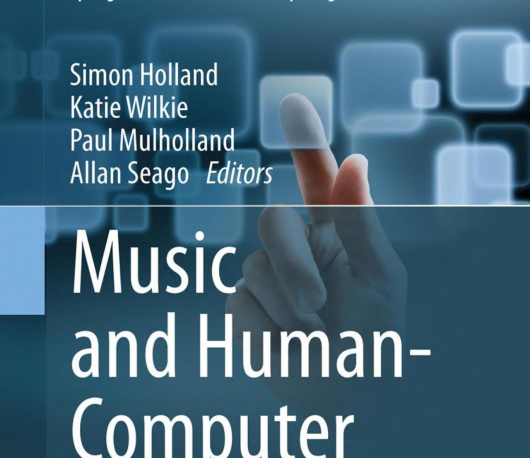
Springer Series on Cultural Computing



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Music and Human-Computer Interaction

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ISSN 2195-9056
ISBN 978-1-4471-2989-9 ISBN 978-1-4471-2990-5 (eBook)
DOI 10.1007/978-1-4471-2990-5
Springer London Heidelberg New York Dordrecht

Library of Congress Control Number: 2013933708

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Printed on acid-free paper

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Chapter 1
Music Interaction: Understanding Music and Human-Computer Interaction

Simon Holland, Katie Wilkie, Paul Mulholland, and Allan Seago

Abstract We introduce, review and analyse recent research in Music and Human-Computer Interaction (HCI), also known as Music Interaction. After a general overview of the discipline, we analyse the themes and issues raised by the other 15 chapters of this book, each of which presents recent research in this field. The bulk of this chapter is organised as an FAQ. Topics include: the scope of research in Music Interaction; the role of HCI in Music Interaction; and conversely, the role of Music Interaction in HCI. High-level themes include embodied cognition, spatial cognition, evolutionary interaction, gesture, formal language, affective interaction, and methodologies from social science. Musical activities covered include performance, composition, analysis, collaborative music making, and human and machine improvisation. Specific issues include: whether Music Interaction should be easy; what can be learned from the experience of being "in the groove", and what can be learned from the commitment of musical amateurs. Broader issues include: what Music Interaction can offer traditional instruments and musical activities; what relevance it has for domains unconnected with music; and ways in which Music Interaction can enable entirely new musical activities.

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S. Holland et al. (eds.), *Music and Human-Computer Interaction*, Springer
Series on Cultural Computing, DOI 10.1007/978-1-4471-2990-5_1,

1.1 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, deep-rooted, 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 unsatisfactory 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 (Jordà 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 bimanual input from Engelbart and English (1963) 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.

1.1.1 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 Chap. 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.

1.2 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 answers to focus on cross cutting issues that appear in two or more chapters, and some chapters to appear in several answers, while other answers focus principally on a single chapter. Parts of the FAQ may better fit Graham's (2011) notion of Rarely Asked Questions – questions asked once or twice, but which seem interesting.

The FAQs

1.2.1 What is Music Interaction?
1.2.2 What is a Digital Luthier?
1.2.3 What is the Scope of Research in Music Interaction?
1.2.4 Should Music Interaction Be Easy?
1.2.5 How Can Music Interaction Benefit Traditional Musical Instruments?
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    1.2.9.1 How Can Embodied Cognition Be Applied Systematically to Music Interaction?

1.2.1 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.

1.2.2 What Is a Digital Luthier?

A luthier is traditionally someone who makes or repairs stringed instruments. A digital luthier (Jordà 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.

1.2.3 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.

1.2.4 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 Chap. 2 ("Should Music Interaction Be Easy?") of this book, McDermott et al. (2013a) focus squarely on this issue in detail. As McDermott et al. observe, 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 in particular 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 Chap. 2 ("Should Music Interaction Be Easy?") conducts a detailed examination of various different dimensions of difficulty that can apply in Music Interaction – concluding that some are avoidable and others unavoidable.

1.2.5 How Can Music Interaction Benefit Traditional Musical Instruments and Their Players?

In Chap. 7 ("Piano Technique as a Case Study in Expressive Gestural Interaction") 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. (2004) 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, 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 Sect. 1.2.9 in this chapter). Thirdly, it provides a solid foundation for pioneering more subtle means of expression in innovative keyboard instruments.

