for human-machine symbiosis. In conclusion, the applicability of some recent advances in neural modelling and situated robotics for the construction of rhythm technology is discussed.

Keywords
Rhythm, artificial life, music technology, oscillatory networks, situated robotics human-machine symbiosis

Introduction

We have been exploring a type of computer music for several years. What has unfolded is a process, only recognisable in hindsight, where unfocused musical curiosity has became an increasingly self-conscious experimental exploration. Through this we have felt a growing sense of potential for music technology, specifically related to what computing machines are now capable of contributing to our creation and manipulation of rhythm.

In this article we discuss the issues that have arisen from our explorations, and what these may indicate for applying some emerging techniques from Artificial Life research to the arguably neglected aspect of rhythm. We will attempt to contextualise this in relation to some wider musical observations, and then conclude with speculations for future technological development in furthering our particular musical aims.

Reflection on Practice

Our intuitions about music technology arose originally from concerns arising out of our own musical collaborations. Technology has profoundly shaped our collaborations and we feel these insights may interest a broader audience interested in 'real-time' interactive art technology.

Our interest is in developing devices to perform certain roles within the broader studio environment, and not in seeking to simulate that environment within the machine by encoding it with our explicit musical knowledge, intentions and working practices.

Central to this desire is a seemingly paradoxical sense of both an extended creative *reach*, and yet musical *distance* that occurs when applying technology to certain musical processes. Our music would simply not be possible for us without the technology employed to create it, despite the fact that to engage with these machines is sometimes at the cost of disengaging from the creative musical flow. A flow that these same machines are helping to support.

Musical Machines

Our musical machines can be considered passive and musically 'simple' by certain standards. There are no algorithmic composition or artificial intelligence techniques employed. Instead we employ commonly available drum machines, sequencers and samplers.

We have found these devices to be extremely useful as malleable music representations, providing a high degree of access and visibility to the details of music structure. Simple musical technologies still provide many possibilities, depending on how you relate to them. These technologies contribute a musical skeleton, a 'scaffolding' for unfolding musical processes and knowledge.

However, limitations are apparent. While providing a largely transparent window onto the music, sequencers and drum machines essentially utilise a score-like representation system based on the idea of linear musical development. The placement of musical events is represented by a list of MIDI events and sample position markers, and a single basic MIDI clock controls their execution. We have found limitations in our ability to coherently manipulate the musical spacing of these events in real time.

We wish to de-emphasise technology as a route to automating creative processes and creating supposedly autonomous 'artificial musicians'. Instead we want to promote machines as enhancing our own experience of such processes. The 'problem' from a technological viewpoint concerns this desire to facilitate a closer, more adaptive relationship between the ongoing and changing intentions of the musician(s), and the behaviour of the machine.

Embodied Processes

This technology is only part of the story. To say we set out to explicitly 'explore' musical aspects is perhaps giving too much of a conceptual slant to the actual process that occurs. Much of our creative environment is largely un-conceptualised and seems to reside in tacit knowledge, felt intuition and physically embodied processes distributed between ourselves, technology and the wider environment of the music studio. Interpersonal relationships, partly played out through the technology, are equally important.

What results is the creation of music that could not have been achieved in individual, as well as technological, isolation. This music is seen as forming records of our various interactions in the studio, rather than autonomously reflecting the embodiment of an idea in sound. Any 'meaning' is to be found just as much in the process as in the finished musical artefacts.

We have concluded that some of the musical distance arises from an incompatibility between the musical process as a communicative shared act, and the technology used in pursuit of this.

The Living Art Form

This communication seems to involve practice that is highly improvised, requiring successive, and often spontaneous, musical adaptations. So far no consistent strategy has been applied in our musical explorations. More often than not the rhythms, as with other musical elements, are found due to a complex arising out of prior concepts, experimentation, and even errors and mistakes made during the creation process.

A sense of what we want emerges through a tightly *coupled* process of hearing, evaluating and acting on the musical behaviour of the machines. Importantly, what we are hearing in the music may be more than our musical machines are actually playing at the time.

Our desire is to achieve a sense of 'aliveness' in the movement of music over time, and for technology to perform an increased role in this emerging strategy. Many musical aspects are played, programmed, or directly digitally altered by the human musicians, often as the machines are playing. The problem with these techniques, used to combat the tendency for heavily quantized, static or repetitive music, is that they have resulted in increasingly time-intensive refinements and revisions of the music's micro-rhythmic structure.

We have come to liken this process to crafting some kind of material, which contains within it a set of unknown potentials. The materials are always throwing up possibilities along the way and may in turn guide further creative decisions, much in the same way as a fine woodcarver incorporates knots, bark and other features of base materials into the final design. This approach reflects a kind of 'digital craft' (McCullough, 1996).

Somewhere in this complex there exists the prior musical experience and knowledge of the musician, whose aspects are potentially machine encodable, and their repertoire of skills developed over time, many aspects of which may resist encoding into the machine.

Human-Machine Symbiosis

What kinds of musical 'knowledge' should we attempt to encode in the machine? Here, it is interesting to reflect on the idea of human-machine symbiosis in music practice. Such symbiosis generates new musical terrains and facilitates their exploration. The realisation of the music's aliveness comes out of this interaction and neither party (person or machine) is capable of quite the same without the other, like a conversation is not quite the same without at least one other person being present. Lee 'Scratch' Perry, in describing his relationship to the studio environment, gives a good sense of this:

> "The studio must be like a living thing. The machine must be live and intelligent. Then I put my mind into the machine by sending it through the controls and the knobs or into the jack panel. The jack panel is the brain itself, so you've got to patch up the brain and make the brain a living man, but the brain can take what you're sending into it and live." *(cited in Toop, 1995)*

Perry, while not claiming his studio was in any sense truly alive, feels the studio to possess a kind of autonomy whilst still being dependent on human input for its 'life'.

Symbiotic relationships exist between both of us and older, 'dumb' musical instruments, particularly the piano, itself a counterbalance to all this digital technology! The genesis of our musical creativity is seemingly not found in the mind of any one individual. Instead it emerges through multiple distributed interactions in the wider environment, a theme which finds resonance with new approaches in cognitive science (an excellent, accessible discussion of which is found in Clark, 1997). This has implications for the desirability of attempting to simulate our understanding of the musical environment within the machine.

Pursuing the autonomous musical machine may detract from furthering the emergence of novel human-machine relationships. Instead, the behaviour of devices can reflect a musical sensibility without their design necessarily encapsulating an explicit representation of it.

Rhythm is a Dancer

> "Rhythm is the most perceptible and least material thing" (Chernoff, 1979)

We both owe much to the influence of funk, hip-hop and elements of jazz on our collective sensibility. This might explain why one of the major musical aspects to have emerged is rhythm. More specifically this interest concerns a sense of creating fluid rhythmical transformations, exploring the shifting 'spaces' between musical events as they occur in time rather than pursuing ever more abstract time signatures. Within simple metrical frameworks, we subsequently seek to shift the dynamics of the rhythm over time, creating coherent shifting conjunctions of simple musical elements.

We situate this in contrast to a perceived view of future music as static, ambient, and full of strange digitally enhanced sound transformations. Kodwo Eshun makes this point about the neglect of rhythm.

> "Traditionally, the music of the future is always beatless. To be futuristic is to jettison rhythm. ... The music of the future is weightless, transcendent, neatly converging with online disembodiment ... [It is] nothing but updated examples of an 18th [century] sublime." (Eshun, 1998)

We speculate, along with Eshun, that an important place will be given to the exploration of certain kinds of rhythms, whose form has more in common with the embodied and socially embedded rhythms of Afro-American music than the conceptualised rhythms of the avant-garde and experimental music traditions. Here new forms of music have emerged in synthesis with other Western musical forms and technology. This is evident in the music of futuristic jazz pioneers Miles Davis and Herbie Hancock, the dub reggae of Lee 'Scratch' Perry and King Tubby, and the emergence of such 'virtualised' forms as hip-hop and drum 'n' bass. In utilising the computer, the process of exploring and shaping these new rhythms has been likened to a kind of experimental enquiry, the results of which may evolve novel musical forms:

> "To go into space today means to go further into rhythm. Far from abandoning rhythm, the Futurist producer is the scientist who goes deeper into the break, who crosses the threshold of the human drummer in order to investigate the

hyperdimensions of the dematerialised Breakbeat ... Moving into the possibility space of hyperrhythm, posthuman rhythm that's impossible to play, impossible to hear in a history of causation." (Ibid.)

Artificial Life

A desire for a sense of rhythmic 'aliveness' in our music prompted research into the possible uses of Artificial Life techniques. With all these emerging possibilities it is easy to lose sight of the most important aims of our practice. Why does an algorithmic approach necessarily become the right one just because the technology exists to enable it? It may be more a question of struggling to keep hold of the musical intention and exploring technology in relation to this, while at the same time recognising the shaping role that this technology has on the resulting intention – a truly cybernetic relationship.

The technology of Artificial Life has displayed behaviour appearing to be highly complex and less predefined, while arising from essentially very simple processes acting in parallel. This large and diverse area of research provides a backbone of ideas and technologies, some seemingly irrelevant, which could be applied to our music creation processes.

