Composing Interactions

Giacomo Lepri

Master Thesis
Instruments & Interfaces
STEIM - Institute of Sonology
Royal Conservatoire in The Hague
The Netherlands

May 2016

“Any musical innovation is full of danger to the whole State, and ought to be prohibited. (...)
When modes of music change, the State always change with them. (...)
Little by little this spirit of licence, finding a home, imperceptibly penetrates into manners and customs; whence, issuing with greater force, it invades contracts between man and man, and from contracts goes on to laws and constitutions, in utter recklessness, ending at last, by an overthrow of all rights, private as well as public.”

Plato, The Republic

Acknowledgements

First of all, I would like to express my gratitude to my family. Their love, support and advice are the most precious gifts I ever received.

Thanks to Joel Ryan & Kristina Andersen, for their ability to convey the magic, make visible the invisible and p(l)ay attention.

Thanks to Richard Barrett, for his musical sensitivity, artistic vision and gathering creativity.

Thanks to Peter Pabon, for his outstanding teachings, competences and support.

Thanks to Johan van Kreij, for his important practical and conceptual advises, suggestions and reflections.

Thanks to Alberto Boem & Dan Gibson, for the fruitful and worthwhile discussion that produced many of the concepts introduced in chapter 2.

Thanks to Kees Tazelaar, for the passion, foresight and expertise that characterise his work.

Thanks to all the people that contribute to the Institute of Sonology and STEIM. Thanks to their ability to valorise the past and project the future.

Thanks to my fellow students Semay and Ivan, for the joy and sharing.

Gracias a Carmen, mi feliz compañera de viaje.

Abstract

This thesis seeks to presents the artistic research advanced during my Master of Research *Instruments & Interfaces* held at the Institute of Sonology in collaboration with STEIM. The investigation focused on the design of interactive musical systems-instruments for electroacoustic improvisation. A compositional framework is outlined in order to introduce the *conceptual tools* that supported the design process of novel instruments-systems.

Two projects were developed during the study period. *InMuSIC* is an interactive system for electroacoustic improvisation, the attempt was to compose a system that, within an improvisational context, could musically collaborate and dialogue with the musician. The *Melotronica* is an hybrid modified melodica. It is equipped with custom sensors for the control of a software unit dedicated to the real-time manipulation of electronic sound material.

The research is grounded on an embodied cognition of music practice. Corporeal intentionality was indeed a key concept to investigate music expressiveness. The interactive systems developed establish musical interactions based on the multimodal analysis of the instrumentalist's behaviour (i.e. detection of embodied motion qualities and sonic parameters). The attempt of composing and exploring sonic and gestural interdependences is the foundation of the inquired interactive paradigm.

Keywords

Interactive musical systems; digital musical instruments; design; electroacoustic improvisation and composition; multimodal interaction; embodied music cognition; expressiveness; real-time interaction.

Related publications

Some of the work contained within this thesis has appeared in the following publications:

Lepri, Giacomo. 2016. "InMuSIC: an Interactive Multimodal System for Electroacoustic Improvisation". In press, *Proceedings of the International Computer Music Conference* .

Lepri, Giacomo. 2015. "Playing with InMuSIC: an InteractiveMultimodal System for Improvised Composition". In *Proceedings of the 2015 ACM SIGCHI Conference on Creativity and Cognition,* 387-388. ACM.

Lepri Giacomo, Canepa Corrado, Volpe Gualtiero, Ghisio Simone and Antonio Camurri. 2014. "Crafting sound with The Potter". In *Proceedings of the 20th Colloquium on Music Informatics*, 101-106. AIMI

Contents

1 Background

1.1 Musical Context

The artistic work matured during my master of research can be situated within the context of electroacoustic improvisation. By using the term *electroacoustic* I refer to a music generated by instruments that produce sound through both acoustic and electronic means. More specifically, my interest relies on looking for ways to negotiate the electronic and acoustic dimensions. In the context of electronic music, one of the reference related to this musical approach is *Musica su due dimensioni*[1] composed by Bruno Maderna at the Studio di Fonologia Musicale RAI in Milan. In my view, this composition is the first piece that merged the two principal European musical trends of the time: *musique concrète*(focused on the manipulation of given physical phenomenons) and *elektronische Musik* (concerned with the organisation of musical materials starting from the generation of the single sonic components). Maderna revealed the possibility of a dialogue between the electronic and concrete extents. In my view, *Musica su due dimensioni* represent an archetype of a mixed reality able to capture the potentialities of both the synthetic and physical world.

Within my research, the parallel development of these two dimensions implies mutual influences and often foresees fusions and contrasts. This musical context is characterised by the need of balancing theoretical knowledges and practical experiences related to both musical domains. After a particularly inspiring talk from Joel Rayn, in which he was describing his electroacoustic collaborations as "two musicians and one instrument", I often think about myself as a musician that plays two instruments. These images might be interpreted as two sides of the same coin: electroacoustic music should arise from the close interdependences amongst the various elements involved. I sometime think about my solo electroacoustic setup as an equally distributed situation. During the performance, the sound is simultaneously shaped by me 33%, the acoustic instrument 33% and the electronics 33%. The remaining 1%, essential to the fulfilment of the alchemical unity, might be the contribution of music itself.

The term *improvisation* instead refers to the condition in which the composition of music is essentially simultaneous to the act of playing an instrument. This research aimed to investigate strategies for the generation and transmission of potential musical contents within an open and shared creative process. The efforts were therefore finalised to the purpose of performing impro-

1. Maderna composed two versions of this piece which are completely different one from the other. The first version (1952) for flute, percussion and magnetic tape can be acknowledged as the first composition in which acoustic/instrumental performers interacts with *purely* electronic sounds. The second version (1958) for flute and tape was composed for the flautist Severino Gazzelloni

vised music. On the one hand, the research focused on the design of suitable and convincing technologies (hardware and software) able to promote and facilitate the spontaneous development of human expressiveness in real-time. On the other hand, the extensive use of the designed machineries was important for the achievement of engaging musical performances. Playing instruments (of any kind) and performing improvised music implies a constant training of skills and sensitivities. In this regards I might argue that my research started way before of this research.

In this research, electroacoustic sonorities and improvisational practices are merged in a compositional framework. Compositional strategies and (more likely) intuitions mediated the interrelations between human and technological *agencies*. The approach adopted fits rather well with the concept of *open work* in the avant-garde art and music of the twentieth century (Eco 1962). In particular, my interest was in the configuration of open structures(Sabbe 1987). The intention was to develop compositions (or musical systems) in which the structural elements could emerge from the trajectories of constrained interactions.

This thesis is therefore concerned with fields belonging to music composition, improvisation and instrument design. These disciplines provided an understanding of *digital lutherie* (Jordà 2004) and were strongly associated with an artistic vision. I refer to the activity of *composing* as the more inclusive of the two (etymologically *com-ponere*, put together). The development of digital musical interactions implies the ability to dynamically balance many factors and processes. In this framework a compositional attitude turned effective and fruitful. The research developed aims to be a musical contribution to the overall discourse on the design of tangible and embodied interactive systems.

Two different musical interactive *implementations* are presented in this thesis. In chapter 3 the Interactive Music System (IMS) *InMuSIC* is presented. A prototype of the Digital Musical Instrument (DMI) *Melotronica* is introduced in chapter 4. Generally, when considering and illustrating tangible and embodied interactive musical systems, a lack of consensus on terminology has been observed (Kvifte and Jensenius 2006). Whilst being aware of conceptual and practical differences between the two projects presented, in this text I generally adopt the term IMS to frame the objects of my reflections. This applies especially to the more theoretical chapters (1 , 2 and 5). The choice of the term is dictated by the need to have a comprehensive musical and technical perspective. In my view, the definition of Interactive System includes the notion of Digital Instrument. IMS might also refer to those interactive implementations either not performance-oriented (e.g. compositional tools) or not based on the instrument metaphor (e.g. interactive sound installations). Furthermore, the notions of IMS might imply the presence of an high degree of autonomy within the system's agency and the interactions emerging between the *system* and a performer might develop within a long period of time (e.g. several seconds, minutes or hours). The term DMI (see Miranda and Wanderley 2006 for a review), mainly used in chapter 4, has here a narrower connotation. The term *instrument* denotes a peculiar live-performative dimension and the performer-instrument interactions are mainly influenced by physical, immediate and direct cause-effect relationships.

1.2 Personal Motivations

The research here presented is the union of several experiences that characterise my personal musical path. Since young age, I became interested in the world of the so-called *non-idiomatic* improvisation exploring the use of electronics and new technologies. Improvisation had a key role since the beginning of my musical experience: during my first years of activities I studied jazz piano and percussion specializing in the Afro-Cuban and Brazilian traditions. During the years, I also started to compose electroacoustic music (acousmatic and live electronics) and I worked as sound designer in research environments related to the development of multimedia systems, multimodal human-computer interfaces and applications. My last years of work were mainly focused on both the actual on stage performance of free/non-idiomatic improvised music and development of Interactive Musical Systems (IMS) and Digital Musical Instruments (DMI) for electroacoustic improvisation. The exploration of the social and musical dynamics involved in an improvised act (e.g. development of spontaneous and collaborative creative processes) is one of the central goals of my musical research. Improvisation is certainly one of the most challenging practice for a musician. The required performative skills (e.g. listening, internalisation and reaction) presume sensitivity, awareness and responsibility. Such human abilities are related to the perception and interpretation of the outside world and to the expression of individual musical identities within a shared musical context. In my view, improvisation presumes the development of a holistic discipline concerned with a broad range of human domains. Indeed, the creative processes associated to improvisation display an excellent context for scientific and humanistic investigations. Amongst other, research on the study of improvisation was developed within the frameworks of psychology (Sloboda 1988), philosophy (Peters 2009), neuro and cognitive sciences (Roads 1985) and social/anthropological studies (Born 2005).

My background as electroacoustic composer, particularly interested in the Sound and Music

Computing (SMC) research, allows me to assess the potential contributions that the study of music improvisation suggests regarding the development of interactive technologies. An important research path, within the Music Information Research (MIR) framework, is related to the development of models for music representation (Serra et al. 2013). This research is mainly concerned with the design and implementation of strategies for the analysis and abstraction of musical information. Often, this research aims to define algorithms able to recognise well defined musical genres and styles. Indeed MIR investigations are generally characterised by a semantic approach. The attribution of specific meanings, usually consistent with the concepts and language used by musicians and audiences, allows for the categorisation of the information encoded.

If applied to humanistic and artistic contexts, I perceive this approach extremely reductionist. My interest relies on the exploration, use and abuse of performative expressive traits related to specific instrumental practices. The search for meaningful and affective musical behaviours is the first important step for the development of a technology able to mediate musical interactions. One of the most considerable challenges presented by the design of IMS for improvisation is related to the investigation of strategies for the real-time detection of expressive sonic and physical behaviours. It is not my intention to define any specific taxonomy or general criteria for the analysis of music practice. My research is strongly based on subjective intuitions and feelings. A personal inner search is therefore one of the central aspects of the artistic path here developed. The composition of real-time interactions, within the context of music improvisation, demands significant questions concerning how music is socially created and shared. The precarious answers sketched during the development of this research are based on my personal conception of music performance and interaction. Thus, the object of this exploration is deeply related with those dynamics that affect my own expressiveness and shape my perception of other musical identities.

The IMS context offers the possibility to tackle another fundamental issue related to the conception of the notions of improvisation and composition. One of the aim of this research was to practically explore the shared areas belonging to both disciplines. As Bruno Nettl suggests *"perhaps we must abandon the idea of improvisation as a process separated from composition and adopt the view that all performers improvise to some extent "* (Nettl 1974 p.19). This is one of the assumptions that inspired and grounded the research here presented. My belief is that, regardless of the musical context, what makes the difference amongst highly skilled performers is their ability to improvise. As composer and improviser, I perceive the need of musical investigations that could contribute to the development of musical practices in which the notions of composition and improvisation are merged through the performative practice. The ambition is to promote a musical perspective in which the instrumentalists deal with compositional issues and the composers are invited to directly experience the sonic action (Cornelius 1971). In the context of electroacoustic improvisation, the composer and the musician are the same person, and this person is often responsible for the development of the technology used to play (Norman, Waisvisz, and Ryan 1998). This research aimed to challenge the traditional notions of performer and composer in order to explore different synergies and conjunctions between the two figures. I believe that these musical investigations outline one of the most stimulating research context within the musical panorama of today.

Taking into account that this type of inquiries involve ramificated and interdisciplinary areas of study and approaches, I am aware of the complexity and deepness of this topic. Given the nature of the subject, I would probably need a lifelong study to address it properly. Clearly, within this thesis I will present a specific path of study narrowing the field of investigation to specific research questions and areas of study.

Finally, from a more general point of view, this research aimed to explore the valence of interactive art as a place of convergence between humanism and technology. It is easily arguable that, in musical context, this cross-fertilised practice is well established since the dawn of lutherie. More recently this approach strongly characterised also the great majority of investigations related to Human-Computer Interaction (HCI). The technological research, provides useful tools for the manipulation of the physical world. Sometime, when these tools enter in dialogue with the complexity of the human nature, they promote and facilitate the production of aesthetic inventions. On the other hand, the artistic practice can offer ideas, intuitions and scenarios for the development of *intelligent* technologies. The belief is that human behaviours and their ambiguities must be taken into consideration in order to design meaningful and sustainable technologies. The research here presented attempted to combine artistic practices and scientific notions. The hope is to establish a virtuous circle able to develop a contribution of knowledges beneficial for both areas of study.

1.3 The Artistic Research

The presented research was essentially conceived as a compositional act (etymologically *componere*, put together). The general research approach was not based on the development of speculative notions or specific techniques. Instead, the investigation was mainly focused on the exploration of possible ways of combining already existing knowledges, procedures and practices for the purpose of making music in real-time. The main research goals can be formulate as following:

Given a specific scenario related to electroacoustic music and instrumental practices, the presented research focused on the investigation of strategies for the composition of engaging human-machine interactions. The aim was to design interactive systems for music improvisation.

More specifically, the ambition was to design interactive systems that, during the performance, could establish dialogical musical interventions by means of sound and movement analyses. The composition of musical interactions was based on the combination of several techniques for the analysis of performative qualities related to the sounds and movements articulated by the performer. The correlation of these analyses is the foundation of the enquired interactive paradigm. The identified strategy focused on the attempt to define a minimal representation of complex musical behaviours. For this reason, a qualitative analysis of the performer's gestures and sounds was privileged. This approach differentiates the presented interactive systems from the the majority of the existing IMS conceived for music improvisation. Generally, IMS and DMI are conceived to be responsive either to sonic or gestural features related the performer behaviour. The development and implementation of an interactive multimodal framework was a crucial aspect within the presented investigation. Furthermore, based on the analyses implemented, the research focused on the strategies for the real-time generation and elaboration of sonic materials. The purpose was to develop sonic interactions that could dialogically stimulate the continuation of the improvisation. The attempt was to design sonic interventions that could be perceived as consistent and intentional communicative acts integrated within the music performance. The overall compositional challenge took place in the composition of the musical interactions amongst the various elements of the system.

1.3.1 Specific Areas of Research

The research goals displayed a quite broad multidisciplinary investigation. During the development of the research it was necessary to focus on specific fields of study. This section should be considered as a summary of the most relevant research contexts addressed in this thesis. The following areas can also be acknowledged as potential beneficiaries of the outcomes arising from this research.

- **Electroacoustic Improvisation/Composition** - These musical practices define the context in which the research was developed. The compositional research is consequently related to a specific musical aesthetic concerned with the exploration of sonic spectral qualities. The designed interactive systems are intended for the demanding environment of real-time concert use. This prospective displays the framework in which the obtained results should be evaluated (for an overview Hsu and Sosnick 2009 and Linson, Dobbyn, and Laney 2012). Compositional and performative strategies informed the research methodologies and enforced the implementative decisions. The research focused on the implementation of convincing sonic interactions. The outlined approach regards the attempt of designing performative contexts in which the musician is invited to *navigate* heterogeneous timbre spaces (D. L. Wessel 1979) in collaboration with the systems.

- **Embodied Music Cognition** - The framework defined to compose the musical interactions, in addition to the sonic dimension, aims to take into account fundamental performative and expressive aspects complementary to the sound production. The design of the presented systems were informed by research on techniques for upper-body movement and gesture analysis (Leman and Camurri 2006) . The investigation focused on the implementation of already existing techniques for affect recognition and interpretation of expressive movement (Camurri et al. 2005). Therefore, the framework outlined refers to theories concerned with an embodied cognition of music (i.e. Leman 2008 and Godøy and Leman 2010).

- **Music Information Retrieval** - One of the main challenges presented by this research regards the investigation of models and algorithms for the representation of musical notions (for an overview Mitrović, Zeppelzauer, and Breiteneder 2010). In order to facilitate the extraction of useful information from a music performance, a standard practice is to compute intermediate representations at various levels of abstraction. At each level, features can describe an instant in time (e.g. the onset time of a note), a segment or time interval (e.g. the duration of a chord) or the whole piece (e.g. the structural elements of a piece). A strategy for the multimodal analysis and representation of expressive features related to specific instrumental practices was defined and implemented.

- **Interaction Design** - The work advanced had strong implications related to the context of interaction design. The aim was to implement interactive behaviours inspired by musical human abilities such as adaptiveness, imitation and variation. One of the direction explored foresees the design of decision-making procedures emulating cognitive processes related to the auditory memory (Snyder 2000). In relation to the information analysed during the performance, the attempt was to develop and implement an interactive paradigm able to balance different degrees of sonic autonomy.

- **Sound and Music Computing -** The research offered the possibility to explore the use of existing Digital Signal Processing (DSP) techniques for *machine listening*. Particular attention was paid to the simulation of human auditory abilities related to the perceptual recognition of musical cues (e.g. De Cheveigné and Kawahara 2002). In order to design the musical output of the systems developed, various existing DSP techniques for the generation and elaboration of the new sonic materials were extensively explored and implemented (e.g. Trueman and DuBois 2009.

1.3.2 Methodologies and Research Path

Generally, the working methodologies adopted refer to frameworks and design experiences established by those research communities involved in the development of new technologies for the art. The presented investigation mainly draws on methodologies related to research through design (Gaver 2012) and technology probe (Mackay 2004).

After an initial literature review, the research focused on the development of a series of prototypes. During the two years of the master, these prototypes were regularly *evaluated* through extensive rehearsal sessions and public performances. Consequently, the presented systems derive from a of constant process of iteration aiming to improve and refine the initial prototypes. The interactive system InMuSIC was tested from different musicians in informal settings. In order to understand how the different performers perceive the systems, the performances were recorded and the musician interviewed. A qualitative analysis based on grounded theory methodologies (Corbin and Strauss 1990) was carried out in order to analyse the materials collected.

