Music interaction: understanding music and human-computer interaction

Book Section

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1. Introduction

This book presents state of the art research in Music and Human-Computer Interaction (also known as 'Music Interaction'). Research in Music Interaction is at an exciting and formative stage, as this book examines in detail.

The book covers a wide variety of topics including interactive music systems, digital and virtual musical instruments, theories, methodologies and technologies for Music Interaction. Innovative approaches to existing musical activities are explored, as well as tools that make new kinds of musical activity possible. The musical activities covered are similarly diverse, and include composition, performance, practice, improvisation, learning, analysis, live coding, and collaborative music making, with participants ranging from laypeople and music beginners to music professionals.

Music Interaction has serious implications for music, musicians, educators, learners, and those seeking deeper involvement in music. But Music Interaction is also a valuable source of challenges, new ideas and new techniques for Human-Computer Interaction (HCI) more generally, for reasons explored below.

Ball (2010) assembles a series of observations about music. There are some societies without writing and some even without visual arts, but there are none without music. Music is an evolutionary, deeprooted, complex social activity, hypothesized by some researchers to have origins older than language (Wallin et al. 2000). Ethnographers and ethnomusicologists have documented a wide range of social functions for music in different cultures. These functions include social cohesion and group bonding, social criticism, subversion, celebration, calming, institutional stability, work co-ordination, mother-child bonding, courtship, behaviour modification and mood alteration (Wallin et al. 2000; Cross 2001).

Unlike many human activities, such as vision and language, which primarily use localised parts of the brain, music seems to involve almost all of the brain (Ball 2010). Many musical activities involve the whole body, and involve real time co-ordination with other people, while also making significant perceptual and cognitive demands (Leman 2007). Despite the rich array of human capabilities involved in music, engagement with music is often one of the very last higher mental abilities that remain for sufferers of diseases such as Alzheimer's disease (Svansdottir and Snaedal 2006).

Since prehistory, humans have worked over millennia to develop and refine interactive musical technologies ranging from bone flutes to synthesizers. We posit that from a Human-Computer Interaction perspective, such instruments may be viewed as elements in larger socio-technical systems whose components also include performers, composers, repertoires and audiences. The creators and refiners of such instruments typically take pains to create instruments capable of high degrees of expression, and which allow precision and fluency of real time control. Players of such instruments often pay painstaking attention to the effect they have on listeners' experience (even though the listener and player may be the same person). These longstanding preoccupations of musicians have striking commonalities with some of the concerns of modern day Human-Computer Interaction.

From one perspective, Music Interaction may be viewed as a sub-discipline of Human-Computer Interaction, just as Human-Computer Interaction may be viewed as a sub-discipline of Computer Science (or just as Computer Science was once viewed as a sub-discipline of Electrical Engineering). But these are not always the most useful perspectives. Music Interaction borrows countless elements from HCI, and in general is held to the same standard as HCI research. But at the same time, the practice of Music Interaction is intimately bound up with the practices of the music community. For many purposes, Music Interaction must answer to that community. When competing practices conflict, sometimes the judgements of the music community will take precedence. After all, what good is an interactive musical system if it is poor for musical purposes?

To put it another way, because the music community has its own longstanding traditions in the rigorous treatment of interactive systems, Music Interaction has concerns that can sometimes extend beyond the consensus disciplines of HCI. Thus while Music Interaction has great commonality with present day HCI, there are subtle differences in perspective. For these and other reasons, Music Interaction has been, and remains, well placed to make distinctive contributions to HCI. Example contributions from Music Interaction to mainstream HCI include the following:

- In the early days of HCI research, much (though not all) interaction research was limited to command line interfaces. Buxton and colleagues were able to develop a new and influential body of research on gestural interaction for HCI (Buxton et al. 1979) by drawing directly on the needs, traditions and instincts of musicians (though there is also a wider story, as we outline below).
- The commercial development of the data glove, hand tracking technologies, and virtual reality systems stemmed more or less directly from Zimmerman's desire to hear himself play air guitar (Zimmerman et al. 1986; Lanier 1989).
- The Reactable project (Jorda et al. 2006), motivated directly by Music Interaction challenges, led the way in contributing several innovative and influential frameworks and tools for touch-based and tangible interaction.

It would be wrong to claim credit exclusively for Music Interaction in any of the above instances. For example, Buxton (2008) is careful to acknowledge that his pioneering music-related HCI work was informed by previous HCI research on bi-manual input from Engelbart and English (1969) and Sutherland (1963). Buxton notes:

> One thing that I want to emphasize is that the real objective of the system's designers was to study human-computer interaction, not to make a music system. The key insight of Ken Pulfer, who spearheaded the music project, was that to do this effectively he needed to work with users in some rich and potent application domain. And he further realized that music was a perfect candidate. Musicians had specialized skills, were highly creative, what they did could be generalized to other professions, and perhaps most of all – unlike doctors, lawyers and other "serious" professions – they would be willing to do serious work on a flaky system at all hours of the day and night. Buxton (2008)

These tendencies of Music Interaction researchers are another reason for the continuing vigour of Music Interaction research, and its contributions to HCI.

1.1 The origins of this book

This book grew out of the 2011 BCS HCI refereed International Workshop on Music and Human-Computer Interaction, entitled "When Words Fail: What can Music Interaction tell us about HCI?". Following the workshop, a selection of the papers were elaborated, extended and submitted to a refereeing process for inclusion in this book. One book chapter was submitted by authors who had been unable to attend the workshop. The workshop included sessions where subgroups discussed mutually agreed research topics. One such subgroup wrote chapter 2, "Should Music Interaction be Easy?".