Rhythms may be complex, but need not be complicated. The apparent complexity of rhythmical movement results from interactions of simpler patterns and interventions. In this regard:

"What is sometimes called 'nouvelle AI' [Artificial Life, situated robotics and genetic algorithms] sees behaviour as being controlled by an ongoing interaction between relatively low-level mechanisms in the system (robot or organism) and the constantly changing details of the environment." (Boden, 1996)

It is interesting that the behaviour of these devices and simulations can display emergent, collective behaviour, such as the virtual *Boids* that display bird-like flocking behaviour (Reynolds, 1987). We want to be able to explore new ways of collectively transforming musically related elements with simpler musical gestures. However, if we are to retain rhythmic sense, a richer form of behaviour is sought that supports more coherent transformations of its collective elements.

Here *timing* is of the essence. It is not be enough to predict an ordered sequence of events occurring *over* time. We are looking for methods that are adaptive to events as they occur *in* time, methods sensitive to what Andy Clark terms 'the *real timing* of events' (Clark, 1997). Much neural network research has neglected the issue of time (Harvey, 1996), but recent developments appear useful. A class of more biologically plausible 'oscillatory' networks looks particularly promising. With these "... the vehicle of representation is a *process*, with *intrinsic temporal* properties" (Clark, 1997). Networks of this type can entrain to the metre of human speech (Gasser, Eck and Port, unpublished) and have application within music cognition research (Toiviainen, 1997).

Situated robots can display rich behaviours emerging from simple dynamics. Patterned movements emerge from Ezequiel Di Paolo's 'acoustically coupled agents'. His experiments in the evolution of acoustic communication produced pairs of 'communicating' robot agents that "... perform almost perfectly synchronized 'dancing' patterns" (Di Paolo, 2000). Simulations and devices are being created that adapt coherently to unmapped terrain, utilising neural networks particularly suited to such uncertain environments (for example, Beer and Gallagher, 1992). In this way, for example, a six-legged robot can seemingly 'learn' to walk in a way strangely like an insect, its leg movements co-ordinated in time without explicit prior instruction. It's interesting to consider less that it moves 'like an insect'; more that the simple dynamics involved create the patterned movement we recognise as insect-like.

It's Life Jim ... but not as we know it

Our musical environment reflects an exploration of unknown territory, an increasingly significant part of which is related to rhythm. Recent developments in robotics and neural networks display behaviour that shows apparent promise in relation to this environment. In a way similar to how situated robots adapt to their physical terrain we envisage a musical machine that can coherently adapt to an unknown rhythmical 'terrain'. We hope this will also serve to further shape and enlighten our practice and provide for further, highly adaptive, possibilities for experiments in machine-mediated rhythm.

Bibliography

Beer, R., and Gallagher, J. 1992. 'Evolving Dynamical Neural Networks for Adaptive Behaviour'. *Adaptive Behavior.* 1(1): 91-122.

Boden, M. A. 1996. 'Autonomy and Artificiality'. In Boden, M. A., ed. *The Philosophy of Artificial Life.* Oxford: Oxford University Press. pp. 95-107.

Chernoff, J. 1979. *African Rhythm and African Sensibility.* Chicago: Chicago University Press. p. 23.

Clark, A. 1997. *Being There: Putting Brain, Body, and World Together Again.* Cambridge, MA: MIT Press. p. 161, p. 162.

Di Paolo, E. A. 2000. 'Behavioral co-ordination, structural congruence and entrainment in a simulation of acoustically coupled agents'. *Adaptive Behavior.* 8(1)

Eshun, K. 1998. *More Brilliant Than the Sun.* Quartet Books. p. 67, p. 68.

Gasser, M., Eck, D., & Port, R. unpublished. 'Meter as Mechanism: A Neural Network that Learns Metrical Patterns'. Indiana University Cognitive Science Technical Report 180.

Harvey, I. 1996. 'Untimed and Misrepresented: Connectionism and the Computer Metaphor'. *AISB Quarterly.* (96): 20-27.

McCullough, M. 1996. *Abstracting Craft.* Cambridge, MA: MIT Press.

Reynolds, C. W. 1987. 'Flocks, Herds, and Schools: A Distributed Behavioural Model'. *Computer Graphics.* 21(4): 25-34.

Toiviainen, P. 1997. 'Modelling the Perception of Metre with Competing Subharmonic Oscillators'. In Gabriellson, A., ed. Proceedings of the Third Triennial ESCOM Conference. Uppsala: Uppsala University. pp. 511-516.

Toop, D. 1995. *Ocean of Sound*. London: Serpents Tail. p. 113.

Appendix 2 – Track Listing

The following is a list of compositions included on the accompanying Compact Disk, representing significant musical experiments over the period of the last five years. All tracks have been the result of collaboration with Ben Simmonds, and on occasion others have been involved. I have also included brief notes on the main motivations behind each composition. The tracks are included in chronological order.

1. DJ

Date January 1996

This is an adaptation of an earlier track based around some sampled excerpts from David Bowie's 'DJ' (Bowie; Eno, and Alomar, 1991), originally released in 1979. An important intention was to create around this jazz-like rhythmic breaks and shifts, an inspiration that was derived from the fluid, tight rhythms on Herbie Hancock's *Chameleon* (Hancock, 1998). Another collaborator on this track was Mark Ziman who provided the bass line.

2. The Message

Date: April 1998

The modal jazz-like chord progression forms the basis of this track, suggested by a sample (unknown origin). On top of this improvised keyboard lines were added.

3. Venetian Blind

Date: January 1999

The basic rhythmic idea is derived from a loop from Grace Jones' *My Jamaican Guy* (Jones, 1982). What was appealing was its basic syncopation. It is interesting to note that the main trumpet-like sample is in fact not a trumpet at all, but a fragment of a much longer entirely synthesized sound. A significant collaborator on this project was also Mark

Fanciullacci, who added significantly to the use of effects, adding richness to the treatments applied to the various sounds.

4. Venetian Blind ('Flight of the Grumble Bee' mix)

Date August 1999

This is a basic reworking of *Venetian Blind*. Mark Fanciullacci again provided a significant contribution to the treatment of the sounds.

5. The End of a Very Long Day (early working version)

Date January 2000

Inspired by a collection of samples that were being put together for another track, I attempted to explore various rhythmic permutations of their basic arrangement. This version represents an early development of the musical ideas. The vocal sample is derived from Artful Dodger's and Craig David's *Rewind* (Hill, David, Deveraux, 2000)

6. The End of a Very Long Day (finished version)

Date March – August 2000

This is a later, and substantially more complete version of the previous track. This represents a more fully explored working through of the rhythmic permutations of its basic elements.

7. Steve Reich Funk (unfinished)

Date August 2000

Suggested by Steve Reich's *Six Pianos* (Reich, 1974). A simple piano pattern is repeated and slightly modified over time. Instead of extensively modifying the piano pattern however, the intention was to experiment with the rhythmic dynamics. This track is unfinished, and represents a working version that is incompletely developed in places.

Bibliography

AGAWU, K. 1995. *African Rhythm: A Northern Ewe Perspective.* Cambridge: Cambridge University Press.

AGRE, P. E. 1995. Computation and Embodied Agency. *Informatica.* 19 (4), pp. 527-535.

ALCOPLEY, L. 1994. Art, Science and Human Being. *Leonardo.* 27 (3), pp. 183-184.

ALLEN, P. E. and DANNENBERG, R. B. 1990. Tracking Musical Beats In Real Time. *In*: *Proceedings of the 1990 International Computer Music Conference.* Glasgow, Scotland. San Francisco, CA:International Computer Music Association. 140-143.

ALTMAN, I. and ROGOFF, B. 1987. World Views In Psychology: Trait, Interactional, Organismic, and Transactional Perspectives. *In*: STOKOLS, D. and ALTMAN, I. eds. *Handbook of Environmental Psychology.* New York:Wiley. pp. 7-40.

ASCOTT, R. 1998. Seeing Double: spiritism, cyberception and the technology of transcendence. *In*: ASCOTT, R. ed. *Consciousness Reframed II : Proceedings of the Third International Research Conference.* Newport: UWCN.

ASHBY, W. R. 1952. *Design for a Brain.* London: Chapman and Hull.

BAAS, N. A. 1994. Emergence, Hierarchies, and Hyperstructures. *In*: LANGTON, C. G., ed. *Artificial Life III: Proceedings of the Workshop on Artificial Life.* Santa Fe, NM. Reading, MA:Addison-Wesley. 515-537.

BAAS, N. A. and EMMECHE, C. 1997. On emergence and explanation. *Intellectica.* 2 (25), pp. 67-83.

BACON, T., RIESER, M., FLEURIOT, C., HEARD, P., and EASY, G. 1999. Do Engineers and Artists Make Good Love Objects? *In*: CANDY, L. and EDMONDS, E., eds. *Creativity and Cognition: Proceedings of the third Creativity and Cognition Conference.* Loughborough University. New York:ACM. 28-29.

BAILY, J. 1977. Movement Patterns in Playing the Herati Dutar. *In*: BLACKING, J. ed. *The Anthropology of the Body.* London:Academic Press. pp. 275-330.

