

A Performer-Centric Approach to Extending the Saxophone with Live Electronics

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Abstract

The rapid advance of computer technology in the past few decades has transformed the way music is performed and recorded. One aspect of this 'digitization' has been the introduction of computers powerful enough to generate and manipulate audio signals in real-time. These hardware and software tools have recently become affordable, and therefore available to anyone with a laptop computer.

While composers have been quick to adopt these tools to produce music spanning a wide range of genres, the integration of real-time electronics with traditional instruments has proven difficult to achieve. It may be that a more active role on the part of performers would facilitate this integration: a performer working hands-on with his instrument while designing a system of electronics is likely to make different choices than a composer would make, thereby producing a different outcome.

The act of designing an electronics system seems to be an important part of the creative process that leads to the production of new pieces of music, so this shift of responsibility from composer to performer also challenges the traditional relationship and power dynamic between the two. Some performers choose to entirely bypass the composer, by writing and performing their own music, or improvising. However it may also be possible to arrive at collaborative strategies that maintain both the performer and composer's voices.

This hypothesis was tested over a five-year period from 2013 to 2018, in the form of a collaboration between the author, saxophonist Joel Diegert, and composer Adrià Artacho. The resulting musical work, *aubiome* (2017), is offered here as a kind of 'proof of concept', providing one possible example of what could be achieved through this type of collaboration.

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Introduction

Over the past few centuries musical instrument design and performance practice have been primarily motivated by the demands of the orchestra. The instruments are built to favor an efficient and reliable mechanism to allow virtuosic playing with perfect intonation. An instrument's acoustic properties generally emphasize tonal control, allowing a refined, pure tone production.

Instrumental tone production had become increasingly uniform, standardized and 'clean' over the course of the nineteenth century and noise was seen in acoustics texts as somehow an 'error' outside of the perfect model of the instrument.¹

During the second half of the 20th century, many composers and performers were no longer content with this conception of instrumental sound and began to experiment with other modalities: non-traditional ways of playing an instrument that no longer prioritize the purity of tone and intonation above everything else. This experimental approach went on for several decades, and now these extended playing techniques have found a permanent place in the performance practice lexicon.

Instrumentalists now embrace the microtonal possibilities of their instruments, using quarter tones, eighth tones, and other divisions that fall in between the notes of the equal-tempered chromatic scale. Noise is no longer off-limits. Each instrument's capability to produce percussive sounds was explored, as well as ways of distorting the instrument's natural tone. As John Cage pointed out, "...noises are as useful to new music as so-called musical tones, for the simple reason that they are sounds."²

During the same period of time, composers began experimenting with electronic means of sound production. This began with tape music, which was prepared in advance at an electronic music studio and then played in the concert venue. A natural application of this approach was to use a tape track in combination with one or more instrumentalists. The first pieces for performer and 'tape' were not so much of an extension of the instrument as the addition of a fixed chamber music partner. The desire for a more dynamic type of electronics was eventually answered by the development of faster and faster computers, capable of generating and manipulating audio in real-time. The live sound processing abilities of modern computers had suddenly given composers and performers access to a powerful set

1 Emmerson, Simon. (2007). *Living Electronic Music*. pg 83.

2 Cage, John. (1959) "History of Experimental Music in the United States". *Silence*. pg 68.

of completely new tools. This artistic research project addresses some of the questions that arise when computing is integrated with traditional musical instruments: a trend which has become increasingly popular among performers and composers over the past few decades.

Chapter 1 takes a look at the history of electronic music with a focus on the interest of combining computers with traditional instruments. This chapter first looks at the various strategies that have been used, and then turns to the question of composer-performer roles within this context. The idea of the 'performer-centric' approach is introduced, as well as several research questions that arise.

Chapter 2 breaks down the concept of a musical instrument, and through the lens of Actor-Network Theory (ANT), suggests how instruments, and electronically-extended instruments, may be integrated into the social network that gives rise to musical creation. The discussion then turns toward the idea of 'live electronics' and how we might understand the computer as a 'live' agent in the music-making process.

Chapter 3 turns toward my artistic practice, looking at the system of electronics and resulting piece of music, *aubiome* (2017), as a case study about the particular performer-centric approach used during this research project. The chapter traces the five-year working process that eventually led to the current version of the system and discusses the 'sound-as-interface' idea, which ultimately became central to the piece. The chapter concludes with some thoughts about how our performance practice might be expanded to include working with various electronics systems.

Chapter 4 addresses some of the questions that arise related to the social hierarchy and the roles traditionally played by performer and composer, which seem to be under threat as musical creation becomes more and more 'digital.' Models of collaboration are considered, as well as the idea of performer and composer 'voices'. Then the *aubiome* project is used again as a case study to look more closely inside a particular collaboration and some of the collaborative strategies that came out of it over time.

Chapter 5 provides more detailed information about the 2017 version of *aubiome*, meant to supplement a viewing of the video-recorded performance submitted along with this written work.

Chapter 1

Context and Literature Review

As I am writing in 2018, computers have become ubiquitous in all kinds of music production and performance. This reach extends across genres, ranging from Electronic Dance Music (EDM) which relies heavily on computer-generated sound, to pop music, famous for the use of digital 'auto-tune' tools, to classical music, where algorithms have become an important part of the recording, mixing and mastering process. Computers have also taken on a major role in the realm of contemporary classical music, where many musicians are looking to computers as a means of expanding the palette of sounds and performing techniques available to them.

1.1 Institutional context

The first experiments in electronic music took place at only a few studios and research institutes, because at that time the technology and expertise necessary to create electronic music were primarily available only in an institutional context. These beginnings of the electronic music movement took place in the 1950's along two main lines. The first approach made use of phonograph turntables and later magnetic tape to record and manipulate sounds, which would then be used to produce works termed *musique concrète* by Pierre Schaeffer. Schaeffer coined the term in 1948 based on his work at the *Studio d'Essai* in France. This led to the establishment of the *Groupe de Recherche de Musique Concrète* (GRMC) in 1951, a group of composers including Karlheinz Stockhausen and Pierre Boulez who began working with tape and produced works that were premiered in the early 1950's. In 1958 the group was dissolved and reformed under the new name, *Groupe de Recherches Musicales* (GRM).

Meanwhile the *Studio for Electronic Music* was founded in 1951 at the WDR studio in Cologne, Germany, and Karlheinz Stockhausen joined the research team in 1953. After having experimented in France with tape editing, Stockhausen became interested in the possibilities of producing sound and manipulating timbre through analog synthesis techniques. For the following four decades, Stockhausen remained associated with the studio and produced many electronic music works there over the years.

In 1977, more than two decades after the opening of the electronic music studio in Cologne, the *Institut*

de Recherche et Coordination Acoustique/Musique (IRCAM) opened under the direction of Pierre Boulez. It was around the same time that digital computing was becoming powerful enough to be relevant for music production. IRCAM functioned as a meeting point for composers and programmers, leading to major electroacoustic works by composers such as Philippe Manoury, Luciano Berio, Pierre Boulez himself,³ as well as many others. Many of these works in the 70's and 80's could only have been realized at a few institutions around the world, where composers could work with cutting edge new technology in collaboration with expert programmers to help them realize their works. IRCAM's role as a meeting point for composers, technologists and eventually performers provided the social framework which catalyzed the development of electroacoustic music as an art-form. This highly centralized, strongly institutionalized model, located in the heart of Paris, funded by the French ministry of culture, overseen by Pierre Boulez exerted a strong influence on the aesthetic of electroacoustic music as it developed throughout the 80's and 90's.⁴

1.2 Electro-Instrumental Music and STEIM

A major trend in the field of electronic music has been the design of new ways for musicians and instruments to interface with the computer. The researchers and musicians in this field have their own institutions, most notably the Amsterdam-based *Studio for Electro-Instrumental Music* (STEIM) founded in 1969, and the annual *New Instruments for Musical Expression* (NIME) conference, which had its first edition in 2001.

Many of the instruments designed at STEIM are completely new music interfaces which may or may not have any relationship to traditional instruments. Probably the most famous instrument to come from STEIM is *The Hands* designed by composer Michel Waisvisz, which translates physical gestures to musical sound. In order to accomplish this, the performer's movements need to be converted to a language that the computer can decipher. This became possible in 1983 with the release of the *Musical Instrument Digital Interface* (MIDI), and it was only a year later that the first version of *The Hands* was demonstrated publicly. Development continued for 25 years, including new hardware revisions completed in 1990 and 2000, until Waisvisz's death in 2008.⁵

3 The four major works by Pierre Boulez produced at IRCAM are *Répons* (1980/82/84), *Dialogue de l'Ombre Double* (1985), *...explosante-fixe...* (1991-93), and *Anthèmes II* (1997).

4 For an in-depth look at IRCAM from the early 1990's see Born, Georgina. (1995). *Rationalizing Culture: IRCAM, Boulez, and the Institutionalization of the Musical Avant-Garde*. University of California Press.

5 Torre, Andersen, Baldé (2016). "The Hands: The Making of a Digital Musical Instrument". *Computer Music Journal*. vol 40/2. pg 23.

The design principles of *The Hands* provided the groundwork for a flood of new instruments and instrument extensions using sensors to communicate with the computer. The key hardware innovation was to translate gestural data into the digital MIDI format, which could be then used to control the computer to generate or manipulate sound. This research led to the development and release of the *Sensorlab* which converts analog data collected by sensors to MIDI. The *Sensorlab*'s ability to capture gestural data made it useful for musicians looking for ways to extend their instruments. One such example is the 'Meta-Trumpet' designed in 1994 by Jonathan Impett concurrently with his composition *Mirror-Rite* (1994).⁶

Beside the software⁷ and hardware innovations out of STEIM, the institute has also contributed to the way of thinking about digital musical instruments. One approach to electronic music, particularly driven by the *musique concrète* by Pierre Schaeffer and his group of composers at GRM, was to replace live performance with fixed media. In contrast STEIM has always placed performance at the center of its research about electronic music and focused on the relationship between instrument and performer.⁸ Over the past 20 years this approach centered on live performance has become increasingly popular, the term 'liveness' being a key concept in the literature used to describe features of computer electronics systems.⁹

The approach to instrument design at STEIM was described by Joel Ryan:

At STEIM most research is applied towards specific projects of resident artists and composers. A large portion of this work is for live performance with digital electronics. Hardware and software designers are guided to take idiosyncrasy rather than generality as the prime guiding principle but have managed to create recyclable musical tools. An empirical method is promoted for both artist and technologist in order to recover the physicality of music lost in adapting to the abstractions of generic technology. The emphasis is on instrument design as a response to the questions posed by each artist's heterogeneous collections of ideas and tools.¹⁰

6 Impett, Jonathan. (1994). *A Meta-Trumpet(er)*. ICMC Proceedings.

7 LiSa live sampler was released in 1997, the same year as Max/MSP.

8 Ryan, Joel. (1991-92). "As if by Magic." *Contemporary Music Review*. vol.6/1. pg 1.

9 Further discussion on 'liveness' can be found in Chapter 2, and for an in-depth treatment of the topic, see Simon Emmerson. (2007). *Living Electronic Music*.

10 Ryan. pg 1.

1.3 Deinstitutionalization

Beginning in the early 1980's work began at IRCAM on a software project that would eventually have a profound impact on the course of electroacoustic composition and performance. Miller Puckette began to develop the software platform, *Max*, in the mid-1980's with the aim of giving composers an intuitive method of designing their own system configurations. Without the need for extensive programming experience, musicians were able to develop sophisticated 'patches', which defined the computer's behavior for a given piece of music. This software was first released in 1990, followed by an updated version released in 1997, named *Max/MSP*. The MSP extension provided built-in tools for digital signal processing (DSP), allowing live sound manipulation to be done entirely in the software domain without the need for dedicated hardware. Since its release twenty years ago, *Max/MSP* has continued to be developed commercially, and it is the platform of choice for many new pieces that use real-time electronics processing.¹¹

Meanwhile the 1990's saw the personal computer come into force, making it affordable for individuals to have increasingly powerful machines at home which could be used to create, edit and manipulate musical sound. In the 2000's laptops became available which could do all the same processing, but with the portability to be brought on stage. Now in the 2010's we have access to tablets and smartphones with far more processing power than the computers that Miller Puckette used at IRCAM in the 1980's. The hardware and software required to write or perform real-time electronic music and now readily available, a development referred to by Harry Lehmann as the “digital revolution of music.”¹² Lehmann argues that the digitization of music has led to a shift: a deinstitutionalization¹³, or democratization, of music production. This move away from the major research institutions provides the backdrop for this artistic research project.

With this overview of the institutional history of electronic music in mind, we will now turn our attention to the methods used in the production of electronic music with a more in-depth look at how computers have become part of music making.

11 An open source alternative, *Pure Data*, was also designed by Miller Puckette and released in 1996.

12 Lehmann, Harry (2012). *Die Digitale Revolution der Musik: Ein Musikphilosophie..*

13 *ibid.*

1.4 Fixed Media

In 1948 Pierre Schaeffer coined the term *musique concrète* based on a method of assembling recorded sounds into musical works. Beginning in 1951 this was done with tape, which allowed recorded material to be cut, manipulated and reordered. This method was used for decades until the arrival of digital technology which streamlined the process. Whether it is done with tape or computers, this approach to using recorded sounds to be played back in performance remains a staple of electronic music production.

Over several decades composers have been drawn to integrating pre-recorded audio with live performers, a hybrid approach that maintains the engaging performative aspect of live performance, while introducing a new sonic dimension. This approach remains attractive to many composers, because creating a fixed media track allows a high degree of control of the final result. However this advantage on the composition side is balanced by potentially serious performance-related challenges, as described by Elizabeth McNutt.

For the player, performing with fixed accompaniment is like working with the worst human accompanist imaginable: inconsiderate, inflexible, unresponsive and utterly deaf. While the performer commands the audience's attention, she is in an ironically submissive relationship to her chamber music partner, focusing most of her attention on coordination with her accompanist – since she has full responsibility for keeping the ensemble together!¹⁴

In addition to the performance challenges imposed by pieces with fixed accompaniment, there are also certain artistic limitations. McNutt is describing a musical situation where communication occurs in only one direction. The electronics track is predetermined and does not react to the performer, whereas the performer must constantly react to the electronics. These performance conditions might be uncomfortable for the performer, but the one-way direction of communication also means that there can be no reciprocal, causal relationship between the performer and electronics. The ability of chamber music partners to subtly influence each other during a concert lends a sense of immediacy to a live performance. Composers can only create the illusion of a causal relationship by coordinating the audio track and the live performer, such that an impulse in the written score is followed by a 'reaction' in the

¹⁴ McNutt, Elizabeth. (2003). "Performing Electroacoustic Music: A Wider View of Interactivity". *Organised Sound* 8(3): pg. 297–304.

tape part.¹⁵

Various strategies are employed to deal with this performance constraints. Many pieces use a 'click-track', which essentially requires the performer to perform with metronome which he hears with headphones or earbuds. This allows precise timing between events in the tape part and the live performance, but performers often complain that it limits their flexibility in concert.¹⁶ A more flexible but potentially less precise method of coordination is the use of a stopwatch or timer. In this case the written score may include timing marked in seconds or may be written entirely in graphic notation.¹⁷

1.5 Triggering

After three decades of composition for tape, digital technology eventually supplanted analog techniques as the predominant method. While tape allowed composers to cut, paste and manipulate fragments of audio, digital tools streamlined the process, allowing composers to work with recorded material without needing to physically cut and fuse strips of tape. It became possible to achieve much more complicated manipulations than would have been practical working with tape. One example of this is the use of 'triggering', where digital audio can be easily divided into segments to be launched individually during performance. This can be done with several different types of interfaces: a foot pedal operated by the performer, another musician at the computer, automatic triggers based on a timer or other conditions. The decision about which triggering method(s) to use, along with the structure of the material being triggered, can have major performative implications.

Here is an example of a piece that uses a standard triggering scheme. In May 2014 I performed *El Gran Cabrón* (2012) by Germán Alonso in Graz. The piece uses a pedal to trigger the electronics to advance from one section to another. There are moments where the triggers need to occur precisely with events in the score, so the pedaling needs to be done by the saxophonist. In rehearsal everything worked perfectly, I only had to pay attention at a few moments in the piece where it can happen that the distraction of complicated passagework results in a missed pedal hit. The piece begins with a 30-second audio track which is abruptly interrupted by the saxophonist's entrance. I hit the pedal and began to play, with no reaction at all from the system. I looked with wide eyes at my colleague, David, operating

¹⁵ Emmerson, Simon. (2007). *Living Electronic Music*.

¹⁶ For more about my own experience working with a click track see the section on *CRISPR/Sax9* in chapter 3.

¹⁷ An example of a successful implementation of this approach is Mikel Kuehn's *Crack* (2001) for flute, saxophone and electroacoustics.

the electronics. He looked back at me the same way, and we both realized at that moment that the pedal had failed. At that point we had the choice to stop and apologized for the technical problem, or for David to manually trigger the system from the computer. I knew that David was reading from a score, but it is hand-written and difficult to follow, so it would not be possible to accurately coordinate from the score alone. I made a snap decision to continue playing the piece, stomping on the dead pedal as a way of signaling to David when to advance. 37 cues later we arrived together at the end, but that was a stressful ten minutes!

1.6 Score following

Manually triggering with a foot pedal is an effective way to coordinate computer events with precise moments in the score. Taking this idea a step further, what if a piece requires a new trigger on every note, or many in fast succession? Pedaling is somewhat awkward to do and demands a lot of concentration of the performer, if the score is otherwise challenging to play. As computers have become faster, pitch tracking algorithms are now able to identify notes being played with only a few milliseconds of latency.¹⁸ Fast and reliable pitch-tracking capability eventually translated into the ability for the computer to listen to a performance and follow along in the score. Using this technique events can be triggered at any moment, always synchronous with the performer. Research toward this end was done at IRCAM beginning in 1983, and has passed through several iterations over more than two decades.¹⁹ Pierre Boulez's work for violin and live electronics mentioned early, *Anthèmes II*, is a prime example of a piece that could only be realized with the assistance of score following. The computer processing is often synchronized with the violin on a note by note basis, making it impossible to trigger with a foot pedal or other manual input strategy.