Note that the style of referencing used in this book is designed to deal with two different modes of dissemination: as a book, and as individually downloadable chapters.

2. Music Interaction FAQ

In the remainder of this chapter, we will give an overview of the contents of this book and of the themes and issues raised. When organising such an overview, the diverse perspectives adopted by different Music Interaction researchers tend to make any single classification system unsatisfactory. The chapters have overlapping perspectives, themes and issues, but these form interconnected networks rather than a single tree. For this reason we have structured this overview as an FAQ. This allows some FAQs to focus on cross cutting issues that appear in two or more chapters, and some chapters to appear in several FAQs, while other FAQs focus principally on a single chapter. Some of the FAQs may better fit Graham's (2011) notion of Rarely Asked Questions – questions asked once or twice, but which seem interesting.

The FAQs

(Some FAQ titles appear above in abbreviated form.)

2.1 What is Music Interaction?

Music Interaction refers to "Music and Human-Computer Interaction". Music Interaction encompasses the design, refinement, evaluation, analysis and use of interactive systems that involve computer technology for any kind of musical activity, and in particular scientific research on any aspect of this topic. Music Interaction typically involves collaboration between researchers, interaction designers and musicians, with individuals often able to play more than one of these roles.

2.2 What is a Digital Luthier?

A luthier is traditionally someone who makes or repairs stringed instruments. A digital luthier (Jorda 2005) is someone who designs and makes digital musical instruments, or who designs and makes digital augmentations to instruments. Music Interaction has a considerably wider scope than digital musical instruments alone, but digital luthiers are a respected part of the Music Interaction community.

2.3 What is the scope of research in Music Interaction?

Music Interaction covers a wide variety of research. There are several reasons for this. Firstly, musical roles themselves are varied (e.g., digital luthier, composer, performer, analyst, soloist, accompanist, listener, amanuensis, timbre designer, improviser, learner, teacher). Secondly, many of these roles can be played by individuals or groups, and by humans or machines, or by some combination thereof. Musical materials themselves are multidimensional (e.g. they may involve melody, rhythm, harmony, timbre, gesture, language, sound, noise, and various kinds of expressivity). Diverse social contexts, genres and repertoires in music span wide ranges of human experience. Beyond the kinds of variety inherited from music itself, Music Interaction research spans diverse research areas. As noted earlier these include interactive music systems; digital musical instruments; virtual instruments; theories, frameworks, methodologies and technologies for Music Interaction; new approaches to traditional musical activities; and tools that make new kinds of musical activity possible. Interaction styles also vary widely, and may involve gesture, interface metaphor, conceptual metaphor, conceptual integration, non-speech voice control, formal language, and many other approaches. The chapters in this book populate various broadly representative points in this large multi-dimensional space.

2.4 Should Music Interaction be Easy?

In 1989, at a NATO Science workshop on Interface Design in Education Sterling Beckwith (1992), the pioneer computer music educator, reflected on music interfaces for beginners, and enquired whether ease of use was an appropriate goal for interfaces for music education. In the workshop, Beckwith drew on his personal experience with the composition teacher Nadia Boulanger, whose pedagogical strategies, he noted, often involved making musical actions harder for students, rather than easier. Such an approach may be viewed as a special case of a general technique for encouraging creativity in the arts by adding constraints (Holland 2000), or, from a psychological perspective, as adding costs to encourage greater mental evaluation before action (O'Hara and Payne 1998).

The issue of whether Music Interaction should be easy was an insightful question to raise at a time when HCI focused predominantly on usability and ease of use. Parts of this question have been explored before, for example, by Wessel and Wright (2002) in an examination of virtuosity. But in Chapter 2 of this book, McDermott et al. (2013a) focus squarely on this issue in detail. As Wallis et al. (2013) observe in chapter 3, the concept of 'ease of use' sits a little uneasily with musical instruments, since:

> One does not "use" an instrument to accomplish some ultimate goal: one plays it, and often that is the only goal.

Two issues that McDermott et al. consider are *engagement* and *flow* (Csikszentmihalyi 1991) for Music Interaction design. In order to remain engaging, consuming and flow-like, activities that involve musical instruments must offer continued challenges at appropriate levels of difficulty: not too difficult, and not too easy. However, as McDermott et al. argue, an activity which remains engaging in the long term often does so at the expense of being rather painful to a beginner—in other words there is a trade-off between ease of learning and long-term power and flexibility (Gentner and Nielsen 1996).

McDermott et al. argue that activities such as: instrumental performance and practice; recording, mixing and production; live-coding and turntabling; the study of theory and notation; are all activities which take place in sessions that can last for hours and must be mastered over years. Therefore the best interfaces for these tasks tend to fall towards the long-term power end of the trade-off. When the end-goal of an activity is for the sake of enjoyment of the activity itself, a suitable level of difficulty becomes acceptable and even beneficial.

McDermott et al. also consider the issue of transparency. This feeling is important to instrumentalists as artists and to skilled use of tools and systems in general. As Leman (2007) observes,

> "Transparent technology should [...] give a feeling of non-mediation, a feeling that the mediation technology 'disappears' when it is used"

Leman suggests that the capacity for an instrument (in the hands of an experienced player) to disappear from consciousness transforms it into

> "a conduit for expression rather than an object in its own right"

The issue of the distinction between embodied cognition and symbolic mental processing is considered. Embodied cognition is a view of perception in which perception and action are inextricably linked (Wilson 2002). Leman (2007) argues that musical experience involves embodied cognition, rather than symbolic mental processing.

Finally chapter 2 conducts a detailed examination of various different dimensions of difficulty that can apply in Music Interaction – concluding that some are avoidable and some unavoidable.