BAILY, J. 1985. Music Structure and Human Movement. *In*: HOWELL, P., CROSS, I., and WEST, R. eds. *Musical Structure and Cognition*. London:Academic Press. pp. 237-258.

BAILY, J. 1992. Music Performance, Motor Structure, and Cognitive Models. *In*: BAUMANN, M. P., SIMON, A., and WEGNER, U. eds. *European Studies in Ethnomusicology: Historical Developments and Recent Trends*. Wilhelmshaven:Florian Noetzel Verlag. pp. 142-158.

BALABAN, M. 1996. The Music Structures Approach to Knowledge Representation for Music Processing. *Computer Music Journal*. 20 (2), pp. 96-111.

BALABAN, M., EBCIOGLU, K., and LASKE, O. E. 1992.*Understanding Music with AI: Perspectives on Music Cognition*. AAAI Press/MIT Press.

BAUDRILLARD, J. 1983.*Simulations*. FOSS, P., PATTON, P., and BEITCHMAN, P., trans. New York: Semiotext(e) .

BECK, S. D. 1996. The Virtual Instrument Paradigm: An Alternative Approach to Interactive Computer Music. *Computers and Mathematics With Applications*. 32 (1), pp. 5-10.

BEER, R. D. and GALLAGHER, J. C. 1992. Evolving Dynamical Neural Networks for Adaptive Behaviour. *Adaptive Behavior*. 1 (1), pp. 91-122.

BERGSON, H. 1998.*Creative Evolution*. New York: Dover Edition. (originally published 1911).

BIJKER, W. E. 1997.*Of Bicycles, Bakelites and Bulbs : Toward a Theory of Sociotechnical Change (Inside Technology)*. Cambridge, MA: MIT Press, (Inside Technology Series.

BIJKER, W. E., HUGHES, T. P., and PINCH, T. F. 1989.*The Social Construction of Technological Systems : New Directions in the Sociology and History of Technology*. Cambridge, MA: MIT Press.

BIJKER, W. E. and LAW J. 1992.*Shaping Technology/Building Society: Studies in Socio-Technical Change*. Cambridge, MA: MIT Press, (Inside Technology Series.

BILMES, J. A. 1992. A Model for Musical Rhythm. *In*: *Proceedings of the 1992 International Computer Music Conference*. San José, California. San Francisco, CA:International Computer Music Association.

BILMES, J. A. 1993. Techniques to Foster Drum Machine Expressivity. *In: Proceedings of the 1993 International Computer Music Conference*. San Francisco, CA:International Computer Music Association. 276-283.

BLACK, M. 1962. *Models and metaphors*. Ithaca, New York: Cornell University Press.

BLACKING, J. 1973. *How Musical is Man?* Seattle: University of Washington Press.

BLUECHER, H. 1968. A Lecture from the Common Course. *Bard*. 11 (6).

BONABEAU, E. W. and THERAULAZ, G. 1995. Why Do We Need Artificial Life? *In*: LANGTON, C. G. ed. *Artificial Life: An Overview*. Cambridge, MA:MIT Press. pp. 303-325.

BOREL, A. 1983. Mathematics: Art and Science. *The Mathematical Intelligencer*. 5 (4), pp. 9-17.

BORISYUK, G. N., BORISYUK, R. M., KHIBNIK, A. I., and ROOSE, D. 1995. Dynamics and Bifurcations of Two Coupled Neural Oscillators with Different Connection Types. *Bulletin of Mathematical Biology*. 57 (6), pp. 809-840.

BORISYUK, R. M., BORISYUK, G. N., and KAZANOVICH, Y. B. 1998. The Synchronization Principle in Modelling of Binding and Attention. *Membr. Cell Biol.* 11 (6), pp. 753-761.

BORTOFT, H. 1986.*Goethe's Scientific Consciousness*. Tunbridge Wells: Institute for Cultural Research, London, (Institute for Cultural Research Monograph No. 22.

BORTOFT, H. 1996. *The Wholeness of Nature: Goethe's Way Toward a Science of Conscious Participation in Nature*. Hudson, NY: Lindisfarne Press.

BOURDIEU, P. 1990.*The Logic of Practice*. NICE, R., trans. Stanford, CA: Stanford University Press.

BOWIE, D., ENO, B., and ALOMAR, C. 1991. D.J. *In*: *Lodger*. Compact Disk. EMI: CDEMD 1026. (Original release date 1979)

BOYD, G. M. 1993. Educating Symbiotic P-individuals through Multi-level Conversations:

From the Integrity of Concepts to the Symbiosis of Cultures. *Systems Research.* 10 (3), pp. 113-128.

BRADY, M. and PAUL, R. 1984.*Robotics Research: The First International Symposium.* Cambridge, MA: MIT Press.

BRAHAM, R. 1995. Math and Visualization: new tools, new frontiers. *IEEE Spectrum*(November), pp. 19-21.

BRINNER, B. 1995. *Knowing Music, Making Music: Javanese Gamelan and the Theory of Musical Competence and Interaction.* Chicago and London: University of Chicago Press.

BROOKS, R. A. 1986. A Robust Layered Control System for a Mobile Robot. *IEEE Journal of Robotics and Automation.* 2 (1), pp. 14-23.

BROOKS, R. A. 1990. Elephants Don't Play Chess. *Robotics and Autonomous Systems .* 6 pp. 3-15.

BROOKS, R. A. 1991a. Intelligence without Reason. *In*: *Proceedings of the Twelfth International Joint Conference on Artificial Intelligence (IJCAI-91).* Morgan Kauffmann Publishers. 139-159.

BROOKS, R. A. 1991b. Challenges for Complete Creature Architectures. *In*: MEYER, J.-A. and WILSON, S. W., eds. *From Animals to Animats: Proceedings of the First International Conference on the Simulation of Adaptive Behavior (SAB90).* Cambridge, MA.:MIT Press/Bradford Books. 434-433.

BROOKS, R. A. 1991c. Intelligence Without Representation. *Artificial Intelligence.* 47 pp. 139-159.

BROOKS, R. A. 1994. Coherent Behavior from Many Adaptive Processes. *In*: CLIFF, D., HUSBANDS, P., MEYER, J. A., and WILSON, S., eds. *From Animals to Animats 3: Proceedings of the Third International Conference on Simulation of Adaptive Behavior (SAB-94).* Brighton, UK. Cambridge, MA:MIT Press. 22-29.

BROWN, C., BISCHOFF, J., and PERKIS, T. 1996. Bringing Digital Music to Life. *Computer Music Journal.* 20 (2), pp. 28-32.

BROWN, J. W. 1999. On Aesthetic Perception. *Journal of Conscious Studies*. 6 (6-7), pp. 144-160.

BRYSON, J. J. 1992. The Subsumption Strategy Development of a Music Modelling System [MSc dissertation].: Department of Artificial Intelligence, Edinburgh University. (originally published <21 Original Pub Date>).

CAMBOUROPOULOS, E., NELSON, P., SMAILL, A., and WIGGINS, G. A. 1996. Introduction (to a special issue on Music and Artificial Intelligence. *Journal of New Music Research*. 25 (3), pp. 211.

CHADABE, J. 1984. Interactive Composing: An Overview. *Computer Music Journal*. 8 (1), pp. 22-27.

CHALMERS, A. F. 1982. *What is This Thing Called Science?* Buckingham: Open University Press.

CHANDRASEKARAN, B. 1988. Generic Tasks as Building Blocks for Knowledge-Based Systems: The diagnosis and routine design examples. *The Knowledge Engineering Review*. 3 (3).

CHERNOFF, J. M. 1979. *African Rhythm and African Sensibility*. Chicago and London: University of Chicago Press.

CHESTER, A. 1970. Second Thoughts on a Rock Aesthetic: The Band. *New Left Review*. 62 pp. 78-79.

CHOMSKY, N. 1957. *Syntactic Structures*. The Hague: Mouton.

CHOWNING, J. 1973. The synthesis of complex audio spectra by means of frequency modulation. *Journal of the Audio Engineering Society*. 21 (7), pp. 46-54.

CLANCEY, W. J. 1996. Conceptual coordination: Abstraction without description. *International Journal of Educational Research*. **27** (1), pp. 5-19.

CLANCEY, W. J. 1997a. The Conceptual Nature of Knowledge, Situations, and Activity. *In*: FELTOVICH, P., HOFFMAN, R., and FORD, K. M. eds. *Human and Machine Expertise in Context*. CA:AAAI Press. pp. 247-291.

CLANCEY, W. J. 1997b. *Situated Cognition: On Human Knowledge and Computer Representations*. Cambridge, UK: Cambridge University Press.

CLARK, A. 1997. *Being There: Putting Brain, Body and World Together Again*. Cambridge, MA: MIT Press.

COPE, D. 1991. Recombinant Music: Using the Computer to Explore Musical Style. *IEEE Computer*. 24 (7), pp. 22-38.

COPE, D. 1996. *Experiments in Musical Intelligence*. Madison, Wisconsin: A-R Editions.

COVACH, J. R. 1994. Destructuring Cartesian Dualism in Musical Analysis. *Music Theory Online*. 0 (11).