1.2.6 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 broader field than that might imply. 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 ("Affective Musical Interaction: Influencing Users' Behaviour and Experiences with Music", Bramwell-Dicks et al. 2013) and Chap. 10 ("Pulsed Melodic Processing – The Use of Melodies in Affective Computations for Increased Processing Transparency", Kirke and Miranda 2013) in this book explore two illuminating possibilities for applying Music Interaction to non-musical purposes.

1.2.6.1 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 Chap. 4 ("Affective Musical Interaction: Influencing Users' Behaviour and Experiences with Music") 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 ("Affective Musical Interaction: Influencing Users' Behaviour and Experiences with Music") discusses how 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 caused by music have been identified. There has been less research on the application of such techniques to 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.

1.2.6.2 How Can Computation Be Organised to Communicate Emotion Musically?

In Chap. 10 ("Pulsed Melodic Processing – The Use of Melodies in Affective Computations for Increased Processing Transparency") 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 chapter 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.

1.2.7 What Lessons Does the Experience of 'Being in the Groove' Offer for Music Interaction?

In Chap. 5 ("Chasing a Feeling: Experience in Computer Supported Jamming"), 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 Sects. 1.2.10 and 1.2.15 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 musicians

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 widely.

1.2.8 What Issues Face Agents for Real-Time Collaborative Improvisation?

In Chap. 16 ("Appropriate and Complementary Rhythmic Improvisation in an Interactive Music System"), 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 et al.'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 to generate 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.

1.2.9 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 1985; Blacking 1977); in music psychology (Clarke 1993; Todd 1989); and in computer music (Desain and Honing 1996; Waiswisz 1985) More recently, Zbikowski (1997a, b), 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 12 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: Chap. 7 ("Piano Technique as a Case Study in Expressive Gestural Interaction", McPherson and Kim 2013); Chap. 6 ("The Haptic Bracelets: Learning Multi-Limb Rhythm Skills from Haptic Stimuli While Reading", Bouwer et al. 2013a); and Chap. 12 ("Song Walker Harmony Space: Embodied Interaction Design for Complex Musical Skills", Bouwer et al. 2013b).

However, there are other, less obvious ways of exploiting embodied cognition in Music Interaction. In Chap. 15 ("Towards a Participatory Approach for Interaction Design Based on Conceptual Metaphor Theory: A Case Study from Music Interaction"), 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.

1.2.9.1 How Can Embodied Cognition Be Applied Systematically to Music Interaction?

In Chap. 15 ("Towards a Participatory Approach for Interaction Design Based on Conceptual Metaphor Theory: A Case Study from Music Interaction"), 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 et 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 guide the design of new musical interfaces in collaboration with musicians. This approach is of wide generality, and could be applied in principle to any kind of Music Interaction.

1.2.10 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 (Jordà 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 Chap. 12 ("Song Walker Harmony Space: Embodied Interaction Design for Complex Musical Skills") 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 Sect. 1.2.9 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.

1.2.10.1 How Does Research in Collaborative Forms of Music Interaction Relate to CSCW?

In Chap. 11 ("Computer Musicking: HCI, CSCW and Collaborative Digital Musical Interaction") 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, Chap. 11 ("Computer Musicking: HCI, CSCW and Collaborative Digital Musical Interaction") 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 Sect. 1.2.7 in this chapter). In order to help frame distinctions between CSCW in general, and Computer Supported Musical Collaboration in particular, Chap. 11 ("Computer Musicking: HCI, CSCW and Collaborative Digital Musical Interaction") 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.

1.2.10.2 How Can Social Science Methodologies Be Adapted to Study Collaborative Music Interaction?

In Chap. 14 ("Video Analysis for Evaluating Music Interaction: Musical Tabletops"), Xambó 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 et al. 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).

Xambó 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.

1.2.11 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 et al. 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 Chap. 13 ("Evolutionary and Generative Music Informs Music HCI—And *Vice Versa*"), 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 Chap. 13 ("Evolutionary and Generative Music Informs Music HCI—And *Vice Versa*", McDermott et al. 2013b) 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

Chap. 13 ("Evolutionary and Generative Music Informs Music HCI—And *Vice Versa*", McDermott et al. 2013b) 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 ("Evolutionary and Generative Music Informs Music HCI—And *Vice Versa*", 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 Chap. 13 ("Evolutionary and Generative Music Informs Music HCI—And *Vice Versa*", McDermott et al. 2013b) on applying evolutionary interaction to composition, in Chap. 9 ("A New Interaction Strategy for Musical Timbre Design"), 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 is 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.