The software from the 1990's originally used for *Anthèmes II* could be thrown off by errors in pitch tracking, as well as performer errors. A new approach was adopted, using a probabilistic model for a time during the mid-2000's. In 2007 Arshia Cont released the score following software, *Antescofo*, which adds another layer of precision by analyzing the performer's tempo to anticipate when each note is likely to occur.

¹⁸ Latency refers to the time delay between the input to the computer and its response. More discussion on the implications for real-time processing can be found in chapter 3.

¹⁹ “Antescofo”. IRCAM website. <http://repmus.ircam.fr/antescofo/videos>. Accessed 10 July, 2018.

While the various score followers developed at IRCAM used progressively more sophisticated techniques to accurately time computer events with a live performers, this is a tool that is only useful for certain types of composition. The assumption is that the composer needs a high degree of timing precision in order to align computer events with the live performer, all of which are fixed and written linearly in the score. Boulez's writing for instruments and electronics, evidenced in both *Anthèmes II* and *Dialogue de l'Ombre Double*, actually follows a traditional compositional approach, which was enabled by powerful software that took decades to be developed.

1.7 Machine listening

The difficulty of programming score following algorithms sheds some light on the nature of human-computer interactions, related to the fundamentally different ways in which humans and computers 'listen' to sound. Trained human performers are able to listen to each other and react to each other's musical gestures with an incredible level of sensitivity. Human hearing is an embodied phenomenon, subject to cognitive processes, whereas the computer's digital slicing of a waveform bears little resemblance. Although human-like machine listening is probably as far off as general artificial intelligence is, it is possible to train computers to recognize certain parameters of musical sound.

An example of a piece that uses a machine listening is Artemis Gioti's *Neurons*, which she wrote for a May 2017 performance in Graz. Instead of a foot pedal, *Neurons* uses machine listening to trigger events non-sequentially. Artemis programmed the system to learn to recognize distinct types of sounds produced on the saxophone. We worked together for several months recording material which was used to train the computer. The ability of the computer to selectively recognize different classes of sounds was the central feature of the work, allowing different reactions to different inputs from the saxophone. The score for *Neurons* is written to highlight the two-way interactions between the performer and the computer, and in order to perform it, the saxophonist has to understand the system's behavior and constantly adapt.

1.8 Real-time sound manipulation

Beginning in the 1980's digital technology started to become fast enough to offer real-time sound manipulation. At first this took the form of dedicated digital hardware units,²⁰ but by the 1990's,

20 Hagan, Kerry. (2016). "The Intersection of 'Live' and 'Real-time'." *Organised Sound*, vol 21. pg 141.

powerful software solutions were available. *Max/MSP* provided software versions of hardware effects units, along with the flexibility to route and modulate them in complicated ways far surpassing what would be feasible using physical cables.

Another important piece of software called *LiSa* was also released the same year out of STEIM. Before *LiSa*, the sampling procedures of recording, cutting, manipulating and reassembling audio clips was done entirely offline. *LiSa*, derived from 'live sampling', was developed by Frank Baldé in order to provide a real-time method for sampling. This software was used in many instruments at STEIM, including Waisvisz's *The Hands* and eventually lead to the 2013 release of *RoSa*, short for 'Real-time OSC-controlled Sampler'.

Real-time audio processing provides a solution to the performative problems associated with the fixed tape pieces that had come before. Tape pieces only allow a one-way channel of communication, so the electronics part is often nothing more than a straight-jacket that serves to restrict the musician. Real-time computing provides the means to establish a two-way flow of information, lifting the technological restraints imposed by a fixed media approach. In practice however the mere fact that sound is produced or manipulated in the moment is insufficient to establish the kind of 'liveness' demonstrated by human performers. These real-time strategies need to be integrated with well thought-out instrument designs.

1.9 Early Electronic Instruments

The basis of the electronic music movement could be traced all the way back to the end of the 19th century with the Telharmonium: an electric organ, thought to be the first instrument to produce sound by combining electric and mechanical elements. The instrument was invented by Thaddeus Cahill and patented in 1897. It produced sine tones using a kind of synthesis foreshadowing the approach that Stockhausen would later experiment with fifty years later. However the instrument was too unwieldy, and despite the inventors efforts at revision, the instrument never caught on. In 1929 the Hammond Organ came along, making use of a similar electroacoustic mechanism.

Another early electronic instrument was developed in 1920 in the Soviet Union and patented in 1928 in the United States: the Theremin, invented by Léon Theremin. It has become well-known, particularly

for its novel interface that allows the performer to control the instrument's pitch and volume by the position of his hands in space without touching the instrument. Despite the instrument's limited timbral variety, the Theremin provides an early example of how the interface design of electronic instruments plays a critical role in the musical results they can achieve.²¹ The Theremin possesses two particularly desirable features of electronic instrument design: 1. The instrument's interface provides an interaction that can be learned and eventually mastered, as any other musical instrument; 2. The strong visual element of a performance makes the instrument's behavior transparent to the listener.²²

The same year that the theremin was patented, the Ondes Martenot was invented by Maurice Martenot. The instrument uses vacuum tubes to produce sounds similar to the theremin, and it is played in a way somewhat similar way: the pitch produced can be controlled by two different methods: 1. A keyboard that functions like an organ manual; 2. A metal ring whose left-right position varies pitch, allowing theremin-like glissandi. The musical dynamic of the chosen pitch is controlled by a button made of glass, the 'touche d'intensité', which can be progressively depressed to produce an increasingly loud sound. Unlike the theremin, later versions of the instrument allow a variety of timbres to be produced. The instrument is still known today primarily for its inclusion in several of Olivier Messiaen's works, and it is taught at the Paris Conservatory.²³

1.10 Repurposed Recording Devices

Other early experiments made use of phonographs and tape recorders, treating them as musical instruments. John Cage's *Imaginary Landscape No. 1* (1939) made use of two variable-speed phonograph turntables performed alongside two other performers playing a muted piano and cymbal. In 1966 Karlheinz Stockhausen's *Solo, für Melodie-Instrument mit Rückkopplung*, followed in Cage's footsteps, experimenting with the tape player in order to produce a real-time feedback delay line. An instrumentalist performed a notated score, which was recorded and manipulated by the tape system, controlled by four assistants. After having a difficult time realizing the piece as originally conceived, Stockhausen would later combine fixed media elements with the live instrument and feedback system.

21 For readers unaware of the level of virtuosity achievable by some trained 'thereminists', an online search is recommended.

22 For a more in-depth discussion of features of electronic instruments, see chapter 2.

23 Ondes Martenot (initiation). <http://www.conservatoiredeparis.fr/disciplines/les-disciplines/les-disciplines-detail/discipline/ondes-martenot-initiation/> Accessed April 12, 2018.

1.11 Synthesizers

The electronic music studios founded after World War II in Germany and France mentioned earlier in this chapter were the sites of research into synthesis techniques during the 1950's. For most of the decade these efforts were primarily 'off-line', meaning that the sound was not produced in real time. The shift from vacuum tubes, used in instruments like the theremin and ondes Martenot, to transistors was the technological advance that catalyzed the development of analog modular synthesizers in the 1960's and 70's including most famously Robert Moog's self-named instrument first demonstrated in 1964. The original Moog synthesizer was meant to be installed in a studio, so while it produced sound in real time, it was not portable. The Minimoog was released in 1970, which was portable and could be used in performance on stage.

Synthesizers really became popular with the move to digital technology in the mid-1970's, using 'digital signal processing' (DSP) to produce sound. By the mid-1980's digital synthesizers had essentially replaced analog instruments, particularly with the introduction of Yamaha's DX7 in 1983. Further investigation of this digital synthesizers falls outside the scope of this study, except to mention that many of these DSP processes can also be used to manipulate the sound of traditional instruments. Our discussion of integrating the saxophone with computer-based DSP therefore owes a lot to this research done in the 1980's and 90's.

1.12 Augmented Instruments

The goal of augmenting traditional instruments represents an entirely different direction in the field of electronic music, which also dates back long before the digital revolution. These instruments often use sensors to expand the possibilities of an acoustic instrument. Several augmented instruments, which were designed at the MIT Media Lab beginning in 1986, are known as "hyperinstruments". A hyperviolin has been performed by Joshua Bell, the hypercello was first demonstrated in 1991 by Yo-Yo Ma, and a more recent hyperpiano uses sensors and Max/MSP to manipulate the acoustic sound. These instruments were designed by composer Tod Machover, and they feature in his compositions, such as *Jeux Deux*, a concerto for hyperpiano, premiered in 2005 by the Boston Pops Orchestra.

The 'Metasaxophone', developed in 1999 by Matthew Burtner at Stanford University's Center for Computer Research in Music and Acoustics, also uses sensors and *Max/MSP*-based software with the

aim of providing new methods of interaction between the saxophone and the computer. This research led to several pieces, *Noisegate67* (1991), *S-Trance-S* (2001) and *Delta 2* (2003). It seems that the Metasaxophone was not conceived as a general-purpose instrument, rather its design was compositionally motivated: the instrument's capabilities are strongly connected to Burtner's own works and personal performance style.

The *Sensor Augmented Bass Clarinet* (SABRe) is an augmented bass clarinet developed at the Institute of Computer Music and Sound Technology (ICST) in Zürich, Switzerland. The prototype was first used in performance in 2012 by clarinetist Matthias Mueller, who is dedicated to the development of the instrument. The clarinet uses an accelerometer to track movement, a breath sensor to measure air pressure, and has sensors on each key that measure their positions. The concept behind the instrument is to create a standard instrument that can be learned by clarinetists and written for by composers. In addition to promoting the instrument, Mueller is working to expand the repertoire of music written for the instrument. It does not seem that the full version of the instrument will be made commercially available, but a reduced version is being designed. As of this writing, none of the components were available to me for testing.

The Yamaha Corporation holds several patents describing a hybrid saxophone which can function either acoustically or electronically, by changing the mouthpiece.²⁴ The design seems to be a successor to Yamaha's 'Silent System', which allows a piano to either function normally, or as a MIDI keyboard that can be heard with headphones. If a corresponding 'silent saxophone' were ever produced, it would likely rely on sensors to track the positions of the keys and the wind pressure. Although the development of this instrument would be motivated by concerns unrelated to the performance of electronic music, if it were ever developed, it might be used as an augmented instrument, similar to the SABRe clarinet.

1.13 Real-time Electronics and Instrument Design

The computer itself has turned out to be an effective tool in music production, and it has also become more and more relevant for live performance with the advance of technology. However the computer is not necessarily a musical instrument in itself. It is not predisposed to generating musical sound the way

²⁴ Yamaha Corporation. Hybrid Wind Musical Instrument And Electric System Incorporated Therein. US Patent 7,829,780, filed 6 June 2008, issued 9 November 2010.

a violin or saxophone is. Joel Ryan describes the computer as “the most general of all human inventions after only logic and mathematics itself.”²⁵ Every time the computer is used to create or manipulate musical sound, some amount of design is involved, and this design process in turn dictates much about the type of music that it will eventually produce. Whereas the computer itself is the ultimate general tool, the systems that enable music-making are highly specific. It is for this reason that the production of electronic music is often related to instrument building.

For us, composing a piece of music is like building a new instrument, an instrument whose behaviour makes up the performance. We act at once as performer, composer and instrument builder, in some ways working more like sculptors than traditional musicians.²⁶

This instrument-based approach includes composers like Michel Waisvitz, who design completely new instruments to perform their works, as well as those who aim to extend the possibilities of traditional instruments. Some interesting work has been done in this direction by improvising musicians. For example jazz trumpeter Jeff Kaiser has developed his own interactive electronics system using Max/MSP to process the sound of his quarter-tone trumpet.

My goal ... was to create a single, personal software instrument that would simply and fluidly interface with the trumpet in a variety of performance environments. It would become part of the instrument, not just an added effect, and it would be as seamless as possible in its interactivity in an improvisational musical setting, within the confines of the physical restrictions imposed by my playing the trumpet.²⁷

While Kaiser has designed his personal system after decades of experience performing with electronics, it can be much more difficult for a composer to design such a system. It is here where the composer-performer gap is the most obvious. Without the instrument itself in hand during the composition process, a composer is severely limited in the types of extensions he could hope to design. Therefore composers usually prefer to integrate simple types of sound manipulation into an otherwise system-based approach.²⁸

²⁵ Ryan. pg 10.

²⁶ Perkis, Bischoff .(1989). Liner notes to *Artificial Horizons: Music for New Software Instruments*.

²⁷ Kaiser, Jeff. (2007). “How I lost 150 lbs. thanks to Max/MSP!” paper for the Spark Festival of Electronic Music.

²⁸ A few examples that have come up during my own practice are Pierre Boulez *Dialogue de l'Ombre*

Anthèmes II is a model example of this approach. The computer behavior could be described in two parts. The first is the signal processing used directly on the violin sound, which is not at all complicated and only sometimes employed²⁹. The rest of the computer's part is the triggering of samples which must be precisely coordinated with the violinist³⁰. In order to do this, programmers at IRCAM have developed sophisticated score-following software. Although the signal processing techniques are simple, the systems-level design necessary to realize Boulez's complex score represent many years of work. In fact the score-following tradition at IRCAM continued for another decade after *Anthèmes II*, and in 2007 a new score follower system was used to support a piece for saxophone and electronics, *...of Silence..* by Marco Stroppa.³¹ All of this technology allows the instrumentalist to rely on the system and a well-prepared collaborator at the computer, without needing to know much about the inner workings of the computer.³²

In the case of *Anthèmes II*, the traditional composer-performer roles are maintained. The widening gap between them is bridged to whatever extent the software is able to accurately follow the violinist's actions.³³ In the 20 years since *Anthèmes II*, as composers have gained access to more and more sophisticated technology, there has been new interest in the instrument-based approach. Much work has been done with the goal of developing various types of interactive systems, but here again the massive composer-performer gap is once again revealed. It is time for performers of contemporary music to claim some control of the extended instruments they are being asked to play.

1.14 Composer-performer Roles: Past and Present

Looking back at the history of western concert music, the hierarchical relationships between composer, performer and the audience have been a long-standing aspect of that tradition. The masterpieces of the baroque, classical and romantic periods are widely regarded as transcendent artworks, captured from the pen of genius composers. Despite the revolutionary spirit of the modernists, these roles remained

Double (1985), Nathan Davis *Cipher* (2012), Germán Alonso, *El Gran Cabrón* (2012), Naoki Sakata, *Phytolith I* (2015).

29 The effects used on the live violin are primarily pitch shifting, frequency shifting, reverb and delay.

30 The triggered samples are also manipulated in real-time using reverb, ring modulation, comb filtering and spatialization.

31 *Antescofo* was designed by Arshia Cont, and it is now used in many contexts, including performances of *Anthèmes II*.

32 This type of opaque system behavior is often referred to as a 'black box'. Further discussion of this idea can be found in Chapter 2.

33 Although the modern score-following software is extremely sophisticated, it still remains an imperfect solution to a very difficult problem.

firmly in place through the 20th century, and today most new music production relies on the same assumptions.

With the acoustic extension of the instrumental possibilities and the normalization of noise-based sounds, microtonality and other non-traditional playing techniques, composers have enjoyed a significant expansion of the types of sound material available to them. These new expressive possibilities have also come with a steeper learning curve. Multiplied by the number of instruments in the orchestra, plus a few newcomers like the accordion and saxophone, the sheer amount of information required to write for a full-instrumentation new music ensemble can be quite a challenge to face. To take the example of the saxophone, few composers are themselves virtuoso saxophonists, so they generally rely on performers' expertise to inform their writing. It is a common working process for the saxophonist to demonstrate possible techniques to the composer and to give feedback about playability during the composing process.³⁴ The past thirty years have also seen several publications by saxophonists that aim to provide information about extended techniques to both composers and other saxophonists alike. This community of willing saxophonists in combination with extensive written resources has led to a robust working process by which composers are able to continue working in a more-or-less traditional role. Many contemporary works in the saxophone repertoire originated from this working process.³⁵

With the addition of live electronics processing and the ability to integrate acoustic instruments with computers, the available material has expanded so drastically that it would be difficult for a composer who does not play the instrument himself to explore the range of possibilities by himself. It would seem that this vacuum would be filled by eager performers willing to experiment themselves with these new software and hardware tools. However the community of performers has not undertaken the exploration and documentation of electroacoustic sound possibilities with the same vigor that they undertook the exploration and documentation of the acoustic extended playing techniques. For various reasons few performers have taken up the challenge to work directly with computer music, even including specialists in contemporary music experienced at working with composers. While they are generally

³⁴ This working relationship has been termed 'consultative.' More discussion of alternative working relationships can be found in Chapter 4.

³⁵ In addition to original works, this consultative approach has also yielded many successful adaptations of pieces originally written for other instruments. Examples include Luciano Berio's *Sequenza VIIb*, *Sequenza Ixb*, Pierre Boulez's *Dialogue de l'Ombre Double*, and Karlheinz Stockhausen's *In Freundschaft*.

comfortable providing suggestions about the acoustic possibilities of their instruments, they usually draw the line where electronics are involved: this is considered part of the composer responsibility.³⁶

This point was reinforced anecdotally when I played with a major contemporary music ensemble in early 2017. We were playing *Snatches of a Conversation* (2001) by Peter Eötvös for an ensemble including a particular keyboard-triggered sampler which is now essentially obsolete. I noticed that the keyboard player was using a laptop to trigger the samples: a necessary but potentially messy work-around in this situation. When I asked him how he got his hands on the sample bank to prepare the laptop, he was surprised by the question. “You didn't build your own saxophone did you? I don't know how they set it up, I just play it!”. Of course then during the first rehearsal when there was a problem with the laptop, he was helpless because he didn't know how his own instrument was configured. He played the rest of the rehearsal on the piano, leaving us with only one more rehearsal before the concert where the electronics functioned properly.

This near-total abdication by instrumentalists has meant that the responsibility for designing electronics systems has been largely taken over by composers and technologists. As mentioned above, these works are often developed at an institute like IRCAM, where the institutional approach allows a prolongation of the traditional role of the composer. It is not necessary for composers to learn much about programming, when that work is delegated to a technologist. This allows the composer the freedom to focus on his compositional processes in order to produce an inspired score. The performer is still generally brought late into the process, in the role as an interpreter, not as a contributor to the creative process. *Anthemes II* could be seen as the culmination of this approach: a highly-structured piece, notated precisely, performed with an essentially parallel computer process that follows and reacts to the performer on a note by note basis.