CUSICK, S. G. 1994. Feminist Theory, Music Theory, and the Mind/Body Problem. *Perspectives of New Music*. 32 (1), pp. 8-27.

CYTOWIC, R. E. 1989. *Synesthesia: Union of the Senses*. New York: Springer-Verlag.

CYTOWIC, R. E. 1993. *The Man Who Tasted Shapes: A Bizarre Medical Mystery Offers Revolutionary Insights into Emotions, Reasoning, and Consciousness*. London: Abacus.

DANCE, J. 2000. Phenomenology and Consciousness: Review Article. *Journal of Consciousness Studies*. 7 (10), pp. 69-74.

DANNENBERG, R. B. 1996. A Perspective on Computer Music. *Computer Music Journal*. 20 (1), pp. 52-56.

DARLEY, V. 1994. Emergent Phenomena and Complexity. *In*: BROOKS, R. A. and MAES, P., eds. *Artificial Life IV: Proceedings of the Fourth International Workshop on the Synthesis and Simulation of Living Systems*. Cambridge, MA:MIT Press. 411-416.

DAVIS, E. 'ROOTS AND WIRES': Polyrhythmic Cyberspace and the Black Electronic [Web Page]. 1996; Accessed 2000 Feb 15. Available at: http://www.telefonica.es/fat/edavis.html.

DAVIS, M. 1997. Ife. *In*: *Miles Davis in Concert*. Compact Disk. Sony Music Entertainment Inc.: C2K 65140. (Original release date 1973)

DAVIS, M. 2000. Black Satin. *In*: *On The Corner*. Compact Disk. Sony Music

Entertainment Inc.: CK 63980. (Original release date 1972)

DAWKINS, R. 1976. *The Selfish Gene*. Oxford: Oxford University Press.

DAWKINS, R. 1986. *The Blind Watchmaker*. New York: W. W. Norton & Company.

DE BRUIN, G. and VAN WALSTIJN. 1995. Physical Models of Wind Instruments: A Generalized Excitation Coupled with a Modular Tube Simulation Platform. *Journal of New Music Research*. 24 pp. 148-163.

DELAERE, M. 1990. Mutations in Systems in the Natural Sciences and Music in the First Half of the Twentieth Century. *International Review of the Aesthetics and Sociology of Music*. 21 (1), pp. 3-28.

DELANDA, M. 1995. Virtual Environments and the Concept of Synergy. *Leonardo*. 28 (5).

DELLAERT, F. and BEER, R. D. 1996. A Developmental Model for the Evolution of Complete Autonomous Agents. *In*: MAES, P., MATARIC, M. J., MEYER, J.-A., POLLACK, J. B., and WILSON, S. W. eds. *From Animals to Animats 4: Proceedings of the Fourth International Conference on Simulation of Adaptive Behavior (SAB96)*. Cambridge, MA:MIT Press/Bradford Books.

DESAIN, P. and HONING, H. 1991. Tempo Curves Considered Harmful. *In*: ALPHONCE, B. and PENNYCOCK, B., eds. *Proceedings of the 1991 International Computer Music Conference*. Montreal, Canada. San Francisco, CA:International Computer Music Association. 143-149.

DESAIN, P. and HONING, H. 1994a. Foot-tapping: A Brief Introduction to Beat Induction. *In*: *Proceedings of the 1994 International Computer Music Conference*. Aarhus, Denmark. San Francisco:International Computer Music Association. 78-79.

DESAIN, P. and HONING, H. 1994b. Advanced Issues in Beat Induction Modelling: Syncopation, Tempo and Timing. *In*: *Proceedings of the 1994 International Computer Music Conference*. Aarhus, Denmark. San Francisco:International Computer Music Association. 92-94.

DI SCIPIO, A. 1994. Micro-Time Sonic Design and Timbre Formation. *Contemporary Music Review*. 10 (2), pp. 135-148.

DI SCIPIO, A. 1995b. Centrality of *Téchne* for an Aesthetic Approach on Electroacoustic Music. *Journal of New Music Research.* 24 pp. 369-383.

DI SCIPIO, A. and PRIGNANO, I. 1996. Synthesis by Functional Iterations. A Revitalization of NonStandard Synthesis. *Journal of New Music Research.* 25 pp. 31-46.

DOMIK, G. O. 1993.*in*: *Educational Multimedia and Hypermedia Annual 1993 (Proceedings of ED-MEDIA 93).* Orlando, Florida. Charlottesville, VA:Association for the Advancement of Computing in Education. 153-160.

DREYFUS, H. L. and DREYFUS, S. E. 1991. Making a Mind Versus Modelling the Brain: Artificial Intelligence Back at the Branchpoint. *In*: NEGROTTI, M. ed. *Understanding the Artificial.* London:Springer-Verlag. pp. 33-54.

EDWARDS, P. 1996. *The Closed World: Computers and the Politics of Discourse.* Cambridge, MA: MIT Press.

EGLASH, R. 1995. African influences in cybernetics. *In*: GRAY, C. ed. *The Cyborg Handbook.* New York:Routledge. pp. 17-28.

ELLIS, C. 1985. *Aboriginal Music: Education for Living.* St Lucia: University of Queensland Press.

EMMER, M. 1994. Art and Visual Mathematics. *Leonardo.* 27 (3), pp. 237-240.

EMMERSON, S. 1994. 'Live' versus 'Real-time'. *Contemporary Music Review.* 10 (2), pp. 95-101.

ENO, B. 1983. The Studio as Compositional Tool. *Downbeat* (July), pp. 56-57.

ESCHER, M. C. 1989.*Exploring the Infinite: Escher on Escher.* FORD, K., trans. Harry N. Abrams Inc.

ESHUN, K. 1998. *More Brilliant Than The Sun: Adventures in Sonic Fiction.* London: Quartet Books.

FARRETT, P. W. 1996. Intelligent Musical Instrument System. *Computers and Mathematics With Applications.* 32 (1), pp. 37-48.

FELD, S. 1988. Aesthetics as iconicity of style, or 'lift-up-over sounding': getting into the Kaluli groove. *Yearbook for Traditional Music.* 20 pp. 74-113.

FETZER, J. H. 1996. Biological Adaptations and Evolutionary Epistemology. *Adaptive Behavior.* 4 (2), pp. 201-210.

FEYERABEND, P. 1996. Theoreticians, Artists and Artisans. *Leonardo.* 29 (1), pp. 23-28.

FISCHER, E. 1959. *The Necessity of Art.* Baltimore, MD: Penguin.

FRAYLING, C. 1993. Research in Art and Design. *Royal College of Art Research Papers.* London:Royal College of Art.

FREED, A. 1995. Improving Graphical User Interfaces for Computer Music Applications. *Computer Music Journal.* 19 (4), pp. 4-8.

FRITH, S. 1987. Towards an Aesthetic of Popular Music. *In*: LEPPERT, R. and MCCLARY, S. eds. *Music and Society: The Politics of Composition, Performance, and Reception.* Cambridge:Cambridge University Press. pp. 133-149.

GARDNER, M. 1996. Computers Near The Threshold. *Journal of Consciousness Studies.* 3 (1), pp. 89-94.

GAROIAN, C. R. and MATHEWS, J. D. 1996. A Common Impulse in Art and Science. *Leonardo.* 29 (3), pp. 193-196.

GASSER, M., ECK, D., and PORT, R. F. 1999. Meter as Mechanism: A Neural Network that Learns Metrical Patterns. *Connection Science.* *11* pp. 187-216.

GERZSO, A. 1992. Paradigms and Computer Music. *Leonardo Music Journal.* 2 (1), pp. 73-79.

GESSERT, G. 1993. Notes on Genetic Art. *Leonardo.* 26 (3), pp. 205-211.

GIBSON, J. J. 1979. *The Ecological Approach to Visual Perception.* Boston: Houghton Mifflin.

GILL, K. S. 1996a.*Human Machine Symbiosis. The Foundations of human-centred systems design.* London: Springer-Verlag.

GILL, K. S. 1996b. The Human-Centred Movement: The British Perspective. *AI & Society*. 10 (2), pp. 109-126.

GILROY, P. 1993. *The Black Atlantic: Modernity and Double Consciousness*. Cambridge, MA: Harvard University Press.

GJERDINGEN, R. O. 1993. 'Smooth' Rhythms as Probes of Entrainment. *Music Perception*. 10 (4), pp. 503-508.

GLASER, B. and STRAUSS, A. L. 1967. *The Discovery of Grounded Theory: Strategies For Qualitative Research*. Chicago: Aldine.

GLASER, B. G. 1992. *Basics of Grounded Theory Analysis: Emergence vs Forcing*. Mill Valley, CA: Sociology Press.

GODWIN, J. 1992. Speculative Music: The Numbers Behind the Notes. *In*: PAYNTER, J., HOWELL, T., ORTON, R., and SEYMOUR, P. eds. *Companion To Contemporary Musical Thought, Volume 1*. London:Routledge. pp. 256-271.

GOMBRICH, E. H. J. 1960. *Art and Illusion: A Study in the Psychology of Pictorial Representation*. Princeton, NJ: Princeton University Press.

GOODWIN, A. 1992. *Dancing in the Distraction Factory*. Minneapolis: University of Minnesota Press.