1.2.12 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 ("The Haptic Bracelets: Learning Multi-Limb Rhythm Skills from Haptic Stimuli While Reading" 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 Chap. 3 ("Amateur Musicians, Long-Term Engagement, and HCI"), Wallis et al. (2013) explore some of the possibilities for rhythm games in connection with Parkinson's disease.

Chapter 6 ("The Haptic Bracelets: Learning Multi-Limb Rhythm Skills from Haptic Stimuli While Reading") 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.

1.2.13 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 to HCI research than might be expected 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. Xambó et al. (2013), in Chap. 14 ("Video Analysis for Evaluating Music Interaction: Musical Tabletops") 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, Xambó 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 Chap. 8 ("Live Music-Making: A Rich Open Task Requires a Rich Open Interface"), Stowell and McLean (2013) observe:

> Wanderley and Ori (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 (Gaver et al. 2003), 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; Wanderley and Ori (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 (2011) 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 Sect. 1.2.10.2 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 and McLean (2013) observe in Chap. 8 ("Live Music-Making: A Rich Open Task Requires a Rich Open Interface"):

> 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.

1.2.14 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 Chap. 12 ("Song Walker Harmony Space: Embodied Interaction Design for Complex Musical Skills", Bouwer et al. 2013b) demonstrates. Other examples include Prechtl et al. (2012), Holland and Elsom-Cook (1990) and Milne et al. (2011a, b). There are strong overlaps between spatial cognition, gesture and embodiment, as explored in Chap. 6 ("The Haptic Bracelets: Learning Multi-Limb Rhythm Skills from Haptic Stimuli While Reading", Bouwer et al. 2013a), Chap. 7 ("Piano Technique as a Case Study in Expressive Gestural Interaction", McPherson and Kim 2013) and Chap. 15 ("Towards a Participatory Approach for Interaction Design Based on Conceptual Metaphor Theory: A Case Study from Music Interaction", Wilkie et al. 2013). See also Sects. 1.2.5, 1.2.9, and 1.2.16 in this chapter.

Chapter 12 ("Song Walker Harmony Space: Embodied Interaction Design for Complex Musical Skills", 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 ("Song Walker Harmony Space: Embodied Interaction Design for Complex Musical Skills", Bouwer et al. 2013b) 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 intuitions by having players physically enact harmonic movements and operations.

Chapter 12 ("Song Walker Harmony Space: Embodied Interaction Design for Complex Musical Skills", Bouwer et al. 2013b) 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.

1.2.15 What Lessons for Music Interaction and HCI Can Be Learned from Amateur Instrumentalists?

In Chap. 3 ("Amateur Musicians, Long-Term Engagement, and HCI"), 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

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2.1 Introduction

In interaction studies, there is a fundamental assumption that all else being equal, systems should be as easy as possible to use. This focus is evident in the literature. Nielsen's (2003) list of five components of usability (learnability, efficiency, memorability, errors, and satisfaction) uses the terms "easy" and "easily" three times in five short sentences. It is good to remember both halves of the phrase attributed to Einstein (though apparently only a paraphrase): *everything should be as simple as possible, but no simpler*. There are cases where other goals must take priority at the expense of ease of use, and music interaction (the interactions between humans and tools in the domain of music) seems to be one of them. So what makes music interaction different?

We can begin with language. The term "user", prevalent in the language of interaction studies, is a bad fit in music. It contains an implicit assumption that the computer is viewed as an inanimate object, in which the relationship of the computer to the user is that of a tool (Karlstrom 2007). Music systems occupy a spectrum of autonomy including what Rowe (2001) calls the "instrument paradigm" and the "player paradigm". In the *player* paradigm the computer is viewed as an agent, and the human is better described as an interactor than a "user". Even in the *instrument* paradigm the term "user" strikes some discord. One does not "use" an instrument to accomplish some ultimate goal: one plays it, and often that is the only goal. As Tanaka (2000) says, an instrument is not a utilitarian tool, which only needs to be easy to use in a specific context and whose development need only be characterised by ever greater efficiency. Instead, "What might be considered imperfections or limitations from the perspective of tool design often contribute to a 'personality' of a musical instrument" (Tanaka 2000). Indeed, efficiency is less important than *engagement*, a term which brings to mind the concept of *flow* (Csikszentmihalyi 1991; for more see Sect. 2.3).