1.15 Composer-centric Approaches

Over the past twenty years, working with *Max/MSP* has become par for the course for young composers, and the production of new works based on live electronics processing has exploded. Yet

³⁶ This is a characterization of the current status quo, not a blanket statement meant to apply to every performer. However it should also be noted that the few performers who do work hands-on with electronics systems are usually improvisers or 'performer-composers'. In these cases the design of the electronics is still tied to authorship of the works produced. I am suggesting a role for working with electronics consistent with a performer's role as an interpreter or collaborator, not a solitary author.

few of these works can be said to have entered the saxophone repertoire. In fact many of the most effective works, which will continue to be performed in the future, are still being produced in an institutional context³⁷. Why does it remain so difficult for independent composers to take advantage of the powerful new tools available to them? There may be several possible explanations.

Programming with modern software is much easier than it used to be, but there is still a learning curve requiring at least a couple years to really master. The programming is considered a proprietary part of each musical work, so rather than building on the best of what has come before, composers often tend to 'reinvent the wheel'. Another tendency is to treat the software as if it were a traditional musical score: a snapshot in time. Once a piece has been premiered there is a strong desire among many composers to freeze the software system at that point, rather than continue to develop it. This attempt to subsume electronics system design under the same logic that governs the production and replication of a traditional musical score seems to deny the nature of electronics software.

The oft-cited problem of obsolescence in electronic music³⁸ is a valid concern with this view of the role that electronics should play in the production and performance of new electroacoustic works. Twenty years may be a long time in the field of technology, where the increase in computing power generally follows an exponential curve. However work in the arts usually takes a much slower pace. It could be argued that the music world simply has not caught up from an aesthetic point of view with the fast-paced innovation of the technology sector. For example it might take a composer many years to arrive at a mature compositional style, while the technological landscape may have significantly shifted in the meantime.

To take an example from my own experience, I began programming and working with live electronics in 2012, but it was only in 2014 that a major piece of software³⁹ was released which now serves as the core of my own system. Over five years' time, my system design has shifted several times before arriving at the current version.⁴⁰

37 *...of Silence* (2007) by Marco Stroppa, for example

38 The argument goes that electronic music suffers from an inherent problem that the hardware and software used to produce a piece may not be available or relevant in the future. An example of this was described above in relation to the samples required for a performance of *Snatches of a Conversation*.

39 *Molekular* is a software effects processor developed by Native Instruments, which runs in their *Reaktor* environment.

40 For more information on the progression of my system design, see Chapter 3.

These considerations related to the current technological landscape in computer music composition and performance expose an underlying problem related to the relationship between composer and performer. I would argue while the advance of technology has allowed access to live electronics tools to anyone with a laptop, it has also exposed a 'gap' between the composer and performer. Traditionally this gap in communication between the author of a work and its interpreter has been bridged by the musical score and a highly structured system of musical notation. While this has proven to be a robust system, implemented and refined over the course of centuries, this process by which a composer conveys his musical instructions is necessarily an imperfect representation.⁴¹

The imprecise nature of musical notation leaves open questions to be addressed by the performer, and his personal solutions to these musical problems form an integral part of his own musical identity: his 'voice' as a performer. While the score is fixed and unchanging, its realization in performance is alive and ephemeral. The composer's creative act begins with the empty page and ends with a final score, whereas the performer's creativity is offered up anew with every performance. This co-creative process between composer and performer, mediated by a written score is a foundational aspect of western art music. Over the past several decades, this composer-performer gap has been widening; first with the addition of extended playing techniques, and later with the addition of live electronics processing. Institutions like IRCAM may provide provisional ways of bridging this gap, but in the *Max/MSP* era, the majority of new works are being written by independent composers without the weight of an entire research studio behind them. In addition to the traditional challenge of composing an interesting musical score, composers are now faced with a second task of designing an electronics system that can interface with traditional instruments in a musically relevant way. This system design can be approached in several ways, each of which comes with strong aesthetic and performative implications. Some of these approaches have been well-explored, others have hardly been touched.

1.16 Performer-based Systems

This research project is based on the proposition that a performer-based system of live electronics would look and sound distinctly different from what a composer would design. My intuition was that by limiting the performer's role in integrating the instrument and electronics, a lot of potential is left

⁴¹ Karlheinz Stockhausen's work is an example of this communication issue. He insisted that his works be performed in exact accordance with the written score, however there remains a lot of necessary information that cannot be notated with sufficient detail. Stockhausen worked in-depth with performers to train them on how to perform his music. Since his death in 2007 this type of instruction is continued by other musicians in Kürten, Germany.

unexplored. Some questions immediately come to mind:

- By enabling the performer to work hands-on with live electronics systems, what kind of musical outcomes could be achieved?
- What impact would this approach have on my voice as a performer and my experience performing on stage?
- What implications would this approach have on performance practice for the wider repertoire?

These performance-related questions lead to a further line of inquiry about the role of the performer and his working relationship with composers. The suggestion here is not for the performer to take over the role of composer, as has been done by a growing number of 'performer-composers', but rather to interrogate the traditional roles between composer and performer.

- How could a performer-based approach to system design lead to collaborative strategies that bridge the gap between composer and performer?
- To what extent might the performer participate in the creative process?
- What effect would this approach have on the composer's voice?

Chapter 2

Electronic Music-Making: Social Networks and Instrument Design

This research project was originally motivated by the interest in exploring possibilities of live electronics processing from a performer's point of view. If the range of results achievable through a performer-centric instrument design were to differ significantly from the existing body of work offered by composers, then this insight could have an impact on the field of electro-acoustic composition. The research problem was initially defined as a gap between composer and performer: a kind of inefficiency in the process by which new music is usually produced. Composers generally do not have the expertise to truly integrate live electronics with traditional musical instruments so they miss out on certain possibilities. On the other hand, performers rarely take much responsibility for, or even interest in, the workings of the electronics. It seems that traditional composer-performer working model has encountered a major stumbling block in the form of real-time electronics processing. While it is true that some composers manage to include real-time processing in their works, the most common approach remains using fixed media elements in parallel with the performance of acoustic instruments. Could there be an entire range of possibilities left unexplored by the composer-centric approach?

At first glance the problem seems to be related to the roles taken on by performer and composer. What exactly falls into the purview of the performative act as opposed to the compositional act? To take the example of fixed media mentioned above, the responsibility to imagine and compose the electronic elements of a piece falls squarely in the composer's domain. Fixed media elements are so distinctly separate from the performer and his instrument, that their preparation in the studio is could be seen as analogous to writing a piano accompaniment, where the need for a live performer is entirely dispensed with. McNutt's objections aside, this is clearly a part of the compositional process.

The addition of triggering and score-following add some flexibility to the computer system, but when they are used with pre-recorded electroacoustic sound, the fundamental compositional procedure is retained; these are all activities that fall within the composer's purview. What does that mean for the role of the performer? Apart from finding a way to navigate the “inflexible, unresponsive”

accompaniment, a performance of these piece is not fundamentally different from a performance of music from the classical repertoire.⁴² The demands on performers may have increased over time, but their basic role in the process has not.

The shift of the technology toward a digital landscape has opened up new avenues for exploration, while simultaneously forcing us to re-think some of our beliefs about the nature of music itself.⁴³ Computers have become powerful enough in the past twenty years to offer real-time sound manipulation, and the desire to integrate computer processing with live instrumental performance is well-established among both performers and composers. However I would argue that this goal has turned out to be more elusive than expected, particularly when compared with the rich history of electronic music written for fixed media. Our technological resources have developed much faster than artists have been able to implement it in their work, leaving many avenues unexplored. I would further argue that the work being done is largely asymmetrical in regard to the variety of possible approaches. The post-Boulez, *Anthèmes II* model has become the dominant approach: a fully-notated score and triggering are used to integrate real-time sound manipulation and fixed media with acoustic instruments.⁴⁴ However alternative approaches like the computer-as-improviser model⁴⁵ and the extended instrument model seem to have been less thoroughly explored. I suggest that we have arrived at a moment when the drive to maintain traditional composer and performer roles is limiting the range of artistic work being done. It is time that we re-examine that relationship.

2.1 Social Networks

For many performers of new music, the relationship with composers is central to the entire practice. Until we are ready to entirely eliminate this type of collaboration⁴⁶, these relationships will remain at the heart of human music-making. The addition of real-time electronics processing has significantly

42 The role of the performer in these two types of performance may not be entirely identical. For example when performing well-known pieces of the classical repertoire, a performer draws on a body of existing performance practice to inform his interpretation. This performance practice is often absent when performing new works. For more on the topic of performance practice, see chapter 3.

43 Take for example the controversy around Kendrick Lamar's recent Pulitzer prize for the album *DAMN*. Many composers from the classical tradition do not recognize the album as a composition in the same sense that a string quartet is 'composed'. The work does not exist as a written score, but rather is composed of Lamar's lyrics, his performances, and the album's production.

44 It is tempting to name this the 'IRCAM model'.

45 Two notable examples of this approach are George Lewis's *Voyager* and saxophonist Ben Carey's *derivations*.

46 It is true that some composer-performers and improvisors manage to work successfully alone, without collaborating with a composer.

complicated this relationship and its modes of communication. With this in mind, my concern over this 'composer-performer gap', gradually expanded to a concern of the entire social network that underlies the production of new musical works.

These are networks with many nodes and interactions, constantly in flux with channels of communication opening and closing, being established, broken, re-established and modified. Despite the unstable nature of these social networks, the works that they produce are as concrete as can be.⁴⁷ While the work itself is defined by its observability, offering itself for scrutiny and criticism, its underlying social network resists observation. Nonetheless an analysis of these shifting constellations of actors may give some hint about the artistic work that will ultimately be produced.

2.2 Actor-Networks

Actor-Network Theory (ANT) is an approach to sociology that provides the means for analysis by tracing the connections between points in a network. Insights about social structure can be drawn by looking at the nature of this web of connections and its constituent actors. We do not begin with the social forces that we want to examine, but rather begin with a blank slate and assemble the network.

The first concept taken from ANT is the idea of a heterogenous network⁴⁸: both humans and non-humans play a role in establishing the nature of a network. A musician engages and interacts with the saxophone in several ways: lip-reed contact, air pressure and resistance, pressing and releasing keys, and he receives tactile and auditory feedback from the instrument. These connections between the performer and instrument create a heterogenous network that comes into existence as long as he plays it, which is re-established anew each time the instrument is played. In order for a successful performance to take place, the resistance of the network must be overcome. Otherwise the network breaks down and the flow of music is interrupted.

The saxophone itself is an instrument, a network of interacting parts, that when functioning properly and in unison, allow the instrument to be understood as a single object. This is known in ANT as

47 For a thought-provoking discussion about the nature of works of art, see Mersch, Dieter. (2015). *Epistemologies of Aesthetics*.

48 Law, John .(1992). "Notes on the Theory of the Actor-Network: Ordering, Strategy and Heterogeneity", *Systems Practice*, 5. p 380.

'punctualization.'⁴⁹ When there is a breakdown somewhere in the network, the instrument's nature as a series of smaller parts becomes painfully obvious and has undergone 'depunctualization.' When dealing with complex networks, we normally do not interact with each individual component, but rather the network is engaged with as a whole, as a 'single block.'⁵⁰ This block is itself an actor that engages with other actors. The name 'Actor-Network' refers to the nature of every actor as a network in itself.

In this type of analysis, human actors and non-human entities are treated on equal ground: both exert their 'will' on other actors in the social network in ways that affect its ultimate effect. Figure 1 shows the core interaction between instrumentalist and instrument, where both actors play an active role in shaping the music that is produced. Here our attention is focused on the two-way flow of information between the two: a link between the performer and his instrument cultivated through deliberate practice and placed on public display during performance.

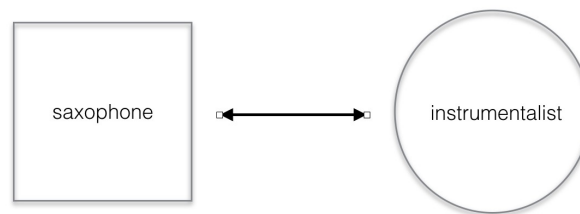


Figure 1: instrument-instrumentalist

These networks are not static structures that are established once, but rather 'a site of struggle, a relational effect that recursively generates and reproduces itself.'⁵¹ Every time the saxophonist puts the instrument to his lips, a new struggle begins, and the same applies as the network becomes more complex with the addition of the composer. At this moment the composer is interacting with the instrument-musician pair, with only indirect access to the instrument, mediated by the performer.

49 Law. pg. 384.

50 Ibid.

51 Law. pg. 386.

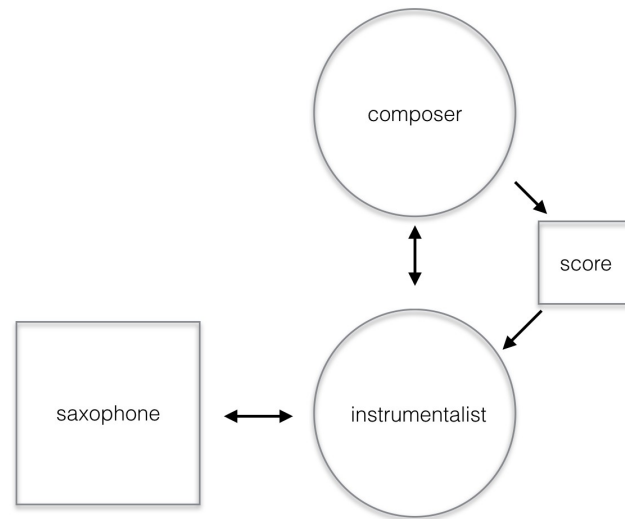


Figure 2: composer-instrumentalist

As the social network expands to include additional actors, our attention remains on the nature of the connections between them, which are never stable but rather constantly in flux. Each actor has his own set of 'preferences' which can produce resistance to being brought together into a functioning network. This may be related to the power relations between actors, which are not fixed but constantly renegotiated. The process by which actors are brought into relation with one another, overcoming inherent resistances, is termed 'network ordering'. In the case of a performer-composer collaboration, we are interested in how the two come together for a period of time to produce a musical performance.

To the social network depicted in figure 2, we might choose to add electronics, in which case the nature of the web shifts again, requiring new ordering strategies. The most common such strategy is shown in figure 3: a composer-based model. Here the composer is responsible for both designing the electronics system and writing the score. Here the electronics fall into the domain of composition and are generally treated as a separate process that occurs in parallel with the instrumental performance. The link between the saxophonist and electronics is likely to be weak⁵², so this must be taken into account when writing the piece. These conditions favor an electronics design that functions well on its own, without need of a control-intimate connection with the performer. The range of possible musical results arise from, and are limited by, the nature of the relationships between the particular actors in a particular

⁵² This link is assumed to be weak because the performer generally does not have the opportunity to practice extensively with the system before the concert. This is discussed further in the 'performance practice' section of Chapter 3.

network.

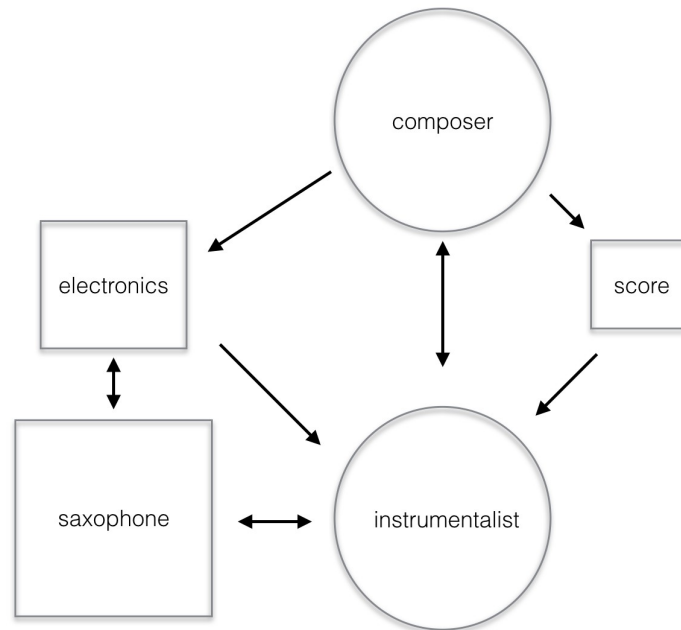


Figure 3: composer-instrumentalist with electronics

An alternative network configuration that allows for a more robust cultivation of the links between the performer and electronics, as well as the instrument and the electronics is described in figure 4. In this case the electronics are brought into a network with the performer and instrument, treated as an extension of the instrument with priority placed on the integration of the computer into the live performance. The performer is responsible for designing the electronics⁵³, which leads to a completely different situation where the three elements come together as a punctualized, heterogenous network.

⁵³ Or he may be involved in other, collaborative working relationships. Many variations of these network configurations could be explored by future composer-performer collaborations.

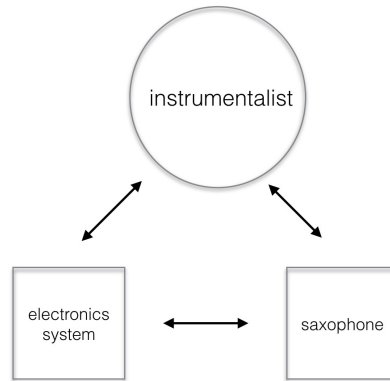


Figure 4: instrumentalist-instrument-electronics

If the instrumentalist is empowered to cultivate the relationships in the network configuration shown in figure 4, drawing the electronics system into his instrumental practice, then this punctualized network could itself engage with an extended network of actors.