2.5 How can Music Interaction benefit traditional musical instruments and their players?

In chapter 7 of this book, McPherson and Kim (2013) explore how perspectives drawn from Music Interaction can be used to cast light on the nature of expressive expert performance on traditional keyboard instruments. They further use the resulting analysis to pioneer new and subtler means of expression. McPherson and Kim take as a starting point the objective measurement of the results of striking a traditional piano key. The striking velocity is shown, for most practical purposes, to be the sole determinant of the sound produced by a given note. This is contrasted with the subjective experience of expert players who carefully control diverse aspects of the gestures they make, in order to influence specific expressive outcomes.

Drawing on empirical studies by Goebl et al. (2008) and Suzuki (2007), McPherson and Kim confirm that the differences in objectively measured note production produced by diverse carefully executed variants in aspects of gesture are negligible. However, they argue that there is strong evidence that for expert performers, the overall sequence of gestures constitute a key part of how the performer is able to conceive of, remember and integrate an expressive performance. McPherson and Kim go on to identify specific dimensions of key motions that are important for expert performers, and use principal components analysis to establish a meaningful correlation between these dimensions of movement and expressive intent. This work has several useful outcomes. Firstly, it aids our understanding of the nature of expert expressive keyboard performance. Secondly it exemplifies one way in which embodied cognition can illuminate music cognition and Music Interaction (see also 2.9 in this chapter). Thirdly, it provides a solid foundation for pioneering more subtle means of expression in innovative keyboard instruments.

2.6 How can Music Interaction be applied to interaction in non-musical domains?

There is a large research literature on sonification and auditory user interfaces – loosely speaking, user interfaces that employ non-speech audio to communicate information – though this is a broad field. A good place to start exploring such research is the annual proceedings of ICAD, the International Conference for Auditory Display, for example Bearman and Brown (2012). Music Interaction research has some overlaps with sonification, for example where musical tones are used to communicate information in the background (Brewster et al. 1993). However, Music Interaction research has other kinds of application in domains that are not themselves musical – for example Affective Music Interaction, as outlined below. Chapter 4 (Bramwell-Dicks et al. 2013) and chapter 10 (Kirke and Miranda 2013) in this book explore two illuminating possibilities for applying Music Interaction to non-musical purposes.

2.6.1 How can music be used to alter users' behaviour and experience in non-musical applications?

In user interfaces for non-musical domains, when music or audio is part of interaction design, the purpose is generally to communicate information, sometimes redundantly, or to take advantage of background human auditory pattern recognition (Bearman and Brown 2012; Brewster et al. 1993) or to help focus attention when needed.

In chapter 4 of this book, Bramwell-Dicks et al. (2013) examine the use of music in interaction design for a different purpose – namely to alter users' behaviour and experience – i.e. for persuasive and affective purposes. Chapter 4 explains that the use of music to affect mood and behaviour in real world contexts has been the subject of a great deal of research, for example in supermarkets, religious ceremonies, cinema, medical procedures, casinos, sports performance, and telephone hold systems. In such contexts, consistent measurable changes in behaviour and experience have been identified. There has been less research focusing on computer-mediated systems – where the technique is known as 'Affective Musical Interaction' – but there have been some studies in computer-related areas such as computer gaming, virtual learning environments and online gambling (Bramwell-Dicks et al. 2013). This chapter presents a case study examining an affective musical extension designed for general computing. The case study focuses in particular on modifying users' behaviour when using email clients.

2.6.2 How can computation be organised to communicate emotion musically?

In chapter 10 of this book, Kirke and Miranda (2013) propose an imaginative reorganisation of the fundamentals of computing, dubbed "Affective Computation". The aim is to give all executing processes properties such that users may aurally monitor them in terms of emotional states. The proposal starts from the smallest elements of computation (bits, bytes and logic gates – for example as implemented in virtual machines) and continues up to higher levels of computational organisation such as communication protocols and collaborating agents. Models of computation generally prioritise efficiency and power, but Kirke and Miranda propose partially trading off efficiency in return for better emotional understandability by users, in the following sense. Taking the Valence/Arousal model of emotion as a starting point (Kirke and Miranda 2009), this chapter reviews existing research about musical ways of communicating emotions, and considers how this might be applied to data streams. A proposal is made for encoding data streams using both pulse rates and pitch choice in a manner appropriate for general computation, but which can also encode emotional states. Music Logic gates are then specified which can simultaneously process data and, as an inherent side effect, modulate representations of emotional states. The paper then presents three case studies: a simulation of collaborating military robots; an analyser of emotion in texts; and a stock market analyser. Through the case studies, the case is made that such a framework could not only carry out computations effectively, but also communicate useful information about the state of computations. Amongst other benefits, this could provide diagnostic information to users automatically, for example in the case of hardware malfunction.

2.7 What lessons does the experience of 'being in the groove' offer for Music Interaction?

In chapter 5, Swift (2013) analyses improvisational group music making, or jamming, and considers what implications can be drawn for Music Interaction design and HCI more generally. Swift argues that musicians who are jamming are generally not motivated by money, nor audience, or by reputation (see also sections 2.10 and 2.15 in this chapter). Rather, what is sought is the feeling of "being in the groove". This term can have several meanings, some of which have been explored by ethnomusicologists such as Doffman (2009), and by musicologists such as Hughes (2003). The notion of being in the groove that Swift examines has strong links with the ideas of flow (Csikszentmihalyi 1991) and group flow, as studied in musical and other improvisational contexts by Sawyer and DeZutter (2009). Swift notes:

> "The jamming musician must both play and listen, act and react; balancing the desire to be fresh and original with the economies of falling back on familiar patterns and the need to fit musically with the other musician"

Swift presents a longitudinal study of musicians learning to improvise and interact via a novel iPhone-based environment called *Viscotheque*, and proposes a range of approaches to explore the nature of jamming more deeply. Swift argues that as general computing continues to impinge on creative, open-ended task domains, analysis of activities such as jamming will increasingly offer lessons to HCI more generally.