Engaging, consuming, flow-like activities such as music are characterised by being at an appropriate level of difficulty: not too difficult, and not too easy. Often an activity which remains engaging in the long term does so at the expense of being rather painful to a beginner—in other words there is an important trade-off between ease of learning and long-term power and flexibility (Gentner and Nielsen 1996). Instrumental performance and practice, recording, mixing and production, live-coding and turntabling, the study of theory and notation—all of these are activities which take place in sessions that can last for hours and are mastered over years. Therefore the best interfaces for these tasks tend to fall towards the long-term power end of the trade-off.

One of the most characteristic aspects of music interaction is the extent to which skilled musicians become one with their instruments. Leman (2008) identifies the importance of this *transparency*: "Transparent technology should [. . .] give a feeling of non-mediation, a feeling that the mediation technology 'disappears' when it is used" (Leman 2008: 2). This feeling is important to instrumentalists as artists and to skilled use of tools and systems in general.

Hand-in-hand with transparency goes the crucial concept of *embodied cognition*. Embodied cognition is a view of perception in which perception and action are inextricably linked (Wilson 2002). Leman (2008) argues that musical experience involves embodied cognition, rather than symbolic mental processing, even in the case of passive listening. On the other hand, Hunt and Hermann (2011) emphasise the divergence of experience between the player, inside the control loop, and the listener outside it.

Paine (2009) proposes that "the issue of embodied knowledge is vital in both the learning and teaching of musical performance skills and the relationship the musician has to their instrument". He 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". A musical tool which encourages *internalisation* of its concepts (van Nimwegen et al. 2004) seems essential for fluid, real-time use.

Armstrong (2006) suggests that the "prevailing guiding metaphors of [. . .] HCI are at odds with the embodied/enactive approach". Within interaction design, two subfields that do embrace the embodied perspective are haptics (Gillespie and O'Modrain 2011) and tangible interfaces (Hornecker 2011), both of which have frequently been used in music interaction design (Jordà et al. 2007).

Another distinction between music interaction and more general interaction studies is made explicit by Stowell and McLean (2013) in this volume: they say that applying typical experimental HCI techniques to musical tasks is in some ways useful, but "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." Music interaction, it seems, must be studied in its native environment. More broadly, the language of experience design is perhaps more appropriate than that of usability for discussing music interaction. Experience design privileges consideration of the holistic experience of the interaction, which by nature is longitudinal, and must incorporate temporal changes in the human due to the interaction—see Sect. 2.3.

In order to do productive research in music interaction, it is necessary to correctly specify our goals. In many cases they do coincide with the typical goals of interaction studies, including the elimination of unnecessary difficulty. In others it is better to identify the aspects where ease of use should not be made a priority. In this chapter, then, we consider where and why music interaction should be difficult. Our goal is not a set of definitive findings but a framing of the questions and distinctions. Our scope includes all types of creative music interaction, including instrumental performance, virtual instruments and effects, laptop performance, turntabling and similar, notation and sequencing tasks, and production.

The remainder of this chapter is laid out as follows. In Sect. 2.2, a simple framework of multiple types of difficulty is set out. The learning curve model of time-varying difficulty, crucial to understanding long-term activities typical of music interaction, is described in Sect. 2.3. In Sect. 2.4, the sometimes counter-intuitive *advantages* of difficulty in music interaction are categorised. Section 2.5

describes aspects of music interaction where difficulty is genuinely undesirable and unnecessary, corresponding to areas where HCI and interaction design have the opportunity to contribute. Section 2.6 concludes.

2.2 Dimensions of Difficulty

Difficulty is not a one-dimensional variable. Various real and virtual instruments, software interfaces, and music hardware all exhibit their own characteristic types of difficulty, with different interfaces making some things easier and some things more difficult. Sometimes, there is a trade-off between these factors. In this section some *dimensions of difficulty* are categorised.

2.2.1 Physical Difficulty

Most computer software requires of users a minimal set of physical abilities: typing, pointing and clicking with the mouse, and looking at the screen. The same is true of music software in general, and studio hardware adds little to this set. However musical instruments can require a lot more. Pianists require at least an octave span in each hand. Stringed instruments require finger strength and, in early stages, some endurance of pain in the fingertips. Wind instruments can require great physical effort to produce the required air pressure, while holding a long note also requires physical effort and practise. The intense physical demands of rock drumming have been demonstrated by Smith et al. (2008). Long-term practice of instruments can lead to muscle and nerve injuries. In contrast, non-contact instruments such as the theremin and Sound Spheres (Hughes et al. 2011) make minimal physical demands.

Physical inconvenience can also be relevant, ranging from immobile equipment such as studios and church organs, to highly inconvenient equipment such as the double bass, down to pocket-size smartphone instruments and even to "disappearing" equipment (Kock and Bouwer 2011).