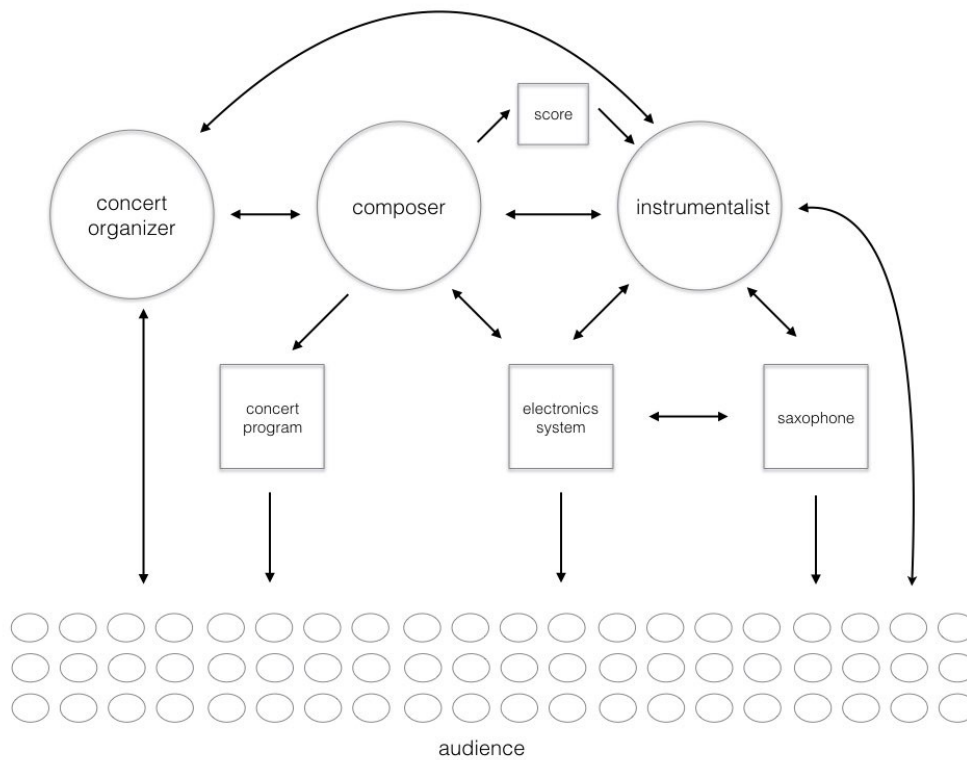


Figure 5: a possible social network

In figure 5 we see how the network from figure 4 might be reintegrated into a larger social network. Each of the links of the network deserve their own analysis, but only a few are addressed in this paper. The interface between the saxophone and computer system will be discussed in chapter 3, the connection between composer and performer is further addressed in chapter 4, and the role of a notated score is discussed in chapter 5.

2.3 The Dreaded Black Box

As our digital tools become more sophisticated, networks of relationships more complex, we run into the idea of the 'black box': a punctualized network that resists our efforts to untangle its constituent parts. While we are able to engage with these kinds of networks, establish reliable expectations of outputs for given inputs, their inner workings remain mysterious to us. Learning how to 'look under the hood' may or may not be a worthwhile investment as we work to develop our relationship with them. The more complex a black box's inner workings, the greater the gap that appears between its user and its maker. By the time we arrive at tools such as modern musical instruments, the musician has become entirely dependent on the luthier to build and repair his instrument for him. The relationship between them can be seen as a part of the bigger social network, working toward the eventual goal of producing musical sound. Situated between them the instrument itself becomes a node in the network, a punctualized actor-network, whose inner workings are only partially grasped by the musician.

In the domain of acoustic instruments, the orchestral instruments seem to have found a nearly final form. For the most part little additional complexity is being added to the violin or saxophone, for example.⁵⁴ The instruments' designs have been stable enough for a long enough time, that performers are able to gain partial understanding of what goes on 'inside the black box'. This knowledge informs how we play and teach the instrument, and its availability to composers enable them to write idiomatic works. The story is slightly different when acoustic instruments meet computer processing.

We have already considered Pierre Boulez's piece for violin and live electronics, *Anthèmes II*, produced at IRCAM in 1997, as a highlight of the music that has been produced in an institutional context. The social network that enabled the production of the piece could be traced to show the web of technicians, software and hardware that enabled not only its first performance in 1997, but also each subsequent

⁵⁴ Christopher Redgate's work on the Howarth-Redgate oboe is a notable exception! For more on this project see his website: <http://www.21stcenturyoboe.com/>

revision to the software over the past two decades. Such an analysis does not fit here, but needless to say, it would be scattered with black boxes, opaque to both the performer and Maestro Boulez himself.

Bits of software and hardware that present themselves as black boxes are not necessarily anti-musical per se. Analog effects pedals are a prime, and often literal, example of black boxes, which musicians have effectively integrated into their practice. Sometimes known as 'stompboxes' these pedals take an input, run it through certain circuitry to modify the signal, and produce an output. The details of the pedal's inner workings are mostly irrelevant to the musician, who is primarily concerned with what kinds of sound he can get out of it. By experimenting with various types of input, while noting the corresponding outputs, the performer gains understanding of the black box's behavior, without needing to know how it works.

Stompboxes can be chained together in serial or parallel, to create increasingly complicated networks of sound manipulation. This approach has an appeal for many musicians, because they are able to configure the pedals to meet their particular needs. As long as they understand the function of each component part, and internal routing of the system is known, the larger system as a whole does not function as a second-order black box to the musician who compiles it. While the system is comprised of multiple black boxes in its network structure, the system's overall behavior is essentially predictable. However the more complicated the chain of pedals, the more difficult it would be for another musician to master, and indeed, the more personal the system becomes.

Modern software allows the digital configuration of networks, orders of magnitude more complex than what could be achieved with analog equipment: interdependent black boxes connected to one another and organized hierarchically. The software designed in Max/MSP for a piece like *Anthèmes II* is one black box nested inside of another whose inner workings are essentially opaque to the user. In that particular case, the highly-notated score shows both the input to be provided by the violinist and the corresponding output expected from the system. This rigid, inscrutable system design does not establish a stable, explorable extended instrument, but rather provides a framework designed to realize Boulez's particular compositional ideas.

The approach to live signal processing in *Anthèmes II* could be seen as a natural continuation of the

way composers have employed fixed elements since the early days of electronic music. Working with fixed media allows composers to directly shape the sound which will eventually be heard by the listener, and the appeal to many composers is clear. Software is marketed to composers with endorsements like “For a composer, it's like being God.”⁵⁵ This impulse to exert control over every sound produced by the system is evident not only in *Anthèmes II*, but also in many other pieces written in the following 20 years.

However, the wide assortment of 'digital black boxes' now at our disposal could be employed toward an entirely different end from the 'composer-as-God' model epitomized by *Anthèmes II*. If system configurations are designed to prioritize the integration of the real-time processing into performers' existing performance practices, to what extent could we expect computers to join in the live music-making process?

2.4 Living Electronic Music

What exactly is meant by 'live electronics'? The term has been used in various ways and does not seem to have an agreed-upon definition. The matter is further complicated by the competing term: 'real-time'. We could begin with Simon Emmerson's definition of 'live': the presence of a human performer. Drawing on the idea of a “human agent in an environment”, Emmerson suggests the terms “local” and “field” in order to establish a framework for how to think about the relationship between live performer and electronics.

Local controls and functions seek to extend (but not break) the perceived relation of human performer action to sounding result. *Field* functions create a context, a landscape or environment within which *local* activity may be found.⁵⁶

The nature of the causal link between performer action and computer reaction determines whether a resulting sound is attributed to the local or field domain. In other words the production of sound by real-time processes does not guarantee that it is perceived as live, nor does it necessarily lead to a more effective musical result. Indeed there are many situations where the use of pre-recorded sounds is

55 Quotation by Véronique Robert used for promotion of the *Kyma* software platform on the official website. (Translation from French by the author). <https://kyma.symbolicsound.com/kyma-sound-design-environment/> Accessed 3 April, 2018.

56 Emmerson, Simon. (2007). *Living Electronic Music*. pg. 92.

preferable to producing them in real time.

An example of this came up when I performed Nathan Davis's piece for baritone saxophone and electronics, *Cipher* (2012) in Graz in 2015. During the first two pages of the piece, the saxophonist uses a foot pedal to trigger the computer to record short slices of sound which are saved to be used later in the piece. There is no immediate feedback for the player that the sound was properly recorded, so the function of the computer during that section is completely opaque. When I rehearsed and performed the piece, I used an updated version of the software, but I did not know that any changes had been made to its basic function. After my performance I had the chance to speak with the composer, who told me that he had rewritten the software for the opening section to achieve a more consistent result. He had replaced all of the real-time processing at the beginning with pre-recorded sound: a more reliable strategy. I had rehearsed and performed the piece without even recognizing that my sound was not being recorded, because of the lack of feedback. Davis had replaced a weak real-time technique with a strong fixed-media strategy.

However there may be other times when real-time processing strategies offer possibilities that are unavailable via fixed methods. To get at this idea, John Croft proposes a difference between “procedural liveness” and “aesthetic liveness”. Procedural liveness pertains to any real-time transformation of sound, whereas aesthetic liveness requires that “aesthetically meaningful differences in the input sound are mapped to aesthetically meaningful differences in the output sound.” Croft continues by focusing in on the performer-computer connection:

Thus the onus of justification of liveness is shifted to the causal link between the performer’s action and the computer’s response. It is a question of the specificity of the relation: if many perceptibly different inputs generate outputs with no pertinent differences ... then the liveness is merely procedural and not aesthetic – pre-recorded sounds would do the job as well or better. At the other extreme, if the mapping is too explicit, too transparently one-to-one, the result is not only tedious but may have the effect of shifting the procedural into the foreground, turning the piece into a lamentable ‘showcase’ of the technology. (‘Look – I do this, and the computer does that!’)⁵⁷

57 Croft, John. (2007). “Theses on Liveness.” *Organised Sound* 12, pg. 61.

Kerry Hagan's 2016 article continues the discussion about liveness. Whereas Emerson and Croft both assume a human participant and focus on the relationship between performer and computer, Hagan does not assume a human performer and approaches the topic from a slightly different angle. Instead she proposes several attributes of liveness: spontaneity, risk of failure, an acceptance of error and fault, audience/performer contract, indeterminacy, living presence, and audience experience.⁵⁸ Every one of these attributes demonstrates the disparity between human and computer actors. The freedom to act spontaneously, accepting risks and reacting to mistakes without compromising the overall integrity of a performance are the skills of an experienced performer. On the other hand unplanned computer glitches (or crashes!) almost always disrupt the musical flow, because the computer does not naturally react in an aesthetically meaningful way. With human performers the fact that no two performances are exactly alike gives live performance a feeling of immediacy which engages audience members as active participants in a one-time event. By contrast computers are deterministic machines, built to reproduce the same results time and again.

Hagan goes on to argue that liveness is not binary, but rather exists on a spectrum, depending on the way the computer is configured.

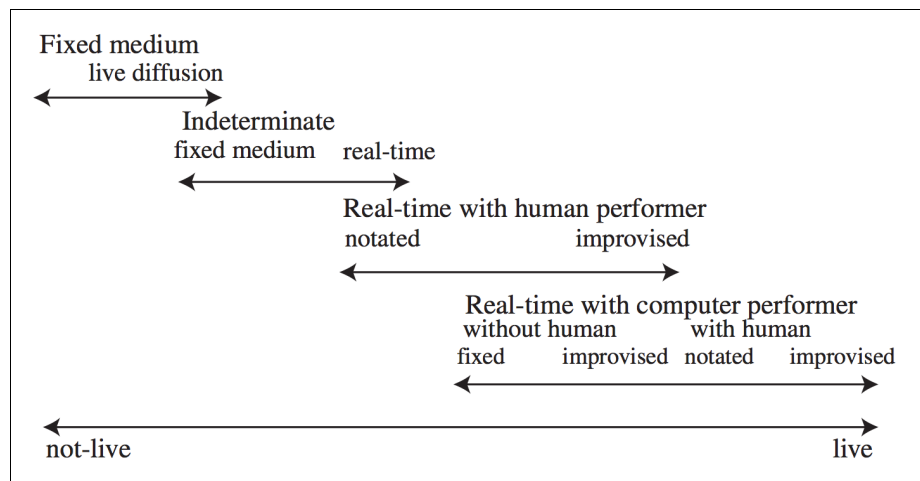


Figure 6: *Liveness of electroacoustic music*⁵⁹

58 Hagan, Kerry. (2016). *The Intersection of 'Live' and 'Real-time'*. Organised Sound, vol 21. pg. 139.

59 Hagan. p 144.

These analyses by Croft, Emmerson and Hagan provide a framework that helps contextualize this artistic research project. The left side of Hagan's spectrum has been much more thoroughly explored than the right side, so it may be that the structural and formal approaches fundamental to compositional practice are better suited for exploring the non-live than the live. While many composers include real-time processes in their works, the instrumental part and the computer part are usually treated as two separate processes that unfold in parallel. The distance between these parallel streams may also be related to the liveness of a given piece. By thinking of real-time electronics not as a structural element of composition, but rather an integral element of the instrument itself, we potentially open the door to new musical possibilities.

2.5 *Signos Oscillantes*

Signos Oscillantes (2012) by Germán Toro Perez is a major piece for soprano and alto saxophones and electronics, conceived of as a duo for the instrumentalist and the computer musician who runs the system. In addition to some fixed media material and interactive elements under the control of a computer musician, Toro Perez makes use of an interesting treatment to the saxophone which persists through the entire first section. A type of compression is used to selectively amplify softer sounds while suppressing louder ones. The tone of the saxophone is naturally much louder than key clicks or air sounds, but by isolating and amplifying these noise elements, Toro Perez brings them up to the level of the sounding instrument, creating a balanced, three-layered texture.

This works well because of the organic way that the electronics manipulate the natural sounds produced by the saxophone. The interface between instrument and computer is controlled by the instrument's sound itself, without the need for extra sensors or other complicating factors. This method works well because it takes advantage of the computer's real-time analysis capabilities, in order to create a response that is intelligible to the performer. By setting up conditions that allow the performer to understand and anticipate the computer's response, *control intimacy* can be achieved.

2.6 Control Intimacy

With the release of the general MIDI standard in 1983, it became possible to design musical interfaces that took advantage of the new digital technology. As seen in Chapter 1, *The Hands* designed at the STEIM lab was an example of such an instrument that converted musical gestures to MIDI data that

could be used to generate and manipulate sound. Unlike fixed mediums that came before, this allowed a real causal link between gesture and sound to be established where only an imaginary one had been possible. While this new technology seemed to promise a whole new generation of musical instruments, there was some question as to whether MIDI was fine-grained enough to allow musical control on the same level as acoustic instruments.

For subtle musical control to be possible, an instrument must respond in consistent ways that are well matched to the psychophysiological capabilities of highly practiced performers. The performer must receive both aural and tactile feedback from a musical instrument in a consistent way – otherwise the instrumentalist has no hope of learning how to perform on it in a musical way.⁶⁰

In this passage from 1988, Richard Moore was reacting specifically to the limitations of MIDI-based instruments to function expressively in real time. While the technological landscape has completely changed over the past 30 years, many of Moore's observations about the nature of musical instrument control remain relevant. It remains a challenge to establish control intimate interfaces that rival the level of control offered by traditional instruments. Moore's line of argumentation about the subtlety of computer response is probably the most relevant to this research.

In order to ‘learn’ a relationship and how to control it, the ability to articulate often very small changes in a parameter or group of parameters demands a consistent and clearly perceivable ‘cause-effect’ relationship, in the ‘right’ proportion. An example from the mechanical music world would be subtle control of string or wind vibrato. A complex of small changes in finger position, pressure, velocity, and so forth, produce a correspondingly subtle yet quite perceptible change in the sound. Maintaining this sensitivity in the technologically mediated world demands sensitive and complex mappings of performer action to sound result.⁶¹

The opening section of *Signos Oscillantes* is a prime example of a control-intimate interface. The system is sensitive to small differences in the sounds produced by the saxophonist and the computer response is equally subtle. This computer response is not perceived as taking place parallel to the

60 Moore, Richard. (1988) “The Dysfunctions of MIDI”. *Computer Music Journal*. p 21.

61 Emmerson (2007).

saxophone, but rather it is a transformation of the saxophone sound itself; a kind of remapping of the saxophone's own acoustic sounds.

Toro Perez's approach is also notable because the extension to the saxophone produces a rich musical environment to explore, but that is achieved by a simple, transparent design. This demonstrates an idea articulated by Wessel and Wright:

Getting started with a computer-based instrument should be relatively easy but this early stage ease-of-use should not stand in the way of the continued development of musical expressivity. Most of the traditional acoustical musical instruments are not easy to play at first but do afford the development of a high degree of musicality. On the other hand many of the simple-to-use computer interfaces proposed for musical control seem, after even a brief period of use, to have a toy-like character and do not invite continued musical evolution.⁶²

Wessel and Wright were writing about the design of new, computer-based instruments, but their comments are doubly important when the computer works in tandem with a traditional instrument. If the interface is difficult or awkward to use, then it will interfere with the performer's basic ability to perform on his instrument. At the same time an overly simplistic design can wash out the instrument's natural subtleties.

Control intimacy essentially boils down to the nature of the causal link between input and response. Technology now allows the mappings to be fine-grained enough to capture the smallest subtlety, but the question of control intimacy goes beyond mechanical relationships. More important is the perception of causality: both the performer's perception of how he influences the computer's behavior, and the audience's perception of these relationships as they unfold in concert.

2.7 Interactivity

The two-way connection enabled by real-time computing is not only useful for designing control intimate interfaces, slaved to the performer's will, but it also enabled other kinds of computer

⁶² Wessel, David and Wright, Matthew. (2002) "Problems and Prospects for Intimate Musical Control of Computers" *Computer Music Journal*. vol 26 issue 3. p1

responses. Emmerson defines interactivity as the “substitute of machine response for human response.”⁶³

An instrument that reacts to the musician in a passive, predictable way exhibits the lowest level of interactivity. Its reaction is determined by a simple mapping, similar to the way an acoustic instrument produces sound. The saxophonist chooses a fingering and a particular note comes out. A two-way flow of communication between instrumentalist and instrument is crucial for establishing control intimacy, but the saxophone does not independently produce any musical gesture of its own.

Emmerson suggests a distinction here between a computer's “reply” and response”. A reply is a simple answer, whereas “a true response adds value or meaning, solves problems or develops ideas.”⁶⁴

Interactivity happens when the computer's behavior is sophisticated enough to produce a musically meaningful response. As we saw earlier that there are different degrees of liveness that can be understood as points on a spectrum, interactivity can be seen the same way.⁶⁵

On the one end of the spectrum we find 'passive' systems, designed with a one-to-one mapping resulting in a predictable output, a mere “reply” to the saxophonist's gestures. This design might result in a control-intimate instrumental extension, but the result often sounds one-dimensional. On the other end of the spectrum, a computer system functions as an independent performer: a computer-based chamber music partner. A truly independent system not only listens and responds, but can also initiate its own musical gestures. George Lewis's system *Voyager* is a classic example from the 1980's and 90's of the computer-as-performer model which could both react to musical gestures and initiate its own.