2.8 What issues face agents for real-time collaborative improvisation?

In chapter 16, Gifford (2013) examines in detail the issues faced in the design of real time improvisatory agents that play in ensembles, typically alongside human improvisers. Real time improvisatory agents must generate improvised material that is musically appropriate and that fits in with the rest of the ensemble. If they do not contribute anything new, their contribution risks being boring. This mirrors the more general need in music for a balance between predictability and novelty, to avoid the twin dangers of boredom or incoherence (Holland 2000). Gifford traces related analyses back to Aristotle's theory of mimesis (350 BCE), Meyer's tension-release theory of expectation and ambiguity (1956), Narmour's expectation theory of melody (1990) and Temperley's cognitive approach to musical structure (2001). The issue of ambiguity in this context as noted by Meyer and others has interesting links with Gaver's (2003) analysis of ambiguity as a resource for HCI designers.

In order to explore the need for improvisatory agents both to fit in with others and generating appropriate novelty, Gifford presents a system that balances both imitative and inference-based techniques. Imitative techniques are an example of what Rowe (1993) calls transformative systems, and the inference-based techniques are an example of Rowe's category of generative systems. Gifford notes that from a Music Interaction point of view, a key characteristic of the inference-based component of such systems is that they must be "humanly tweakable". Other important issues in agent improvisation include: criteria for switching between imitative and intelligent action; criteria for deciding which kinds of imitative actions to initiate and when; and criteria for deciding how much latitude to allow in imitation.

2.9 What can the study of Embodied Cognition offer to Music Interaction?

Embodiment in cognitive science is associated with the view that many kinds of knowledge, cognition and experience are intrinsically bound up with gesture, perception and motor action, rather than with symbolic processing (Leman 2007). The view that musical knowledge, cognition and experience are embodied has long been a theme (both explicitly and implicitly) in music-related research disciplines, for example in ethnomusicology (Baily 1977; Blacking 1997); in music psychology (Clarke 1993; Todd 1989); and in computer music (Desain and Honing 1996; Waiswisz 1985) More recently, Zbikowski (1997a, 1997b), Leman (2007) and others have offered evidence that many musical activities are carried out through mechanisms of embodied cognition, rather than symbolic mental processing.

Embodiment has also become highly influential in HCI, as part of the so-called third wave of HCI (Harrison et al. 2007), and in connection with physicality and tangible interaction (Hornecker 2011). An influential early account of the implications of embodiment for interaction design can be found in Dourish's seminal work (2001) on Embodied Interaction.

Dourish argued that the shift towards embodied perspectives in HCI was driven by "the gradual expansion of the range of human skills and abilities that can be incorporated into interaction with computers". Subsequent research in embodiment explored diverse views: Anderson (2003) surveyed three contrasting approaches grounded in three different traditions (namely, Artificial intelligence, Linguistics, and Dourish's philosophically grounded approach); Rohrer (2007) enumerated twelve different dimensions of embodiment in cognitive science ranging from neurophysiology and conceptual metaphor to phenomenology; Klemmer et al. (2006) itemized five thematic implications for interaction design as follows: *thinking through doing, performance, visibility, risk, and thickness of practice.* As regards the last of these thematic implications, notions of 'communities of practice' have particular relevance to Music Interaction. Klemmer et al. (2006) explored the roles that well designed interfaces can play in learning by doing, and learning in communities of practice. There are many ways in which embodied perspectives can be put to good use in Music Interaction. In broad terms, embodiment encourages a focus on gesture and perception and on physical and tangible interaction styles - for examples see: chapter 7 (McPherson et al. 2013); chapter 6 (Bouwer et al. 2013a); and chapter 12 (Bouwer et al. 2013b).

However, there are other, less obvious ways of exploiting embodied cognition in Music Interaction. In chapter 15, Wilkie et al. (2013) suggest a way in which universal low-level sensorimotor patterns can be exploited to simplify Music Interaction of more or less any kind, whether overtly physical or not.

2.9.1 How can Embodied Cognition be applied systematically to Music Interaction?

In chapter 15, Wilkie et al. (2013) focus on a specific detailed theory of embodied cognition, the theory of conceptual metaphor (Lakoff and Núñez 2000; Johnson 2005; Rohrer 2005, 2007) and its application to Music Interaction design. Note that this approach is distinct from the older and better-known approach of user interface metaphor (Preece at al. 1994) which utilizes familiar aspects of the domain in order to assist users in making inferences about the behavior and operation of interactive systems.

By contrast, the theory of conceptual metaphor draws on linguistic and other evidence to argue that all human cognition is grounded in universal low-level sensory motor patterns called image schemas (Lakoff and Núñez 2000; Johnson 2005; Rohrer 2005, 2007). Many image schemas have associated special purpose inference mechanisms. For example, the CONTAINER image schema is associated with reasoning about containment relationships.

Conceptual metaphor theory details how image schemas, and their associated inference mechanisms can be mapped onto other concepts to create new cognitive mechanisms, which can then be composed to deal with any kind of cognitive activity. For example, the CONTAINER image schema is mapped onto abstract concepts to allow reasoning about abstract forms of containment, such as categories.