Below, several specific methodologies that particularly influenced the research are introduced. A challenge for human-computer interaction researchers and interface designers is to construct information technologies that support creativity. Within this research, a methodological approach that could provide tools for the development of technologies conceived to be used in creative contexts (e.g. Shneiderman 2000) was adopted. Due to the implications related to the development of embodied interaction it was opportune to take into account methodologies for the design of technologies involving the human body (e.g. Svanæs 2013). The research was strongly related to the investigation of the dynamics occurring during an improvised musical act, methodologies for the design of interactive technologies based on the user experiences were also considered (e.g. Buchenau and Suri 2000). The artistic research outlined aimed to imagine, develop and explore unknown technologies. Therefore, methodologies for the design of *not yet existing* technologies (e.g. Andersen and Wilde 2012) were taken in consideration.

Finally, it was important to follow the compositional and performative intuitions deriving from my artistic/musical background. The overall research was therefore supported by empathic decision related to musical aesthetic (aesthetics of interaction), affective computing and ludic engagement (Wright and McCarthy 2008).

2 Composing Interactions

2.1 Improvisation and Algorithmic Composition

This section will introduce some thoughts on the relation between improvisation and algorithmic composition. The belief is that algorithmic composition provides a particularly useful framework for the development of technologies conceived for improvisational contexts. Indeed, in my view, algorithmic composition can help to merge several elements usually distinguishing composition from improvisation.

In the context of Western music, improvisation has often played an important role. From the vocal practices related to Gregorian and Ars Antiqua until the twentieth century experimentations belonging to contemporary music and free jazz, it is possible to indicate improvisation as a significant component of many musical traditions. Since the Sixties, composers, performers and researchers have explored the practice of music improvisation in the context of electronic music. The attempts to design and develop spontaneous convincing interactions using experimental musical languages and new technologies is contributing to shift (if not to dissolve) the boundaries between composition and improvisation in the Western culture. It is possible to observe that, in the European culture, the dichotomy amongst *erudite* and *popular* musics had strongly contributed to the clear separation between improvisation and composition. This dichotomy was certainly accentuated by the use (or abuse) of the musical notation in the *classical* environments. Today, improvisation and composition often coexist within the artistic life of many musicians. Nevertheless, the impression is that the institutions engaged on the promotion of contemporary and new music are often ignoring this well established condition. The musicological and cultural debate related to the similarities and differences of composition and improvisation is fortunately very active. It is not my intention to discuss here this interesting topic. However, I would like to develop a simple argument in order to highlight some considerations useful to the artistic investigations presented in this thesis.

First I present three simple elements that, in my view, *traditionally* differentiate improvisation from composition. Secondly I discuss the same arguments for the specific case of algorithmic composition. For the sake of clarity, this attempt will certainly reduce and generalise the reality. I ask to the readers of this text to kindly forgive this simplification. The aspects taken into consideration regard: (i) the nature of the compositional process, (ii) the relation between composer and performer and (iii) the mindsets that generally distinguish the musicians involved with composed and improvised music.

The first remarkable difference between improvisation and composition is related to the nature of the processes that lead to the definition of musical forms. The organisation of the sonic material takes place within two different time-scales. Generally, during an improvisational act, the overall musical architecture is not linked to a form previously well defined. Almost all the structural elements are developed during the performative time, which is ultimately irreversible. Improvisation implies a sort of cruel *competition* between the process and the form: inexorably they have to proceed simultaneously. On the other hand, the compositional time can be *frozen* and it allows for reiterations, afterthoughts and refinements. During the compositional process, the development of musical structures is more flexible and the influences between the process and the structure can mature within larger temporal frames.

The second aspect is related to the sound generation. During an improvisation, the musicians are usually materially engaged with the real-time production and elaboration of the sonic material. They have to either physically generate the sound or bodily interact with the *tools* that produce it. This situation implies the development of musical skills that are traditionally *delegated* to the instrumentalists. An improviser have to muster an *instrument*. The composer is clearly concerned with the instruments and techniques used to produce the music. Nevertheless, during the execution of a composition, usually he is not physically involved in the actual real-time generation of the sound. The training of highly refined instrumental skills and the *art of interpretation* are indeed well defined and specialised fields of study. In acousmatic music instead, during the performance of a composition, the composer in often actively engaged with the sound projection. This *interpretation* is usually concerned with the acoustic properties of the concert space. Even if the performer actively manipulates the sound production, he usually interacts with a previously fixed media. Nevertheless, the compositions for live electronics generally involve the real-time manipulation of pre-composed materials. In these contexts, the roles of composer and performer frequently overlap.

The third feature regards the different mindset usually characterising the musicians involved in the performance of improvised and composed musics. Improvisers are generally interested in the becoming of an *always diverse* music. Even if the resources for the development of new music are based on previous musical experiences, internalised patterns and physical constrains (i.e. nothing is purely improvised), improvisers are open to explorations and share the curiosity towards the unexpected. Improvisers look for social interactions, striking interplay and spontaneous coactions. On the other hand, the composers and their performers are usually concerned with a music that, to be performed, required specific trainings and iterations. Generally, the ambition relies on the achievement of refined and sophisticated expressive traits. Once reached a certain sonic organisation or a suitable performative condition, the aim is to fix it in time in order to share it with the audience.

Let me now briefly discuss these three distinctive elements within the algorithmic composition framework. Algorithmic composition – composing by means of formalisable methods – has a century old tradition not only in occidental music history. The automatisation of the procedures for the generation of music is usually associated to processes of abstraction (Berg 1996). Nowadays, within micro and macro timeframes, it is possible to isolate and control the generation of a great variety of musical elements. Spectral qualities, motions and gestures, structural properties are just few of the aspects that the composer can symbolically represent. In the framework of the algorithmic composition, a given set of instructions can represent and generat an entire composition. This musical approach is therefore based on the definition of processes. As in improvisation, the compositional processes are strictly linked with the organisation of the sonic materials. These processes are simultaneously able to generate sounds and organise them from a structural viewpoint. Indeed, within the communities interested in algorithmic composition, it is often possible to notice a compositional attitude that tend to not strictly distinguish these two elements. The sonic materials and the formal-structural aspects are usually perceived as firmly tangled. As previously argued, this is one of the quality characterising the practice of improvisation.

The computational possibilities of modern machine allow for the definition of extremely complex procedures that can be computed in real-time. This particular condition allow for the symbolic description of compositional ideas conceived to organise information *on the fly*. To a certain extent, it is therefore possible to design algorithms for the generation of musical elements during a live performance. The parameters of the algorithm (or the algorithm itself) can be modified in real-time by the composer-performer. Alternatively, the processes of sound generation can be influenced by data deriving from sensors that capture physical energy. As already mentioned, the act of composing while performing can be acknowledged as one of the conditions characterising improvisation.

Finally, in algorithmic composition, the use of probability allows for *stochastic* behaviour. The same process, with the same initial values, can produce different results. This approach can be found in most of the systems designed for algorithmic composition. Indeed, many composers involved with algorithms develop compositional techniques that often imply a process of discovering. One of the advantages of algorithmic composition (or computer assisted composition) relies on the definition of process that can easily generate variations at different rates of change. This is particularly useful to survey sound properties, formal relationships and behaviours (variation in time of the sonic energy). The interest in the exploration of musical materials through the use of algorithmic composition is maybe comparable to the desire of musically experience and interact with the unknown becoming of an improvised performance.

In this section, many of the aspects distinguishing improvisation and composition were deliberately ignored. Amongst the most important aspects are the crucial conditions of social interaction usually distinguishing the performance of improvised and composed music. However, the practice of designing systems or instruments for the context of electroacoustic improvisation offers the possibility to deeply explore the relationships between composition and improvisation. By composing interactive behaviours it is possible to *freeze* in time some of compositional intuitions potentially useful in a live performance. A set of symbolic instructions (essentially a score) can potentially become a mirror able to reflect some of the complex processes involved within an improvised session. Algorithmic composition allows the implementation of formal processes for the real-time generation and organisation of musical materials. Improvisation implies the possibility to be closely involved in the compositional process while performing. It seems that, to a certain extent, the two musical disciplines converge. The synergies emerging from the junction of the two practices outline a promising framework for electroacoustic improvisation.

2.2 Music and Technology: an Embodied Cognition

The research here presented is grounded on an embodied cognition of music (Leman 2008 and Godøy and Leman 2010) which influenced compositional and implementative choices. Music perception and expression are here conceived as processes deriving from the interaction between physical properties of matter and subjective human experiences. In classical (disembodied) music cognition approaches, this interaction is mainly intended as a complex set of relationships between sound and mind. Reasoning about an embodied cognition of music implies the introduction of the *human body* component within the sound/mind liaison. While discussing the idea that music consists of *"form relationships without defined meanings"* (Hanslick 1885), Leman points out: *"the notion of moving sonic form, with emphasis on the fact that these sonic forms move and* *have a physical impact on our bodies, is highly interesting. Moving sonic forms do something with our bodies, and therefore have a signification through body action rather than through thinking. Therefore, this type of signification could be called corporeal signification, in contrast with cerebral signification"* (Leman 2008 p.17). Indeed, one of the ambition of this research was to design interactive systems within an action-based notion of music involvement and expression. In my view, the human body should not only be conceived as a mediator that transfer the physical energy to a mental level and *vice versa*. The belief is that the motor and perceptual systems and the higher level of mental constructs influence each other to such and extent that is not often possible to decouple the two entities. While involved with music, humans *interpret* and *shape* physical energy, the alliance of body and mind critically contribute to this active experiences.

The IMS presented in this thesis were developed in order to capture and exploit corporeal and sonic aspects related to specific instrumental practices. Rather than building new instruments or interfaces, my research focused on the composition of music starting from the exploration of sonic and corporeal synergies related to already existing instruments (clarinet and melodica). Borrowing concepts from Gibson, the attempt was to develop technologies that could perceive the *action-relevant* properties of the instruments considered (Gibson 1978). The aim was to compose musical interactions that could overcome the duality human body - musical instrument. This by investigating and developing some of the embodied *practical opportunities* (affordances) that the instruments offer to the human body. It is important to bear in mind that the presented research has grown upon specific *natural* and *cultural* constraints. The embodied affordances considered are strongly related to the interaction of my own body with the instruments. In this regard, the systems developed are not intended to fit every player. Nevertheless, my hope is that in future developments some of the intuitions presented in the next chapters might be potentially valid for other musicians and instruments. Furthermore, the designed IMS were conceived within the cultural and aesthetic constrains characterising electroacoustic improvisation. This influenced the search of particular sound-body-instrument dynamics and interactions. The impression is that, within another musical context, the same physical energy (corporeal and sonic) may reveal different affordances and entail diverse musical interactions.

By handling notions deriving from different philosophical frameworks - activity theory (Bedny and Karwowski 2004), ecological philosophy (Gibson 2014), flow (Csikszentmihalyi 1990) and presence (Riva 2006) research - Nijs et al. defend the idea of *"the instrument as a natural extension of the musician"* (Nijs, Lesaffre, and Leman 2009). Indeed, one the understandings of instrumental music practice introduced by the embodied cognition research implies the necessity of a *fusion* between the musician and his instrument. The human body is considered as the most natural mediator between subjective music experience and physical reality. Learning an instrument implies a dialectic process that leads to an intimate relationship between the human body and the instrument. On the one hand, the musician manipulates the instrument according to his needs (i.e. he establishes musical functions and physical modalities). On the other hand, the instrument influences the musician by stimulating the development of cognitive and physical behaviours. Mastering an instrument entails the constant training of specific motor and perceptual skill. Thanks to the high-level skills developed, the musician can focus on the music rather than on the technicalities of playing the instrument. These fine motor routines become *unconscious* through the practice. The intimate physical coupling of the musician and the instrument allows for the achievement of an integrated set of functionalities and the instrument is somehow incorporated within the human body. The mediation between musical ideas and sound is not anymore an exclusive prerogative of the human body. This condition enables the actual possibility to engage with the more musical aspects of the performance. Within the musical flow, the musician's attention can be directed towards specific expressive traits and most of the body-instrument interactions become automatic and instinctive. This conception of music performance inspired the IMS developed during the research. The attempt was to implement interfaces able to grasp some of the embodied and *unconscious* behaviours related to the performance of the considered instruments. Indeed, the design process was characterised by an *ecological* approach. In order to play with the IMS, the performer is not required to develop additional technical-performative skills. The musician can *normally play* his instrument.

Further developments of this embodied cognition of music move towards a notion of expressiveness concerned with the human ability to perceive corporeal intentions through sound. Instrumental music practice is conceived as the act of moving sonic forms via the human body. Music is acknowledged as a medium able to vehiculate corporeal articulation. One of the reasons that enable humans to empathise with the expressive contents sonically conveyed is linked to their ability of recognise corporeal intentions. The perception of music, as autonomous presence, is therefore partially related to the perception of the corporal actions that produced the sound. Leman argues that *"the corporeal intentionality can be conceived as an emerging effect of action/perception couplings, the underlying engine of which can be defined in terms of a sensorimotor system"* (Leman 2008 p.84). This sensorimotor model assumes a tight coupling between action and perception and it refers to behavioural and neurological research (e.g. Meltzoff and Prinz 2002 and Rizzolatti et al. 2002) concerned with human abilities such as intentionality, imitation and prediction.

These last considerations particularly informed the design process of the InMuSIC system. It was conceived as an autonomous social agent, able to interprete and generate actions on its own. The attempt was to compose interactive behaviours able to musically dialogue with the performer. In order to communicate it is necessary to recognise the presence of another *actor*. In my view, this identification also relies on the human ability to recognise cognitive and corporeal intentions. Namely, I acknowledge the Other because I recognise intentional actions that potentially I could also perform. Many of the choices made for the design of InMuSIC aimed to define performative conducts able to stimulate the perception (or illusion) of an action-intended presence.

From a more general point of view, the interactive musical framework developed within my research is based on psychological and social theories that describe human communication as a *set of signals* belonging to many different *channels* of communication (Watzlawick et al. 2011). This often implies a transmission of information through different sensory modalities (e.g. auditory and visual). Furthermore, in HCI contexts related to communication and social semiotic, these theories are well established and implemented(Kress 2009). During a performance of music, the expressive contents are conveyed through different *modes of expression* (e.g. sonic and gestural). In ensemble music conducts and cues often depend on visual exchanges. Furthermore, the presence of a musician on stage almost displays a theatrical condition in which body gestures and movements contribute to the expression of feelings and intentions.

The design of new DMI and IMS that emphasise both embodied and sonic interactions is a well established musical practice. It is particularly distinctive to the New Interface for Music Expression (NIME) context. Physical engagement is an important aspect of music-making often missing in academic electroacoustic contexts. The idea of a compositional practice free from any negotiation with the human body may lead to aseptic and ineffective results. As Ryan argues: *"one of the main risks related to electroacoustic music consist in the circumstance in which composers become completely dependent upon software, algorithms and techniques operating as their hands and ears by delegation. Technicisms become dominant and the desktop composers drift apart from the empirical reality"* (Norman, Waisvisz, and Ryan 1998).

Instrumental music practice is here conceived as an expressive act, synthesis of an intricate creative process involving physicality, cognition, (e)motions and sound. This research aimed to explore relevant embodied aspects related to musical affective intentions. The ambition was to develop systems able to *perceive* action-oriented affordances related to the musician-instrument interactions.

2.3 A Compositional Model

A fundamental aspect for the design of the presented IMS concerned the definition of a conceptual model. Such reasoning crucially helped to frame the final desired outcome. In my view, a suitable model defines the various units of the platform and, by providing a clear understanding of their functions, facilitates the various stages of implementation. Furthermore, an exhaustive conceptual model should also focus on the composition of the interactions amongst the different elements constituting the system.

Various frameworks and principles for reasoning about the design of computer-based musical instruments have been developed (amongst others see Impett 2001, Ciufo 2003 and Todd and Werner 1999). In this section, the compositional model for the IMS developed during my research is presented. Figure 1 illustrates a layered model based on the work of Leman and Camurri 2006. It is composed of five modules located on three different conceptual levels. These levels range from the representation of physical energy to the more abstract extent related to performative and compositional intuitions. Consequently, it is possible to conceive a *continuum* linking the physical world to its musical interpretation. The lowest level is associated to those units that perform tasks related to the physical domain such as the detection of sound and movements. The highest level is related to the more abstract components of the system, responsible for the compositional choices that define the sonic interactions. This representation defines an interactive loop distributed over different conceptual areas and it offers the possibility to frame the essential structural functions associated to the musical behaviour of the system.

The compositional model presented is also inspired by the Systems Theory introduced by Bertalanffy 1968. The design of the relations between the various system's units is influenced by specific criteria: (i) any change in a single unit causes a change in all the units, (ii) the system's behaviour reacts to the incoming data and modifies them in order to either cause change, or to maintain the stationary state (positive and negative feedback) and (iii) the same results may have different origins (i.e. the same causes do not produce the same effects, and vice versa). The presented model might be interpreted as a mapping strategy, but I prefer not to strictly refer to the term *mapping* itself. It seems to loose effectiveness in contexts where complex and abstract algorithmic processes are implemented to affect the generated sound material (Chadabe 2002).

The individual modules will be now introduced.

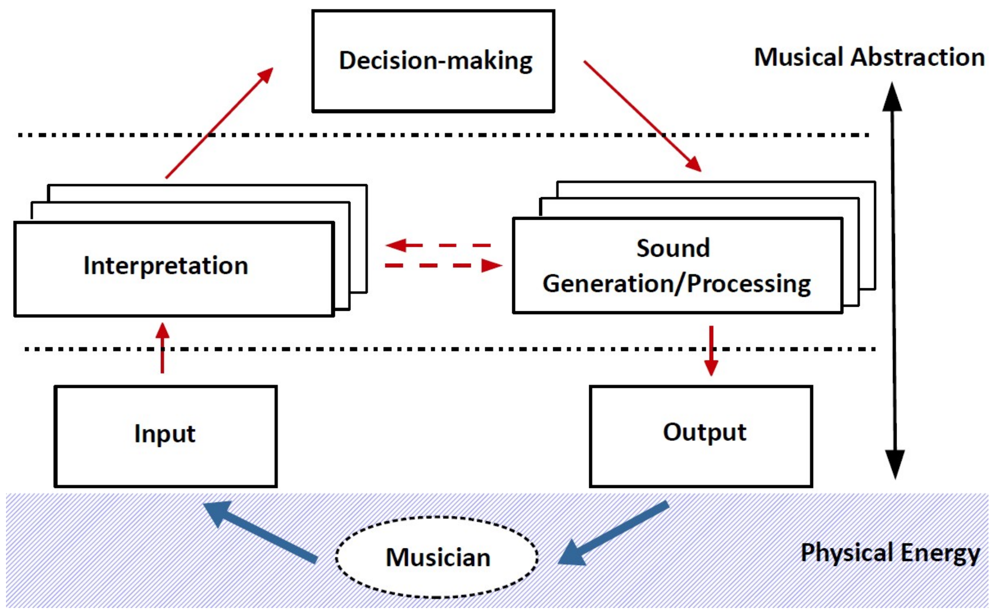

Figure 1: A compositional model for the design of IMS

- **Input** - This module, located on the lower level, deals with the physical energy involved in changing the internal state of the instrument. Generally in IMS, some of the most common physical features usually detected include: kinetic energy, electromagnetic forces, sound and light. The main design concerns related to this module are: (i) the detection and conversion of physical energy (i.e. use of different types of sensors with regards to the nature of the energy involved in the interaction), (ii) the properties of the interface (i.e. the material and tangible characteristic of the interface, the physical interactions that it enables and the physical constraints that it imposes) and (iii) the physical affordances (i.e. the practical opportunities *suggested* by the interface). Usually, in the NIME literature researchers are referring to this element as a *gesture acquisition* module (Miranda and Wanderley 2006). From my perspective, concentrating solely on the detection of gestures may be limiting. There is something more in capturing events or actions in the physical world: an instrument can be designed in order to allow only a specific type of physical interaction, but unintentional movements or environmental noise can also influence the performer's musical intentions. Therefore, during the design of this module these elements might be considered relevant to various extents. From my point of view, all the decision made regarding the different aspects of this module (i.e. the type of sensors, the physical and embodied properties of the instrument and the kind of movement inspired/required by the interface) already represent a fundamental compositional act.