GOODWIN, B. 1994. *How the Leopard Changed Its Spots: The Evolution of Complexity*. London: Weidenfeld & Nicholson.

GRAY, C. and PIRIE, I. 1995. 'Artistic' Research Procedure: Research at the Edge of Chaos? *In*: *Proceedings of Design Interfaces Conference vol. 3*. European Academy of Design, University of Salford. Salford:University of Salford.

GREGORY, D. 1993. Distinguishing Gordon Pask's Cybernetics. *Systems Research*. 10 (3), pp. 59-71.

GRIFFITH, N. J. L. and TODD, P. M. 1999.*Musical Networks: Parallel Distributed Perception and Performance*. Cambridge, Massachusetts: MIT Press.

HAKEN, H., KARLQUIST, A., and SVEDIN, U. 1993.*The Machine as Metaphor and Tool.* Berlin: Springer-Verlag.

HAMEL, P. M. 1976. *Through Music to The Self: How to appreciate and experience music anew.* Boulder, CO: Shambhala Publications.

HANCOCK, H. 1998. Rain Dance. *In*: *Sextant.* Compact Disk. Sony Music Entertainment Inc.: CK 64983. (Original release date 1973)

HARDY, G. H. 1940. *A Mathematician's Apology.* Cambridge, UK: Cambridge University Press.

HARLEY, J. 1995. Generative Processes in Algorithmic Composition: Chaos and Music. *Leonardo.* 28 (3).

HARNAD, S. 1995. Levels of Functional Equivalence in Reverse Bioengineering. *In*: LANGTON, C. G. ed. *Artificial Life: An Overview.* Cambridge, MA:MIT Press. pp. 293-301.

HARRIS, C. 1994. Visualizing Music and Sound: An Annotated Bibliography. *Leonardo Electronic Almanac.* 2 (9).

HARVEY, D. 1990. *The Condition of Postmodernity.* Oxford: Blackwell.

HARVEY, I. 1996. Untimed and Misrepresented: Connectionism and the Computer Metaphor. *AISB Quarterly.* Winter (96), pp. 20-27.

HARVEY, I., HUSBANDS, P., CLIFF, D., THOMPSON, A., and JAKOBI, N. 1997. Evolutionary Robotics: The Sussex Approach. *Robotics and Autonomous Systems.* 20 pp. 205-224.

HAUS, G. and MORINI, P. 1992. TEMPER: A System for Music Synthesis from Animated Tessellations. *Leonardo.* 25 (3-4), pp. 355-360.

HEIDEGGER, M. 1962.*Being and Time.* MACQUARRIE, J. and ROBINSON, E., trans. New York: Harper and Row. (originally published 1926).

HEIDEGGER, M. 1966.*Discourse on Thinking.* ANDERSON, J. and FREUND, H., trans. New York: Harper and Row.

HEIDEGGER, M. 1977. *The Question Concerning Technology and Other Essays.* New York: Harper & Row.

HELMUTH, M. 1996. Granular Synthesis Composition with StochGran and Max. *Computers and Mathematics With Applications.* 32 (1), pp. 57-74.

HENDRIKS-JANSEN, H. 1996a. In Praise of Interactive Emergence, Or Why Explanations Don't Have to Wait for Implementations. *In*: BODEN, M. A. ed. *The Philosophy of Artificial Life.* Oxford:Oxford University Press. pp. 282-299.

HENDRIKS-JANSEN, H. 1996b. *Catching Ourselves in the Act: Situated Activity, Interactive Emergence, Evolution and Human Thought.* Cambridge, Mass.: MIT Press.

HESSE, M. 1980. *Revolution and Reconstruction in the Philosophy of Science.* Indiana University Press: Bloomington.

HICKMAN, C. 1991. Why Artists Should Program. *Leonardo.* 24 (1), pp. 49-51.

HILL, M., DAVID, C., AND DEVEREAUX, P. 2000. *Rewind* Compact Disk. Republic. 1569162.

HO, M.-W. 1991. Reanimating Nature: The Integration of Science with Human Experience. *Leonardo.* 24 (5), pp. 607-615.

HOFSTADTER, D. R. 1979. *Gödel, Escher and Bach: An Eternal Golden Braid.* London: Harvester Press.

HOFSTADTER, D. R. 1985. On Viral Sentences & Self-Replicating Structures. *In*: HOFSTADTER, D. R. *Metamagical Themes.* New York:Basic Books. pp. 49-69.

HOLTZMAN, S. R. 1994. *Digital Mantras: The Languages of Abstract and Virtual Worlds.* Cambridge, Mass: MIT Press.

HUSSERL, E. 1970. *The Crisis of European Sciences and Transcendental Phenomenology.* Evanston: Northwestern University Press.

HUTCHINS, E. 1995. *Cognition in the Wild.* Cambridge, MA: MIT Press.

HYBS, I. 1996. Beyond the Interface: A Phenomenological View of Computer Systems

Design. *Leonardo.* 29 (3), pp. 215-223.

IHDE, D. 1979.*Technics and Praxis.* Dordrecht: Reidel, (Boston Studies in the Philosophy of Science. 24).

IHDE, D. 1990. *Technology and the Lifeworld: From Garden to Earth.* Bloomington: Indiana University Press.

IVERSON, E. and HARTLEY, R. 1990. Metabolizing Music. *In*: *Proceedings of the 1990 International Computer Music Conference.* Glasgow, Scotland. San Francisco, CA:International Computer Music Association.

IYER, V., BILMES, J. A., WRIGHT, M., and WESSEL, D. L. 1997. A Novel Representation for Rhythmic Structure. *In*: *Proceedings of the 1997 International Computer Music Conference.* Thessaloniki, Greece. San Francisco, CA:International Computer Music Association.

JACOB, B. L. 1995. Composing with Genetic Algorithms. *In*: *Proceedings of the 1995 International Computer Music Conference.* Banff, Alberta. San Francisco, CA:International Computer Music Association. pp. 452-455.

JACOB, B. L. 1996. Algorithmic Composition as a Model of Creativity. *Organised Sound.* 1 (3), pp. 157-165.

JAIN, A. K., MAO, J., and MOHIUDDIN, K. M. 1996. Artificial Neural Networks: A Tutorial. *IEEE Computer.* March pp. 31-44.

JAMESON, F. 1991. *Postmodernism, or, The Cultural Logic of Late Capitalism.* Durham, NC: Duke University Press.

JENNINGS, P. 1996. Narrative Structures for New Media. *Leonardo.* 29 (1), pp. 345-350.

JOHNSON, G. J. 1992. Talking About Computers: From Metaphor to Jargon. *AI & Society.* 6 pp. 263-293.

JONES, A. M. 1954. African Rhythm. *Africa.* 24 pp. 26-47.

JONES, G. 1982. My Jamaican Guy. *In*: *Living My Life.* Compact Disk. Island Records:

ILPS 9722.

KANDINSKY, W. 1912. *Sounds.* New Haven, CT. and London: Yale University Press.

KANDINSKY, W. 1947. *Point and Line to Plane.* New York: Museum of Non-Objective Paintings.

KAPTELININ, V. 1996a. Computer-Mediated Activity: Functional Organs in Social and Developmental Contexts. *In*: NARDI, B. A. ed. *Context and Consciousness: Activity Theory and Human-Computer Interaction.* Cambridge, MA:The MIT Press.

KAPTELININ, V. 1996b. Distribution of Cognition between Minds and Artifacts: Augmentation of Mediation? *AI & Society.* 10 (1), pp. 15-25.

KAY, A. C. 1984. Computer Software. *Scientific American.* 251 (3).

KELLER, E. F. 1991. Language and Ideology in Evolutionary Theory: Reading Cultural Norms into Natural Law. *In*: SHEEHAN, J. J. and SOSNA, M. eds. *The Boundaries of Humanity: Humans, Animals, Machines.* Berkeley:University of California Press. pp. 85-102.

KELLY, K. 1994. *Out of Control: The New Biology of Machines.* London: Fourth Estate.

KELSO, S. 1995. *Dynamic Patterns: the self-organisation of brain and behaviour.* Cambridge, MA: MIT Press.

KERMAN, J. 1985. *Musicology.* London: Fontana Press.

LAKOFF, G. and JOHNSON, M. 1981. *Metaphors We Live By.* Chicago: University of Chicago Press.

LAKOFF, G. and JOHNSON, M. 1998. *Philosophy in the Flesh: The Embodied Mind and Its Challenge to Western Thought.* Basic Books.

LANGTON, C. G. 1989. Introduction. *In*: LANGTON, C. G., ed. *Artificial Life: The Proceedings of an Interdisciplinary Workshop on the Synthesis and Simulation of Living Systems.* Los Alamos, NM. Redwood City, CA:Addison-Wesley.

LANGTON, C. G. 1992a. Preface. *In*: LANGTON, C. G., TAYLOR, C., FARMER, J. D., and

RASMUSSEN, S., eds. *Artificial Life II.* Santa Fe, NM. Reading, MA:Addison-Wesley. xiii-xviii.