2.2.2 Difficulty of Dexterity and Coordination

All instruments require some dexterity and coordination. Many require the fingers, the hands, or the limbs to do different things at the same time. Often, there is a disassociation between the choice of notes and the control of timing and expressiveness. Some instruments require additional tools to be used as extensions of the body (or instrument), such as drum sticks or the bow for string instruments.

On string instruments such as guitar and electric bass, the presence of frets supports playing in tune, which is much harder to learn on a fretless instrument, such as violin or double bass. However, fretted instruments do not allow for the same flexibility in intonation and expressiveness (e.g., vibrato) as fretless instruments. In the case of guitar, this lack has been addressed by the use of additional devices such as the bottleneck slide and the tremolo bar (allowing vibrato to go down as well as up).

An analogous distinction can be made in wind instruments, where the trombone has one telescopic slide, instead of valves to control pitch. Circular breathing, required for some wind instruments, seems to present both a physical and a coordination problem.

Mixing on studio hardware requires coordination in terms of handling various controls in a timely manner, but many of these actions can nowadays be recorded and coordinated automatically by computer controlled systems. Interactive music software seldom requires much dexterity or coordination.

2.2.3 Difficulty Between Imagination and Realisation

A chief difficulty in the tasks of mixing and mastering of recordings is that of *identifying* the required changes, for example noticing an undesirable compression effect or an improvement that could be made to an equalisation setting. When the required change has been identified, making that change is often trivial. Although the main requirement is an internal "auditory imagination", a good interface can help, for example by making A/B comparison convenient or by showing a spectrogram visualisation.

2.2.4 Nonlinearities, Discontinuities and Interactions in Control

The tin whistle's scale is linear: within an octave, each higher note just requires the removal of the next finger. In contrast, the recorder's scale has nonlinearities in which previously-removed fingers must be replaced for later notes. There is also a discontinuity in both, and in many wind instruments, when overblowing is required to produce higher octaves. Extreme examples of nonlinearity include the *rackett*, a Renaissance double-reed instrument with unusually complex fingering, and the button accordion, which features a two-dimensional layout of controls for each hand, and in some cases can be *bisonoric* ("push" and "pull" notes are distinct).

Nonlinearities and discontinuities are also common in synthesizer parameters. Interactions between parameters also cause problems (Seago 2013, in this volume). Much research into timbre control is aimed at reducing unnecessary nonlinearities, discontinuities, and interactions (e.g. Hughes et al. 2011).

2.2.5 *Polyphony, Multiple Streams and Multiple Paths*

It would be problematic to state that polyphonic instruments are more difficult than monophonic ones, since a fair comparison would require aspects other than polyphony to be equalised between the instruments, a condition that can rarely be achieved in practise. However it seems fair to state that playing a monophonic melody on a polyphonic instrument is easier than playing multiple lines simultaneously. Playing a pseudo-polyphonic piece such as a Bach Partita on a "mostly monophonic" instrument like the violin requires the performer not only to handle the multiple streams of music but to differentiate between them through dynamics and articulation. Live computer performers, turntablists, and studio mixers often have to handle multiple streams of music simultaneously, again imposing a larger cognitive burden (see Stowell and McLean 2013, in this volume). Some instruments and equipment allows any given action to be performed in multiple different ways, the simplest example being the choice of guitar string for a given pitch. This flexibility can be both an advantage and a disadvantage.

2.2.6 *Difficulty of Repertoire*

The violin and viola are very similar instruments, but because of the greater number of compositions written for violin, and the generally higher demands imposed on playing skills, the violin can be said to be more difficult in terms of repertoire.

2.2.7 *Tuning Systems and Graphical Layout*

In the case of traditional instruments, the tuning system embedded in the instrument's design and graphical layout determines to an important degree how players conceptualize the interaction with their instrument.

On a piano, the notes in the scale of C are easily recognizable and playable as they correspond to the white keys on the instrument. Transposing a piece to another key makes the black keys necessary, and therefore changes the spatial pattern of keys to be played and the pattern of finger movements required. On a guitar, on the other hand, it is often possible to transpose a tune to another key by moving all the notes up or down the neck. Determining whether there are any flat or sharp notes being played is much easier on a piano than on a guitar, however. These are examples of how the graphical layout of notes on a musical instrument offers "representational guidance" (Suthers 2001) by facilitating the expression and inspection of certain kinds of information rather than other kinds.