- **Interpretation -** The module is located on a second level of abstraction. This implies that the raw data coming from the physical world are interpreted here with relation to specific contextual analysis. The aim of this process is to extract meaningful expressive information from the performer's behaviour. Many different approaches for the interpretation, isolation or (selective) amplification of features can be implemented. The choice might be influenced by the nature of the physical interactions and the behaviour of the incoming data. This implies the definition of the most significant aspects of an incoming signal. For instance, in the motion domain, this analysis might regard either specific cues (e.g. pattern or gesture recognition) or more generic motion qualities (e.g. quantity of motion, velocity and acceleration). In the audio domain, a first level of interpretation might extract features such as sound pressure level, onset detection, periodicity, sound spectral qualities and so on. In addition, the unit could also analyse the electronic interventions generated by itself. Thus, a feedback process is activated: instead of evaluating the sonorities produced by the musician, it analyses its own output. This feedback might be related to the choice of implementing some self-organisation processes. In spite of the techniques used - in order to allow the extraction of higher levels of information - I conceive this module as able to contain various additional layers of interpretation. This analysis can be quantitative (e.g. statistical analysis, classification, time series analysis, etc.) or qualitative (e.g. based on perceptual and expressive contents). An additional layer might contextualise over various time frames the previously extracted features. This can be useful in order to create any kind of accessible history (database) of the expressive gestures most occurred during the performance (memory metaphor).

- **Decision-making -** The unit concerns the highest level of musical abstraction within the model. Its function consists on establishing connections between the interpreted data and the organisation of generated sounds. Many different metaphors can be adopted to define the function of this module. It is possible to conceive it as a sort of *conductor* that, by analysing a constantly updated *score*, organises and influences the various sections of the *orchestra*. Alternatively, the module might act like an autonomous *performer* listening to the incoming information, playing his own *instrument* and introducing autonomous behaviours and new elements. A *fly-by-wire* approach (Chadabe 2002) or the organ metaphor could also be useful analogies: a limited number of instructions control many complex processes in order to generate the sound material. However, the module should be designed in order to establish musical interactions according to compositional intuitions. The unit might also affect large structural elements of the produced music. In other words, this module can allow the organization of large time scale musical *narratives*. Here the physical inputs and sound synthesis are not necessarily in a strict cause/effect relationship.

- **Sound generation/processing** - Let us consider the orchestra and conductor metaphor previously introduced. The function of the sound generation unit can be easily associated to the role of the musicians in a standard orchestra. Multiple sound synthesis (orchestra sections) can be here defined and *played*. Furthermore, if the analogy is expanded, we could conceive the possibility of accurately control any single player. Within the same sound synthesis, many different levels of control can be explored. Similarly to the interpretation module, this unit can be characterised by a multi-layered structure. Moreover, the sound syntheses implemented can be influenced by different units of the system. If the Decision-making unit can be used to organise in time the various *sections of the orchestra*, the data coming from the interpretation module might be associated to specific parameters of the sound processes defined. In this way, the performer behaviour can directly (in real-time) modify the spectro-morphological qualities of the generated sounds: from atomic internal timbral properties up to larger time scale features (e.g. envelopes, spectral ranges and motions). Therefore, this procedure allows for a more direct interaction between gestures and sounds. Finally, I locate the module on the second level of abstraction as it deals with the generation and modification of digital information strictly related to the actual physical sonic output.

- **Output** - The essential tasks of the module consists in (i) transferring the generated information from the more abstract units into the physical domain and (ii) providing additional *feedback* (e.g. visual or haptic) regarding changes in the system's internal state. The first task concerns aspects such as the (analogue or digital) amplification and compression of the generated audio signal, the digital to analogue conversion, the use of specific loudspeakers and their disposition in the performative space (i.e. sound spatialisation). By taking inspiration from the acoustic instrument's sound production, it is possible to design IMS that integrates the speakers within the body of the instrument. Alternatively it could be useful to conceive a software unit that can *tune* the sound output in relation to the performative space (e.g. using reverberation and equalisation techniques). The second task aims to provide feedback associated to the fulfilment of specific processes led by the intentional control of the performer. Visual feedback can therefore be useful to *confirm* internal changes to the system that are either not instantly verifiable or that will affect the sound production in the future. Here, an analogy with the acoustic instruments can again be inspiring. Usually, traditional instrument provides a large amount of non sonic feedback regarding to what the musician physically articulates. For instance, a clarinet gets warmer after few minutes of practice, the instrument's body differently resonates and vibrates according to the played note and each reed variously behaves in relation to its own physical properties. In the design of IMS those aspects have to be *composed* and they can easily overlap with the reflections presented in the Input module.

Far from being a definitive and strict model, the bestowed description aims to provide a partial overview of the enormous potentiality that technology currently offers in regards to the design of interactive music applications. I conceived this compositional model as a neutral space, open to interpretations according to artistic needs. The model represents a synthesis (or simplification) that introduces the essential elements that, in my view, characterise the design of a IMS. Furthermore, the functions described are not meant to be rigidly assigned to the specific units: the same task can be shared among various modules. Similarly, this principle can be applied regarding the interconnections between the diverse parts of the model: different paths are possible and can be taken. According to the typologies of musical interactions desired, not all of the units have to be implemented. In my view the model can be used in several contexts (see the two projects described in this thesis) and it allows to define the main desired properties of an IMS. For example, an IMS characterised by strong *interpretational* and *compositional* components should be able to extract and process a large amount of information from a very basic and constrained set of sensors. Let us think about the *telegraph key* metaphor where a complex codification of timing elements is fundamental to achieve communication. On the other hand, if the design focuses on the lower layers, it can provide the instrument with intimate, fluid, clear and direct gesture/sound interactions (Wessel, Wright, and Schott 2002).

2.4 The Musical Notions of Effort and Complexity

In my view, the musical notions of effort and complexity are crucial to the achievement of expressive musical interaction. In this section they are introduced as complementary to the compositional model presented. Effort is discussed from both physical and cognitive viewpoints. Complexity is related to the sonic output of the system. The correlation of these two concepts was found to be useful when informing the overall design process of a novel IMS. A two-dimensional chart is presented to convey the relationships between effort and complexity (see figure2). Here the horizontal axis is associated to the quantity of effort (high to low). Similarly, the vertical axis represents the presence of sonic complexity (high to low). Thus, this representation defines four main areas (the four quadrants) characterised by different effort/complexity ratios. Effort is considered as an *input* activity that the musician carries out in order to interact with the system (i.e. towards the system). Complexity instead, concerns the sonic feedback of the system: an *output* influenced by the performer activities. In order to imagine and evaluate the relations amongst the two notions in a particular context, it is possible to locate a specific IMS inside this effort-complexity space. For this *accomodation*, a possible approach consists of outlining an area that defines the borders within which the IMS can act. Another useful practice may involve drawing a line (function) that relates the variation of the two components. An interesting experiment is to draw complex shapes on the graph (e.g. discontinuous forms) and wonder about the type of interactions that might be associated to them.

The considerations introduced in this section, rather than strictly focus on a compositional discourse, are related with the broader context of interaction design. The effort-complexity space is proposed as a conceptual tool for the development of IMS. To better understand its potentiality I propose to examine two practical examples in which music is involved, but it is not the primary target of the interaction. In HCI contexts, the use of music has been extensively studied and applied in a great variety of research areas. Music education (e.g. Harrison 2005 , Varni et al. 2013), rehabilitation (e.g. Camurri et al. 2003 and Gorman et al. 2007), disability (e.g. Bergsland and Wechsler 2015) and sport training (e.g. Wijnalda et al. 2005) are just few of the contexts in which interactive applications exploit the use of music to achieve specific goals.

Let's now consider the two hypothetical IMS represented in figure 2. The yellow are represent a IMS mainly located on the fourth quadrant. This implies that the application can potentially generates an high-level of sound complexity with relatively little effort. In contexts related to rehabilitation or disability this type of interaction might be ideal. People with highly reduced amount of physical possibilities could be able to musically interact with the system. This might allow them to *play* a music that, in standard settings, requires effort and training (e.g. simulation of traditional musical instruments). The idea of drawing an area on the effort-complexity space is related to the idea of providing a degree of freedom. For instance, the system might be designed to allow the exploration of gestural and sonic relations. Each person can freely interact with the application also in relation to their cognitive and physical possibilities.

The red line instead shows an IMS in which, in order to reach an high-level of sonic complexity, a great amount of effort is necessary. This system might be designed for training porpoises. High-level athletes or musicians are usually required to develop effortful technical skills. By using techniques for movement sonification, an IMS might be used to provide a constant monitoring of a specific exercise-performance. Furthermore, the system might reward the subject with more complex and engaging sounds when the task is successfully executed. The fact of representing a system using a line (function) implies that the relationship between effort and complexity is well defined. In this case, the two axes might be associated to specific gestural and sonic features in order to promote constrained interactions and train well defined behaviours.

While considering *pure* musical systems, where the aim of the interaction is to make music, the first quadrant of the effort-complexity space might appear as the most interesting area for the exploration of interactive dependences. Nevertheless, my impression is that, for each specific musical project implying a human-machine interaction in real-time, this approach could help to investigate, reveal and clarify the potential outcomes of the system.

Complexity and effort can be contextualised within the compositional model presented. Their presence (or absence) can be distributed among the various units. For example, physical effort can be obtained through specific choices related to the lower modules related to the detection and interpretation of the physical energy. Likewise, the range of sonic complexity can be defined through decisions regarding the design of the units associated to the sound generation and organisation.

Before attempting to provide a more detailed interpretation of what I mean with the terms of effort and complexity, it is important to clarify a concept *a priori*. The ultimate goal of this reflections is to provide a tool for the composition of IMS. This implies that the composer is the only person that can define the explicit meaning of the terms effort and complexity. With regards to the specificities of a particular project, the signification of the two terms can considerably change. Furthermore, once exactly defined what effort and complexity stand for, it is necessary to delimit the high-low boundaries. In other words: it is also crucial to define what high-low, effort and complexity do mean. For instance, a negative effort might imply that the musician is performing one simple action over a long period of time. If the effort is positive, the payer might be *simultaneously* engaged with different tasks. Within the design of an IMS, the effort-complexity space is ultimately an invitation to reflect about the relationship between physical engagement and sound generation. Nevertheless, seeking to better define these reflections, the musical notions of effort and complexity are now further discussed.

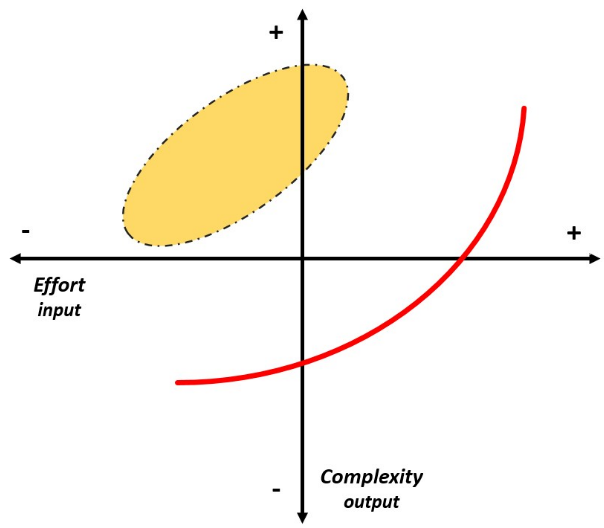

Figure 2: The effort-complexity space: two possible way of representing effort-complexity relationships.

2.4.1 Effort

A frequently discussed aspect of embodied interaction design is physical effort. Many works have addressed this question, either for emphasizing it (e.g. in relation to education or games) or avoiding it (the idea of effortless interactions). Already some studies have been conducted on physical exertion as a possible way to enhance more expressive interactions (Lyons et al. 2012). This attention and predominance of strong physical involvement is present also in music practice. Instead of exertion I prefer the the idea of *effort*. Usually exertion is something limited to a physical and vigorous action, whereas effort is much broader and can be related to creative activities such as music making. In this context I'm using the concept of effort introduced by Ryan as a fundamental element to consider in the design of digital musical instruments (Ryan 1991 and Ryan 1992).

The considerations presented by Ryan are interesting because his idea of effort includes the physical aspects of it but also emphasizes its cognitive, performative and expressive qualities. The historical development of musical instruments has focused not in the reduction of the effort but in the expansion of the sonic possibilities. This makes an important point: I agree with Ryan that effort (either physical or cognitive) is intimately connected to expression. It's a common assumption that learning to play an instrument implies an effort, that sometimes can become synonymous to suffering. In this way, the amount of effort that is exerted in practising an instrument can correspond to the level of virtuosity achieved by the performer. This is also linked to the longevity of the relationship between the performer and instrument, as the performer uncovers increasing layers of more detailed control (Wessel, Wright, and Schott 2002).

Even if effort seems to be a consequence of playing an instrument, I believe that it should be considered as an element to include in the design process of a novel IMS. But this is not a quantitative rule: an instrument that requires a lot of effort is not always the most expressive instrument. In this case effort is not a value, but an element that will affect the conceptual model, the realization and the playing of a musical tool. Because of this I believe it is important to consider the amount of effort a designer/composer wants to allow, how this is linked to musical and expressive values, and which functions it has in the performance.

2.4.2 Complexity

In this context, the word complexity is a general term that should be substituted by the composer with more specific indications. Complexity can be here conceived as the musical behaviour emerging from the variation of specific sonic parameters. The possibility of influencing specific sonic qualities in order to increase to overall complexity of the generated music should be taken into consideration when designing IMS. Within a specific musical interactive context, reasoning on the implications of this possibility, contribute to the development of engaging interactions and musically interesting results. Sonic complexity can be related to the spectral possibilities (e.g. timbre variety, juxtaposition of various sonic layers, harmonicity or nosiness, etc.) or to the articulation of the produced sounds (e.g. variation of the events density, sound/gesture relationships, variation of dynamics, etc.). Furthermore complexity might refer to the chance of developing complex harmonic, melodic or metrical progressions.

Alternatively, more cognitive and psychoacoustic aspects can contribute to the degree of complexity perceived (e.g. natural or acoustic sounds vs artificial or abstract sounds). Elaborated treatments of the incoming data focused (e.g recognition of patterns or interpretation of more abstract musical notions) can allow for the definition of structural-formal elements. This might contribute to the emergence of a complexity that develop in time. Clearly, the degree of intricacy and sophistication implemented with the various elements of a system directly affects the overall potential amount of complexity.

Finally, I firmly believe that complexity *per se* is not musically interesting. It should be justified by some expressive reasons. The attempt to establish an interaction between the sonic complexity and the behaviour of a performer might provide effective and expressive significations. Furthermore, I generally think that to develop sonic complexities there is no need of complex procedures. Efficient musical intuitions are usually more powerful than highly technical approaches. The search for simple (not banal) processes potentially able to generate complex outcomes is particularly valuable.

3 InMuSIC

3.1 An Interactive Systems for Electroacoustic Improvisation

The design of IMS for real-time improvisation poses significant research questions related to human computer interaction (e.g. Cont, Dubnov, and Assayag 2006), music cognition (e.g. Addessi 2012), social and cultural studies (e.g. Lewis 1999). During the last twenty years, the interest on the design of IMS, intended for use in purely improvisational contexts, has grown significantly. Within this field of research, it is possible to delineate different approaches, Rowe (Rowe 1992) provides an useful taxonomy for the classification of various interaction models in *computer-mediated improvisation* (Ciufo 2004). A possible way to frame an IMS consists in outlining its degrees of freedom. The modalities defined to produce and control the system's sonic output can be associated to various interactive paradigms. Amongst others, extended instrument (Van Nort, Oliveros, and Braasch 2010), self-organised system (Blackwell and Young 2004) and musical reflective system (Addessi 2012). Each of them might be associated to the intention of implementing different degrees of control and unpredictability. A specific research approach concerns the design of systems conceived as autonomous agents (Collins 2006). George Lewis' *Voyager* (Lewis 2000) is an early important example of this type of IMS. In *Voyager*, the author's compositional approach plays a crucial role: specific cultural and aesthetic notions are reflected in the sonic interactions developed by the system.

Hsu, while presenting his timbre-aware improvisation system *ARHS* (Hsu 2010), provides a exhaustive overview of related works. An earlier system is Ciufo's *Eighth Nerve* (Ciufo 2003), for guitar and electronics, which combines sensors and audio analysis. Processing and synthesis are controlled by timbral parameters. Collins (Collins 2006) describes an improvisation simulation for human guitarist and four artificial performers. His emphasis is on extracting event onset, pitch and other note-level information from the input audio. Van Nort's system (Van Nort, Braasch, and Oliveros 2009) works with timbral and textural information, and performs recognition of sonic gestures in performance. It has been used primarily in a trio with accordion and saxophone. Young's NNMusic (Young 2007) works with pitch and timbral features such as brightness. It has participated in a variety of score-based and improvisatory pieces, with instruments such as flute, oboe and piano. Casal's *Frank* (Casal 2008) combines Casey's *Soundspotter* MPEG7 feature recognition software (Casey 2009) with genetic algorithms; *Frank* has performed with Casal on piano and *Chapman Stick*. More recently, systems able to generate improvisations in the style of a particular performer (e.g. Pachet's *Continuator* (Pachet 2003) and *OMax* from IRCAM (Assayag et al. 2006)) were developed. In these systems, the implementation of a particular type of finite-state machine, highly refined for the modelling of cognitive processes, allows for the simulation of humanised behaviours such as imitation, learning, memory and anticipation. Indeed, the aim of these investigations is often related to the simulation human improvisational abilities. This allow for the development IMS able to engage with human improvisational contexts.

The system presented in the designed around a complex set of musical interactions that, in relation to the behaviour of the musician, aim to establish an improvised sonic dialogue. Therefore, the interactive paradigm conceived involves the objectification of the system as an autonomous agent able to musically act and re-act. During the design process of InMuSIC, the main focus was on the composition of sonic interactions (behaviours) able to stimulate musical engegment, collaboration and intimacy.