In order to apply this approach to embodiment to Music Interaction design, Wilkie et al. review previous work in applying conceptual metaphor theory to user interface design and to music theory. Previous work has suggested that interface design approaches based on conceptual metaphor can make interaction more intuitive and more rapid to use (Hurtienne and Blessing 2007) and can be used to identify points of design tension and missed opportunities in interface design (Wilkie et al. 2010). Wilkie et al. propose a method by which an approach using conceptual metaphors can be used to guide participative design of new musical interfaces. This approach is of wide generality, and could be applied in principle to any kind of Music Interaction.

2.10 How does Collaborative Digital Music Interaction contrast with collaboration in HCI?

One of the distinctive challenges of Music Interaction research is to explore ways in which technology can help people to make music together. Such approaches can be diverse. For example, the Reactable (Jorda et al. 2006), and earlier systems such as Audiopad (Patten et al. 2002) created new approaches to collaborative musical systems based on touch surfaces. By contrast, NINJAM (Mills 2010) offers quasi-real time musical collaboration over the Internet by sharing synchronised compressed audio from distributed participants. NINJAM sidesteps uncontrollable variations in network latency by delaying all contributions by precisely one measure. In a further, contrasting approach, Song Walker Harmony Space (Holland et al. 2011) makes use of asymmetrical collaborative whole body interaction. The word 'asymmetrical' here indicates a departure from the traditional collaborative approach to performing tonal harmonic sequences. Traditionally, each participant contributes a voice or instrumental part. By contrast, in this particular asymmetrical approach, different participants are responsible for different layers of abstract musical structure e.g. harmonic path, modulation and inversion (see chapter 12 of this book, Bouwer et al. 2013b). Further, by rotating their roles, participants can discover how such harmonic abstractions interact. Because enacting each role involves physical movements of the whole body, awareness of others' actions and intentions is promoted. By this and other means, this design makes use of embodiment and enaction to provide concrete experience of abstract musical structures (see also section 2.9 of this chapter and Stoffregen et al. 2006).

Diverse approaches to collaborative music making, such as the three approaches outlined above, reflect the diversity of approaches in Music Interaction. Two chapters that explore distinctive aspects of collaborative digital Music Interaction in detail are outlined below.

2.10.1 How does research in collaborative forms of Music Interaction relate to CSCW?

In chapter 11 of this book, Fencott and Bryan Kinns' (2013) work on collaborative Music Interaction draws on the discipline of Computer Supported Cooperative Work (CSCW). This is a specialized area of

HCI that focuses on the nature of group work and the design of systems to support collaboration. CSCW emphasizes social context and borrows from related disciplines such as ethnography and distributed cognition.

Fencott and Bryan Kinns note that many systems for collaborative musical interaction require specialised hardware. The resultant inaccessibility tends to inhibit widespread take-up of otherwise useful systems. This leads Fencott and Bryan-Kinns to focus on commonplace tools such as laptops as vehicles for musical collaboration, and on the development of collaborative software to match. Traditional philosophies and theories of music emphasize the role of concrete musical artifacts such as scores and recordings. By contrast, chapter 11 makes use of Small's (1998) argument that in collaborative contexts, instances of creative behaviour, and perceptions, or responses to them, are a more useful focus (see also section 2.7 in this chapter). In order to help frame distinctions between CSCW in general, and Computer Supported Musical Collaboration in particular, chapter 11 draws on Small's (1998) notion of 'Musicking'. This viewpoint sees many kinds of musical engagement as social rituals through which participants explore their identity and relation to others. Other useful perspectives include Flow (Csikszentmihalyi 1991) and Group Flow (Sawyer and DeZutter 2009). Fencott and Bryan Kinns have created custom designed collaborative software for their empirical work to explore how different software interface designs affect characteristics such as: group behavior; emergent roles; and subjective preferences. Key issues include privacy, how audio presentation affects collaboration, how authorship mechanisms alter behavior, and how roles are negotiated.

2.10.2 How can social science methodologies be adapted to study Collaborative Music Interaction?

In chapter 14, Xambo et al. (2013) focus on shareable musical tabletops, and examine how video analysis can be used for various purposes: to improve interaction design; to better understand musical group interactions; and to explore the roles that coordination, communication and musical engagement play in group creativity and successful performance. Various approaches, concepts and distinctions that are useful in evaluating new musical instruments are considered. These approaches include:

- task-based evaluation (Wanderley and Orio 2002);
- open task approaches (Bryan-Kinns and Hamilton 2009);
- musical metaphors for interface design (Bau, Tanaka and Mackay 2008);
- measures of degrees of expressiveness and quality of user experience (Bau et al. 2008; Kiefer et al. 2008; Stowell et al. 2008);
- usability versus usefulness (Coughlan and Johnson 2006), and
- measures of collaboration such as mutual engagement (Bryan-Kinns and Hamilton 2009).

Xambo et al. note that analytic and methodological techniques for exploring collaborative Music Interaction typically draw on the tradition of video-based studies of interaction in social sciences (Jordan and Henderson 1995; Heath et al. 2010). This chapter explores how these methodologies and approaches such as grounded theory (Glaser and Strauss 1967, Lazar et al. 2009) can be better adapted for the needs of exploring collaborative Music Interaction.

2.11 What is the role of Evolutionary Interaction in music?

Evolutionary computing encompasses a range of loosely biologically inspired search techniques with general applications in computer science. These techniques tend to have in common the following: an initial population of candidate solutions to some problem; a fitness function to select the better solutions (for some executable notion of "better"); and techniques (sometimes, but not always, mutation and recombination) that can use the survivors to create new promising candidate solutions. Evolutionary computing is typically highly iterative, or highly parallel, or both, and is generally suited to large search spaces. Evolutionary computing techniques have been widely applied in music computing, particularly for composition (Biles 1994; Collins 2008; MacCallum et al. 2012) and less often for sound synthesis (McDermott et al. 2007; Seago 2010). Music often involves large multidimensional search spaces, and in that respect is well suited to evolutionary computation. However, for many musical purposes, some human intervention is needed to guide search in these spaces, which gives rise to crucial issues in Music Interaction. Two chapters in this book examine contrasting perspectives on these Music Interaction issues.