2.8 An Unfulfilled Promise

Thirty years in, the expectation has yet to be fully realized that real-time technology will provide the means to the full integration of computers and acoustic instruments. This does not come as a result of any technical limitation, particularly during the past decade, but rather a more fundamental incongruity between human and machine that few composers have been able to overcome.

63 Emmerson, Simon. (2013). “Rebalancing the discussion on interactivity.” *Proceedings of the Electroacoustic Music Studies Network Conference*.

64 Emmerson (2013). p. 2.

65 Jordà, Sergei. (2007). “Interactivity and live computer music”. *Cambridge Companion to Electronic Music*.

There are now sophisticated modes of technical relation between performer and computer, both in terms of the live treatment of sound and of the collection of non-sonic information by means of sensors. But the poetic relation between the two too often tends either to the banal or the meaningless. The idea of interaction is seductive; it is also understandably attractive in an arts funding environment which favours a superficial and naïve notion of ‘innovation’. But the material result rarely measures up the appeal of the idea.⁶⁶

Croft goes on to contend that there is a “surprisingly narrow”⁶⁷ area between the banal and meaningless where it is possible to achieve aesthetic liveness. Looking at the repertoire from the last thirty years, including a full decade since the publication of Croft's *These on Liveness*, his argument seems difficult to refute. However it may turn out that this narrow area is more fertile than it seems as we develop better tools for exploring it: tools that will likely come from a performer-centric approach.

66 Croft (2007). pg. 59.

67 Croft (2007). pg. 61.

Chapter 3

The Extended Saxophone: Design and Performance

What does it mean to adopt a 'performer-centric' approach to extended instrument design, and how could this be achieved in practice? This artistic research project aimed to address this important 'how' question by working toward a concrete example of the integration of the saxophone and real-time electronics processing, which took place during the time period from 2013 to 2018, through a hands-on, experimental approach. I was particularly interested in exploring these possibilities with my preferred instrument, the soprano saxophone, although I also worked with alto, tenor and baritone saxophones at times.⁶⁸ This five-year period was punctuated by several public performances, which gave an overarching structure to the research process and provided periodic feedback that was useful in moving the project forward.⁶⁹

This eventually led to the production of a work for soprano saxophone and live electronics, titled *aubiome*, which has now been performed multiple times around the world and was video-recorded in Graz in May, 2017. The insights about the integration of the saxophone and electronics described in this chapter are the result of my practice-based artistic research leading to the eventual production of *aubiome*, and a reading of this paper may be accompanied by a viewing of the May 2017 video recording of the piece. It is not to be considered a definitive work for saxophone and electronics, but rather it is offered to give a taste of what can be done with a performer-centric approach to instrument design.⁷⁰

3.1 Design of the Saxophone

Adolphe Sax himself was a prolific instrument builder, having devised many successful wind instruments, as well as a performing clarinetist. In designing the saxophone, Sax's creative insight was his idea to combine elements from woodwind and brass instruments to create a new hybrid instrument that would possess both agility and power. There was no direct predecessor to the saxophone that could have served as inspiration for Adolphe Sax. Sax must have done a great deal of experimentation to 'get

⁶⁸ The members of the saxophone family are quite different from one another in the ways that they can be integrated with real-time electronics, but there is still a large carry-over between them. Some of this carry-over may apply to other instruments, as well.

⁶⁹ For more on this iterative process, see Chapter 4

⁷⁰ For a more detailed look at *aubiome*, see chapter 5.

it right', but by the time he demonstrated it publicly in 1842 in Paris, he had solved the mechanical and acoustic problems to bring his idea from the blueprint to reality.

The very existence of the saxophone is an example of the performer-centric model of instrument design in action. Adolphe Sax's instrument building practice was informed by his experience as an accomplished clarinetist, so once he had invented the saxophone, he became the instrument's first performer. He was also the first to develop a pedagogy for the saxophone, which he taught for years at the Paris Conservatory. It was Sax's unique combination of craftsmanship skills and artistic vision gave rise to an entirely new, hybrid instrument.

3.2 Affordances

The term “affordance”, coined by psychologist James Gibson in 1966⁷¹, refers to the relationship between an animal and its environment. “The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill.”⁷² Gibson expanded the concept to include social interaction, and others have applied it in other domains, notably in relation to technology and design. This idea is particularly useful in considering the relationship between instrument and performer.

For example the low register of the saxophone is easily played at loud dynamics. When a beginning student first encounters the low register of the saxophone, he will naturally begin playing louder to make the notes sound. This is a simple affordance of the saxophone, based on its particular design: nearly every saxophonist's first attempts in the low register are loud and honky. This feature of the saxophone is not necessarily shared by other instruments. To take the clarinet, for example, the instrument's low register is naturally produced with a softer, more mellow tone. This feature of the saxophone, resulting from the instrument's conical bore, would have been recognized by Adolphe Sax during the design process.

Our first encounters with the saxophone reveal certain built-in affordances, much the same way an animal would discover new terrain in its environment. However the exploration does not end at the surface level. After years of practice, saxophone students will discover another, less obvious,

71 Gibson, J.J. (1966). *The Senses Considered as Perceptual Systems*.

72 Gibson, J.J. (1979). *The Ecological Approach to Visual Perception*.

affordance in the low register: a technique called 'subtone', which allows extremely soft dynamics to be produced.⁷³ Once the saxophonist learns this alternative method of tone production, the instrument begins to function in an entirely different way than before. A new mode of function has been revealed: a less-obvious, but equally characteristic affordance offered by the saxophone.

3.3 Resistance

Gibson's original definition mentions that an affordance of the environment is not necessarily beneficial to the animal, "The affordances of the environment are what it offers the animal, what it provides or furnishes, *either for good or ill.*" When the concept is taken into the domain of musical instrument design, we might reframe that with the term 'resistance'. A musical instrument offers certain affordances, but it also presents resistances. To return to the example of the subtone technique on the saxophone: while subtone is an effective mode of tone production in the low register, allowing extremely soft dynamics, it becomes increasingly difficult to maintain as the register rises. The saxophone provides resistance to this method of playing in the upper register and particularly in the altissimo (extreme upper) register. An expert saxophonist will be able to shift between subtone and normal tone production methods as he moves between registers and dynamics. Learning to play an instrument is to become familiar with the interplay of these affordances and resistances, exploiting an instrument's potential, while somehow overcoming, or avoiding, the obstacles it presents.

One may think of the way in which a musician learns to play with the resistances and the affordances of an instrument, a process that may call for ten thousand rehearsal hours and is the heart of the formation of a performer's habitus. Here, embodied knowledge is gradually built; it may consist of musical strategies towards the shaping of materials, particular ways of controlling rapid finger work, ways in which an instrument would best resonate with a hard attack and so on. We may, following Merleau-Ponty, think of the function of the instrument as an extension of the body similar to a blind man's stick.⁷⁴

This well-rehearsed connection between performer and instrument, where the instrument seems to become a part of the performer, is often understood as virtuosity when emphasis is placed on the

⁷³ A notable example of a piece which exploits this technique is Phillipe Hurel's piece for solo tenor saxophone, *Opcit* (1984).

⁷⁴ Gorton, Östersjö. (2017). "Choose Your Own Adventure Music: On the Emergence of Voice in Musical Collaboration" *Contemporary Music Review*, 35:6, pg. 585.

performer's skill.⁷⁵ However virtuosity could be understood here in a much more expanded form: the embodied knowledge built by the performer over many hours (or decades) of exploration and interaction with his instrument. The performer-instrument relationship is understood not as a master-slave relationship, but rather as an interaction between the two shaped by its particular affordances and resistances. This performer-instrument union ultimately provides the basis for the emergence of a musical voice. Gorton/Östersjö describe it as follows, “A musician's voice emerges from the interplay between the affordances of an instrument, one’s habitus, and the natural body.”⁷⁶ This analysis is appealing, because it confirms the agency of the instrument itself as playing an important role in the process of music-making.

3.4: Interface

If we discuss the connection between performer and instrument as a “union”, or a network, then connection between performer and instrument takes on a particular importance. To take again the example of the saxophone, this connection takes place at several points of contact: the fingers on the instrument's keys, the embouchure formed around the mouthpiece, and the tongue coming in contact with the reed. In fact the space in the performer's mouth and throat join the air column inside the saxophone. Learning to establish this delicate connection can be a source of much frustration for saxophone students as they learn to play the instrument. When our understanding of the instrument is extended to include real-time sound manipulations, these connections must be relearned.

William Gaver takes brings the concept of affordances into the context of technology:

In general, the affordances of complex objects are often grouped by the continuity of information about activities they reveal. Affordances are not passively perceived, but explored. This point of view leads to a reconception of metaphor which emphasizes its role as a design tool for importing consistent affordances from one domain to another. From this perspective, users need not know metaphors explicitly. Exploration of afforded actions leads to discovery of the system, rather than knowledge of the system metaphor leading to expectations of its affordances. Learning is seen as a matter of attention rather than inference. The role of a good

⁷⁵ For a more detailed look at the idea of virtuosity, and what it might mean in an electro-acoustic setting, see Kaiser, Jeff (2013). *Improvising Technology: Configuring Identities and Interfaces in Contemporary Electro-Acoustic Music*. (Doctoral dissertation).

⁷⁶ Gorton, Östersjö. pg. 585.

interface is to guide attention via well-designed groups of sequential and nested affordances.⁷⁷

Gaver's analysis is relevant to our discussion of extended instruments for several reasons. Once we begin to view affordances in the context of technology, we are now talking about an entirely artificial environment. Whereas Gibson's affordance describes the way an animal interacts with its environment, Gaver is concerned with the creation of new environments, designed explicitly to achieve a particular goal. Insofar as the design process is an intentional act, it is necessarily infused with its designer's assumptions, biases as well as his aesthetics. The instrument builder's intention plays a major role when it comes to musical instrument design.

The integration of an acoustic instrument with real-time signal processing can quickly lead to complex interfaces with both overt and hidden cascades of affordances. These are rich environments that take time and attention to discover through careful practice. As Gaver put it, the system is discovered by the exploration of afforded actions. With this analysis in mind, we might describe the design of musical interfaces as creating rich, complex environments, comprised of groups of sequential and nested affordances.

3.5 The 'CUBE' Project

Interface design played a major role in the working process leading to *aubiome*, and took various forms during the five-year time period. Working at the Institute for Electronic Music and Acoustics (IEM) at the University in Graz, we had access to equipment and working spaces that would be hard to find elsewhere. Most of our experimentation during the first two years took place in the 'CUBE': IEM's largest working space, equipped with a 24-speaker system for spatial audio, as well as a highly accurate infrared motion tracking system. This system allowed us to track the position and orientation of the saxophone in the room with a very high level of precision. Although we never reached the point of a full concert performance, we produced a set of short pieces that demonstrated some of the system's capabilities, which we called system 'etudes'. These were performed in the context of a lecture presentation, which we gave in December 2015.

For example one of the more successful etudes worked as follows: the room was divided into four

⁷⁷ Gaver, William. (1991). "Technology Affordances." *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*.

areas, each of which was associated with a predefined set of pitches. The system listens to the saxophone, selectively 'freezing' notes that are part of the currently active pitch set. By changing orientation of the saxophone - aiming it at one of the four corners of the room - the set of active pitches would change. Furthermore the frozen pitches were played through selected speakers in the space, corresponding to the orientation of the saxophone. The overall effect of this system etude was to associate a particular set of notes to each corner of the room, which could be activated on a note-per-note basis by the saxophone, making for a dynamic performance. Although it may be difficult to imagine from this description, the system's behavior was quite apparent to listeners and the demonstration was a success.

After this we decided not to continue working with this type of interface for several reasons. There was a practical consideration of being limited to performing in the CUBE, where we had access to the sophisticated technology required for accurate motion tracking and spatial audio. However the choice to rework our system at this point was not a result of technological limitations, but rather we began to conceptualize the role of the computer differently than we had originally imagined it. By the time we had arrived at our final system etudes for the CUBE's motion tracking system, our software had become completely focused on achieving a few highly specific behaviors. In order to achieve the orientation-based etude described above required us produce patching software in Pure Data to achieve the following: Open Sound Control (OSC) data from the tracking system had to be handled and parsed into a useable format, the saxophone pitch had to be accurately tracked and a strategy for holding the pitches had to be devised, the areas of the room had to be defined so that they were quickly and accurately selected by the saxophone's orientation, the behavior of each corner had to be defined to choose only particular notes, and finally the frozen notes had to be properly spatialized. In order to get a simple demonstration of the tracking system to work, we essentially had to grapple with a whole series of unexpected problems and challenges. The software that we ended with had become so complicated and convoluted, that it was only useful to produce a few musical outcomes. In addition, these outcomes that had been appealing to us at the beginning, turned out in practice to be less exciting than expected. We could have continued with the system to write a piece that made use of these limited behaviors, but we did not like the feeling of being strait-jacketed by our system and decided to rebuild it from scratch.

3.6 *Labyrinth*

We took the experience of working in the CUBE to our second major system design, which later became associated with a piece called *Labyrinth*. The first full version of the piece was performed in March 2015 at the Vienna Saxfest using this system, and we performed it again in Graz in October 2015.⁷⁸

At this point we decided on a shift of focus for the design of the system's interface and a move away from using the movement or position of the saxophone to produce control data. Instead we wanted to further explore some of the sound manipulations that we had begun to work with during the CUBE project. This meant finding new ways to implement real-time signal processing strategies including looping, freezes, distortion, delays, and pitch shifting. We decided to go with a system of foot pedals, that could control the computer's behavior by both trigger and continuous control inputs. This type of interface gave a much more direct way of interacting with the computer and experimentation with various combinations of effects and computer behaviors. This ability to tap into the electronics directly was liberating in several ways, coming on the heels of the CUBE project. For example I had access to over 100 unique triggers that could be programmed to various behaviors. I made use of this at the end of the piece by defining five separate freezes, which could be individually triggered and re-triggered. By playing long, sustained notes on the soprano saxophone and launching the freezes one at a time, I could create a thick, layered sound of five saxophones playing at once. The ability to trigger them individually was much more flexible than the way we had implemented freezes in the CUBE. In effect we had moved from a compositional approach: predefining sets of notes to be tied to predefined areas in the room, to a performer-centric approach.

The software system for *Labyrinth* was designed to imitate a multi-channel mixer with multiple routings and serial or parallel signal chains. For example the piece begins with several long delay lines, initiated individually by a pedal triggers. Each of these delays could then be set to loop re-triggering the same pedal that initiated it. Then these loops are manipulated separately with a kind of microtonal pitch shifting inspired by Kaiji Saariaho's *Petals* (1988) for cello and electronics. *Petals* was originally written to be performed with an external harmonizer and a reverb unit, the type of external digital effects units designed for electronic instruments like the electric guitar, bass and keyboards. *Petals* is a

⁷⁸ There was some overlap during which we developed both the motion-tracking project and the *Labyrinth* systems in parallel during 2015.

great example of what can be achieved by integrating these simple effects with acoustic instruments, because she does not put the electronic manipulations in the foreground, but rather treats them as part of the cello's sound.

Our approach to systems design in *Labyrinth* was essentially an attempt to integrate guitar pedal effects with the saxophone, but taking it a few steps further than would be feasible with external processing units. The system behavior in *Labyrinth* could be broken down into several sections, each defined by a particular set of parallel signal chains. This takes advantage of the flexibility afforded by a software system to quickly establish and modify the signal chain, which would not have been possible in the pre-computer days. Unlike our experiments in the CUBE, *Labyrinth* represents our first, fully-formed work which was performed publicly. We also produced a video recording of the piece in April 2015, which provides an interesting comparison to the following iterations of the project.



Figure 7: Screen capture from the April 2015 video recording of Labyrinth

If we had continued to develop the labyrinth system beyond the first performances, it could have been a viable platform to work on a wide range of composed and improvised music. However there were a few downsides to this type of interface, as well as some software issues, that needed to be resolved before we could bring the piece to stage again. While the pedals gave me a great deal of control over the system's behavior, this came at the cost. As seen in figure 7 this piece was performed with both

Adrián and me sitting on stage, with our equipment between us and the audience. It also involved a lot of micromanaging the pedals, which sometimes meant multiple actions with no obvious reaction from the system. The “dance” on the pedal board was a distraction from the delicate sound manipulations that were going on, and did not really fit with our developing concept of how we wanted to present ourselves on stage. At this point we were also performing together on stage, with Adrián monitoring and controlling some system parameters that were not easy to control by pedal. The problem here was that there was no perceivable link for the audience between Adrián and the sound produced. It seemed to the audience that all of the sound was generated by the saxophone, and in fact it was. *Labyrinth* was our first attempt to rely entirely on live sound as the source of material for the electronics. I later worked on a presentation version of the piece that did not require Adrián to monitor the computer during the performance, but it was not a comfortable experience. Our project was conceived as a duo, so every iteration of the system has been designed with the expectation that a second performer would be monitoring it. Adrián's role in *Labyrinth* was relatively modest, but that would change as our project moved forward.

In addition to these performance-related issues, we also struggled with our software system during the preparation of *Labyrinth*. We designed the system from scratch, only using a few fragments of the work we had done for the CUBE project. This allowed us a second chance to solve programming issues that had presented themselves previously, effectively re-writing the software with some foreknowledge about where problems would arise. However we still found that as we developed the software, it tended to become locked into a particular mode of function. Similar to the situation in the CUBE, our programming decisions were made with a particular end result in mind, and it often took a long time to make progress with the software. For example when we decided that we wanted to have multiple, parallel signal chains going at once, which could be independently manipulated, this required a complete redesign of the mixer system which took several weeks. This was often a frustrating working process, where there was often a period of weeks or months when little artistic work could be done. Once the system was finally updated and debugged, it was hard to remember the artistic spark that had lead us down that path. This feedback loop⁷⁹ would have likely become more efficient over time if we had continued working in this direction, however we ran into another major software problem in the lead up to the March 2015 performance.