LANGTON, C. G. 1992b. Introduction. *In*: LANGTON, C. G., TAYLOR, C., FARMER, J. D., and RASMUSSEN, S., eds. *Artificial Life II.* Reading, MA:Addison-Wesley. 3-24.

LANIER, J. 1997. Death: The Skeleton Key of Consciousness Studies. *Journal of Consciousness Studies.* 4 (2), pp. 181-185.

LARGE, E. W. 1995. Beat tracking with a nonlinear oscillator. *In*: *Working Notes of the IJCAI Workshop on AI and Music.* 24-31.

LARGE, E. W. 1996. Modeling beat perception with a nonlinear oscillator. *in*: *Proceedings of the Eighteenth Annual Conference of the Cognitive Science Society.*

LARGE, E. W. and KOLEN, J. F. 1994. Resonance and the perception of musical meter. *Connection Science.* 6 (2/3), pp. 177-208.

LASKE, O. E. 1991. Towards an Epistemology of Composition. *Interface.* 20 (3-4), pp. 235-269.

LASKE, O. E. 1993. A Search For a Theory of Musicality. *Languages of Design.* 1 pp. 209-228.

LAUREL, B. 1991. *Computers as Theater.* Reading, MA: Addison-Wesley.

LAW, J. and HASSARD, J. 1999.*Actor Network Theory and After.* Blackwell Publishers, (Sociological Review Monograph Series.

LEACH, J. and FITCH, J. 1995. Nature, Music and Algorithmic Composition. *Computer Music Journal.* 19 (2), pp. 23-33.

LEE, M. and WESSEL, D. L. 1992. Connectionist Models for Real-Time Control of Synthesis and Compositional algorithms. *Proceedings of the 1992 International Computer Music Conference.* San José, California. San Francisco, CA:International Computer Music Association. 277-280.

LEPPERT, R. and MCCLARY, S. 1987.*Music and Society: The Politics of Composition,* *Performance, and Reception.* Cambridge: Cambridge University Press.

LESBROS, V. 1996. From Images to Sounds, A Dual Representation. *Computer Music Journal.* 20 (3), pp. 34-44.

LEVY, S. 1993. *Artificial Life: The Quest for a New Creation.* Harmondsworth: Penguin.

LEWIS, G. 1997. Singing the Alternative Interactivity Blues. *Grantmakers in the Arts.* 8 (1).

LILLIESTAM, L. 1996. On Playing by Ear. *Popular Music.* 15 (2), pp. 195-216.

LONGHURST, B. 1995. *Popular Music and Society.* Oxford: Polity Press/Blackwell Publishers Ltd.

LOREN, L. A. and DIETRICH, E. 1997. Merleau-Ponty, Embodied Cognition, and the Problem of Intentionality. *Cybernetics and Systems.* 28 (5), pp. 345-358.

LOY, D. G. 1989. Composing with Computers - a Survey of Some Compositional Formalisms and Music Programming Languages. *In*: MATHEWS, M. V. and PIERCE, J. R. eds. *Current Directions in Computer Music Research.* Cambridge, MA:MIT Press.

LÜCKE, A. A Real-Time 3D Visualization Toolkit for Sound and Other Signals Center for New Music and Audio Technologies (CNMAT): University of California, Berkeley; 1997.

LYOTARD, J.-F. 1984.*The Postmodern Condition: A Report on Knowledge.* BENNINGTON, G. and MASSUMI, B., trans. Minneapolis, MN: University of Minnesota Press.

MACCORMAC, E. 1976. *Metaphor and Myth in Science and Religion.* Durham, NC: Duke University Press.

MACHOVER, T. 1992. Hyperinstruments: A Composer's Approach to the Evolution of Intelligent Musical Instruments. *In*: JACOBSON, L. ed. *Cyberarts: Exploring Art and Technology.* San Francisco:Miller Freeman. pp. 67-76.

MACHOVER, T. and CHUNG, J. 1989. Hyperinstruments: Musically Intelligent and Interactive Performance and Creativity Systems. *In*: *Proceedings of the 1989 International Computer Music Conference.* San Francisco:International Computer Music Association.

186-190.

MACKENZIE, D. and WAJCMAN, J. 1985.*The Social Shaping of Technology: How the Refrigerator Got Its Hum.* Milton Keynes: Open University Press.

MACONIE, R. 1997. *The Science of Music.* Oxford: Oxford University Press.

MAES, P. 1994a. Modeling Adaptive Autonomous Agents. *Artificial Life.* 1 pp. 135-162.

MAES, P. 1994b. Agents that Reduce Work and Information Overload. *Communications of the ACM.* 37 (7).

MAIOCCHI, R. 1991. Can You Make a Computer Understand and Produce Art? *AI & Society.* 5 (3), pp. 183-201.

MALOUF, F. L. 1985. A System for Interactive Music Composition Through Computer Graphics. *In: Proceedings of the 1985 International Computer Music Conference.* San Francisco:International Computer Music Conference. 225-232.

MANDELBROJT, J. 1994. In Search of the Specifity of Art. *Leonardo.* 27 (3), pp. 185-187.

MANDELBROT, B. 1982. *The Fractal Geometry of Nature.* New York: Freeman and Company.

MARTIN, A. 1996. Reaction-diffusion Systems for Algorithmic Composition. *Organised Sound.* 1 (3), pp. 195-201.

MARTIN, E. 1991. The Egg and The Sperm: How science has constructed a romance based on stereotypical male-female roles. *Signs: Journal of Women in Culture and Society.* 16 (3), pp. 485-501.

MARX, L. and SMITH, M. R. 1994.*Does Technology Drive History?: The Dilemma of Technological Determinism.* Cambridge, MA: MIT Press.

MASON, S. and SAFFLE, M. 1994. L-Systems, Melodies and Musical Structure. *Leonardo Music Journal.* 4 pp. 31-38.

MATARIC, M. J. 1992. Behaviour-Based Systems: Key Properties and Implications. *In: Proceedings, IEEE International Conference on Robotics and Automation, Workshop on*

Architectures for Intelligent Control Systems. Nice, France. 46-54.

MATARIC, M. J. 1997. Studying the Role of Embodiment in Cognition. *Cybernetics and Systems.* 28 (6).

MATHEWS, J. D., MCCART, C. L., KLEVANS, E. H., WALKER, R. A., FISHER. R., KUNZ, K. S., and BRIGHTON, J. A. 1990. An Artist-in-Residence Program at the Pennsylvania State University College of Engineering. *Leonardo.* 23 (2/3), pp. 227-230.

MATURANA, H. R. and VARELA, F. J. 1973. *De Máquinas y Seres Vivo: Una teoría de la organización biológica.* Santiago de Chile: Editorial Universitaria.

MATURANA, H. R. and VARELA, F. J. 1980.*Autopoiesis and Cognition: The Realization of the Living.* Dordrecht: D. Reidel Publishing Company, (Boston Studies in the Philosophy of Science. 42).

MATURANA, H. R. and VARELA, F. J. 1992. *The Tree of Knowledge: the Biological Roots of Human Understanding.* Shambhala.

MAZZIOLI, G. 1992. The Evolving Model of Communication in Sociotechnical Systems. *AI & Society.* 6 pp. 221-231.

MCCULLOUGH, M. 1996. *Abstracting Craft: The Practiced Digital Hand.* Cambridge, MA: MIT Press.

MCMILLEN, K. 1994. ZIPI: Origins and Motivations. *Computer Music Journal.* 18 (4), pp. 47-51.

MCMILLEN, K., SIMON, D., and WRIGHT, M. 1994. A Summary of the ZIPI Network. *Computer Music Journal.* 18 (4), pp. 74-80.

MCNABB, M. 1986. Computer Music: Some Aesthetic Considerations. *In*: EMMERSON, S. ed. *The Language of Electroacoustic Music.* London:Macmillan Press. pp. 141-153.

MERLEAU-PONTY, M. 1962. *Phenomenology of Perception.* London: Routledge & Kegan Paul.

MILANO, D. 1988. *Multi-Track Recording.* Milwaukee: Hal Leonard Books.

MILLER, A. I. 1995. Aesthetics, Representation and Creativity in Art and Science. *Leonardo*. 28 (3).

MINSKY, M. 1981. Music, Mind and Meaning. *Computer Music Journal*. 5 (3), pp. 28-44.

MOORE, F. R. 1988. The Dysfunctions of MIDI. *Computer Music Journal*. 12 (1), pp. 19-28.

MORAVEC, H. 1988. *Mind Children: The Future of Robot and Human Intelligence*. Cambridge, MA: Harvard Univ. Press.

MORGANTINI, M. 1989. Man Confronted by the Third Technological Generation. *In*: MARGOLIN, V. ed. *Design Discourse: History, Theory, Criticism*. Chicago, IL:University of Chicago Press.

MULDER, A. G. E. 1994. Virtual Musical Instruments: Accessing the Sound Synthesis Universe as a Performer. *In*: *Proceedings of the First Brazilian Symposium on Computer Music*. Caambu, Minas Gerais, Brazil. Belo Horizonte, MG, Brazil:UFMG. 243-250.

MUMFORD, L. 1959. An Appraisal of Lewis Mumford's Technics and Civilization. *Daedalus*. 3 pp. 527-536.