In their examination of evolutionary interaction in music in chapter 13, McDermott et al. (2013b) note that much research in interactive evolutionary computing in music has focused on music representation. This has had the great merit of allowing evolutionary search to be carried out on high-level musical structures rather than relying on laborious note-level search. But McDermott et al. note that far less attention has been paid to applying insights from HCI to the conduct of the search. Two of the principal Music Interaction issues identified in chapter 13 are as follows. Firstly, for many musical purposes, the selection or 'fitness' decisions involve aesthetic judgements that are hard to formalise. Consequently human interaction is typically required for each round of the evolutionary process. But crucially, human decisions are much slower than machine decisions – a problem known as the fitness evaluation bottleneck (Biles 1994). Therefore, as chapter 13 points out, interactive evolutionary computation of all kinds is typically restricted to small populations and few generations. Even then, without careful interaction design, "users become bored, fatigued, and annoyed over long evolutionary runs" (Takagi 2001). The second principal Music Interaction issue that McDermott et al. identify is that, typically, the fitness evaluation interaction paradigm does not allow much flexibility and creative use. There is a risk that users simply end up working on an assembly line composed of repetitive choices. Chapter 13 (McDermott et al. 2013b) explores in depth, with case studies, strategies by which the application of approaches from Music Interaction might address this situation.

By contrast with the focus in chapter 13 on applying evolutionary interaction to composition, in chapter 9, Seago (2013) considers musical timbre design. Musical timbre is complex and multidimensional, and there is a 'semantic gap' between the language we use to describe timbres, and the means available to create timbres (Seago et al. 2004). In other words, most musicians find it hard, using existing synthesis methods, to generate an arbitrary imagined sound, or to create a sound with given properties specified in natural language. This does not generally reflect a limitation of the expressivity of synthesis methods, but rather a Music Interaction problem. After reviewing various potential approaches, Seago explores how an evolutionary interaction approach can be applied to the timbre design problem. The broad idea is that a user selects among candidate timbres, which are used to seed new candidates iteratively until the desired timbre is found.

Various kinds of timbre spaces are examined, and criteria necessary for timbre spaces to support such an approach are established. Seago then describes the search procedure employed to generate fresh candidates in a case study timbre design system. The fundamental interaction design behind this approach is amenable to a variety of tactically different design instantiations. A representative set of variant designs are compared empirically.

2.12 What Music Interaction issues are raised by rhythm?

Music, unlike, say, painting or architecture, is organized in time. Rhythm plays a central role in the temporal organization of music. Rhythm also plays a key role in organising the attentional resources of the listener (Thaut 2005). In the case of visual input, fragments of visual information gathered from discontinuous saccades (i.e. fast eye movements) are unconsciously assembled into a subjectively smooth visual field. Similarly, when we listen to music and other rhythmic sounds, our subjective experience of a continuously available stream of sound is assembled without conscious intervention from fragments of information gathered during bursts of aural attention whose contours depend on the periodicity of the sound. This process helps to husband the limited cognitive resources available for live processing of auditory data.

Early theoretical treatments of rhythm musicology stressed organising principles such as poetic feet (Yeston 1976) and emphasised a priori integer ratio treatments of meter and polyrhythm (Lerdahl and Jackendoff 1983). However, more recent theories (Large 2008) describe phenomena such as meter as emergent features of the way our brains perceive and process periodic events, using biological mechanisms of neural entrainment (Angelis et al. 2013). Due to the temporal nature of rhythm and its relationship to entrainment and attentional resources, embodied and enactive approaches (Dourish 2001; Stoffregen et al. 2006) to Music Interaction that engage with active physical movement rather than symbolic representation alone can be particularly appropriate.

Chapter 6 (Bouwer et al. 2013a) explores an example of such an approach, through a Music Interaction system for rhythm called the Haptic Bracelets. The Haptic Bracelets are designed to help people learn multi-limbed rhythms, that is, rhythms that involve multiple simultaneous streams. Multi-limbed rhythm skills are particularly important for drummers, but are also relevant to other musicians, for example particularly piano and keyboard players. Dalcroze and others (Holland et al. 2010) suggest that the physical enaction of rhythm plays an important role in the full development not only of performance skills, but also of skills in composition and analysis. Beyond music, there are claims that these skills may contribute to general well being, for example in improving mobility (Brown 2002) and alertness, and helping to prevent falls for older people (Juntunen 2004; Kressig et al. 2005). The development of skills of this nature may also be relevant in rehabilitation, for example from strokes or injury (Huang et al. 2010). In chapter 3, Wallis et al. (2013) explore some of the possibilities for rhythm games in connection with Parkinson's disease.

Chapter 6 investigates in particular how well the Haptic Bracelets can help wearers to learn multi-limbed rhythms in the background while they focus their attention on other tasks such as reading comprehension.