⁷⁹ For more on this 'feedback loop', see the discussion of system design in chapter 4.

The *Labyrinth* project was done using the software, *Pure Data*, running on a *Linux*-based laptop. The strength of this type of system is that it can function with very low latency when properly configured. However even with some expert help, we struggled to get the system to run stably. During the rehearsal period leading to our March 2015 concert, a series of system crashes left us unable to even boot our laptop into *Linux*⁸⁰ only 48 hours before we had to step on stage. We were forced to run the system in *Windows 7*, which is generally not optimized at all for real-time audio. Running in these conditions, the *Labyrinth* system was compromised by audio glitches, massive latency, and an unresponsive user interface, and we were lucky to get through the performance. After this stressful experience we decided to move to a *Mac*-based system for the next project and to switch our software from *Pure Data* to *Max/MSP*.

3.7 *CRISPR/Sax9*

After moving on from the *Labyrinth* system, we began working with our new laptop and software configuration for a performance that would take place in June 2016 on an outdoor stage. Around this time we also met with Vienna-based composer Jorge Sánchez-Chiong, who is known for a particular style of electro-acoustic composition informed by his own practice performing with turn tables. He showed us how he had produced the fixed media accompaniment for his 2009 piece for saxophone and electronics, *Ciudad Dormitorio for saxophone and electronics*.⁸¹ The electronics part of for this piece might be described as chaotic, noisy, loud, intense, industrial. However it is essentially a piece for saxophone and fixed media without much interactivity. We decided to incorporate some of this approach for our June concert, which we thought would work better for an outdoor stage than the material from *Labyrinth*, which was too soft and subtle to present in those conditions.

A second thread that we decided to incorporate in this system was a module that Adrià had developed previously for another project, which he called the 'shredder'. This was a patch in *Max/MSP* which takes pre-recorded audio file and plays it back in a fragmented way by having the playback position jump around at given intervals. This effectively allowed him to load a pre-existing drum and bass track, and essentially shuffle the beats in real-time. Adrià's patch allowed control over several parameters,

80 This problem might sound unlikely to typical laptop users, but linux systems require more user knowledge to configure. It is entirely possible to get into this kind of trouble if you do not know what you are doing!

81 Written for *Duo Saxophonic*, consisting of Lars Mlekusch, saxophone and Thomas Peter, electronics.

which we expanded as we integrated it into the new system. We wanted the shredder to produce sounds based on the saxophone, so instead of using produced drum beats, we recorded our own samples of noisy saxophone sounds such as slap tongues, key clicks and air sounds. Using the shredder's capability to randomize its playback position within the audio file, we were able to create a kind of “saxophone beat”. This beat could then shift over time by manipulating the playback parameters and overlapping multiple instances of the shredder.

With the first version of *CRISPR/Sax 9*, we were taking our project in a completely different direction from the previous two projects by relying more on fixed media elements and a pre-planned course that the piece would take. This was not an entirely interactive piece, but instead we had to address the challenge of integrating real-time processing of the saxophone with simultaneous fixed material. For example this was our first attempt to perform groove-based music, and it was a struggle to sync properly with the randomized beat produced by the system. This was a result of two issues: 1. the need for a very low system latency, and 2. the ability to constantly monitor the system sound during performance.

Latency is the time delay that occurs between the moment that the system is given an input and its response. Software tools like *Pure Data* or *Max/MSP* process audio using a buffer, which needs to be chosen carefully to optimize latency. Smaller buffer sizes introduce less latency to the system, but they also increase the likelihood of audio dropouts, glitches and crackling when the system is under intensive load. This is why the progress made in computer hardware in the past 20 years has been such a game-changer for real-time audio applications. Many of the signal processing techniques used in *CRISPR/Sax9* and particularly in our final piece, *aubiome*, are highly taxing to the computer and probably would have been impossible to achieve with laptops 10 years ago. In addition to fast, powerful hardware, the software configuration is also an important part of the puzzle. The *Windows*-based configuration that we had used for our previous performance of *Labyrinth* required a very large buffer size, so the latency was far too high to be usable with any kind of groove-based material. Our new system using a 2015 *MacBook Pro* and *Max/MSP* was capable of a much more stable, low latency result.

The first performance of *CRISPR/Sax 9* was not entirely successful. We managed to rebuild our

system, while addressing the latency issue and incorporating several new elements into the project. However we did not manage to work out a good solution to the monitoring problem: the ability of both Adrià and me to clearly hear the system audio. In principle this problem is no different from the acoustic problem that musicians sometimes face when they can not clearly hear their chamber music partners. This is a particularly difficult problem when working with real-time electronics and a microphone, because of the potential for feedback.

The issue of feedback deserves a special side note here, being a feature that can appear when using a microphone to capture sound. The ideal position for the saxophone would be in front of the speakers, where he would be able to hear the system audio from the same source that the audience does. However that would place the capsule of the microphone close to the speaker, causing feedback. If the microphone is being used to amplify the instrument, then this would be the well-known type of feedback, also called 'acoustic feedback'. If there is not direct amplification on the instrument, then the danger is a different kind of feedback, where the system's output cycles back into the signal chain. Both of these types of feedback can provide interesting musical material⁸², but in *CRISPR/Sax9* this was not the desired effect. Placing the instrumentalist behind the speakers outside their coverage area reduces the danger of feedback, but also makes it more difficult for the performer to monitor the system during the performance.

In addition to this timing issue, there is also a question of balancing the sound of the saxophone with the sound of the system. As any experienced performer knows, the sound from stage can vary greatly from the sound heard in the public, and this is particularly true when loudspeakers are involved. For the June 2016 performance we had decided to continue with the positioning that we had used in previous performances; namely, that Adrià would perform with me on stage. We also decided to use headphones to monitor the sound output and to allow precise timing at certain points during the piece. As a result of these choices, it was an unsatisfying and uncomfortable performance that felt similar to performing a difficult piece with a click track. My playing and the system behavior seemed far removed from one another, and it was a struggle just to get through the piece.

⁸² *Feedback Study #1 (2016)* by Takuto Fukuda is one of many examples that uses acoustic feedback, which I performed in Graz in May 2016. An interesting example of cycling sound multiple times through a signal processing chain is *Contraction Point (2015)* by Kosmas Giannoutakis which I performed in July 2017 in Lisbon for the *xCoAx* conference.

We had the opportunity to perform this version of *CRISPR/Sax9* a second time a few days later in the CUBE in Graz. For this performance we decided to place Adrià in the room behind the audience, rather than with me on stage. This was a break from our performing concept that had guided our decisions until this point, putting me alone on stage and “hiding” Adrià from public view. However having Adrià in this position was clearly the best option, as he was able monitor the sound and adjust the balance much more accurately than in previous performances. I performed the piece using headphones to monitor the tempo and event cues, like I had in the previous performance. However this time only had the earbud in one ear, rather than both, allowing me a little bit more contact with the audience than I had had previously. This was the last time that we used in-ear monitoring, but this remains a possibility for the future.

3.8 *CRISPR/Sax9 2.0*

Following the two performances in June 2016, the next step was to update the system and present the work we had done for the *ARTikulationen* conference/festival, which took place in Graz in October 2016. We again decided to make significant changes to the software system, although this was the first time that we did not decide to start from scratch. Instead we decided to combine the strongest elements of previous performances to create the most convincing version to date. This meant returning to a more interactive system behavior and dropping most of the fixed media elements. In addition we began working with two pieces of commercial software: *Ableton Live* and *Molekular* by *Native Instruments*.

The rhythmic material generated by our “shredder” patch was probably the most interesting part of the June 2016 performances, so we decided to build on that concept. The issue of syncing real-time processing with the randomized beat was still not entirely solved, so we decided to abandon the shredder and move to using *Live* to produce all the rhythmic material in the piece. *Live* is a sophisticated piece of software, built for EDM performances where various audio sources need to be synced on the fly. It was relatively easy to replicate most of the features of our patch in *Live*, so it was an easy choice to rely on it for that part of the piece.⁸³

It was around the same time that we began to experiment with the *Native Instruments* plug-in,

⁸³ Not everything that we had done with the 'shredder' in *Max/MSP* could be replicated in *Live*. If we were to continue development in that direction, we could use *Max for Live* to design a plug-in that would allow us to run the shredder directly in *Live*. This is one of many examples where our research only touched the surface of what could be done.

Molekular, a 'modular multi-effect system', built on *Native Instruments'* platform, *Reaktor*. As we began to experiment, we got some exciting results and decided to incorporate the plug-in into our system for the October performance. It turned out that most of the real-time processing we had done up to that point could be done in *Molekular* with equal or better-sounding results, so it eventually became the core of our system.

We decided for the new version of *CRISPR/Sax9* to return to using pedals, in order to tap into some of the potential that *Molekular* offers for manipulating effect parameters in real time. We also began to adapt our system to give Adrià more control of the system's behavior. Until now he was primarily responsible to monitor the system, adjusting the balance and making corrections when things did not work as expected. Adrià was particularly interested in reintroducing some of the spatialization work that we had done in the first CUBE project, but until the October performance, we had not had the chance to perform again in a space with more than two channels. We were able to perform with four audio channels at *ARTikulationen*, so Adrià took the opportunity to rework his spatialization code. We managed to get a four speaker setup in our rehearsal studio for testing during the period leading up to the concert, and we had some success using spatial audio in the performance. From my position on stage, I did not really perceive the positioning of sound in the room, so the responsibility for designing that part of our system and managing it during performance fell on Adrià.

In the end we presented a three-movement work at *ARTikulationen*: the first movement was essentially a structured improvisation performed as a duo, the second movement was a transplant of the “groove” material we had developed and migrated into *Live*, and the third movement was a newly composed segment relying on precise saxophone playing combined with notated pedal movements.

3.9 *Aubiome*

After the October 2016 performance of *CRISPR/Sax9*, we had a discussion about which parts of the system had contributed most to the performance and what further work needed to be done. This opportunity to revise and rework our system through multiple iterations allowed us to center in on an effective working model for the integration of the saxophone and real-time processing and to reflect on our performance concept. How did we envision a mature version of this system presented on stage? During the rehearsal period leading up to the first performance of *aubiome*, we decided to focus our

efforts toward exploring wide range of sounds the system could produce and how they might interact with the live saxophone. Meanwhile this meant less emphasis on the physical interface between the saxophone and the computer. As we had begun to move more responsibility to Adrià during our performances, we decided to take it a step further and completely remove the foot pedal system from the stage, leaving me alone with only my saxophone and a few microphones. We were moving toward a 'sound-as-interface' model, which meant a major reduction in control from stage while simultaneously elevating Adrià's interface with the system to a full-fledged instrument of its own. Even though Adrià would remain out of the public's view, his role in the performance would be elevated, bringing us closer to realizing the original idea performing as a duo.

The choice to focus our attention away from physical interfaces and toward a sound-as-interface model came as a result of our experiences up to that point. Our experimentation with motion tracking and foot pedals tended to place those interfaces in the spotlight. When working with the motion tracking system, it took a great deal of effort to configure the system such that manipulations of sound would correspond visually to the movement of the saxophone in space in a way that a listener could appreciate.

Demonstration of the system's behavior took over the artistic process in a way that the system itself *became* the piece of music. Take for example the system etude described above that used the orientation of the saxophone to filter different series of notes and freeze them when played by the saxophone. The act of rotating the saxophone around the room required me to play without reading a score, so that meant memorizing the series of notes for each area and switching quickly between them. If I would change orientations and then accidentally play a few notes outside that series, then the system would not respond at all; an unsatisfying, or even embarrassing, result. My saxophone performance was entirely motivated by an interest in showing off what the system could do; we had fallen into the trap described by John Croft, “shifting the procedural into the foreground turns the piece into a lamentable ‘showcase’ of the technology. (‘Look – I do this, and the computer does that!’)”⁸⁴

The feeling that our work was too focused on showing off the technology had been a growing concern, and for the next iteration of the system, we aimed to make the interface as invisible as possible. There would be nothing at all physically between me and the audience, and without needing to sit down to activate the pedals, my performance might be more effective in bringing the listener into our sound

84 Croft. *Theses on Liveness*. pg. 61.

world.

3.10 Different Sound Worlds

As we began to work on our new systems design, and I experimented with some of the possibilities offered by *Molekular*, some advantage of a performer-centric system design began to emerge. One such advantage is that we finally began to grapple with the wildly different sound worlds occupied by the saxophone and by the computer.

Acoustic instruments are constrained by their material conditions. The range of sounds producible by the saxophone are dictated by the instrument's physical properties: the instrument body is conical and made of brass⁸⁵, uses a mouthpiece with a single reed, the keys placement follows a particular spacing, etc. Control of tone quality is a primary preoccupation for instrumentalists, who generally invest a great deal of time and practice to refine their sound and reduce unwanted noise. This priority of acoustic music performance comes in contrast to the world of computer music, where the strength of digital music production is its ability to create and manipulate sound in real-time with an enormous range of possible results. The incongruity between these two sound worlds is a major source of resistance to their integration. Simon Emmerson describes this problem and points to three possible solutions:

1. Making the instrument fit to the acousmatic sound world
2. Adopting instrumental sounds in the electronics
3. The two can “cohabit but remain sonically separate”⁸⁶

After experimenting with various types of systems, it became clear that our choice of interface design, with its inherent set of affordances and resistances, would also dictate to a large extent the sound world the system would inhabit. We were tempted to pursue novel interface designs, but we found that this comes at the risk of diverting our attention from the actual music that might eventually be produced. The sound-as-interface approach turned out to be the most appealing option, sacrificing some amount of control from my position on stage while allowing for a much more sound-oriented working process. Once we developed a new system based on this set of priorities, the resulting platform was the first in

85 Saxophones are normally made out of brass, but instrument manufacturers have experimented with other materials as well.

86 Emmerson. (2007). pg. 104.

the multiple-year long project that seemed to allow a smooth workflow for experimenting with new system configurations. With our focus now squarely on the integration of the saxophone and computer system's sounds, we began exploring a variety of sound manipulations, which formed the basis of the material we would eventually use in *aubiome*.

3.11 Sound-as-interface

The term 'sound-as-interface' requires a word of explanation. Whereas motion tracking, foot pedals, or other sensor data can offer the performer various physical or gestural methods of interacting with the computer, the sound-as-interface model looks to the saxophone's sound itself⁸⁷ as the sole means of interfacing with the computer. Control data can be derived from features of the sound such as pitch, volume and frequency spectrum. This data can be extracted from a signal in real time, or it can be done over a period of time by recording the audio signal to a buffer and performing analysis on selected segments of the stored audio. A major advantage of these strategies is that they allow sophisticated methods of manipulating or generating sound in a way that can be naturally integrated with the live performer's sound. This approach is particularly well-suited for extending the sonic capabilities of an acoustic instrument, and it is for this reason that we adopt the term 'extended instrument' to refer to the types of system configurations used in *aubiome*.

A primary feature of a sound-based system design is the ability to create natural musical 'environments' that the performer can explore.⁸⁸ We spent a great of effort in writing *aubiome* to finding multi-layer environments which could produce compelling musical results, while avoiding one-dimensional configurations that would produce a short-lived, novel effect. As an example, the opening section of *Sonocatalysis*⁸⁹ is based on a configuration on two parallel signal chains, providing interesting sound manipulations for multiple modes of saxophone playing: key clicks, slap tongue, air sounds and whole-tone based scale patterns. Once we had designed the system behavior during our experimentation period, the opening section of this movement emerged as a result of these built-in affordances.

87 The microphone is an important part of the interface in a sound-as-interface system design, because the 'saxophone sound' can be captured in various ways which can affect how the computer receives the signal. We addressed this in *aubiome* by using three microphones to capture various aspects of the saxophone sound: a DPA 4099S as the main microphone, an AKG C411 contact microphone on the body of the instrument to capture key sounds, and an AKG headset microphone to capture air sounds.

88 For a more complete discussion of the 'ecosystem' approach, see Di Scipio, A. (2003). 'Sound is the interface: From interactive to ecosystemic signal processing.' *Organised Sound*, 8(3). pg. 269-277.

89 A video recorded performance of *aubiome* is provided as a supplement to this dissertation. For more information on the video and *aubiome*, see chapter 5.

If you continue to view the performance of *Sonocatalysis* beyond the opening section, it becomes clear that there is an eventual shift in the system's behavior, highlighting a potential deficiency of the sound-as-interface model. While this approach affords the exploration and establishment of rich, interactive musical environments, the performer's ability to impact the system's behavior is limited. For example the system's behavior can be designed to change over time, either progressing through a fixed trajectory and/or as a result of inputs from the performer. However this approach generally works best when the system is meant to “evolve” from one state to another. Slow, predictable changes are generally desirable in order to avoid disrupting the relationship between performer and computer. We discovered through our experimentation that sudden shifts in the system behavior often lead to unsatisfying performance conditions.

At one point during our research, we expected that each movement of the final piece would be a single system configuration. However even when working with rich environments like the opening to *Sonocatalysis*, we found ourselves looking for opportunities to introduce contrasting material that could not easily be generated from within the established environment. We decided that we would need to multiple systems configurations for each movement of *aubiome*, consequently requiring some method of controlling the flow of the piece from one section to another. The final version of the piece that we recorded in May 2017 consists of eight movements, each of which using between three and ten distinct system configurations. Imagine in this case the utility of a motion tracking system: the performer's position in the room could be tied to a particular configuration, giving a visual cue to the audience about the unfolding relationships in the piece. The sound-as-interface approach does not afford such a system, since the computer only has the saxophone sound itself to guide it.

One solution that might come to mind, would be to use a 'cue' in the saxophone line to trigger behaviors in the system, incorporating a modified score-following strategy.⁹⁰ For example when the saxophonist plays a certain note, the computer begins to shift from one configuration in some predetermined way. This could also be done with a sudden loud note or even a particular multiphonic,⁹¹

⁹⁰ For more discussion about score following, see chapter 1.

⁹¹ The possibilities here for communicating with the computer via sound can go beyond what is achievable through envelope and frequency tracking. Artemis Giotti's piece *Neurons* (2017) mentioned in chapter 1 makes use of neural networks to 'train' the computer to recognize different sounds produced on the saxophone. The computer's immediate behavior, as well as overall structure of the piece, are impacted by the particular sounds produced by the saxophone at a given moment.

and while we used some of these strategies to exert control over the system on a moment-to-moment basis, we decided not to trigger changes in the larger structure of the piece in this way.