In this field of research, the chosen framework for the composition of sonic interactions reflects particular cultural and musical models, performative intuitions, as well as specific cognitive paradigms and technological notions. Music improvisation is here conceived as a wide-ranging creative practice: a synthesis of intricate processes involving physicality, movement, cognition, emotions and sound. Therefore, the design approach of InMuSIC derived from an embodied cognition of music practice (Leman 2008). The majority of the interactive system for improvisation developed during the last years are not based on an embodied cognition of music practice and they focus on the sonic aspects of the performance. Nevertheless, a multimodal approach for the design of improvising IMS was adopted within various research. For example, Ciufo (Ciufo 2003), Kapur (Kapur 2011) and Spasov (Spasov 2011) developed IMS able to extract in real-time both gestural and sonic qualities of the performer interacting with the machine. However, these applications are concerned with the recognition of specific body parts and particular gestures (e.g. hands movements). One of the main goal of the presented research is related to the definition of strategies for a qualitative analysis of upper-body features pertinent to a wide range of gestures, not restricted to specific types of movement.The following sections present the system's overall design approach sketching a strategy for the real-time multimodal analysis and representation of instrumental music practice.

3.2 The Interactive Framework

The notion of interaction investigated within this research focuses on the development of processes that are capable of generating their own musical conditions during an improvised session. In other words, the attempt is to design a system that, interpreting outside contributions, composes/improvises music through a dialogical modality. The InMuSIC interactive framework is inspired by the spontaneous and dialogical interactions characterising human improvisation. The intention is to provide the system with an autonomous nature, inspired by the human ability to focus, act and react differently in relation to diverse musical conditions. In regards to each specific performance, the close collaboration between the musician and InMuSIC should enable the constitution and emergence of specific musical forms. The generation, modification and temporal organisation of new sonic materials are established negotiating the musical behaviour of the performer and the system's internal procedures. In order to facilitate the development of a spontaneous musical act, the platform should then be able to assess different degrees of musical adaptiveness (e.g. imitation/variation) and independence (e.g. contrast/discontinuity). InMusic has been conceived for real-time concert use within contexts related to electroacoustic improvisation. The compositional research has developed alongside a specific musical aesthetic concerned with the exploration of sonic spectral qualities within flexible fluctuations in time rather than actual melodic/harmonic progressions and metrical tempo (Smalley 1997). InMuSIC relies on the analysis and comparison of sonic and motion qualities. This is by identifying and processing abstracted expressive musical hints of the performer. The attempt of composing and exploring sonic and gestural interdependences is the foundation of the inquired interactive paradigm. Thus, the framework composed to frame and shape the musical interactions, in addition to the sonic dimension, aims to take into account fundamental performative and expressive aspects complementary to the sound production.

With regards to the compositional model presented in section 2.3, InMuSIC was designed to include all the components described. The following sections will attempt to describe them. Inside the effort-complexity space (see section 2.4, InMuSIC should be mainly located in the first quadrant (see figure 3). His sonic output is characterised by a high level of complexity. InMuSIC performs a large number of tasks (e.g. multimodal analysis and interpretation of musical cues) generating both complex responses to the musician's playing and independent behaviour arising from the system's own internal processes. Regarding the horizontal axis, the InMuSIC doesn't require an high level of physical effort. The attempt was to implement a system that is able to detect expressive features in a *natural* context for the user. The performer is therefore required to *normally play* without the need of learning or developing additional technical performative skills. On the other hand, the effort required is mainly cognitive. In order to actually develop a convincing musical performance (i.e. including formal decisions and real-time reactions) the musician has to intensely interact with the system's output.

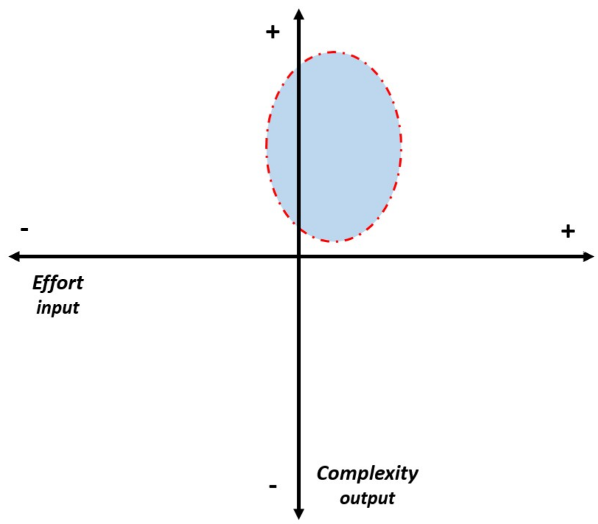

Figure 3: The InMuSIC system within the effort-complexity space.

3.3 The System Architecture

From a practical point of view, whilst a musician plays a freely improvised session, the system performs five main tasks: movement analysis, sound analysis, sound and movement comparison, decision-making and sound generation (see Figure 4). Specific software units compute each of these tasks. The various components are implemented using Max/MSP and EyesWeb. The two platforms communicate through an Open Sound Control (OSC) protocol (Wright et al. 2001). It is possible therefore, to run the system on different machines connected by a network. A description of the five modules and their functions will now be presented.

3.3.1 Sound Analysis

The unit extracts three low-level audio features: loudness, onset detection and fundamental frequency. The audio signal is analysed by matching and evaluating the outputs of several algorithms

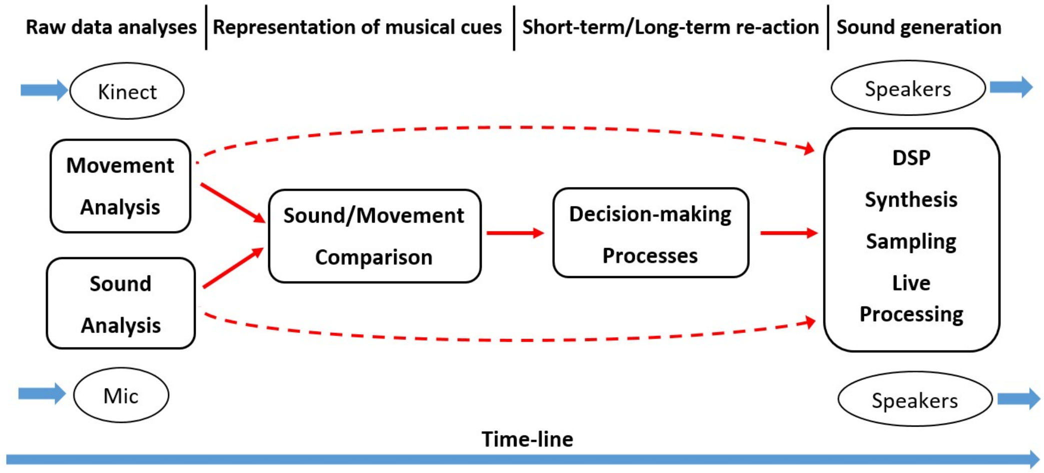

Figure 4: The InMuSIC data flow over time.

(De Cheveigné and Kawahara 2002; Malt and Jourdan 2009; Jehan and Schoner 2002). Each of these is tuned for specific dynamic and frequency ranges.

A first level of analysis is associated to the variation in time of the detected data. Initially the features are interpreted through different low-pass filtering and moving average processes. Subsequently the derivative of each feature is computed. By mapping the obtained values using different logistic functions, two thresholds are fixed. In relation to the data previously analysed, the information extracted is defined by three possible states: higher, lower or stable. Consequently, this procedure displays a minimal representation of each audio feature: (i) high, low or stable dynamics (*crescendo vs. diminuendo*); (ii) high, low or stable onset detection (increase *vs.* decrease of the event's density); (iii) high, low or stable pitch deviation (expansion *vs.* reduction of the used frequency range). The algorithms implemented interpret the incoming values by means of an *inertial behaviour*. In order to detect any positive or negative change, a certain amount of variation is required. This conduct, simulating the function of a short-term memory, is specifically calibrated for each feature. This is crucial to the fine-tuning of the system's sensitivity.

The understanding of the performer's sonic behaviour is therefore associated to the variation in time of the extracted features. The methodology adopted is influenced by psychological research on human communication (Watzlawick et al. 2011). The main assumption is that we can only perceive the relationships or models of relationships that substantiate our own experience. Our perceptions are affected by processes of variation, change or motion. Any phenomenon is perceived only in relation to a reference: in this case the music previously played.

3.3.2 Movement Analysis

Based on the research by Glowinski et al. (Glowinski et al. 2011) for the analysis of affective nonverbal behaviour using a reduced amount of visual information, the module extracts expressive gestural features.

Based on Kurtenbach and Hulteen's definition of gesture (Kurtenbach and Hulteen 1990) as "a movement of the body that contains information", a gesture can be said to be expressive since the information it carries has an expressive content, i.e. an "implicit message" (Douglas-Cowie et al. 2003). This information usually introduces an additional open and interpretable quality to the communication. The chosen approach refers to the framework developed by Camurri et al., to analyse affective gestures (Camurri et al. 2005). This interpretation implies the analysis of behavioural features pertinent to a wide range of gestures and not restricted to specific types of movement. The challenge consists of detecting information representative of an open sphere of possible expressive motions: the chosen strategy focuses on a minimal representation of affective movements. A qualitative approach to the analysis of upper-body movements and affect recognition, is hereby adopted (Camurri, Lagerlöf, and Volpe 2003). Considering a reduced amount of visual information (i.e. 3D position, velocity, and acceleration of the musician's head, hands and elbows - see 5), three expressive features are extracted: smoothness (degree fluidity associated to the head movement), contraction index (degree of posture openness) and quantity of motion (QOM) (overall kinetic energy).

Applying the same procedure, illustrated in the section 3.3.1, the features are further interpreted. Each analysis is reduced to three possible states: (i) high, low or stable smoothness (detection of fluidity and continuity *vs.* jerky or stillness in regards to the head movements); (ii) high, low or stable QOM (overall QOM variation - presence of motion *vs.* stillness or isolated movements); (iii) high, low or stable contraction index (variations in the degree of posture - open *vs.* close).

3.3.3 Sound and Movement Comparison

The module is designed to combine and compare the data coming from the movement and sound analyses. The various *stable* states are ignored: the detection of a *stable* state does not produce any change to the internal conditions of the system (i.e. maintenance of the current stationary state). Figure 6 illustrates the available combinations in regard to each *high-low* state. Through a

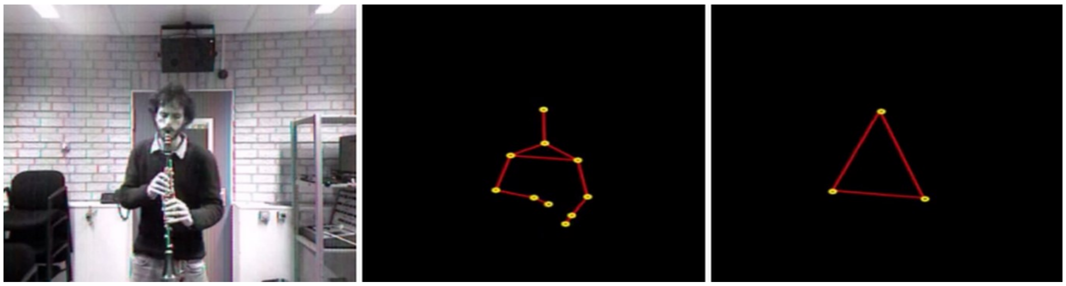

Figure 5: The detected skeleton of a musician playing the clarinet. The data are interpreted in order to obtain a minimal representation of affective gestures.

Graphical User Interface (GUI) it is possible to manually select which combinations the module will consider during the performance. Figure 6 presents a possible selection of the states combinations often used by me performing with InMuSIC. Once a specific combination is chosen (e.g. low QOM and low loudness), the unit constantly verifies if the two states are simultaneously detected: to each selected combination, a simple boolean condition is applied. In addition, the unit tracks how long each condition is verified. In short, during the performance, the data sent to the decision-making module defines (i) which condition selected is currently true and (ii) the time associated to the persistence of each verified condition.

The computation of the various *high-low* states allows for the gathering of information related to the variation in time of the extracted features (continuous inertial interpretation). For instance, in regards to the past trends, the QOM is now increasing or decreasing. The combination and comparison of the *high-low* states associated to the various features is conceived as a further level of abstraction within the expressive analysis of the performer. The organisation of the processes for the generation of new electronics interventions is therefore related to the detection of specific *high-low* conditions (finite-state machine like behaviour). The strategy implemented aims to achieve a minimal and qualitative interpretation of instrumental music practice: the focus is oriented to analyse *how* the musician plays instead of *what* the musician plays.

3.3.4 Decision-making

The function of the unit mainly concerns the time-based organisation of new musical information (e.g. activation, duration, cross fade and muting of the various system's *voices*). Here the main focus is oriented towards the composition of decision-making processes allowing for the development of both long-term musical structures and immediate sound interventions. The unit establishes

		Loudness		Events Density		Pitch Deviation	
		high	low	high	low	high	low
QOM	low		✓				
	high			✓			
Contraction Index	low			✓			
	high	✓					✓
Smoothness	low						
	high		✓				✓

Figure 6: The available combinations of sound and movement comparisons in InMusic. The ticked boxes illustrate a combination often used by me while performing with the system.

sonic interactions that develops inside a *continuum* ranging between two different temporal durations: from short-term immediate re-actions (maximum duration of 4 seconds), to long-term re-actions (maximum duration of 4 minutes). The reference paradigm refers to studies on human auditory memory (Snyder 2000) (short-term and long-term). An *awareness* of different *real-times* is here sought. The overall timing of the unit (i.e. the actual clock that triggers the various sonic processes) is controlled by an irregular *tactus* generated by a stochastic process. The rate of this clock is constantly modified by the variation in time of the onset analysis: the system's *heart beat* increases when the performer articulates a music dense of sonic events and *vice versa*.

The generation and organisation of both short-term and long-term interventions is associated to the detection of the *high-low* conditions occurring during the performance (e.g. simultaneous detection of low QOM and low loudness). To each condition a set of sound processes is applied, a particular type of synthesis can be associated to more then one condition. The more a condition is detected, the higher the probability is to trigger the related sound processes. Furthermore, stochastic procedures influence the relative weight of each probability with a specific set. The duration of an active sonic process is affected by the persistence in time of the associated *high-low* condition.

Simultaneously, the unit regulates two further parallel procedures. Once a particular sound process is activated, timbral adjustments can occur. The unit can establish a direct link between the performer's sonic and gestural behaviours and the processes for the sound synthesis. This relates to the modification of current electronic materials (i.e. manipulation of the control-rate data associated to the triggered sound) using the information coming from the sound and movement analyses. During the performance, the unit can also send the produced electronic materials to the sound analysis module. Thus, a feedback process is activated: instead of evaluating the sonorities produced by the musician, InMuSIC analyses its own output. This situation mainly takes place when the performer is not playing. The possibility of 'listening to itself' is conceived as a further degree of autonomy within the system's agencies.

The described procedures enables the potential generation of a wide range of *musical narratives*, emerging and evolving with regards to each specific performance.

3.3.5 Sound Generation

The sound generation module is conceived to produce heterogeneous sound materials. The sonic interactions generated entail a multiplicity of possible changes concerning diverse musical circumstances. In relation to the different performative and expressive contexts, the variety of timbral and sonic articulation appears to be an important requirement for the development of an engaging interactions.

The algorithms implemented for the generation of the electronic materials can be organised into three categories: (i) synthesis (FM, additive, subtractive and physical models Trueman and DuBois 2009), (ii) sampling (real-time processing of pre-recorded sounds) and (iii) live processing (live sampling, live granulation, Fast Fourier transform analysis and re-synthesis and reverberation).

The individual techniques used can be conceived as system's *voices*. Each *voice* is characterised by specific qualities, that are spectro-morphological (i.e. related to the distribution of energy inside the sonic spectrum) and gestural (i.e. associated to the articulation and transformation of sound material over time). In relation to the generated sonorities, each algorithm has been designed to guarantee a certain degree of indeterminacy. The goal is to define processes able to develop extensive variations and manipulations of the electronic materials within predefined physical scopes (e.g. frequency, dynamic and temporal ranges). In other words, every single voice is conceived to explore diverse *sound spaces*. The musician is invited to *navigate* these timbre spaces D. L. Wessel 1979 in collaboration with the system. Once a voice is active, timbre variations may occur: these changes are shaped by the external interventions inferred by the performer's musical behaviour. The intention is to develop a close dialogue/collaboration between acoustic and electronic materials (e.g. fusion, separation, imitation, variation and contrast).

This approach, influenced by the procedures related to algorithmic composition (Nierhaus 2009) (Trueman and DuBois 2009), allows to partially solve a dichotomy that emerges when attempting to combine the practices of composition and improvisation. Through the real-time interactions with the performer, InMuSIC organises and shapes pre-composed musical materials. The challenge relies on balancing the processes that leads to the development of musical forms within a *performative time* and the musical choices previously made over a *compositional time*.

3.4 Playing with InMuSIC - InMuSIC as Player

This section aims to explore some of the most relevant artistic implications of InMuSIC. I introduce this considerations as an important aspect of the research: they strongly contribute to the development of the system. The following reflections attempt to outline my own understanding of the notions of *interactivity* and *agency* when considering improvising IMS. Indeed, they can be considered as modest and rudimentary answers to questions such as “what is an interactive system for electroacoustic improvisation?" and “which are the particular circumstances that allow us to perceive it as such?". Furthermore, in his famous article *Computing Machinery and Intelligence*, Turing introduce the last two paragraphs with these words: “*These last two paragraphs do not claim to be convincing arguments. They should rather be described as 'recitations tending to produce belief*” (Turing 1950 p.18). Due to the naive artistic flavour permeating some of the next passages, this section should be acknowledged in the same way.

As previously mentioned, the InMuSIC project aims to develop a system as autonomous agent able to collaborate with the musician in real-time. In computer sciences, many definitions of agency have been proposed (for an overview see Franklin and Graesser 1996). Amongst other, Wooldridge and Jennings 1995 (p. 2) argue that an agent could be defined as “*a hardware or (more usually) software-based computer system that enjoys the following properties:*

- *autonomy: agents operate without the direct intervention of humans or others, and have some kind of control over their actions and internal state;*
- *social ability: agents interact with other agents (and possibly humans) via some kind of agent-communication language;*
- *reactivity: agents perceive their environment, (which may be the physical world, a user via a graphical user interface, a collection of other agents, the INTERNET, or perhaps all of these combined), and respond in a timely fashion to changes that occur in it*;
- *pro-activeness: agents do not simply act in response to their environment, they are able to exhibit goal-directed behavour by taking the initiative."*

InMuSIC was not developed by attempting to implement specific cognitive or neuroscientific guidelines. Indeed, it is not my intention to discuss if my system actually is or not an autonomous agent. I agree with Russell and Norvig's approach: "*the notion of an agent is meant to be a tool for analysing systems, not an absolute characterization that divides the world into agents and non-agents*" (Russell, Norvig, and Intelligence 1995 p. 33).