2.13 How much HCI is used in Music Interaction?

Up until recently, many designers of new musical instruments (though this is only one part of Music Interaction research) have paid less attention than might be expected to HCI research when designing and evaluating new musical instruments. This is reflected in the history of two relevant scientific conferences. The ACM SIGCHI Conference on Human Factors in Computing Systems (CHI) is the principal scientific conference for Human Computer Interaction. The 'New Instruments for Musical Expression' conference (NIME) is the premier conference focused on scientific research into new musical instruments and new means of musical expression. Historically, NIME began life as a workshop at CHI in 2001. However, the nascent NIME community very quickly opted instead to form an independent conference. Xambo et al. (2013), in chapter 14 of this book, note that as NIME developed:

> an analysis of the NIME conference proceedings (Stowell et al. 2008) shows that since the beginning of the conference in 2001 (Poupyrev et al. 2001), few of the papers have applied HCI methods thoroughly to evaluate new music instruments

There may be good reasons for this. Sengers (2006), in the wider context of design, queried the extent to which it is beneficial for interaction design to become 'scientific; and made a "plea for a recognition of creative design's unique epistemological status". Linson (2011) makes a related point in the context of digital musical instrument design. However, Xambo et al. go on to observe

> …. the benefits of adapting HCI evaluation to these novel interfaces for music may benefit both the designers who can improve the interface design, and the musicians who can discover or expand on the possibilities of the evaluated tool ……

In chapter 8, Stowell and McLean (2013) observe:

> Wanderley and Orio (Wanderley and Orio 2002) made a useful contribution to the field by applying experimental HCI techniques to music-related tasks. While useful, their approach was derived from the "second wave" task-oriented approach to HCI, using simplified tasks to evaluate musical interfaces, using analogies to Fitts' Law to support evaluation through simple quantifiable tests. This approach leads to some achievements, but has notable limitations. In particular, the experimental setups are so highly reduced as to be unmusical, leading to concerns about the validity of the test. Further, such approaches do not provide for creative interactions between human and machine.

Still, in recent years, HCI has greatly broadened its perspectives, methods and techniques. The growth of the third wave of HCI, which draws on influences such as ethnography, embodied cognition, phenomenology and others has led HCI to embrace a range of perspectives, including the value of ambiguity, values related to play and games, and the importance of experiential characteristics (Dourish 2001; Harrison et al. 2007). A steady stream of new applications and adaptions of mainstream HCI ideas to Music Interaction can be seen in the literature. To take just a few examples: Borchers (1999) applied HCI patterns to the design of interactive music systems; Wanderly and Orio (2002) advocated the systematic borrowing of tools from HCI for musical expression; Hsu and Sosnick (2009) considered approaches borrowed from HCI for evaluating interactive music systems; O'Modhrain (2010) proposed a framework for the evaluation of Digital Musical Instruments; Wilkie et al. (2010) applied new ideas from embodied interaction theory to Music Interaction; and there have been two recent special issues of Computer Music Journal on HCI (CMJ 34:4 Winter 2010, and CMJ 35:1 Spring 2011). See section 2.10.2 of this chapter for further examples.

In general, there are currently many rich opportunities for the continued mutual exchange of ideas between Music Interaction and HCI. Stowell et al. observe in chapter 8:

> Music-making HCI evaluation is still very much an unfinished business: there is plenty of scope for development of methodologies and methods

They continue:

> Much development of new musical interfaces happens without an explicit connection to HCI research, and without systematic evaluation. Of course this can be a good thing, but it can often lead to systems being built which have a rhetoric of generality yet are used for only one performer or one situation. With a systematic approach to HCI-type issues one can learn from previous experience and move towards designs that incorporate digital technologies with broader application – e.g. enabling people who are not themselves digital tool designers.

2.14 What role does Spatial Cognition play in Music Interaction?

As observed in other FAQ answers, one of the most important developments in HCI has been "the gradual expansion of the range of human skills and abilities that can be incorporated into interaction with computers" (Dourish 2001). Spatial cognition, a powerful aspect of embodied cognition, is one area that has considerable scope for such application in Music Interaction.

Applications of spatial cognition in Music Interaction can arise whenever an appropriate spatial mapping onto some musical domain can be identified or constructed. The key requirement is that the mapping should enable spatial cognition to be re-appropriated to carry out rapidly and intuitively some set of useful musical operations or inferences. For example, the guitar fret board and piano keyboard are two elegant instrument designs that exploit mappings of this kind. Applications are not limited to instrument design, as chapter 12 demonstrates. Other examples include Prechtl et al. (2012), Holland and Elsom-Cook (1990) and Milne et al. (2011a, 2011b). There are strong overlaps between spatial cognition, gesture and embodiment, as explored in chapter 6 (Bouwer et al. 2013a), chapter 7 (McPherson et al. 2013) and chapter 15 (Wilkie et al. 2013). See also sections 2.5, 2.9, and 2.16 in this chapter.

Chapter 12 (Bouwer et al. 2013b) explores Harmony Space, a multi-user interactive music system (Holland et al. 2011). Harmony Space employs spatial mapping to allow universal human spatial skills such as identification of direction, containment, intersection, movement and similar skills to be re-appropriated to deal with complex musical tasks. The system enables beginners to carry out harmonic tasks in composition, performance, and analysis relatively easily, and can give novices and experts insights into how musical harmony works. Tonal harmony is a demanding area of music theory, and harmonic concepts can be difficult to learn, particularly for those who do not play an instrument. Even for experienced instrumentalists, a firm grasp of abstract harmonic concepts can be hard to acquire.

Harmony Space uses a spatial mapping derived from Balzano's group theoretic characterization of tonal harmony (Holland 1989). Harmony Space extends this mapping by a process known as conceptual integration (Fauconnier and Turner 2002) to allow various higher level harmonic abstractions to be visualised and manipulated using extensions of a single principled spatial mapping. Harmony Space forms an interesting contrast with systems such as Milne and Prechtl's Hex Player and Hex (Milne et al 2011a; Prechtl et al. 2012), which uses a two-dimensional mapping of pitches to promote melodic playability. By contrast, Harmony Space uses a three-dimensional mapping of pitch, and a two-dimensional mapping of pitch class, to promote harmonic insight, visualization of harmonic abstractions, and explicit control of harmonic relationships.