Another solution would be to place the instrumentalist into a musical 'ecosystem', where the sound he produces is treated as part of a larger environment. Composer Agosto di Scipio describes a shift from interactive system models to 'ecosystemic' ones⁹², where the man-machine interaction is replaced by what he describes as a man-ambiance-machine one seen in figure 8.

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

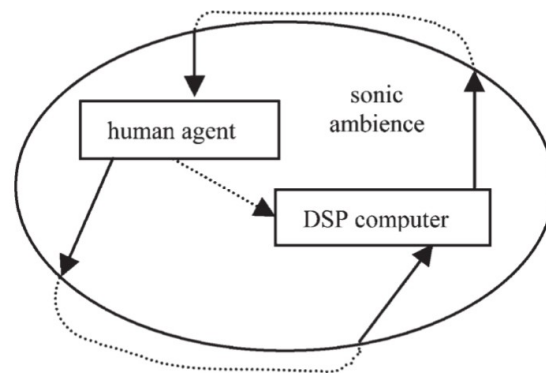


Figure 8: di Scipio's 'triangular, ecosystemic connection'

At times we were tempted to design our system with this approach, where the input from the saxophone does not only elicit a proximal response from the computer, but also has the potential to modify the

⁹² Di Scipio, A. (2003). 'Sound is the interface: From interactive to ecosystemic signal processing.' *Organised Sound*, 8(3), 269-277.

trajectory by which its internal processes may unfold over the course of the piece. However di Scipio's ecosystemic approach conceptualizes the human agent entirely differently from our 'extended instrument model'. In fact the presence of a human actor in this type of model is entirely optional, as this approach to system design is motivated from a compositional standpoint rather than a performative one. While Di Scipio's is not a 'performer-centric' model, it remains an open question as to how ecosystemic and performer-centric approaches may be integrated. This would be a logical 'next step', and possible motivation for the development of a future '*Aubiome 2.0*' system.

3.12 Performance Practice

One of the motivations for this artistic research work is the difficulty musicians often face when trying to become proficient with new systems for electronics. The wide range of possible systems means that each one needs to be learned individually. It is unlikely that any kind of a standard system will come along, and such a system is probably undesirable for artistic expression. Joel Ryan points out that while engineers work toward general purpose solutions, this is not the right approach for music making, where the concern is in the particular: “in particular forms, in the phenomenal, in personal intuition.”⁹³ In fact the strength of using electronics is that the system can be custom designed to achieve specific artistic goals.

The challenge for the performer is therefore to learn to adapt to a wide range of systems. When engaging in a new project, he brings with him a repertoire of playing techniques and strategies which he has acquired through past experience, but how and when to apply them will be dependent on the system's specific conditions. In short, proficiency is related to a performer's flexibility, as described by Sergei Jordà by analogy to a bullfighter:

Distinct virtuosity paradigms definitely coexist: whereas the classical virtuoso, with her infinite precision and love for details, may appear closer to the goldsmith, the new digital instruments virtuoso, not unlike the jazz one, could be compared to the bullfighter for their abilities to deal with the unexpected. ... Only when a certain level of confidence is reached will performers feel a sense of intimacy with the instrument that will help them in finding their own voice and developing their expressiveness.⁹⁴

⁹³ Ryan. pg. 12.

⁹⁴ Jordà, Sergei. “Interactivity and live computer music”. *Cambridge Companion to Electronic Music*. pg. 105.

By learning a system's behavior and how to interact with it, the performer takes on a more creative role in shaping the final result when it comes time to present the piece in public. In other words whether or not he had a role in designing the electronics system, when it comes time to perform the piece, he should take responsibility for the actual sound that is produced. When performing other styles of music instrumentalists invest a great deal of time to be able to exert a high degree of control over the type of sound they can produce. The performer should not give up this responsibility (or have it taken from him) only because his sound is also manipulated by real-time processing. When this shift of responsibility happens the performer is giving up nothing less than his own musical voice.

Our work on *aubiome* is an example of this negotiation around voice. Because we decided not to use any fixed media material, Adrià's role was generally not to produce sound, but rather to adjust the parameters of the system's relationship to the saxophone. We spent our rehearsal time to establish control-intimate relationships with the computer, which could be easily disrupted. Without the experience of performing the saxophone with the system, Adrià was often not sensitive to that danger, so it required a lot of rehearsal time and discussion to work out a performance practice for this new, unusual type of instrument. During these countless hours of rehearsal, I became increasingly sensitive to the various system configurations and Adrià's performing style. When performing *aubiome* during our 2018 tour in the US, I often reached a kind of “flow state” that I have rarely experienced otherwise.

How can performers achieve this level of integration with real-time electronics systems? It may seem like our five-year *aubiome* project is incomparable to the way new pieces with electronics are written, learned and performed. The question of how they are written will be further addressed in chapter 4. As for the interpreter's job to learn and perform these works? I think that some general principles of this process can be extrapolated, which apply to a wide range of pieces. I would break it down into three areas of focus:

1. Practicing with electronics systems
2. Looking 'inside the black box' of various signal processing techniques
3. Working hands-on with system designs

3.13 Set-up and Practice

Assuming that the musician has the equipment and expertise to work on his own, then he will be able to become familiar with each system and develop a practice for performing with it. Take for example *Phytolith I* (2015) for tenor saxophone and live electronics by Naoki Sakata, which I performed in Graz in 2016. The piece uses a foot pedal and a click track to precisely time events to trigger events, which include both fixed media elements and live treatments to the saxophone sound. Using a click track to sync with fixed electronic sounds is a strategy that allows precise coordination, but does not allow the performer much flexibility. In addition to using fixed sounds, the composer also uses live processing of the saxophone sound that is turned on and off at predetermined moments on the timeline. However they do not persist for more than a few seconds each time, so there is not much time to establish control intimacy.

In many cases performers are limited by the simple fact that they rely on a technician to set up the equipment for them and therefore do not have the opportunity to practice with the system. Perhaps more than any other factor, this is responsible for reinforcing the incentive for composers to treat the electronics and the instrument as two parallel processes. *Phytolith I* is an example of such a piece. In conversation with the composer, he was surprised that I was able to work with his software by myself, and this expectation is evident in how he wrote the score itself. The saxophonist could prepare the score by practicing only with a metronome in place of the click track. The majority of sounds produced by the computer are fixed electronics, and the real-time processing techniques used are relatively basic.

When practicing *Phytolith I* the performer will need to integrate his own sound with the fixed elements, as well as interacting with the intermittent processed sounds, all while performing with a click track and executing all of the foot pedal cues. Without any opportunity to practice and only two rehearsals, this would be a very stressful situation, and the saxophonist could only hope for an accurate performance of his 'part'. On the other hand with the appropriate preparation time it is actually quite comfortable to play. Despite the unforgiving nature of the click track, *Phytolith I* is a well-written piece with an electronics system that can be learned and integrated with the saxophone sound.

The inability of performers to work with electronics alone during their practice sessions is a case where a seemingly uninteresting logistical problem can have a major impact on the entire process by which

new pieces are written and performed. This situation could be called the 'two-rehearsal' problem: composers have write in such a way that everything works with one rehearsal plus the dress rehearsal. In many cases these rehearsals are the only time that the musicians have the chance to play with the electronics system, which is a serious limitation to what can be achieved.

The musician who is not versed to work with electronics ... [is] therefore a musician who does not know the composition and does not know how the electronics work right until the concert. This results in a more or less unrehearsed performance, with no ability to react to eventual flaws of the electronics.⁹⁵

This limitation not only can make for uncomfortable or ineffective performances, but it is also a constraint on the type of music a composer might write. Given the two-rehearsal problem and the last-minute nature common with performances that involve electronics, the thorough exploration of what could be possible with real-time processing is discouraged. Insofar as performers are expected to faithfully convey a composer's intention, knowledge related to live electronics and the ability to practice with them is clearly part of the job. This is an area where even contemporary music-focused musicians are generally lacking, and I would argue that a change in culture is indicated. Berweck suggests a solution related to educational opportunities that could be offered:

Since playing with live-electronics is a specialization of any instrumentalist – as is the playing of an uncommon instrument – it will probably not become part of the basic curriculum of music schools. However, since there is a need to convey this information the creation of degree programmes for instrumentalists who want to specialize in the performance of electroacoustic music is proposed.

3.14 Looking Inside the Black Box

What exactly does it mean for the performer to 'take responsibility' for the sound produced by the electronics system? The saxophone itself, or any other traditional instrument, produces sound mechanically. While the saxophonist does not need a deep knowledge about the physics of sound propagation to play his instrument, he will have become familiar with certain basic principles, such as

⁹⁵ Berweck, Simon. (2012). *It Worked Yesterday*. (Doctoral dissertation). pg. 192.

the overtone series and its role in the perception of timbre. His understanding about the production of sound will derive from embodied knowledge that is acquired through practice. In short he knows what he needs to know to play his instrument. The same should be true when it comes to the use of real-time signal processing to manipulate sound. The programming of many digital effects are much more complicated 'under the hood' than they sound.

By working with electronics, a performer can cultivate a working knowledge about common processing techniques and how to perform with them, without necessarily understanding all of the programming that goes into it. What he 'needs to know' is learnable through practice with individual real-time audio effects the same way practicing long tones and scales on the saxophone provides a technical base. When reduced to the individual building blocks, there is not a huge range of real-time processing techniques to learn, and *Max/MSP* provides an effective platform for experimenting with them.

An example of why it might be important to work with a particular type of processing and to understand how it works can be seen in *aubiome*. Many of the instrumental extensions used in the piece make use of dynamics processing applied directly to the saxophone input signal before any other sound manipulation takes place. These kinds of dynamic controls establish an interface between the saxophone and computer that has a strong impact on how it feels to interact with the computer. A successful performance of the piece requires that the saxophonist has developed a sense of how this works in context.

3.15 Design

The role of the performer has been emphasized in the design of systems when the electronics are meant to extend the instrument's natural capabilities. What is the relationship between performance with a system and the design of the system? In some cases the result could be a highly personal system that is not easily transferred to other musicians, as is often the case with improvisors who work with live electronics. However in many cases the system design will take place in the context of a composer-performer collaboration with the aim of producing a work that can also be performed by others. The goal of such a collaboration is therefore to establish instrumentality as described by Croft, while maintaining a low enough 'entry fee' that other musicians can learn to use it.

When the system behavior is not immediately evident, then some form of documentation needs to be provided in the form of some kind of written instructions, video documentation, or another way of conveying important information to future performers. This need for communicating information about performance practice points to the eventual need for a supporting pedagogy. It is surprising that performance practice with electronics has not really become part of the instrumental training at the conservatory/university level. This is likely to change over time as professor positions turn over and are filled by the next generation of musicians who are themselves 'digital-natives' with an interest in working with electronic music.

Chapter 4

Collaboration

Over the course of the three preceding chapters, I have examined some of the factors involved when attempting to integrate acoustic instruments with real-time electronics processing and argued for a 'performer-centric' approach to the design of such 'extended instruments'. I also traced the five-year period during which the artistic research project unfolded, ultimately leading to the work *aubiome* for saxophone and live electronics. *Aubiome* provides examples of musical material that can be discovered through experimentation, but would be difficult to imagine and notate without the instrument in hand. In this case the computer programming is not treated as part of the compositional process, but rather as a part of the instrument itself. The design of these extended instrument configurations precede the musical compositions that will eventually be written for them, thereby preserving a traditional notion of the musical instrument while simultaneously capturing the potential of low latency real-time processing to join the act of live music making.

While performers may have a legitimate claim to treat this design process as a part of their instrumental practice, the shift in responsibility for the electronics from the composer to performer brings along significant implications for the creative process. Just as Adolphe Sax's instrumental design was motivated by certain aesthetic goals, designing electronic extensions to the saxophone is a highly personal, creative process. In other words the electronics configurations heard in *aubiome* are not general-purpose instruments, but rather they emerged as a result of the search for particular musical material: embodied material, in the sense that the extended instrument cannot be easily separated from the improvisation-based exploration that led to its invention. While this realization may lead some performers to work alone, abandoning the traditional composer-performer working relationship, it must also be possible to preserve these collaborations. The adoption of a performer-centric approach provides the means to bridge the composer-performer 'gap' described in chapter 2, but it also prompts us to rethink the traditional roles taken on by composers and performers.

4.1 Composer-performer Hierarchies

It has already been argued in Chapter 1, that the broadening of instrumental practice during the second half of the 20th century placed a great deal of stress on the traditional composer-work-performer model.

The addition of real-time electronics processing only exacerbated the situation, and even if this widening gap between composer and performer was somehow bridged by the centralization of new music production at institutions like IRCAM in the 70's and 80's, these collaborative models usually are not feasible outside of a handful of electronic music studios. If the performer-centric model of instrument design proposed in the previous chapters is to be adopted, then new collaborative strategies will be necessary to facilitate communication between composer and performer.

If systems design is considered a fundamental part of the creative process that eventually leads to a new work, then some composers may deny performer participation, preferring sole authorship rather than a collaborative effort. In the case where system design falls entirely within the performer's domain, there is no guarantee that the resulting extended instruments will be useful to a composer who had no hand in developing them. Any discussion about a performer-centric approach to electronics design must be understood in relation to existing composer and performer roles and to what extent these boundaries could be redrawn.

Aslan and Lloyd point to two problems with the traditional, hierarchical model:

The hierarchical model of performer being subservient to the composer presents two significant problems. The first is that it allow a situation of blame to occur. If the piece is not received well, although this may not be articulated, the performer can consider this to be the fault of the composer who wrote something 'impossible' or unintuitive. The composer, meanwhile, may believe that the performer was not committed or able enough. Audience members who are not necessarily impartial may also make similar judgements ... The second problem, feeding the first is that performers often feel that their creative input on the music has not been given adequate credit, a problem that can drive a wedge between performers and more indeterminate works where their inventive or improvisatory offerings may not be clearly identifiable.⁹⁶

Aslan and Lloyd are pointing to a common problem that comes up as a result of the widening gap between performer and composer. Even as performers could be making increasingly substantial contributions to the new works written for them, the single-author model remains the easiest for

⁹⁶ Aslan, Lloyd. (2016). "Breaking Boundaries of Role and Hierarchy in Collaborative Music-Making." *Contemporary Music Review*. Vol. 35, No. 6, pg. 632.

audiences and concert promoters to understand. These issues of 'blame' and 'credit' have motivated a split between performers and composers that has resulted in a breed of contemporary music specialists who demonstrate the dispassionate efficiency of a 'new music ninja'. These musical assassins wield their instruments with a cold virtuosity, unimpeded by near-impossible passage work or the most complex polyrhythms. They learn new pieces of music quickly and move from one project to another just as fast. This musical life leaves little time to become attached to any individual project and provides little incentive to do so. The roles of composer and performer have become so specialized, so separated from one another, the authorship of a musical work so carefully guarded, that it is possible to step on stage without any feeling of ownership over the final result. Aslan and Lloyd describe their own working relationship and propose a non-hierarchical working model:

The solution proposed is to consider any music-making involving more than one person a collaboration. Taking this approach puts forward the concept that all works are to a greater or lesser extent indeterminate, for example, a performer will make interpretative choices leading to an identifiably different performance to that of another performer. Considering one's involvement in the endeavour as collaborative encourages *all* parties to search for solutions and to take responsibility for the overall success of the work. As such, every contributor is afforded credit for their part. The question is not of what one's role ought to be based on their job description, but of what their creative role is in that particular relationship.⁹⁷

4.2 Composer and Performer Voices

David Gorton and Stephan Östersjö provide another angle for thinking about collaboration by framing the discussion around the emergence of performer and composer voices.

While a performer's voice emerges essentially from the concrete listening of performing, and the live, bodily interaction with an instrument, a composer's voice may rather emerge from the inner listening of the writing situation, through the identification of particular ways of shaping music, of solutions to musical problems that have a bearing on form and the physical nature of music as performed.⁹⁸

Figure 9 compares what Gorton and Östersjö call performer and composer "subjectivities." The

⁹⁷ Ibid.

⁹⁸ Gorton, Östersjö. (2016). pg. 589.

performer's voice emerges in an entirely different way from the composer's voice, but combination of the two gives rise to another shared voice, named by Gorton and Östersjö “discursive voice” which “emerges from the process of collaboration”.⁹⁹

Ultimately, the discursive voice of composer and performer is the heart of an expression of subjectivity in musical collaboration. It emerges from embodied interactions with musical materials, traditions, and between people, at levels that are largely beyond the verbal domain, carried out in thinking-through-listening.¹⁰⁰

This emphasis on non-verbal, embodied understanding was also a recurring theme during my collaboration with Adrià on *aubiome*. We struggled to find ways to communicate in the earlier versions of the project, and only over an extended period of time were we able to devise both verbal and non-verbal means of communication eventually allowing the emergence of a shared, collaborative voice, which can now be heard in performances of *aubiome*.