I would like to begin this reflection by considering the context for which InMuSIC was conceived. The ultimate goal of this research is to make music. In particular, the system here presented was developed to play along with a musician within a live performance. My discourse starts by arguing that any performance of music, involving musician(s) and audience, implies a process of expression and communication. This entails that somehow signs (or symbols) are exchanged through sound. This both occurs amongst musicians and between musicians and listeners. The debate on the semiology of music is nowadays open and active. In this field, one of the milestones is the text *Music and Discourse* (Nattiez 1990). Nattiez wisely explores the notion of *musical meaning* mainly referring to the work of Peirce (Peirce 1974). Personally, I am usually critic with the use of the word *meaning* in musical discourses. In my view, the danger is to associate and superimpose linguistic notions to musical contexts. The study of music should clearly also be involved with the comparison between music and language (the similarities amongst the two are evident). Nevertheless, my concern regards the fact that language is often understood as something that aims to manage and resolve ambiguities. Instead, usually art tends to the opposite direction. Often music seduces thanks to the ambiguities that it involves.

Even if the term *meaning* might result reductionist, it is possible to defend the idea that music performance is characterised by the transmission of some sort of *contents*, which are manipulated and interpreted in relation to particular social and cultural systems. Furthermore, I feel the need of distinguishing between the compositional act and the public performance of music. The act of composing music (or playing an instrument) in itself might be free from any expressive intentionality. A composer could potentially produce a piece of music just because he feels the deepest necessity of doing it. On the other hand, when the music is *publicly* performed an exchange inevitably occurs, even if the composer-performer doesn't wants to communicate anything. Quoting Nattiez: "*As Galileo reportedly said, eppur si muove: we must acknowledge that such a thing as [musical] meaning exist, whatever its true nature might be*" (Nattiez 1990 p.9).

Indeed, Paul Watzlawick in *Pragmatics of Human Communication* while attempting to define the axioms of communication suggests that: "*Every communication has a content and relationship* *aspect such that the latter classifies the former and is therefore a meta-communication*" (Watzlawick et al. 2011 p.42). Consequently, the same message within different contexts or relations, might be interpreted in different ways. In order to translate this consideration in musical terms, I would like to consider the example of the computer-based musician performing on stage sitting in front of the laptop and typing on the keyboard. One of the critique to this performative modality is that the audience has no cue on what is it going on. Potentially, the musician could be checking e-mails instead of actually performing. This critique enlightens the importance of the relationship for a given message. The same music (content) might be perceived in different ways depending on the relationships amongst the performer(s) and the audience. Beyond the assumed honesty of the play, each music performance is conceived for particular players, instrumentations, genres and venues. This aspects contribute to the way the music is composed, performed and perceived.

InMuSIC has been developed for the context of music improvisation. The relationship system-musician is similar to (or inspired by) the one occurring between two humans improvising. The system was designed for this type of interaction. The musician is invited to play within this performative modality. I am convinced that if the performer would approach InMuSIC in a different way, the musical interaction would be much less effective. On the other hand, if InMuSIC would be presented as a fixed composition and the musician on stage, while improvising, would fake to read an empty score, the audience would perceive the music in a different way. It is therefore possible to argue that any performance of music is conceived for specific social contexts and involving specific actors (i.e. performer(s) and audience) situated in specific venues. The players of the game, for a certain period of time, interact (or exchange) between each other. This implies particular relations, agreements or regulations. To better understand this particular framework, the text *Man, Play and Games* (Caillois and Barash 1961) might provide useful insights. Caillois, building on the work of Huizinga *Homo Ludens* (Huizinga 1938), argue that "*play can be defined as an activity which is essentially*:

- *Free: in which playing is not obligatory; if it were, it would at once lose its attractive and joyous quality as diversion;*
- *Separate: circumscribed within limits of space and time, defined and fixed in advance;*
- *Uncertain: the course of which cannot be determined, nor the result attained beforehand, and some latitude for innovations being left to the player's initiative;*
- *Unproductive: creating neither goods, nor wealth, nor new elements of any kind; and, ex-*

cept for the exchange of property among the players, ending in a situation identical to that prevailing at the beginning of the game;

- *Governed by rules: under conventions that suspend ordinary laws, and for the moment establish new legislation, which alone counts;*

- *Make-believe: accompanied by a special awareness of a second reality or of a free unreality, as against real life*" (Caillois and Barash 1961 p. 9).

To a certain extent, most of these qualities might be appropriate to outline the act of performing music[2]. Furthermore, the practice of music improvisation seems to particularly resonate with this description. However, the word *play* is characterised by a comprehensive connotation. Amongst other, it might be used with regards to music, theatre and game. Caillois argues that we can understand the complexity of games by referring to four play forms: *Competition* (I would also introduce its opposite *cooperation*), *chance* or alea, *mimicry* (simulation, mimesis, or role playing) and *vertigo* (altering perception). Again, in my view these categorises fit well in the context of music performance. Particularly interesting is to notice the emphasis that Huizinga and Caillois place on the notion of fiction, make-believe and illusion. Huizinga affirms that: "*summing up the formal characteristics of play we might call it a free activity standing quite consciously outside ordinary life as being 'not serious', but at the same time absorbing the player intensely and utterly*" (Huizinga 1938 p.13). Caillois is convinced that "*all play presupposes the temporary acceptance, if not of an illusion (...), then at least of a closed, conventional, and, in certain respects, imaginary universe*" (Caillois and Barash 1961 p. 19).

In fact, from an etymological viewpoint, the term *illusion* derives from the Latin word *in-ludus*: in-play (or in-game). My approach to music is often very concerned with the idea of developing and manipulating temporary *illusions*. In my view, Music is about veiling and revealing. This notion of art suggests that the artist while creating *artefactual* inventions pursuits alchemical processes in order to transform the physical word in symbols.

Technology[3] helps and influences humans to develop these illusions. It allows for the amplification and manipulation of the outlined symbols. In this framework, the masterpieces are works able to merge various layers of possible interpretations (or illusions). The artist shows something, let us speculate on it, he guides our perception and he suddenly brings to our attention a new element

2. Despite the importance of the issue, I will not discuss here in which terms music is either productive or unproductive.
3. Technology is here understood in anthropological terms: *tèchné* (art) + *logos* (discourse or reasoning). Intended as the human ability to make and perform with the implication of knowledges, intuitions, feelings and emotion

that make us doubt. The most successful pieces of art can constantly *speak* to the audience, by revealing always new nuances, possible interpretations and intriguing illusions. Ambiguity is what cause the constant short circuiting between illusion and disillusion. Art lasts in time due to the presence of opened and unsolved expectations and prospectives. In *Art as Technique* (artifact) Shklovsky elaborates on that as follow: "*A work is created artistically so that its perception is impeded and the greatest possible effect is produced through the slowness of the perception. As a result of this lingering, the object is perceived not in its extension in space, but, so to speak, in its continuity*" (Shklovsky 1965 p.8). The main challenge of InMuSIC was to design a system that could promote the perception of a human-human collaboration. This *illusion* can potentially occurs only through the temporary acceptance of a make-believe (or play). In this *theatre* a computer (a quite complicated box) can potentially become *alive*. At least, we might give it a chance. The illusionary qualities of music and the highly developed technology used to produce it allow for the establishment of a human-computer-audience relation clearly outside of *ordinary* life. Of course, this relation has to be proved by the contents of the musical communication. Otherwise the game is over. Indeed the game doesn't finish when somebody cheats. The game is ruined by who refuses to play because the game is meaningless.

In the case of InMuISC, the content is the music emerging from the human-computer interaction. The previous sections of this chapter aimed to explain which are the strategies I explored in order to develop an autonomous-collaborative agent. My impression is that, in the context of electroacoustic music, the design of an IMS should focus on the interpretation of the musical materials articulated by the performer and on the sonic possibilities of the system. The more these two aspects are developed, articulated and sophisticated the more the interaction will be engaging and convincing. Namely, what goes in and what goes out define the nature of the interaction. What happens inside the system is a relatively important issue. I believe that many different *mapping* strategies might be suitable for the establishment of convincing input-output relations (from the very basic one to one direct cause-effect up to the most complex and sophisticated neural network model). On the other hand, everything will be ineffective if the machine fails to *listen* what the musician is doing. A sophisticated and intimate analysis (i.e. able to catch and represent a good variety of expressive musical traits) is crucial for the development of powerful musical exchanges. The same discourse can be applied to what the machine sends out. A pallet of sonic materials that enables the possibility of performing several different musical behaviours, strongly helps to develop engaging interactions.

These ideas are supported by psychological theories arguing that we attempt to analysis the human mind using the human mind. The mind is both the object and the tool of the investigation. This led to the metaphor of the *black box* (Watzlawick et al. 2011 p.36). Since it is impossible to *open it* and understand its functioning, the solution is to focus on what goes in and what goes out (i.e. human communication). The importance of the coupling between action and perception is a well establish notion supported by a large amount of disciplines. The discovery of the so-called mirror neurons is one of the study that evidence this assumptions (Rizzolatti and Sinigaglia 2006). Furthermore, the implications related to the study of the sensorimotor system are discussed in section 2.2. I would like also to mentioned the work of Maurice Merleau-Ponty. In the philosophical framework, his *Phénoménologie de la Perception* (Merleau-Ponty 1945) strongly contributed to the affirmation of the primacy of perception and corporeity.

Finally, since this section started with a quote from *Computing Machinery and Intelligence* by Alan Turing, I would like to conclude by humbly commenting one aspect of his article. At the beginning Turing proses the question "*Can machines think?*". In few lines he smartly turns the question into a game. The *imitation game* is essentially a well defined communicative (behavioural) dynamic, involving specific relations between the actors (e.g. the players do not see each other and they communicate by typing on a teleprinter). The aim of the game is to discover if, on the other end of the teleprinter, there is a human or a computer. With other words, can a machine mimic the behaviour of a human chatting on a computer and be potentially identified as such? Eventually, the question is not any more "*Can a machine think*?" but "*Can a a machine be perceived as able to think*?". The differences between the two questions are crucial. The first regards the very ontology of the machine while the second focuses of the human perception of a behaviour.

3.5 The Evaluation

InMuSIC is a multimodal interactive system for electroacoustic improvisation (clarinet and live electronics). It can be defined as a system that composes/improvises music through a dialogical modality. The aim of the research is to design a platform able to establish a close collaboration with the performer, in relation to the analysed musical information.

Music improvisation is here conceived as a spontaneous expressive act involving cognitive and technical skills conveyed by sonic and physical behaviours. The interactive paradigm developed is therefore based on the combination and comparison of the performer's movement and sound analyses. InMuSIC is tuned to be sensitive to a specific *apparatus* of gestural and sonic behaviours, according to both the instrumental practice of the clarinet and the performative attitudes characterising the my personal expressiveness. Future developments of the system may include the possibility of expanding this *apparatus* in order to explore diverse audio and gestural features and widen the performer's analysis. It is not my intention to categorise or attribute any specific semantics to the various expressive cues represented. Instead, the interest relies on the exploration and use (or abuse) of these musical indications in the contexts of composition and improvisation. Nevertheless, the impression is that, with a more systematic approach, the multimodal analysis presented might allow for the revealing of performative traits pertinent to specific instruments and players. The conceived performance presumes the development of both musical structures and immediate re-action, emerging from the human-computer cooperation.

I have extensively played with InMuSIC in live concerts and it has been presented in several musical events and research contexts (e.g. (Lepri 2015), see figure 7). The performance was often evaluated as engaging and successful. The sonic variety generated and the system responsiveness appear to be the most valued traits of the IMS here presented.

InMuSIC was also tested by five expert improvisers in informal settings. The aim was to explore the use of InMuSIC with different players and instruments (two clarinettists, one trombonist, one cellist and one pianist). After a short introduction, the musicians were invited to freely play with the system. Open interviews were undertaken to investigate their impressions. During the dialogues with the musicians, six areas of discussion frequently emerged: considerations on understanding and controlling the system, impressions on the collaboration with the system, attempt to compare between human-human improvisation and human-machine improvisation, aesthetic considerations (the *sound of the system*), personal sensations and feelings while playing with the system and overall comments. The attached annex, for each participant, resume the most relevant assertions associated to the several areas. The system was essentially perceived as a generative algorithm allowing for a shared exploration of interesting and engaging musical materials. In the annex attached to the thesis it is possible to read a resume of each interview with the various participants.

The experience of playing with InMuSIC was compared to a conversation with a little child: "You don't know very well how it will react. It's a little bit shy at first and you have to draw something out of it". The system was also perceived as able to play both in foreground (leading) and background (either following or leaving space for solos), although some musician felt that

InMuSIC was leading too often. Some improvisers perceived a not always bidirectional interaction: the machine was "not listening much". Furthermore, they expressed the desire for a IMS that would more frequently retrieve and develop the materials proposed by them.

Some musicians were slightly frustrated by the impossibility of clearly understand and control the functioning of InMuSIC. Others referred to this aspect positively comparing this situation to the real human-human interaction. Interestingly, some musicians observed that, during the performance, a turning point occurred. After a first clear and simple interaction (i.e. direct action-reaction relationship) the musicians changed their attitude. Once recognised that the machine was listening and responding (even if not constantly) they started to better engage with the system being more open to the electronic material proposed.

During the sessions, the algorithms for the sound and movement analysis were not modified: the settings normally used by me performing with the clarinet were kept. Compared to my experience with InMuSIC, I noticed that the system was less reactive and always performing with a reduced amount of sonic possibilities. This might suggest that the system has to be tuned according to each specific player. In addition, all the musicians agreed on the need of rehearsing in order to achieve a more satisfying performance. There were no significant differences in the system outcome while playing with different instruments. This might be related to the qualitative approach adopted for the analysis of musical behaviour (i.e. looking at how do we play instead of what do we play).

Figure 7: The author performing with InMuSIC at the The Art School in Glasgow.

4 Melotronica

4.1 A Prototype of a Digital Musical Instrument

Research on the design and development of novel digital instruments and interfaces for music have been carried out within various disciplines, among the others: computer music (Cook 2001), human-computer interaction (Wanderley and Orio 2002), music cognition and perception (Levitin, McAdams, and Adams 2002) and theories of design (Cariou 1992). Various frameworks and principles for reasoning about the design of computer-based musical instruments have been developed (among other see D. Wessel 2006, Malloch et al. 2006 and Cook 2001). The Studio for Electro Instrumental Music (STEIM) is one of the oldest European research institute dedicated to the investigation of new instruments and interfaces (Ryan 1991). The work presented in this chapter has been mainly developed at STEIM under the advises of the STEIM's staff. The helps of Lex van den Broek (head of the Electronics WorkShop at Royal Conservatoire in The Hague) and Nicolò Merendino (STEIM collaborator and designer at the Waag Society in Amsterdam) were crucial for the advancement of the work.

Initially, the Melotronica was conceived as a *side project* within my master research. Nevertheless, during its development I gradually became aware of the musical potentialities of this instrument. The Melotronica is here presented as a prototype: further developments, refinements and optimisations are clearly needed in order to obtain a stable, accurate and reliable instrument. The general aim of the project is to design a hybrid instrument that, providing a tight integration between the acoustic and electronic dimensions, could allow for the simultaneous manipulation of the two.

In past projects, I had the possibility to explore the use of the melodica. My first musical education is associated to the piano, I'm therefore familiar with the *keyboard interfaces.* During the years, I designed different MIDI keyboard based instruments for electroacoustic contexts. While working on this type of interfaces, I came across the melodica and I immediately engaged with the instrument. The melodica offers a minimal configuration of expressive possibilities. This forces the musician to deeply investigate and optimise the sonic possibilities of the instrument. Paradoxically, a very constrained environment promotes an inner search of musical inventions. In order to properly exploit the few material at disposal, the performer has to push further his creativity. Furthermore, the timbre of the instrument (similar to an additive synthesis) has the power to ancestrally seduce my electroacoustic imagination. The sound is produced by the vibration of metallic reeds, using the same mechanism of instruments such as bandoneon, accordion and harmonica. To some extent, its the sonic qualities might be related to the timbre of a church organs in the highest registers. Finally, the reduced dimensions of a melodica allows to easly transport the instrument (for a pianist this is not a marginal feature).

The idea of the Melotronica came out during a workshop on technology design by Kristina Andersen (Andersen 2014). During the two years of the master, I was involved with my fellow students, in several *alchemic* group activities. These meetings were remarkably important to develop and *built* ideas. In this case, we had to draw a sound on one of ours hands. Then, using an extremely reduced amount of materials, we had to built the hypothetical instrument that could produce that sound. At first, I did not realised that the instrument I was building was a melodica. During the process, I discover that what I was doing was a sort of wind instrument (I was supposed to blow into the instrument to produce imaginative sounds). After few minutes of work, I suddenly realise that what I was sketching was related to a melodica. Somehow, the act of imaging and building a not yet existing instrument brought together my previous and future musical experiences.

Figure 8: The workshop of Kristina Andersen: " Drawn a sound in your hand and build the instrument that produces it"

4.2 The Interactive Framework

In order to discuss the Melotronica interactive framework, it is useful to mention the taxonomy proposed by Rowe (Rowe 1992) to classify IMS. Rowe discerns three dimensions: (i) score-driven/performance-driven, (ii) transformative/generative/sequenced and (iii) instrument/player. With regards to the Melotronica, the third paradigm is particularly relevant. Quoting Rowe: "*Instrument paradigm systems are concerned with constructing an extended musical instrument: performance gestures from a human player are analysed by the computer and guide an elaborated output exceeding normal instrumental response. Imagining such a system being played by a single performer, the musical result would be thought of as a solo*". On the other hand, "*Systems following a player paradigm try to construct an artificial player, a musical presence with a personality and behaviour of its own, though it may vary in the degree to which it follows the lead of a human partner. A player paradigm system played by a single human would produce an output more like a duet.*" Lewis further elaborates on the dichotomy that relates the two paradigms: " *I regard the two models of interactive role construction, not as a fixed binary opposition, but as a continuum along which a particular system's computer-human interaction can be located*" (Lewis 1999).

The Melotronica was designed to be able to range within this *continuum*. By using a slider placed on the body of the instrument, the performer can therefore smoothly switch between two different set of algorithms. The information detected by the various Melotronica's sensors is therefore used either to directly control specific sound synthesis (straightforward cause-effect relationship) or to influence stochastic sonic process (emergence of autonomous musical behaviours). This approach was also inspired by the work of Kristina Andersen(Andersen and Knees 2016) on the notion of *strangness* within the design of music software.