NARDI, B. A. 1996a.*Context and Consciousness: Activity Theory and Human-Computer Interaction*. Cambridge, MA: The MIT Press.

NARDI, B. A. 1996b. Activity Theory and Human-Computer Interaction. *In*: NARDI, B. A. ed. *Context and Consciousness: Activity Theory and Human-Computer Interaction*. Cambridge, MA:The MIT Press.

NEGROTTI, M. 1990. *Capire L'artificale*. Torino: Bollati Boringhieri.

NEGROTTI, M. 1991a. Introduction: Artificial Intelligence: Its Future and its Cultural Roots. *In*: NEGROTTI, M. ed. *Understanding the Artificial*. London:Springer-Verlag. pp. 1-11.

NEGROTTI, M. 1991b. Alternative Intelligence. *In*: NEGROTTI, M. ed. *Understanding the Artificial: On the Future Shape of Artificial Intelligence*. London:Springer-Verlag. pp. 55-75.

NELSON, G. L. 1996. Real Time Transformation of Musical Material with Fractal

Algorithms. *Computers and Mathematics With Applications.* 32 (1), pp. 109-116.

NETTL, B. 1983. *The Study of Ethnomusicology.* Urbana & Chicago: University of Illinois Press.

NEWBURY, D. 1996a. The Research Training Needs of Postgraduates in Art and Design: A Practical Response. *In*: *No Guru, No Method? International Conference on Art and Design Practice.* University of Art and Design, UIAH, Helsinki, Finland.

NEWBURY, D. 1996b. Knowledge and research in art and design. *Design Studies.* 7 (2), pp. 215-219.

NEWBURY, D. 1997. Research and Practice in the PhD: issues for training and supervision. *In*: UK COUNCIL FOR GRADUATE EDUCATION. *Practice-based doctorates in the creative and performing arts and design.* Coventry:UK Council for Graduate Education. pp. 6-13.

NORTON, A. 1995. Dynamics: An Introduction. *In*: PORT, R. F. and VAN GELDER, T. eds. *Mind as Motion: Explorations in the Dynamics of Cognition.* Cambridge, MA:MIT Press Bradford Books. pp. 45-68.

NÚÑEZ, R. E. 1997. Eating Soup with Chopsticks: Dogmas, Difficulties and Alternatives in the Study of Conscious Experience. *Journal of Consciousness Studies.* 4 (2), pp. 143-166.

NYMAN, M. 1974. *Experimental Music: Cage and Beyond.* New York: Schirmer Books.

OLSON, E. T. 1997. The Ontological Status of Strong Artificial Life. *Artificial Life.* 3 (1), pp. 29-39.

ONG, W. J. 1982. *Orality and Literacy: The Technologizing of the World.* London and New York: Methuen.

OPPENHEIM, D. V. 1996. DMIX: A Multifacated Environment for Composing and Performing Computer Music. *Computers and Mathematics With Applications.* 32 (1), pp. 117-135.

PAGELS, H. 1988. *The Dreams of Reason: The Computer and the Rise of the Sciences of Complexity.* New York: Bantam Books.

PANDIT, N. R. 1996. The Creation of Theory: A Recent Application of the Grounded Theory Method. *The Qualitative Report.* 2 (4).

PEACOCK, K. 1985. Synesthetic Perception. *Music Perception.* 2 (4), pp. 483-506.

PENROSE, R. 1989. *The Emperor's New Mind: Concerning Computers, Minds and the Laws of Physics.* Oxford: Oxford University Press.

PERKIS, T. 1993. The Impact of Computer Technology on the Artistic Process. *In: Third Conference on Computers Freedom and Privacy.* Burlingame, CA.

PIAGET, J. 1970.*Structuralism.* MACHSLER, C., trans. New York: Basic Books.

PIERCE, J. R. 1996. Computer Music, Coming and Going. *Computer Music Journal.* 20 (1), pp. 49-51.

POLANYI, M. 1958. *Personal Knowledge - Towards a Post-Critical Philosophy.* Chicago: University of Chicago Press.

POLANYI, M. 1967. *The Tacit Dimension.* New York: Doubleday.

POPE, S. T. 1991. The Composer and the Computer. *Computer Music Journal.* 16 (2).

POPE, S. T. 1993. Editor's Note: Putting Max in Perspective. *Computer Music Journal.* 17 (2).

POPE, S. T. 1996. A Taxonomy of Computer Music. *Contemporary Music Review.* 13 (2), pp. 137-145.

PORT, R. F., TAJIMA, K., and CUMMINS, F. 1998. Speech and Rhythmic Behavior. *In:* SAVELSBURGH, G. J. P., VAN DER MAAS, H., and VAN GEERT, P. C. L. eds. *The Non-linear Analysis of Developmental Processes.* Amsterdam:Royal Dutch Academy of Arts and Sciences .

PREM, E. 1997. Introduction to the Special Issues/Epistemological Aspects of Embodied Artificial Intelligence. *Cybernetics and Systems.* 28 (5), pp. v-xi.

PRESSING, J. 1988. Nonlinear Maps as Generators of Musical Design. *Computer Music Journal.* 12 (2), pp. 35-45.

PRESSING, J. 1990. Cybernetic Issues in Interactive Performance Systems. *Computer Music Journal.* 14 (1), pp. 12-25.

PRIGOGINE, I. 1996. Science, Reason and Passion. *Leonardo.* 29 (1), pp. 39-42.

PRUSINKIEWICZ, P. 1985. Graphics Interfaces for MIDI-Equipped Synthesizers. *In: Proceedings of the 1985 International Computer Music Conference.* San Francisco:International Computer Music Association.

PRUSINKIEWICZ, P. 1986. Score Generation with L-systems. *in: Proceedings of the 1986 International Computer Music Conference.* San Francisco:Computer Music Association.

PRUSINKIEWICZ, P. 1995. Visual Models of Morphogenesis. *In:* LANGTON, C. G. ed. *Artificial Life: An Overview.* Cambridge, MA:MIT Press. pp. 61-74.

PRYOR, S. 1991. Thinking of Oneself as a Computer. *Leonardo.* 24 (5), pp. 585-590.

PUCKETTE, M. 1991. Combining Event and Signal Processing in the {MAX}Graphical Programming Environment. *Computer Music Journal.* 15 (3), pp. 68-77.

REICH, S. 1974. Six Pianos. *In: Drumming, Six Pianos and Music for Mallet Instruments, Voices and Organ.* Compact Disk. Deutsche Grammophon: 427 428-2.

REYNOLDS, C. 1987. Flocks, Herds and Schools: A Distributed Behavioural Model. *In: Computer Graphics: Proceedings of SIGGRAPH '87.* ACM Press.

RICHARD, D. 1996. Code-Notes-Music: An Epistemological Investigation of Algorithmic Music. *Organised Sound.* 1 (3), pp. 173-177.

RICHARDS, F. 1997. The Authenticity of the Text - When is a Work a Finished Work? *In:* HOWARD, P. and RICHARDS, F. eds. *What is Composition?* Milton Keynes:The Open University.

RINALDO, K. E. 1998. Technology Recapitulates Phylogeny. *Leonardo Electronic Almanac.* 6 (2).

RISSET, J.-C. 1994. Sculpting Sounds with Computers: Music, Science, Technology.

Leonardo. 27 (3), pp. 257-261.

ROADS, C. 1986. The Second Symposium on Interactive Composition in Live Electronic Music. *Computer Music Journal*. 10 (2), pp. 44-50.

ROBERTSON, P. 1996. Music as a model of the Human Psyche. *Contemporary Music Review*. 14 (1-2), pp. 11-37.

ROTHENBERG, D. 1994. *Hand's End: Technology and the Limits of Nature*. University of California Press.

ROTHENBERG, D. 1996. Sudden Music: Improvising across the Electronic Abyss. *Contemporary Music Review*. 13 (2), pp. 23-46.

ROWE, R. 1993. *Interactive Music Systems: Machine Listening and Composing*. Cambridge, Mass.: MIT Press.

RUCKER, R. 1987. *Mind Tools: The Mathematics of Information*. Harmondsworth: Penguin Books.

RUMSEY, F. and WATKINSON, J. 1995. *The Digital Interface Handbook*. Oxford: Focal Press.

RUSSELL, G. 1953. *The Lydian Chromatic Concept of Tonal Organization*.

RYAN, J. 1991. Some remarks on musical instrument design at STEIM. *Contemporary Music Review*. 6 (1), pp. 3-17.

SAID, E. 1979. *Orientalism*. New York: Vintage.

SALOMON, G. 1993. No Distribution Without Individual's Cognition: A Dynamic Interactional View. *In*: SALOMON, G. ed. *Distributed Cognitions: Psychological and Educational Considerations*. Cambridge:Cambridge University Press.

SCHENKER, H. 1979.*Free Composition*. OSTER, E., trans. New York: Longman. (originally published 1935).

SCHOENBERG, A. 1984.*Style and Idea: selected writings*. STEIN, L., ed. London: Faber.

SCHOLZ, C. 1991. Opcode MAX: Interactive Graphic Programming Environment (Macintosh). *Keyboard.* 17 (4), pp. 132-139.