Different versions of Harmony Space have been designed to allow players to engage with the underlying spatial representation in different ways. Variant interaction designs include the desktop version (Holland 1992), a tactile version (Bird et al. 2008) and a whole body interaction version with camera tracking and floor projection (Holland et al. 2009) Chapter 12 examines Song Walker Harmony Space, a multi-user version driven by whole body interaction (Holland et al. 2011) that involves dance mats, hand controllers and a large projection screen This version encourages the engagement of spatial intuition spatial intuitions by having players physically enact harmonic movements and operations.

Chapter 12 presents preliminary results from a study of the Song Walker system. It examines a study in which beginners and expert musicians were able to use Song Walker carry out a range of collaborative tasks including analysis, performance, improvisation, and composition.

2.15 What lessons for Music Interaction and HCI can be learned from amateur instrumentalists?

In chapter 3, Wallis et al. (2013) examine the case of musical amateurs who practice musical instruments, sometimes over years. Amateurs may spend thousands of hours forming a deep relationship with one or more musical instruments. Generally there will be no monetary incentive or social pressure to practice; there may be no social activity at all involved; issues of reputation may not be involved; recorded outputs may be trivial, irrelevant or non-existent. Such patterns of activity and motivation are unremarkable from the point of view of Music Interaction, but have not been a central concern in mainstream HCI. The relative neglect of this pattern of behaviour in HCI should not be overstated; as Wallis et al. notes, there are HCI strategies for designing interfaces variously for purposes of: fun (Blythe et al. 2003); games (Malone 1984) and enjoyable, positive user experiences (Hassenzahl and Tractinsky 2006). However, none of these quite encompass the distinctive activities and motivations of amateur musicians.

In order to gain better theoretical tools for investigating long term amateur engagement with musical instruments, Wallis et al. use self determination theory (Ryan and Deci 2000) to analyse such engagement in terms of three intrinsic motives: mastery, autonomy and purpose. Wallis et al. point out that self determination theory (SDT) differs from other theories of motivation such as Reiss's (2004), Tinto (1975), and Maslow (1970), in appearing better suited to account for the behaviour of amateur instrumentalists. Wallis et al. argue that all three motives from SDT apply particularly well to engagement with musical instruments. Chapter 3 goes on to analyse musical instruments to look for design characteristics that might encourage these motivations in players. Wallis et al. find seven such abstract design characteristics: incrementality, complexity, immediacy, ownership, operational freedom, demonstrability and co-operation. These design characteristics emerge specifically from analysing amateur musicians, but they are interesting to compare with work by Green and others from mainstream HCI theory on the 'Cognitive Dimensions of devices and notations' (Blackwell et al. (2001). Both may be viewed as lists of high-level design properties that can be applied to analyse interaction problems, but whereas the Cognitive Dimension approach focuses on usability, Wallis et al.'s approach focuses on engagement.

Chapter 3 presents a case study using a rehabilitative rhythm game for Parkinson's patients. This chapter explores how the seven design characteristics might be used as heuristic design tools to help give interaction designs outside of music some of the properties of strong engagement found in the relationship of committed amateur musicians with their instruments.

2.16 How can formal language and gesture be integrated in Music Interaction?

In chapter 8, Stowell and McLean (2013) argue that music making is both rich and open ended, and that this has implications for how Music Interaction should work. 'Rich' refers here both to the many varieties of social and emotional outcomes that arise from engagement with music, and the multidimensional and highly combinatorial nature of the materials that musicians can exchange in performance and composition. 'Open' refers to the unbounded nature of the space of acceptable musical innovations, including compositions, performances, and genres. Stowell and McLean argue that real flexibility and power in computer-mediated systems comes from the ability of processes to *modify themselves*, and that this can be controlled effectively only with the full power of formal languages.

At the same time, there are presently limitations to the effectiveness of formal languages as means of controlling live musical performances. To look at this from another perspective, gestures are intrinsic to the way many musicians engage with music, as explored in detail in chapter 7 by McPherson and Kim (2013).

A separate but related problem is that many composers and improvisers have idiosyncratic conceptualisations of the musical materials they work with. Often, the way that one musician embeds musical materials into a formal language may not be congenial to another musician, or even to the same musician at a different time. Consequently, some researchers have developed techniques such as Aspect

Oriented Music Representation (AOMR) (Hill et al. 2007) to allow dynamic changes to the way musical materials are embedded in formal languages, and changes of formal languages, while preserving musical relationships.

Combining the notions of formal language and gesture, while emphasising the need to balance flexibility, immediacy and power, Stowell and McLean argue that we need to find a new kind of Music Interaction, based on "open interfaces". Such interfaces would be able to respond not only to the fluidity of gesture, and to allow visual thinking where appropriate but which also allow the precision and power of formal language. This chapter explores these ideas in the context of live coding, the practice of making improvised music in public by writing and modifying code in real time, for example using music programming systems such as SuperCollider. This chapter also considers programming languages that use two-dimensional constructions to allow visual and linguistic capabilities to support each other, and discusses a prototype music programming language designed to advance this idea.

3 Conclusion

As the above FAQs outline, this book explores the diversity and energy of recent work in Music Interaction, and demonstrates some of the opportunities for further research. As argued in the present chapter, the book also demonstrates some of the ways in which Music Interaction can act as a source of fresh perspectives and approaches for Human Computer Interaction more generally.

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