In the context of the compositional model presented in section 2.3, the Melotronica can be mainly placed in the lowest area of the scheme. The design of the instrument mainly focused on the input and sound generation modules together with their relations. Even if the Melotronica foresees the possibility of generating autonomous sonic behaviours, little interpretation and decision-making processes were implemented. Instead, within the effort-complexity space (see section 2.4), The Melotronica should be mainly located in the fourth quadrant. It is arguable that the original instrument is already quite effortless and accessible. In addition, the interface designed for the electronics allows for an intuitive and immediate control of the instrument's functionalities. Nevertheless, in order to interact with the autonomous behaviours of the instrument, a more cognitive effort might be required. On the other hand, while playing the Melotronica, it is possible to easily generate complex sonic outputs. Indeed, the instrument was designed to allow the simultaneous activation of multiple processes for the generation and manipulation of the sound.

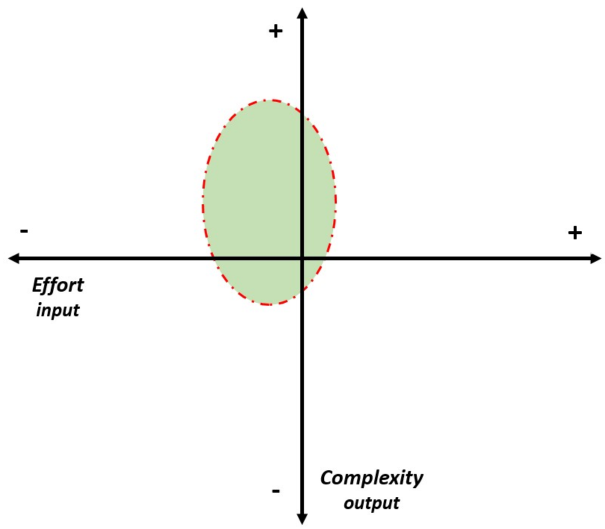

Figure 9: The Melotronica within the effort-complexity space.

4.3 The Design Process

Rather than illustrate in detail the Melotronica design process, I would like to introduce some reflections on the crucial steps that characterised the development of the instrument. Furthermore, these considerations also influenced the design of system introduced in chapter 3.

The design of the Melotronica essentially took place in three phases. First the instrument was imagined and sketched using recycled materials (cardboard and stationery, see figure 10). This allowed for an initial exploration of the potential physical properties of the instrument.In this early phase, the simulation of the physical interactions with the body of the instrument, naturally promoted a first brainstorm on the sonic implication of the various gestural affordances (i.e. which DSP techniques use and how to control them). The impression is that while sketching the interface I was discovering its sonic properties. The second phase regarded the actual design of the prototype. During this process different paths were explored (e.g. use of different sensors, materials and configurations).The design of each instrument's element required attempts, tests and iterations. Finally, once all the components were assembled (software and hardware), the instrument was *crash tested* through rehearsals and public presentations in informal settings. This condition revealed many problematic aspects related to both the functioning of the instrument and the human-machine interaction. After a single rehearsal-performance it was often necessary to adjust or modify the instrument again. The constant transition between these two stages (i.e. prototyping-tuning and performance-evaluation, see figure 11) was at the core of the design process. Crucial improvements and refinements were carried out thanks to this practice based approach. The belief is that through this feedback process, a draft prototype can gradually moves towards more final stages. Furthermore, the designer-performer can become *confident* with the functioning of the prototype and an instrumental performative sense can mature. Here, similarities can be made with the iterative design process presented by Verplank in his *Interaction design sketchbook* (Verplank 2003). The three phases related to the Melotronica design process are now briefly described.

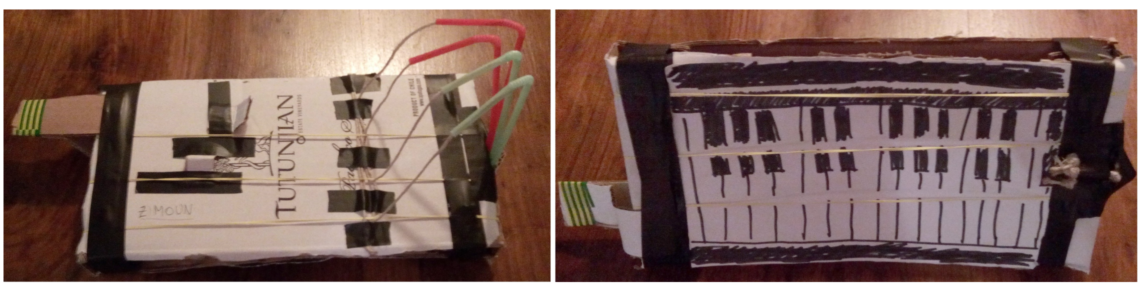

Figure 10: The first sketch of the Melotronica.

- **Sketching the instrument** - In terms of designing a DMI, the instrument sketching focuses around the exploration of materials and ideas in both the physical and digital domains. Thus ensuring that decisions are made with relation to the physical and cognitive experience of playing. Sketching the instrument can be also intended as *sketching the interaction*. The practice of *mimic* interactions through the use of voice and gestures can be a valid initial strategy to stimulate the imagination and clarify vague ideas and intentions (Ekman and Rinott 2010). During the design process, sketching the instrument aims to regularly experience and explore the affordances, constraints, relations and potential of the materials involved. It encourages the development of ideas that are derived from their practical application rather than from a pre-established musical model or interface.

- **Prototyping - tuning** - Once initial decisions have been made, the instrument design takes place through a process of continuous refinement. Thus constantly evaluating the suitability of the introduced changes and clarifying the intentions of the designer/composer. During this tuning practice deeper compositional decisions can be taken, shifting aspects of the project towards new directions. This tuning procedure involves an alternation between small modifications and testing/playing (as within the tuning process of the acoustic instruments). One of the main implication of this practice consists in facilitating the development of an intimate instrument knowledge.

- **Performance - test/evaluation** - In the design process, the performance should be a crucial moment. It allows for the evaluation of many aspects of the instrument within its intended environment. The heightened expectations and the presence of an audience provides a critical set of criteria for the evaluation of the instrument. All the previous work is put *under pressure* and issues such as intuitive navigation, expressiveness, durability and stability become increasingly important. For these reasons, the majority of significant improvements for a DMI often occur after the first performances as they highlight problematic areas, new possibilities and unfulfilled desires. The performance is the experience that allows musical understandings and meanings to be embodied within the instrument.

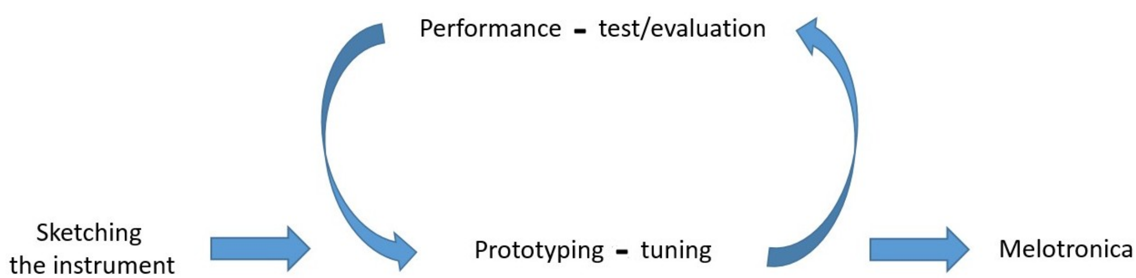

Figure 11: The design process of the instrument.

4.4 The Instrument Architecture

The Melotronica is a modified melodica with sensors mounted on and inside the body of the instrument. The sensors control in real-time a DSP software (Max/MSP and PD) for the manipulation of the acoustic sound and the generation of electronic timbres. The communication between the sensors and the software is implemented using the Ipson64 interface developed by Lex van den Broek. The data are sent using the OSC protocol (Wright et al. 2001) via Ethernet cable. A more detailed description of the hardware and software components will be now introduced.

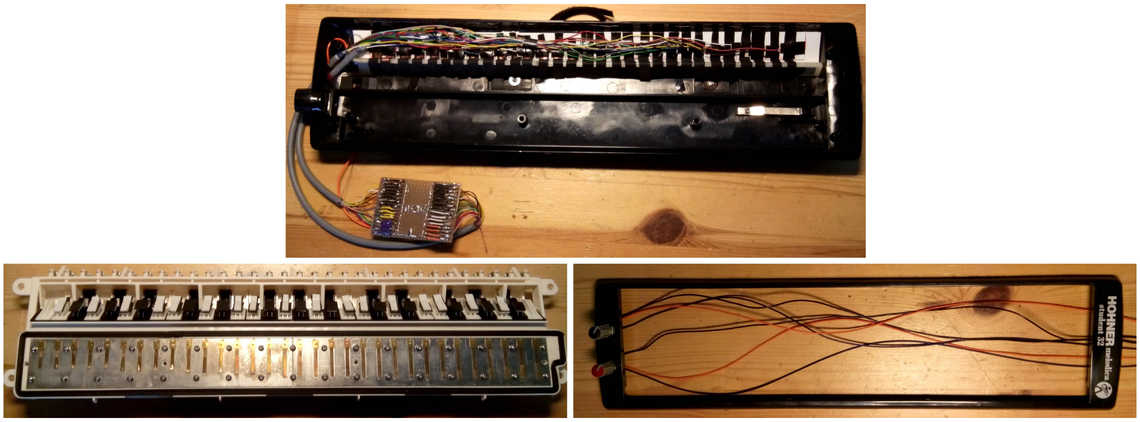

Figure 12: The sensors placed inside the body of the Melotronica.

4.4.1 The Interface

The Melotronica is equipped with forty sensors. Most of them are located inside the body of the instrument and are used to detected the keyboard activity (see figure 12. The remaining sensors were placed on the body of the Melotronica using a custom support. A clip-on condenser microphone is also mounted on the instrument (see figure 15). The used sensors are below listed.

- 30 custom pressure sensors (conductive paper)
- 1 SoftPot membrane potentiometer
- 1 slider bar
- 4 switches
- 2 buttons
- 2 potentiometers
- 1 clip-on microphone

In order to allow immediate access to the sensors located on the body of the instrument, a custom support was designed (see figure 13. The thumb of the hand that holds the instrument can therefore directly interact with the switches, the buttons and the slider. In addition, the support was designed to hold the Ipson64 board. This approach aimed to develop a relatively embedded instrument. The ideas was design a compact instrument that could be easily transportable. The board used to transfer in the digital domain the sensors data is the Ipson64: an OSC interface with 64 independent inputs. The device is designed around a PCI18f2423 chip, which has a 12bit

(0-4096) resolution. The input is realised with 4 x HEF4067 chips. The communication is realised using the Lantronics XPort.

Finally, I usually perform with the Melotronica using an additional hardware module: an Arduino based pedal rack I designed at the beginning of my master studies (see figure 14). The sensors used are (i) three custom pressure sensors (conductive paper) and (ii) a MIDI expression pedal.

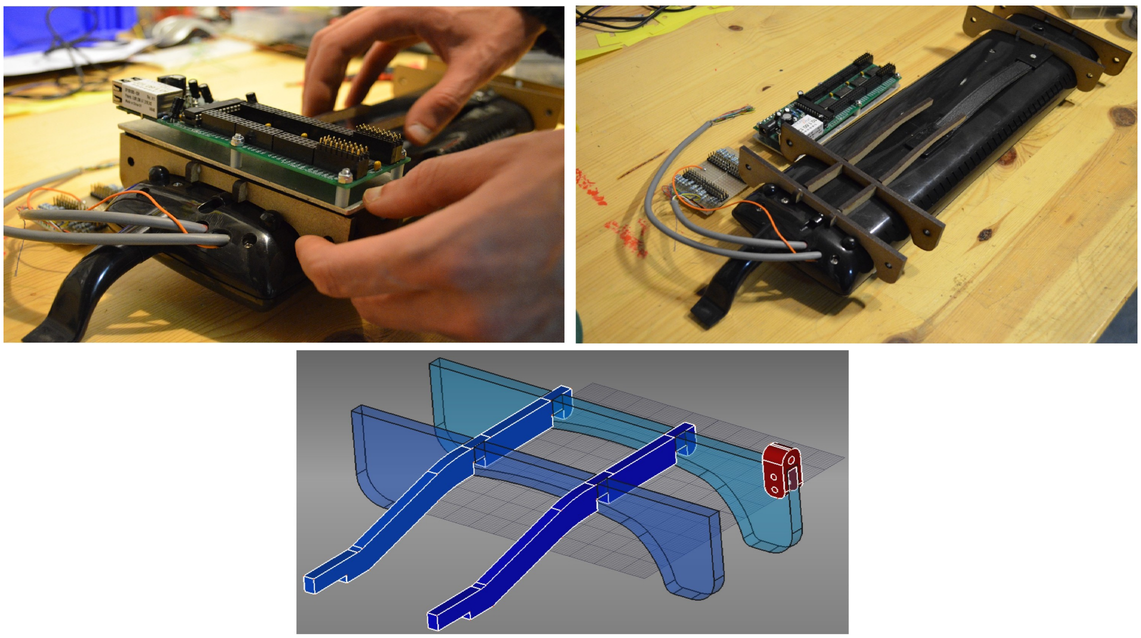

Figure 13: The designed support mounted on the body of the instrument. It function is to hold both the Ipson64 board and various hand controllers.

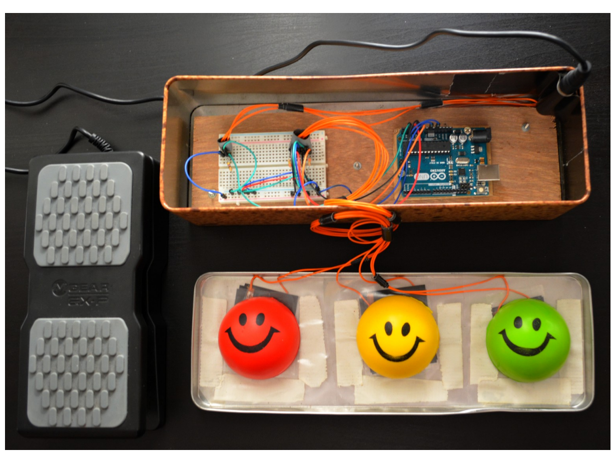

Figure 14: The custom pedal-rack interface designed for the Melotronica.

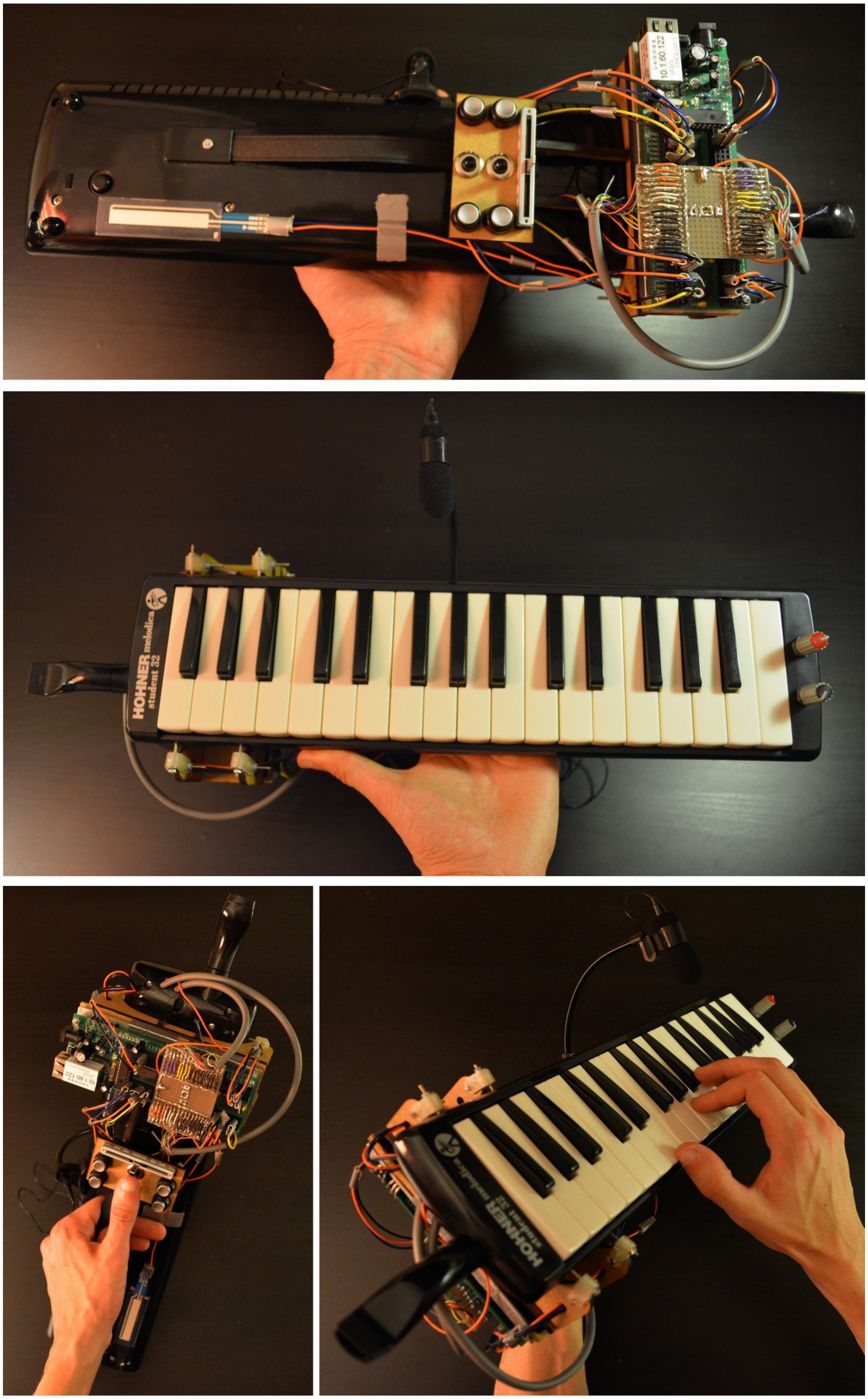

Figure 15: The Melotronica.

4.4.2 Sound Generation

The software unit for the generation and manipulation of the electronic materials is mainly designed in Max/MSP. The DSP can be divided in two categories. The first set of sound processes was conceived to develop sonic interactions in tight relation with the acoustic sound of the instrument. The techniques for the live processing implemented are: FM and AM syntheses, sampling, feedback delays, granulation, pitch shifting and FFT analysis and re-synthesis. The performer can switch between them using the controllers mounted on the body of the instruments. It is also possible to activate more than one process simultaneously. These algorithms mainly react to the data coming from the keyboard and the microphone. The attempt was to design processes for the arising of hybrid timbres directly connected with the acoustic sound of the instruments.