SCHÖN, D. A. 1979. Generative Metaphor: A Perspective on Problem-setting in Social Polity. *In*: ORTONY, A. ed. *Metaphor and Thought.* Cambridge:Cambridge University Press. pp. 254-283.

SCHÖN, D. A. 1987. *Educating The Reflective Practitioner.* San Francisco: Jossey-Bass.

SCHWANAUER, S. M. and LEVITT, D. A. 1993.*Machine Models of Music.* MIT Press: Cambridge, MA.

SCRIABIN, A. 1991. *Prometheus: the Poem of Fire.* Moscow: Belaiev.

SHEEHAN, J. J. and SOSNA, M. 1991.*The Boundaries of Humanity: Humans, Animals and Machines.* Berkeley: University of California Press.

SHEPHERD, J. 1992. Music as Cultural Text. *In*: PAYNTER, J., HOWELL, T., ORTON, R., and SEYMOUR, P. eds. *Companion To Contemporary Musical Thought, Volume 1.* London:Routledge. pp. 128-155.

SILVIA, D., GAGGIOLO, A., MARTINI, M., and MORANDO, M. 1993. Man-Machine Interaction in the Study of Melodic Structures. *In*: *Proceedings of the First International Conference on Cognitive Musicology.* Department of Music, University of Jyväskylä:Finland. 169-185.

SIMON, H. A. 1969. *The Sciences of the Artificial.* Cambridge, MA: MIT Press.

SINDING-LARSEN, H. 1991. Computers, Musical Notation and the Externalisation of Knowledge: Towards a Comparative Study in the History of Information Technology. *In*: NEGROTTI, M. ed. *Understanding the Artificial: On the Future Shape of Artificial Intelligence.* London:Springer-Verlag. pp. 101-125.

SMITHERS, T. 1997. Autonomy in Robots and Other Agents. *Brain and Cognition.* 34 pp. 88-106.

SOTO, J. 1994. The Role of Scientific Concepts in Art. *Leonardo.* 27 (3), pp. 227-230.

STEELS, L. 1995. *The Biology and Technology of Intelligent Autonomous Agents*. Springer Verlag.

STRAUSS, A. L. and CORBIN, J. 1990. *Basics of Qualitative Research: Grounded Theory Procedures and Techniques*. London: Sage.

STRAVINSKY, I. and CRAFT, R. 1980. *Stravinsky in Conversation with Robert Craft*. Berkeley, CA: University of California Press.

SUDNOW, D. 1978. *Ways of the Hand: The Organisation of Improved Conduct*. London: Routledge and Kegan Paul.

TANG, P. 1984. On the Similarities Between Scientific Discovery and Musical Creativity: A Philosophical Analysis. *Leonardo*. 17 (4), pp. 261-268.

THÉBERGE, P. 1997. *Any Sound You Can Imagine: Making Music/Consuming Technology*. Hanover, NH: University Press of New England.

THELEN, E. and SMITH, L. B. 1994. *A Dynamic Systems Approach to the Development of Cognition and Action*. Cambridge, MA: MIT Press Bradford Books.

THOMPSON, R. F. 1966. An Aesthetic of the Cool: West African Dance. *African Forum*. 2 (2), pp. 85-102.

THORPE, J. 1995. Innovative Design and the Language of Struggle. *AI & Society*. 9 (2/3), pp. 258-272.

TODD, S. and LATHAM, W. 1992. *Evolutionary Art and Computers*. San Diego, CA: Academic Press.

TODOROFF, T. 1995. Real-Time Granular Morphing and Spatialisation of Sounds with Gestural Control Within Max/FTS. *In*: MICHIE, E., ed. *Proceedings of the 1995 International Computer Music Conference*. Banff, Alberta. San Francisco:International Computer Music Association. 315-318.

TOIVIAINEN, P. 1997. Modelling the Perception of Metre With Competing Subharmonic Oscillators. *In*: GABRIELSSON, A., ed. *Proceedings of the Third Triennial ESCOM Conference*. Uppsala:Uppsala University. 511-516.

TOOP, D. 1995. *Ocean of Sound: Aether Talk, Ambient Sound and Imaginary Worlds.* London: Serpent's Tail.

TRAYLE, M. 1991. Nature, Networks, Chamber Music. *Leonardo Music Journal.* 1 (1), pp. 51-53.

TRUAX, B. 1992. Musical Creativity and Complexity at the Threshold of the 21st Century. *Interface.* 21 (1), pp. 29-42.

TRUAX, B. 1996. Computer Music as Commercial or Public Culture. *Computer Music Journal.* 20 (4), pp. 27-28.

TUCKER, M. 1996. The Body Electric: The Shamanic Spirit in Twentieth Century Music. *Contemporary Music Review.* 14 (1-2), pp. 67-97.

TURBAYNE, C. M. 1962. *The Myth of Metaphor.* New Haven: Yale University Press.

VAGGIONE, H. 1996. Articulating Microtone. *Computer Music Journal.* 20 (2), pp. 33-38.

VAN GELDER, T. and PORT, R. F. 1995. It's About Time: An Overview of the Dynamical Approach to Cognition. *In*: PORT, R. F. and VAN GELDER, T. eds. *Mind as Motion: Explorations in the Dynamics of Cognition.* Cambridge, MA:MIT Press Bradford Books. pp. 1-43.

VARELA, F. J. 1979. *Principles of Biological Autonomy.* North-Holland: Elsevier.

VARELA, F. J., THOMPSON, E., and ROSCH, E. 1991. *The Embodied Mind: Cognitive Science and Human Experience.* Cambridge, MA: MIT Press.

VAUGHAN, M. 1994. The Human-Machine Interface in Electroacoustic Music Composition. *Contemporary Music Review.* 10 (2), pp. 111-127.

VIOLA, B., MACHOVER, T., and SELLARS, P. 1992. Kiss Your Tired Aesthetics Good-bye. *In*: JACOBSON, L. ed. *Cyberarts: Exploring Art and Technology.* San Francisco:Miller Freeman. pp. 3-10.

VYGOTSKY, L. S. 1978. *Mind and Society* . Cambridge, MA: Harvard University Press.

WATERMAN, R. A. 1952. African Influence on the Music of the Americas. *In*: TAX, S., ed.

Acculturation in the Americas: Proceedings and Selected Papers of the 29th International Congress of Americanists. Chicago:University of Chicago Press.

WATERS, S. 1994. Timbre Composition: Ideology, Metaphor and Social Process. *Contemporary Music Review*. 10 (2), pp. 129-134.

WATERS, S. 1997. *Beyond the Acousmatic: Hybrid Tendencies in Electroacoustic Music*. Swedish Section of the ICEM.

WEBERN, A. 1963. *The Path to New Music*. London: Theodore Presser Universal Edition.

WESSEL, D. L. 1991a. Improvisation with Highly Interactive Real-Time Performance Systems. *In*: ALPHONCE, B. and PENNYCOCK, B., eds. *Proceedings of the 1991 International Computer Music Conference*. Montreal, Canada. San Francisco, CA:International Computer Music Association. 344-347.

WESSEL, D. L. 1991b. Instruments That Learn, Refined Controllers, and Source Model Loudspeakers. *Computer Music Journal*. 15 (4), pp. 82-86.

WHEELER, M. 1996. From Robots to Rothko. *In*: BODEN, M. A. ed. *The Philosophy of Artificial Life*. Oxford:Oxford University Press. pp. 209-236.

WHITBY, B. R. 1988. *AI: A handbook of Professionalism*. Chichester: Ellis Horwood.

WIENER, N. 1948. *Cybernetics, or, Control and Communication in the Animal and the Machine*. Cambridge, MA: Technology Press.

WILDEN, A. 1987. *The Rules Are No Game: The Strategy of Communication*. New York: Routledge and Kegan Paul.

WILLIAMS, R. 1965. *The Long Revolution* . Harmondsworth: Penguin Books.

WINKLER, T. 1998. *Composing Interactive Music: Techniques and Ideas Using Max*. Cambridge, Massachusetts: MIT Press.

WINOGRAD, T. 1979. Beyond Programming Languages. *Communications of the Association for Computing Machinery*. 22 (7), pp. 391-401.

WINOGRAD, T. and FLORES, F. 1987. *Understanding Computers and Cognition: A New*

Foundation for Design. Reading, Massachusetts, USA: Addison-Wesley.

WOOD, J. 1996. The idea of academic 'rigour' in 4-D space: Dynamics of the IDEAbase 'situated knowledge system'. *In*: ROBERTSON, A., ed. *4D Dynamics Conference on Design and Research Methodologies for Dynamic Form.* De Montfort University, Leicester. School of Design & Manufacture, De Montfort University:Leicester.

WRIGHT, M. 1994. A Comparison of MIDI and ZIPI. *Computer Music Journal.* 18 (4).

XENAKIS, I. 1974. *Formalized Music. Thought and Mathematics in Composition.* Bloomington, IN: Indiana University Press.

YAZDANI, M. and WHITBY, B. R. 1987. Artificial Intelligence: Building Birds out of Beer Cans. *Robotica.* 5 pp. 89-92.

ZEKI, S. 1999. Art and the Brain. *Journal of Conscious Studies.* 6 (6-7), pp. 76-96.