The second category instead, regards the generation of sonorities capable of more autonomous behaviours. Consequently, the musician can partially control these processes. The DSP here implemented are associated to higher processes of interpretation. The data coming form the keyboard and the microphone provide information related to the amplitude, onset detection and fundamental frequency of the played notes. These information influence two stochastic processes: a first order Markov chain[4] and LFO based algorithm. The Markov chain analyses and generates pitch values. The LFO algorithm instead, generates new onsets and the amplitudes values. These data are used to control two different sound syntheses (additive and subtractive). Through de controllers located on the body of the Melotronica, the performer can both decide when to activate and deactivate the two processes and control the amount of randomness associated to the stochastic algorithms. Finally, using the a slider bar it is possible to cross fade between the two DSP sets described. The Melotronica was designed to allow a smooth shift between the two interactive modalities described: from an *hybrid instrument* model to a more *stochastic* oriented paradigm.

4. I developed this algorithm with the help of Mario Buoninfante. Being Mario an hardcore PD user we designed the patch in this environment. Within the Melotronica software unit, this Markov model communicate via OSC with the Max/MSP patch

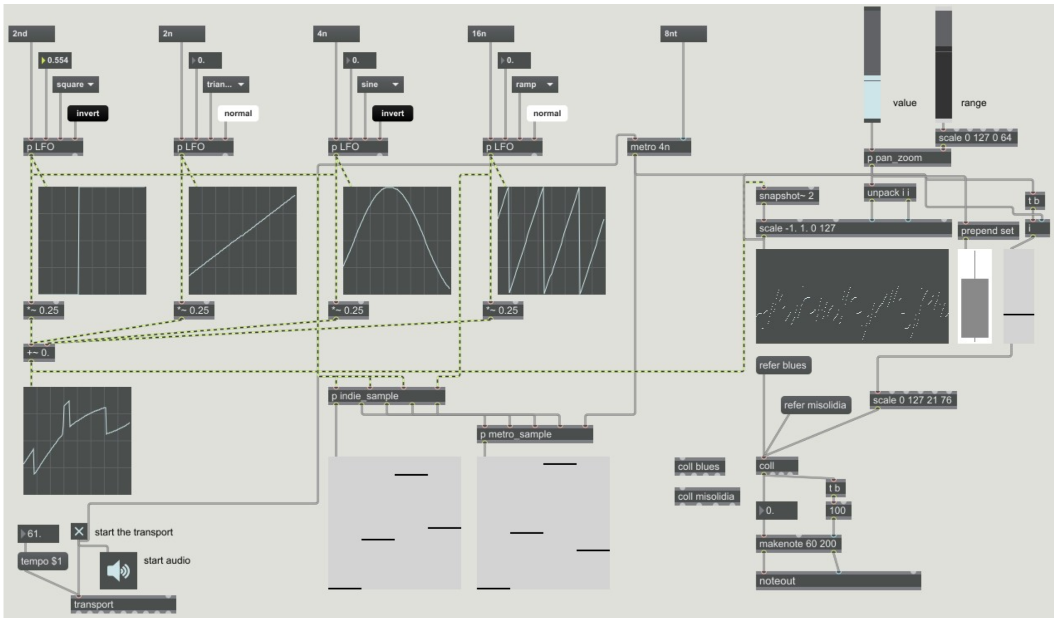

Figure 16: The Max/MSP patch generates stochastic behaviour through the combination of various LFO.

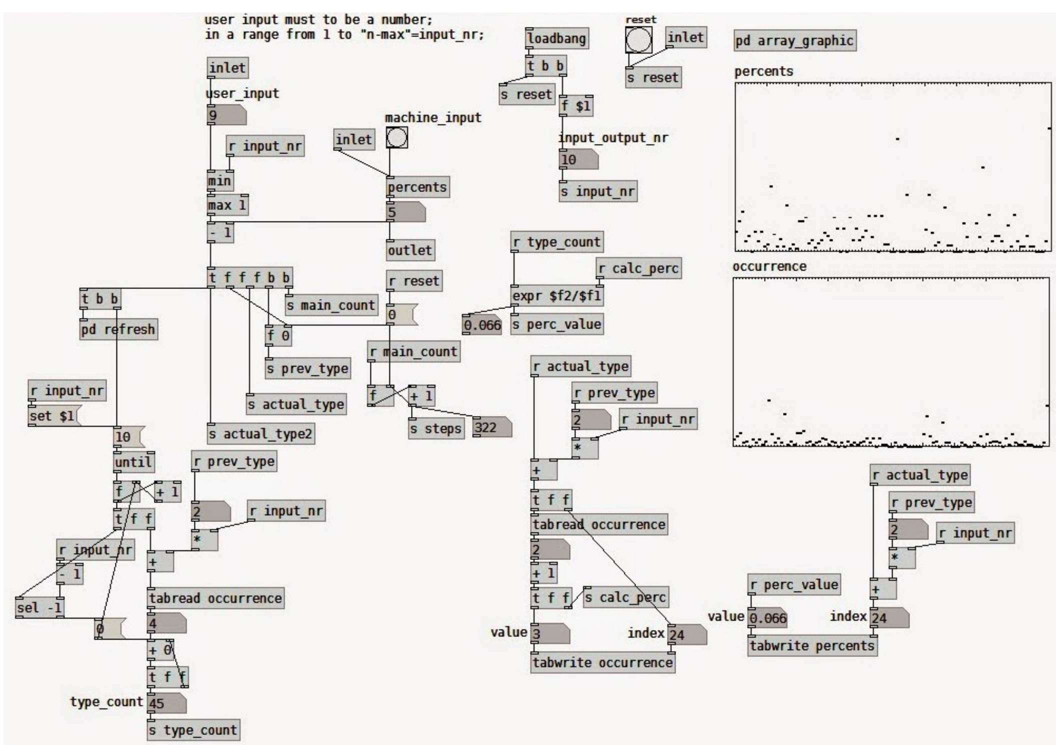

Figure 17: This PD patch, in relation the received information, estimate in real-time the probability of transition from one state to another.

5 Conclusions

In my view, an IMS is the result of an effortful process in which compositional constraints are shaped by performative experiences (Magnusson 2010) and made navigable by means of physicalised models (Ryan 1991). There is no established strategy for the design of IMS. However, to conclude this thesis I would like to sketch few simple considerations. These reflections matured during the research and they where somehow reinforced when I became across the notion of *instrumentation* (Ryan 1991). Essentially, the attempt is to outline a mindset potentially convenient to advise practical decision making.

First of all, I would like to highlight two problematic approaches that have emerged from research experiences summarised in this text. The first approach initially focuses on the elements for the detection of the physical energy (e.g. interface) with the sound becoming a secondary consideration. This can be useful during the prototyping stage, whilst exploring and evaluating the properties and potentiality of various sensor configurations. This practice might produce an instrument-system in which the gestural-sonic qualities needed to interact with the interface do not fit the characteristics of the sounds later designed. For example, the use of continuous gestural data from a breath sensor might be unsuitable for controlling discrete impulsive sounds. In this case, the sonic morphologies generated might not be perceived as complementary to the qualities of the gesture used to control them . On the opposite side is the approach that places too much focus on the design of the sound materials. The physical interface is therefore shaped according to specific compositional ideas, musical notions or superstructures. Examples of this approach include the development of controllers for drum machines and sequencers. This attitude could produce uninteresting results which lack creativity. Pre-existing musical models (e.g. the tonal system) might strongly influence and restrict the conception of the new interface. Again, the design of sound material is a fundamental aspect to consider whilst *composing* an instrument. Nevertheless, the focus should be equally distributed between the design of the interface and the corresponding sounds. Thus encouraging decisions that result in complimentary combinations and meaningful interactions.

However, the relation between physical input and sound output are specific to each individual instrument-system and performer, making it difficult to propose generalised solutions. I refer to the idea of instrumentation as an inclusive process which highlights the interdependence of compositional, performative and technical decisions. This action focuses on the design of the interactions among the different elements constituting the project. Here similarities can be drawn with concepts discussed by Di Scipio (Di Scipio 2003) for the design of IMS.

I have found the notion of *instrumentation* to be beneficial during the design process, it allows for a holistic approach in which the various elements of the IMS are considered both individually and collectively. Modifications made to one element of the instrument influences the behaviour of others. A constant zooming in and out is necessary (similar to the act of using a magnifying glass), shifting focus between specific aspects and the general view of the instrument.

This thesis presents the work I developed during my master of research Instrument & Interfaces at STEIM - Institute of Sonology. The investigation focused on the design of IMS for electroacoustic improvisation. A compositional framework is outlined in order to provide some *conceptual tools* to support the design process of novel instruments-systems (i.e. stimulate the creative processes and organise the implementation). The two IMS developed during the two years research are presented and discussed. Finally, the process of developing interactive musical instruments-systems was here understood as a compositional activity rather than a design practice. This thesis therefore aims to contribute to a conceptual transition: from *designing* IMS to *composing* IMS.

References

Addessi, Anna Rita. 2012. "From Econ to the mirror neurons: Founding a systematic perspective on the reflexive interaction paradigm." *ICMPC-ESCOM2012 Proceedings:* 23–28.

Andersen, Kristina. 2014. "The deliberate cargo cult." In *Conference on Designing Interactive Systems,* 627–636.

Andersen, Kristina, and Peter Knees. 2016. "The Dial: Exploring Computational Strangeness." In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems,* 1352–1358. ACM.

Andersen, Kristina, and Danielle Wilde. 2012. "Circles and props: making unknown technology, interactions, v. 19 n. 3." *May+ June.*

Assayag, Gérard, Georges Bloch, Marc Chemillier, Arshia Cont, and Shlomo Dubnov. 2006. "Omax brothers: a dynamic yopology of agents for improvization learning." In *Proceedings of the 1st ACM workshop on Audio and music computing multimedia,* 125–132. ACM.

Bedny, Gregory Z, and Waldemar Karwowski. 2004. "Activity theory as a basis for the study of work." *Ergonomics* 47 (2): 134–153.

Berg, Paul. 1996. "Abstracting the Future: The search for musical constructs." *Computer Music Journal* 20 (3): 24–27.

Bergsland, Andreas, and Robert Wechsler. 2015. "Composing Interactive Dance Pieces for the MotionComposer, a device for Persons with Disabilities": 20–23.

Bertalanffy, Ludwig V. 1968. *General system theory: Foundations, development, applications.* Technical report. Braziller. New York.

Blackwell, Tim, and Michael Young. 2004. "Self-organised music." *Organised Sound* 9 (02): 123–136.

Born, Georgina. 2005. "On musical mediation: ontology, technology and creativity." *Twentieth-century music* 2 (01): 7–36.

Buchenau, Marion, and Jane Fulton Suri. 2000. "Experience prototyping." In *Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques,* 424–433. ACM.

Caillois, Roger, and Meyer Barash. 1961. *Man, play, and games.* University of Illinois Press.

Camurri, Antonio, Ingrid Lagerlöf, and Gualtiero Volpe. 2003. "Recognizing emotion from dance movement: comparison of spectator recognition and automated techniques." *International journal of human-computer studies* 59 (1): 213–225.

Camurri, Antonio, Barbara Mazzarino, Gualtiero Volpe, Pietro Morasso, Federica Priano, and Cristina Re. 2003. "Application of multimedia techniques in the physical rehabilitation of Parkinson's patients." *The Journal of Visualization and Computer Animation* 14 (5): 269–278.

Camurri, Antonio, Gualtiero Volpe, Giovanni De Poli, and Marc Leman. 2005. "Communicating expressiveness and affect in multimodal interactive systems." *Ieee Multimedia* 12 (1): 43–53.

Cariou, B. 1992. "Design of an alternative controller from an industrial design perspective." In *Proceedings of the International Computer Music Conference,* 366–366. International Computer Music Association.

Casal, D Plans. 2008. "Time after time: short-circuiting the emotional distance between algorithm and human improvisors." In *Proceedings of the International Computer Music Conference 2008.* Citeseer.

Casey, Michael. 2009. "Soundspotting: a new kind of process." *The Oxford Handbook of Computer Music:* 421–53.

Chadabe, Joel. 2002. "The limitations of mapping as a structural descriptive in electronic instruments." In *Proceedings of the 2002 conference on New interfaces for musical expression,* 1–5. National University of Singapore.

Ciufo, Thomas. 2003. "Design concepts and control strategies for interactive improvisational music systems." In *Proceedings of the MAXIS International Festival/Symposium of Sound and Experimental Music.*

———. 2004. "Computer-Mediated Improvisation." PhD diss., Brown University.

Collins, Nicholas M. 2006. "Towards autonomous agents for live computer music: Realtime machine listening and interactive music systems." PhD diss., Citeseer.

Cont, Arshia, Shlomo Dubnov, and Gerard Assayag. 2006. "A framework for anticipatory machine improvisation and style imitation." In *Anticipatory Behavior in Adaptive Learning Systems (ABiALS).* ABIALS.

Cook, Perry. 2001. "Principles for designing computer music controllers." In *Proceedings of the 2001 conference on New interfaces for musical expression,* 1–4. National University of Singapore.

Corbin, Juliet M, and Anselm Strauss. 1990. "Grounded theory research: Procedures, canons, and evaluative criteria." *Qualitative sociology* 13 (1): 3–21.

Cornelius, Cardew. 1971. "Treatise Handbook." *London/Frankfurt/New York: Edition Peters.*

Csikszentmihalyi, M. 1990. "Flow. The Psychology of Optimal Experience. New York (Harper-Perennial) 1990."

De Cheveigné, Alain, and Hideki Kawahara. 2002. "YIN, a fundamental frequency estimator for speech and music." *The Journal of the Acoustical Society of America* 111 (4): 1917–1930.

Di Scipio, Agostino. 2003. "'Sound is the interface': from interactive to ecosystemic signal processing." *Organised Sound* 8 (03): 269–277.

Douglas-Cowie, Ellen, Nick Campbell, Roddy Cowie, and Peter Roach. 2003. "Emotional speech: Towards a new generation of databases." *Speech communication* 40 (1): 33–60.

Eco, Umberto. 1962. "Opera aperta." *Milano, BOMPIANI.*

Ekman, Inger, and Michal Rinott. 2010. "Using vocal sketching for designing sonic interactions." In *Proceedings of the 8th ACM Conference on Designing Interactive Systems,* 123–131. ACM.

Franklin, Stan, and Art Graesser. 1996. "Is it an Agent, or just a Program?: A Taxonomy for Autonomous Agents." In *Intelligent agents III agent theories, architectures, and languages,* 21–35. Springer.

Gaver, William. 2012. "What should we expect from research through design?" In *Proceedings of the SIGCHI conference on human factors in computing systems,* 937–946. ACM.

Gibson, James J. 1978. "The ecological approach to the visual perception of pictures." *Leonardo* 11 (3): 227–235.

———. 2014. "The Theory of Affordances." *The People, Place, and Space Reader:* 56.

Glowinski, Donald, Nele Dael, Antonio Camurri, Gualtiero Volpe, Marcello Mortillaro, and Klaus Scherer. 2011. "Toward a minimal representation of affective gestures." *Affective Computing, IEEE Transactions on* 2 (2): 106–118.

Godøy, Rolf Inge, and Marc Leman. 2010. *Musical gestures: Sound, movement, and meaning.* Routledge.

Gorman, Mikhail, Amir Lahav, Elliot Saltzman, and Margrit Betke. 2007. "A camera-based music-making tool for physical rehabilitation." *Computer Music Journal* 31 (2): 39–53.

Hanslick, Eduard. 1885. *Vom Musikalisch-Schönen: ein Beitrag zur Revision der Ästhetik der Tonkunst.* Leipzig: JA Barth.

Harrison, John. 2005. "SoundBlocks and SoundScratch: tangible and virtual digital sound programming and manipulation for children." PhD diss., Massachusetts Institute of Technology.

Hsu, William. 2010. "Strategies for managing timbre and interaction in automatic improvisation systems." *Leonardo Music Journal* 20:33–39.

Hsu, William T, and Marc H Sosnick. 2009. "Evaluating Interactive Music Systems: An HCI Approach." In *NIME,* 25–28.

Huizinga, Johan. 1938. "Homo ludens: proeve fleener bepaling van het spel-element der cultuur." *Haarlem: Tjeenk Willink.*

Impett, Jonathan. 2001. "Interaction, simulation and invention: a model for interactive music." In *Proceedings of ALMMA 2001 Workshop on Artificial Models for Musical Applications,* 108–119. Cosenza, Italy.

Jehan, Tristan, and Bernd Schoner. 2002. "An audio-driven perceptually meaningful timbre synthesizer." *Analysis* 2 (3): 4.

Jordà, Sergi. 2004. "Instruments and Players: Some thoughts on digital lutherie." *Journal of New Music Research* 33 (3): 321–341.

Kapur, Ajay. 2011. "Multimodal Techniques for Human/Robot Interaction." In *Musical Robots and Interactive Multimodal Systems,* 215–232. Springer.

Kress, Gunther. 2009. *Multimodality: A social semiotic approach to contemporary communication.* Routledge.

Kurtenbach, Gordon, and Eric A Hulteen. 1990. "Gestures in human-computer communication." *The art of human-computer interface design:* 309–317.

Kvifte, Tellef, and Alexander Refsum Jensenius. 2006. "Towards a coherent terminology and model of instrument description and design." In *Proceedings of the 2006 conference on New interfaces for musical expression,* 220–225. IRCAM—Centre Pompidou.

Leman, Marc. 2008. *Embodied music cognition and mediation technology.* Mit Press.

Leman, Marc, and Antonio Camurri. 2006. "Understanding musical expressiveness using interactive multimedia platforms." *Musicae Scientiae* 10 (1 suppl): 209–233.

Lepri, Giacomo. 2015. "Playing with InMuSIC: An Interactive Multimodal System for Improvised Composition." In *Proceedings of the 2015 ACM SIGCHI Conference on Creativity and Cognition,* 387–388. ACM.

Levitin, Daniel J, Stephen McAdams, and Robert L Adams. 2002. "Control parameters for musical instruments: a foundation for new mappings of gesture to sound." *Organised Sound* 7 (02): 171–189.

Lewis, George E. 1999. "Interacting with latter-day musical automata." *Contemporary Music Review* 18 (3): 99–112.

———. 2000. "Too many notes: Computers, complexity and culture in voyager." *Leonardo Music Journal* 10:33–39.

Linson, Adam, Chris Dobbyn, and Robin Laney. 2012. "Critical issues in evaluating freely improvising interactive music systems." In *Proceedings of the Third International Conference on Computational Creativity,* 145–149. Citeseer.

Lyons, Leilah, Brian Slattery, Priscilla Jimenez, Brenda Lopez, and Tom Moher. 2012. "Don't forget about the sweat: effortful embodied interaction in support of learning." In *Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction,* 77–84. ACM.

Mackay, Wendy E. 2004. "The interactive thread: exploring methods for multi-disciplinary design." In *Proceedings of the 5th conference on Designing interactive systems: processes, practices, methods, and techniques,* 103–112. ACM.

Magnusson, Thor. 2010. "Designing constraints: Composing and performing with digital musical systems." *Computer Music Journal* 34 (4): 62–73.

Malloch, Joseph, David Birnbaum, Elliot Sinyor, and Marcelo M Wanderley. 2006. "Towards a new conceptual framework for digital musical instruments." In *Proceedings of the 9th international conference on digital audio effects,* 49–52.

Malt, Mikhail, and Emmanuel Jourdan. 2009. "Real-Time Uses of Low Level Sound Descriptors as Event Detection Functions Using the Max/MSP Zsa. Descriptors Library." *Proceedings of the 12th Brazilian Smposium on Computer Music.*

Meltzoff, Andrew N, and Wolfgang Prinz. 2002. *The imitative mind: Development, evolution and brain bases.* Vol. 6. Cambridge University Press.

Merleau-Ponty, Maurice. 1945. "Phénoménologie de la perception." *Paris: Gallimard:* 381.

Miranda, Eduardo Reck, and Marcelo M Wanderley. 2006. *New digital musical instruments: control and interaction beyond the keyboard.* Vol. 21. AR Editions, Inc.

Mitrović, Dalibor, Matthias Zeppelzauer, and Christian Breiteneder. 2010. "Features for content-based audio retrieval." *Advances in computers* 78:71–150.

Nattiez, Jean-Jacques. 1990. *Music and discourse: Toward a semiology of music.* Princeton University Press.

Nettl, Bruno. 1974. "Thoughts on improvisation: A comparative approach." *The Musical Quarterly* 60 (1): 1–19.

Nierhaus, Gerhard. 2009. *Algorithmic composition: paradigms of automated music generation.* Springer Science & Business Media.

Nijs, Luc, Micheline Lesaffre, and Marc Leman. 2009. "The musical instrument as a natural extension of the musician." In *the 5th Conference of Interdisciplinary Musicology,* 132–133. LAM-Institut jean Le Rond d'Alembert.

Norman, Sally Jane, Michel Waisvisz, and Joel Ryan. 1998. "Touchstone." *Catalogue to the first STEIM Touch-Exhibition.*

Pachet, Francois. 2003. "The continuator: Musical interaction with style." *Journal of New Music Research* 32 (3): 333–341.

Peirce, Charles Sanders. 1974. *Collected papers of charles sanders peirce.* Vol. 5. Harvard University Press.

Peters, Gary. 2009. *The philosophy of improvisation.* University of Chicago Press.

Riva, Giuseppe. 2006. *From Communication to Presence: Cognition, Emotions, and Culture Towards the Ultimate Communicative Experience: Festschrift in Honor of Luigi Anolli.* Vol. 9. IOS Press.

Rizzolatti, Giacomo, Luciano Fadiga, Leonardo Fogassi, Vittorio Gallese, AN Meltzoff, and W Prinz. 2002. "14 From mirror neurons to imitation: facts and speculations." *The imitative mind: Development, evolution, and brain bases* 6:247–266.

Rizzolatti, Giacomo, and Corrado Sinigaglia. 2006. *So quel che fai: il cervello che agisce ei neuroni specchio.* R. Cortina ed.

Roads, Curtis. 1985. "Research in music and artificial intelligence." *ACM Computing Surveys (CSUR)* 17 (2): 163–190.

Rowe, Robert. 1992. *Interactive music systems: machine listening and composing.* MIT press.

Russell, Stuart, Peter Norvig, and Artificial Intelligence. 1995. "A modern approach." *Artificial Intelligence. Prentice-Hall, Egnlewood Cliffs* 25:27.

Ryan, Joel. 1991. "Some remarks on musical instrument design at STEIM." *Contemporary music review* 6 (1): 3–17.

———. 1992. "Effort and expression." In *Proceedings of the International Computer Music Conference,* 414–414. International Computer Music Association.

Sabbe, Herman. 1987. "Open structure in 20th century music: Proceedings of the conference held in Luxembourg, June 1986."

Serra, Xavier, Michela Magas, Emmanouil Benetos, Magdalena Chudy, Simon Dixon, Arthur Flexer, Emilia Gómez, et al. 2013. *Roadmap for Music Information ReSearch.* Creative Commons.

Shklovsky, Viktor. 1965. *Art as technique.* na.

Shneiderman, Ben. 2000. "Creating creativity: user interfaces for supporting innovation." *ACM Transactions on Computer-Human Interaction (TOCHI)* 7 (1): 114–138.

Sloboda, John A. 1988. *Generative processes in music: The psychology of performance, improvisation, and composition.* Clarendon Press/Oxford University Press.

Smalley, Denis. 1997. "Spectromorphology: explaining sound-shapes." *Organised sound* 2 (02): 107–126.

Snyder, Bob. 2000. *Music and memory: An introduction.* MIT press.

Spasov, Miroslav. 2011. "Music Composition as an Act of Cognition: ENACTIV–interactive multimodal composing system." *Organised Sound* 16 (01): 69–86.

Svanæs, Dag. 2013. "Interaction design for and with the lived body: Some implications of merleau-ponty's phenomenology." *ACM Transactions on Computer-Human Interaction (TOCHI)* 20 (1): 8.

Todd, Peter M, and Gregory M Werner. 1999. "Frankensteinian methods for evolutionary music." *Musical networks: parallel distributed perception and performace:* 313.

Trueman, D, and RL DuBois. 2009. "PeRColate: A Collection of Synthesis." *Signal Processing, and Video Objects for MAX/MSP/Nato* 1:b3.

Turing, Alan M. 1950. "Computing machinery and intelligence." *Mind* 59 (236): 433–460.

Van Nort, Doug, Jonas Braasch, and Pauline Oliveros. 2009. "A system for musical improvisation combining sonic gesture recognition and genetic algorithms." In *Proceedings of the 6th Sound and Music Computing Conference,* 131–136.

Van Nort, Doug, Pauline Oliveros, and Jonas Braasch. 2010. *Developing systems for improvisation based on listening.* Ann Arbor, MI: Michigan Publishing, University of Michigan Library.

Varni, Giovanna, Gualtiero Volpe, Roberto Sagoleo, Maurizio Mancini, and Giacomo Lepri. 2013. "Interactive reflexive and embodied exploration of sound qualities with BeSound." In *Proceedings of the 12th International Conference on Interaction Design and Children,* 531–534. ACM.

Verplank, Bill. 2003. "Interaction design sketchbook." *Unpublished paper for CCRMA course Music 250a.*

Wanderley, Marcelo Mortensen, and Nicola Orio. 2002. "Evaluation of input devices for musical expression: Borrowing tools from hci." *Computer Music Journal* 26 (3): 62–76.

Watzlawick, Paul, Janet Beavin Bavelas, Don D Jackson, and Bill O'Hanlon. 2011. *Pragmatics of human communication: A study of interactional patterns, pathologies and paradoxes.* WW Norton & Company.

Wessel, David. 2006. "An enactive approach to computer music performance." *Le Feedback dans la Creation Musical, Lyon, France:* 93–98.

Wessel, David L. 1979. "Timbre space as a musical control structure." *Computer music journal:* 45–52.

Wessel, David, Matthew Wright, and John Schott. 2002. "Intimate musical control of computers with a variety of controllers and gesture mapping metaphors." In *Proceedings of the 2002 conference on New interfaces for musical expression,* 1–3. National University of Singapore.

Wijnalda, Gertjan, Steffen Pauws, Fabio Vignoli, and Heiner Stuckenschmidt. 2005. "A personalized music system for motivation in sport performance." *IEEE pervasive computing,* no. 3: 26–32.

Wooldridge, Michael, Nicholas R Jennings, et al. 1995. "Intelligent agents: Theory and practice." *Knowledge engineering review* 10 (2): 115–152.

Wright, Matthew, Adrian Freed, Ahm Lee, Tim Madden, and Ali Momeni. 2001. "Managing complexity with explicit mapping of gestures to sound control with OSC." In *Proceedings of the 2001 International Computer Music Conference, Habana, Cuba,* 314–317. Citeseer.

Wright, Peter, and John McCarthy. 2008. "Empathy and experience in HCI." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 637–646. ACM.

Young, Michael. 2007. "NN music: improvising with a 'living'computer." In *Computer music modeling and retrieval. Sense of sounds,* 337–350. Springer.

Annex

The interviewed musicians were fully informed about the general purpose, content and output of the study from the onset. Participants were interviewed and recorded ensuring complete privacy. Their names have been kept confidential in order to avoid the disclosure of personal information.

The investigation did not attempt to categorisation the different opinions and reports alongside normative lines. The participants were asked to freely evaluate the experience of playing with InMuSIC. As starting point, at the beginning of the interview, they were asked to elaborate some thoughts on the perceived human-machine interaction and on the musical results of the performance. The interviews were designed as open conversations. During the dialogue, the participants were not pushed to talk about a specific topic if they did not come up with the topic itself.

Various extracts of recorded performances for the evaluation of InMuSIC are available at *giacomolepri.com/inmusic*.

	Participant 1 Clarinet	Participant 2 Clarinet	Participant 3 Cello	Participant 4 Rhodes piano	Participant 5 Trombone
Understanding and controlling the system	"It was really hard at the beginning because it didn't do anything and then when it did do something it was so different to what I was doing, so then you try and play with that but of course you don't get any response.." "There was some stuff in the middle where I suddenly found like there and immediately there were some settings that where taking that and playing with it and that was really engaging. And then I think after once I got the first experience of that something..	"It reacts in a certain way to what I'm doing.. Sometimes.. I assume that you program it to.. I'm trying to wonder.. I was thinking it's a kind of random way to react or it's a form that as being programmed into it?" "I guess it doesn't recognise pitches.. I guess it recognize more "on and off" like I'm playing or not playing and maybe some gestures."	"So it was difficult in a sense to create a musical situation because I didn't really know how it was responding and I put my head a little bit further that way rather than just playing a piece of music, improvising and seeing what turns out." "It was a new system which I am not familiarized with.. I had the notion of trying very simple aspect (e.g. soft-loud or sustained-long sounds) I think I was not getting an instantaneous response.. But then I didn't know what kind of responses they were.." "It was difficult to predict obviously at the beginning, however when things were happening it was difficult to sustain a certain quality of texture." "There were moments on the other side where I wasn't sure how to control the situation because we were two players doing a piece of music" "When we interacted really well there was joy, and then there were other times I wanted to stop playing and let things kind of fall off a bit, because it was kind of almost either too much or something I didn't know how to control."	"I felt I was getting better time to time, because I started to learn the system and learn how to react to it and what to expect to it." "At some point I realised that it works better if I replied to the system and not aspect the system to reply to me." "It's interesting how much the knowledge of the system you have is affecting the way you interact with it. Because you cannot ignore what you know.. For instance, I had no idea on how my movements interact with the system.." "There was one point where you told me: "if you would had continued a bit more, something would had happened!" I was playing and playing and he didn't join and didn't join and I gave up and I moved to something else.. "	"When you play, you have no idea how the system reacts. In the first minutes I tried to find relationships in some way.. Behaviours that I could expect. However, I have not found many."

Collaborating with the system	"Once we had that first .. then I had this realisation like ' ah, ok it's listening'.. So then I am thinking whatever I do is having a result, I listen to that and that changes what I do. And then from that point on..., once you know that's engaged I can accept more readily the idea that it goes off on its own sometimes and it does its own thing." "So I think that's the thing you get used to, like how to trust the beginning of the system." "There were times when it was doing all kinds of stuff and then you had this counterpoint which was really nice... It shouldn't be always reactive to what you're doing because then you don't get any layering, but that was a really nice." "Your system sits in silence white a lot and then emerges and comes back." "It's a little bit shy at first and you have to draw something out of it. I just played it once... but that my impression, it sorts of goes out and then it reacts and then it pushes its own thigs out. it's conversational."	"Nice that it allowed me a little bit of space to play solo." "It wasn't unpleasant except from the time I felt like I had somebody following me every gestures. That's very annoying when people do that and then when a machine is doing it is equally annoying." "The changings of the computer are very slow. What bother me is that there is a lot of material generated by the programme that I can use somehow.. in that sense is not a conversation really.. maybe it make a better composition.. I don't know.. but makes frustrating improvisers." "I'm dealing with a style of improvisation where there are a lot of quick changes and things happen very quickly. There are many improvisers that have a slow approach, maybe it works better for them.."	"When you start to interact well with the system, when it becomes very like specifically connected to you it becomes very interesting and you are not so bothered about what to do next. Because you are interested in the interaction." "I had to say 'well then I am a player just as much as the electronics is a player.' So I would just keep playing. It was a kind of a struggle to separate myself from expecting something in return and just play." "I think there was a large percentage of my mind on that... how does it respond. And then there were moments where I didn't feel that and I felt very much involved in the musical aspect but there was always a question of .. What I do, how will it affect that?" "Well, you certainly are navigating.. So I think in that sense it is finding your voice within this whole stuff."	"I didn't feel that me and the system were creating structures together but the system at some point started a new section and I had to follow." "..at some point I did felt I was leading but when I was leading I felt that the system was not joining. So I felt the system was not really capable to join me. So I felt: I can lead but then I pretty much on my own or the system does something that is not exactly with me but I can join because I was more flexible of the system. So if I was letting the system lead I could join quite well."	"I remember was looking for counterpoints. At one point I was doing rhythmic repeated notes and the system followed me and I was homorhythmic with the system. That surprised me. I remember it as one thing clear. It never happened to be so connected with the system. In any other time of the performance happened to me to have this feeling of being together with the machine." "There was an aleatory component ant it was for me interesting and positive."

Human - Machine comparison	"A little bit like having a conversation with a child.." "I don't know why I ended up looking at the microphone all the time, like 'come on, come on' it's interesting... psychology, like ' I am playing to this' and a part of me needed it to listen... like 'come on you're not listening to me!', so I think that is what I was doing. I became very fixated on this.." "It was really hard at the beginning, it's a bit like playing with a partner that is not listening... like 'I have to grab your attention' In the end its patience and wait for it to change..., because I imagine it has all kinds of different parameters settings and reactive settings... so that was interesting."	"I think that a person would have used the material that I was using while I was introducing new material while I was playing solo. But the machine didn't use that." "When I play with my colleagues there are these considerations like foreground and background. Sometime I'm in the foreground and they are supporting me and sometimes I'm in the background and I'm supporting them also balance and density, all this thing are not much taken into consideration." "If this is free improvisation you should be able to work whit many different aesthetics and styles.. If you want to play with rhythms and harmony you should be able to do that.. not being dogmatic"	"It's much easier to respond to a human being because you know that they're listening.. If people are not playing. It is a conscious decision to not play. There is still that element of not knowing what the other person is going to do though" "If had you been at the computer doing these sounds... that would have been a very different situation." "If you sit in front of the computer as if you were creating these sounds yourself but actually you are not.. Having the other's person presence means that you can allow yourself to not worry.. You know you are not the only responsible one. "When you improvise for the first time with anybody... you don't really know what they are going to do, but you can also push and present and also know the sound quality of what the person is doing to a certain degree."	"It's not like a musician that can play different styles and develop something with you." "I mean, when you play with a musician not always it works. When you play with a musician that you do not know when does your session began to be good? Sometimes is good right from the start. Sometime you play is shitty and the 10% of what you play is really cool. Maybe if we play for an hour also the 10% will be cool with your system. So I don't know how to compare with musician." "With contemporary improvisation and stuff some people are like "I don't join" they are deliberately "I don't join".. So it's really hard to say.. I think most of the people can't resist joining." "Yes I was thinking: how is it when you play with someone for a very long time? It's still very different.. Some time you hear how it is going and you know where he is going to take it.. But I never thought: 'if I do this he is going to do that'. This more unlikely.." "Yes you have cues and maybe it is something similar"	"The system put me in a position as I was playing with another musician.. I was not trying a sonic effect or trying to understand how to change it or do something and wait for the system to reacts.. The creative process is similar to what happens when I play alone or with other musician.."

Aesthetical aspects	"In these kinds of systems, in the end in doesn't matter, like the interaction comes from a kind of convincing reaction. There is lots of talk about what an interactive system should be. To be honest, an interactive system should feel interactive to the performer and to the listener and whatever else goes on doesn't really matter."	"When people make a programme like this they have to choose the sounds to use. That's the crux of the problem.. You can make a beautiful performance and it doesn't have to be particularly responsive.. But really depends on the sounds.." "The interaction is kind of the form and the sound the computer creates is kind of the content."	"Some of the sounds worked extremely well with the quietness and then I thought 'this is some really nice moments which I would like to continue with'" "Aesthetically I found it very interesting, a lot of different sounds. A good variety of sounds... But its whether you want all of that variety.."	"I liked the sonic output of the system, aesthetically was pretty cool." "It is still a very specific aesthetic and very specific machine. It is more a system for generative compositions."	"The fact of having my sound edited and re-assembled was interesting." "It was music. Dense and rich moments. I remember I perceived musical events."
Sensations	"Very psychological. So, then I feel like I am playing, it's like kind of really fun, I feel like I have got influenced..., I am understanding that there is a reaction and I am listening to it and that engages this kind of feedback system.."	"I'm dealing with a style of improvisation where there are a lot of quick changes and things happen very quickly. There are many improvisers that have a slow approach, maybe it works better for them.."	"So it was a lot of mental play. I wanted to be my own player but also 'I needed to make it work'. When it wasn't' responding I felt the need to try and make it respond which in some ways is good and in some ways not every situation suits that." "..interacting with the electronics.. It's the responsibility that you have for that thing happening. Because also you make it grow... you push it and then it has its own life.. You are always looking for ways to find the response that suggests what you would do in a situation or not. So it actually makes you think very much about what you do as a choice in playing; that affects the way you play."	"I often felt that the system wasn't listening." "It was fun to play the system. I liked the sonic output of the system. Aesthetically was pretty cool. I liked when it was processing my sound and I think it was not happening a lot."	"Often it was its will not mine." "For being a machine I felt a not much artificial interaction" "I could not expect any particular reactions I was incline to continue the creative process."

Overall comments	"I think that we have this different expression aesthetic between electroacoustic and electronic music and on these things we kind of privilege the gestural sound, phrasing, speech type. And in electronic music there tend to privilege an aesthetic which is about building fields and then changing the field. It feels like the main thing for a system like this is like having that balance of influence between the elements." "Layering... doing stuff... and also doing stuff that is very kind of electroacoustic in aesthetic, contrast a lot with this thing... and that's really good to play with like that's really nice.. and then I found a really nice ending and I found some stuff that was going on in the end and I was like 'oh' that was almost dialogue like."	It makes a lot more sense when you play with it. It's a nice start and works well with the way you play maybe the programme has change the way you play.. I don't know.. but your job is to open it up so that it can be with other people tempos and parameters.	"It was a lot of fun and I was happy with lots of moments where I really enjoyed the connections that where happening within it. And there some connections that I couldn't control but I was kind of like oh.. So basically it was finding your space within this music.."	"I think it is a cool system and you are getting interesting result from it. Musically appealing results. But from me this is a piece or instrument or project. It has a particular sound and you can make maybe few pieces out of it but they all will sound very similar. You can push it forward but it doesn't seems to me a general system that you can give to people and they will play with it.." "It was fun to play the system."	"The thing that I liked is the research aspect. Like playing with another musician. There was a curiosity to see how my timbre choices were processed by the machine."