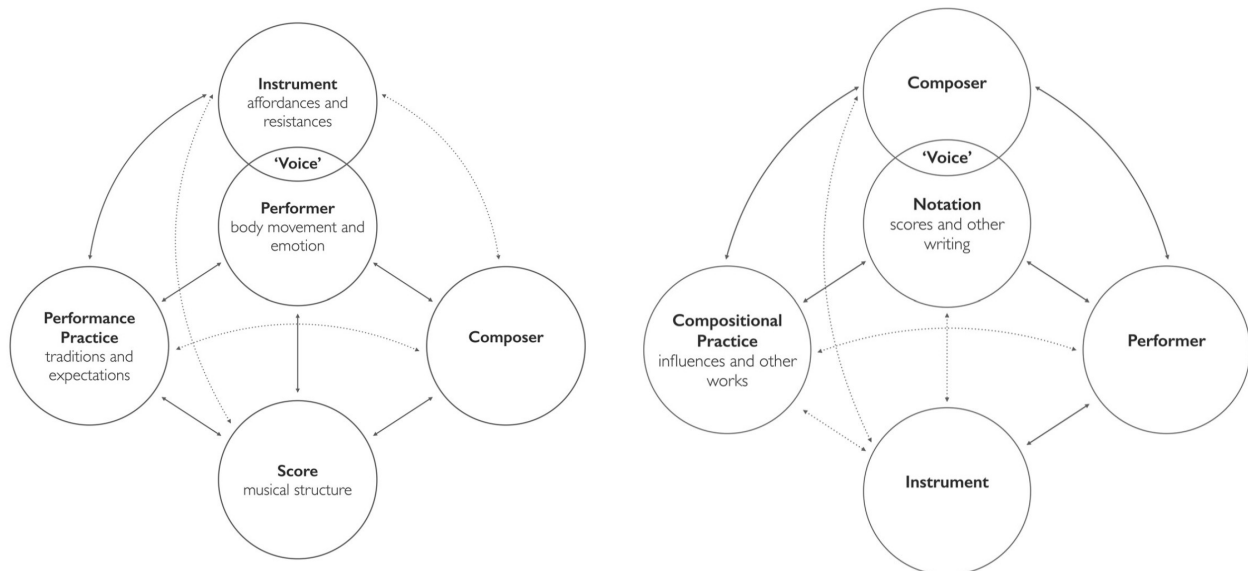


Figure 9: Subjectivity from the perspective of the performer and composer¹⁰¹

99 Ibid, pg 593.

100 Ibid, pg 595.

101 Ibid, pg 584, 589.

4.3 Collaboration with Composer Adrià Artacho

When Adrià and I began our collaboration five years ago, we assumed that it would roughly follow a typical composer-performer relationship, except for the fact that I would participate in building the electronics system. We expected that Adrià would eventually produce a written score which I would perform, but I had no expectation of contributing to the composition process itself. At that time my interest was to gain a higher level of proficiency with the electronics system, somehow subsuming the computer's behavior in my concept of instrumental virtuosity. This shared approach to developing the electronics system would therefore afford Adrià a wide range of musical material that would have been impossible to achieve if Adrià had prepared the system without my involvement. At the outset we were interested in questions related to where the electronics should be situated in the collaborative process. I was motivated to investigate the possibility of shifting the responsibility of designing the computer behavior from the composer to the performer, and to explore the musical implications of such a shift.

At the time it had not yet occurred to us that the act itself of extending the saxophone would be so tightly entwined with the compositional process. We also did not anticipate the degree to which Adrià himself would take on the role of performer, manipulating the computer's live behavior during each performance. As time went by the traditional roles of composer and performer began to dissolve, but at the same time it became increasingly clear that this did not mean that we should completely throw away the idea of having roles at all. While we were looking for an non-traditional way to handle performative and compositional aspects, our project began to move forward once we were able to gain clarity about how the project could be broken down into individual responsibilities.

A more general point could be made about the reason for having pre-defined roles in the first place, which are a result of the greater trend toward specialization not only found in the musical sphere. This specialization is what enables the virtuosic performance of a carefully crafted score: the foundation of western art music. The system has worked for a long time, because it is crystal clear what each participant is responsible to do, making it possible to completely focus his energy in that direction. However this traditional way of thinking about contemporary music may no longer be sufficient with the addition of live electronics to the mix, which has effectively opened a wide gap between composer and performer. This research project does not aim to question the idea of separated roles per se, but

rather to interrogate the collaboration process in order to rethink how some of these roles might be differently distributed.

After several years of working together, Adrià and I have arrived at our own working process: a system for collaboration where the responsibilities have been distributed over a period of time as a result of our particular working relationship. This distribution is not a stable state of affairs, but is always subject to renegotiation as we continue to refine our methods for working together. For example the most recent version of our software system was designed in order to allow both independent and collaborative work, whereas previous versions did not allow this to the same extent. This type of division acknowledges that some types of work are best done individually, while others rely on shared experience. However the question of how this division should be done is not at all obvious, and the answers will probably vary from one collaboration to another as a result of individual preferences and artistic goals.

When working with live electronics, there is a fundamental question about the nature of the collaboration that needs to be addressed. The design of the electronics does not fall clearly into the domain of either the composer or the performer, because there are both performative and compositional considerations in play. Ultimately the electronics will be addressed jointly by the composer and performer as they define the terms of their collaboration.

In my experience with Adrià, we eventually decided that I would be primarily responsible for developing the instrumental extensions by myself, which I would then demonstrate in rehearsal. My own exploration process was highly driven by improvisation, so the results often favored improvisational modes of playing, and it was not easy for Adrià to write a score for this material. Instead we used a collaborative approach to composition which maintains the spontaneity of its source material. There were many other procedural decisions, such as those related to documentation, working terminology, and notation, which are discussed in more detail below. After four years of collaboration, the sum of these decisions constitutes one way of bridging the gap between composer and performer, with a work of music, *aubiome* (2017), serving as a 'proof of concept.'

4.4 Project framework

In the field of contemporary music, new works are usually produced in the context of the commission-premiere cycle. The composer is paid to deliver a new piece for a particular concert date and musicians are engaged to perform it. After the concert is finished, the composer and performers move on to their next projects, and the piece may or may not be performed again. The composer is incentivized to move on to a new piece rather than continue to develop an old one that has already been premiered. For similar reasons performers are incentivized to work on new projects with new composers rather than to continue a long-term collaboration.

In my experience with new music, the result of this process and its incentives is that many new works are performed before arriving at a finished state. This is particularly true for electronic music where there is significant systems design work to be done in addition to the actual musical composition. For example the decades-long journey toward a reliable score-following system at IRCAM serves as a reminder that new works with electronics do not necessarily fit into a six month or one year long time-frame.

In the context of an artistic research project, Adrià and I had the opportunity to collaborate over the course of four years without any of these usual constraints. The short-term pressure to produce a final product was lifted, and we were able to take on an ambitious, multiple-year project that we would almost certainly not have done otherwise. Our project has also been divided into working periods punctuated by public performances and presentations, each time functioning as a snapshot of our work up to that point. After each public performance we had a meeting to discuss how our working process during the previous preparation period lead to particular outcomes, and how we should adapt it for the next period. By adopting this kind of work-in-progress model, each performance became part of a bigger picture, rather than a string of isolated premieres. This is one of the major advantages to framing artistic work in the context of research.

4.5 Four Distinct Phases

Our working process was broken down into distinct phases where one of three aspects was emphasized: systems design, exploration, and composition. Over the course of the project, this cycle repeated about six times, punctuated by each public performance we gave along the way. Each iteration followed

roughly the same pattern. We first met for a feedback session to analyze the previous cycle and to discuss our musical goals for the next performance and how we needed to modify the system to achieve them. The following period was always dedicated to system design, characterized by many hours of computer programming and often no music was played at all at first. Next would follow a period when I would begin to experiment playing with the system, the results of which always prompted us to make further adaptations. As the second phase continued, the emphasis shifted toward exploring new musical material. Finally as the pressure of an upcoming public performance began to increase, experimentation gave way to much more emphasis on composition-related work. This led up to the final performance, which served as a summary, or snapshot, of the work we had done during that cycle.

4.6 Phase 1: Systems Design

Our system of electronics includes hardware and software, both of which changed drastically over the course of these six cycles. We modified the hardware setup by adding new equipment or deciding eliminating pieces of equipment from the setup. Under consideration here are laptops, audio interfaces, speakers, mixing boards, foot pedals and other MIDI controllers, and microphones. The most critical piece of equipment for us turned out to be the microphones we used, eventually leading to the final system where we used an instrument microphone attached to the bell of the saxophone, a contact microphone attached to the body of the instrument, and a headset microphone to capture air sounds.

Most of the systems design work took place at the software level, which changed significantly during each cycle. At the outset we couldn't anticipate precisely what the problems would be in designing our system, so we were essentially stumbling from one problem to another, putting out fires as they came up. As the system's inherent resistances became clear to us over time, we were able to isolate individual problems and focus our energies on designing robust solutions to each one which could be implemented repeatedly. Then whenever a "known problem" would come up in the future, we did not have to reinvent the wheel.

It was at the systems design level where we were able to establish the framework for the interface between the saxophone and the computer. The first versions of this interface were designed for the performance of a particular kind of music, depending on our goals during that period. However we later realized that the system should also be designed in a way that allows hands-on exploration by the

performer, and we were constantly reworking the later versions of the system to support both the exploration and compositional phases that would follow.

It was during the systems design phase where many important decisions were made that would affect the rest of the working process. For example at the beginning of the project I thought that the relationship between the saxophone and electronics would be similar to the electric guitar, and I structured the system with that model in mind. During the first few cycles I came to understand that the interface between the saxophone and the computer would require a completely different kind of system design than the guitar.

Guitarists have been working for decades on extending their instruments via analogue and digital means. The sound of the electric guitar is generated acoustically by a vibrating string, which is then captured by a magnetic pickup, processed, amplified and finally played through a loudspeaker. The initial sound of the vibrating string is normally quite soft, so the sound that makes it to the listener's ear is only the processed, amplified sound. Applying electronics processing to the saxophone is a completely different challenge, because the acoustic sound of the saxophone is captured by a microphone and is always heard in parallel to the processed sound. This means that the range of monophonic sounds are much more limited for the extended saxophone than they are for the electric guitar. However we found that there is a much richer area to explore by taking advantage of the action-response nature of the saxophone-computer relationship. Eventually our systems design evolved to take these considerations into account, and the result can be heard in the final version of *aubiome*, which bears little resemblance to the approach used by electric guitarists.

4.7 Phase 2: Exploration

The exploration of new material normally took place through trial-and-error. During the first years of the project, it happened often that we would work toward a particular musical outcome by imagining the desired result, and then attempting to design the corresponding system. This often meant days or weeks of programming and debugging before we could arrive the point where we were actually playing any music. When we would finally have a testable system, the musical result was usually less effective than we had imagined, sending us back to the beginning again. This came to be known as the 'hope-disappointment cycle', which characterized the first two years of research.

This inefficient process began to change as we realized the importance of designing the system specifically to allow experimentation. This meant that the system should allow fast modifications to its behavior without interrupting the flow of the musical rehearsals. Joel Ryan describes the “interactive software development environment”:

The advantage of interactivity extends into the design of software as well, what programmers call 'interactive software development environments'. What this means is languages which allow the making of incremental changes in the software, each change taking only as much time as it takes the programmer to type it. Such methods allow direct manipulation of the composers' model in a loop with the composers' ears in the middle. The time it takes to cycle this loop is a critical part of the discovery process. If a particular path seems difficult, rapid feedback on one's hypothesis can make the difference between attempting the path or not. If for instance the ratio of interesting to uninteresting discoveries is 1%, a hundred cycles may have to be traversed to find the good bit. If the time to make each change is five minutes, it could take over eight hours to hone in on one answer. If we could reduce the average cycle time to say ten seconds it would take twenty minutes to make one hundred experiments, a much more likely time to consider devoting to hunches or even essential refinements in a composition.¹⁰²

In this passage Ryan hits on several key insights from our experience. Truly relevant musical discoveries are rather rare occurrences, so the system should allow an efficient working process where we could test one “hypothesis” after another quickly. Before we began working toward the idea of an interactive software development environment, we were basically stuck in the systems design phase. By the third year we had arrived at a system design which allowed us to reduce the cycle time from days to hours, and then by the fourth year, to minutes. Ryan's description of the discovery process and feedback loop tracks directly with our experience.

4.8 Phase 3: Composition

The compositional phase was the final step of the cycle, where we took used the material that we had uncovered in the previous phase and attempted to shape it into a musical composition. This was

102 Ryan. pg.8

probably the most difficult step, as a result of the fact that most of the material had been developed through improvisation and often did not lend itself to written composition. The performative considerations of establishing rich, interactive types of configurations largely put Adrià at a disadvantage when it came time to compose a traditional score, and although we had initially imagined a fully-notated score, it turned out quite difficult to put down on paper without compromising the spontaneity we had achieved during the previous phases. We finally decided on a highly reduced type of notation: more a list of instructions than a fully-defined score.

ORGANIC DECAY

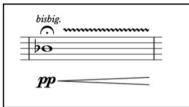





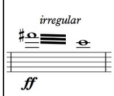



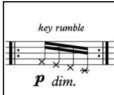




Saxophone	General	DSP 1	DSP 2
 <i>bubig.</i> <i>pp</i>	<div style="border: 1px solid black; padding: 2px; display: inline-block;">1</div> MASTER	[subharmonics] 	 60% [DigiMofa] high 8 
 <i>all trills a half step above</i> <i>tr tr tr tr</i> <i>ff</i>	12" <div style="border: 1px solid black; padding: 2px; display: inline-block;">2</div>		[grumpy giant]  30" 40% 20" 70% 10" 100%
 <i>irregular</i> <i>ff</i>	1'10" <div style="border: 1px solid black; padding: 2px; display: inline-block;">3</div> MASTER	[synapse]  80%	
 <i>fragmented, unpredictable</i> <i>tr tr tr tr</i> <i>ff</i>	50" <div style="border: 1px solid black; padding: 2px; display: inline-block;">4</div>	5"  100%	
 <i>key rumble</i> <i>p dim.</i>	35" 5"  50%  0%	[cytoplasm]  1"	
 <i>key clicks</i> <i>pp dim. al niente</i>	25" 15" MASTER		

Figure 10: Provisional 'score' for one movement of *aubiome*

One might be tempted to place *aubiome* in the category of improvised music, where transcribing a performance of *aubiome* would be analogous to transcribing an improvised jazz solo. While there is

definitely an improvisatory aspect to the piece derived from the fluid interaction between performer and computer, these free choices do not go beyond the lower structural levels. The variability between performances of *aubiome* is nowhere near that seen in most jazz improvisation, for example. In fact whereas improvisors normally practice with the goal of expanding the range of material they might play during a solo, our working process in *aubiome* was always toward a more specific, precisely planned result. Through many hours of rehearsal over five months, we developed a surprising amount of consistency between performances.

This collaborative strategy that we eventually arrived at for the composition of *aubiome* has a parallel in the theater world, a process known as 'devising'.

Devised theatre can start from anything. It is determined and defined by a group of people who set up an initial framework or structure to explore and experiment with ideas, images, concepts, themes, or specific stimuli that might include music, text, objects, paintings, or movement. A devised theatrical performance originates with the group while making the performance, rather than starting from a play text that someone else has written to be interpreted. A devised theatre product is work that has emerged from and been generated by a group of people working in collaboration.¹⁰³

The process of devising a piece of theater or music is an example of an alternative approach to the traditional roles of author and interpreter. An interesting example of a piece of music written in this way came from a collaboration between composer Richard Karpen and guitarist Stefan Östersjö. Karpen describes the collaborative process on his website:

Strand Lines, created in 2007, continues my exploration of collaboration processes for music composition. There is no musical score for *Strand Lines*. Instead the composition was worked out over an extended time of collaborative exploration and rehearsal with guitarist Stefan Östersjö, for and with whom the work was realized. While this kind of experientially developed music has existed in many cultures, I'm drawn to the kinds of techniques that film director Mike Leigh uses for character development in his films. Leigh works with his actors to create their characters

103 Oddey, Alison. (1994). *Devising Theatre: A practical and theoretical handbook*. Routledge. pg. 1.

through an organic and rigorous series of directed improvisation and reiteration until the actors fully embody their characters, their utterances, and the relationships between all of the interacting characters and situations within the environment of the work. Through this process the film becomes its own screenplay. In the case of my own explorations in this mode of composing, the piece of music will itself also be the score.”¹⁰⁴

4.9 Phase 4: Rehearsal

Practice and rehearsal are the usual starting point for a performer after he has been provided a new score from a composer, and they often represent a significant amount of time and work. However in our collaboration we never had much of an opportunity to explicitly prepare the performances. Instead we were always making changes to the piece and to the system until the last moment before the concert, and the rehearsal period effectively became part of the previous three phases. By the time it came to perform on stage, I had spent so many hours with the system, that I did not require much time dedicated only to rehearsal. However this was often not the case for Adrià, who was not nearly as comfortable in a performing situation, nor was he proficient enough with his digital 'instrument' to be able to forgo the necessary rehearsal. This is an example of a potential pitfall when placing a composer into a more performance-oriented role, and being aware of this, our future performances will benefit from a more concrete rehearsal period leading up to the concert.

4.10 Role of Documentation

Our view on documentation evolved over the course of the five-year project as we realized the importance of recording not only final results, the video documentation that accompanies this dissertation, for example, but also as part of the day-to-day working process. In fact it turned out to play an important role in all four phases. This would also be true if I had been working alone, but it was especially important in the context of a collaboration. Especially during the fourth year we realized that the outcomes of our working process were closely related to how we kept track of our ongoing work. In this case documentation was not only done to keep a record of our work for later examination, but it also an integral part of the co-creative working process.

As we placed more attention on our methods of documentation, this became an important part of the

¹⁰⁴ Karpan, Richard. “Strand Lines”. Richardkarpen.com. www.richardkarpen.com/strand-lines-2007/ (accessed 18 June, 2017).

exploration phase, eventually allowing us to capture those shared experiences to some degree. Adrià often took written notes of our working sessions, but these were usually only general sketches, not meant to capture the entirety of what we had played. It happened often that a few weeks after they were taken, these written notes only gave us a general sense of the work that we had done. Important information was being lost, which made the whole process slow and inefficient.

It was necessary to supplement written notes with audio recordings in order to capture a more detailed picture. During the last year we began making audio recordings of our sessions using a handheld recorder placed in the room. We did this for a few months, and Adrià was responsible for organizing the audio files so that we could always come back to previous rehearsals. At first the decision to record our sessions came as a result of how we were dividing the working process at that time. I was spending hours alone to develop the instrumental extensions and then presenting them to Adrià in rehearsal with the expectation that he could write something for those configurations. Adrià needed the opportunity to re-listen to the instrumental extensions and develop a familiarity with them before he could imagine how to write for them. This strategy played an important role, particularly in the final section of *CRISPR/Sax9* (2016) which we performed three times in Graz in 2016.

Aubiome (2017) was the following project which took place over the 2016-17 academic year, during which we took a new approach to documentation, which ultimately led to an entirely different compositional process. We were unsatisfied with the audio quality of the handheld recorder, so we experimented with capturing the sound directly from the computer. This allowed us to record the microphone signal separately from the computer processing, giving us a much more clear picture of the computer behavior than we had had previously.

This was a turning point in our collaboration that led us to use a different method for devising *aubiome* than we had used when writing *CRISPR/Sax9* or any of the preceding pieces. Listening back to the separated audio files, the relationship between the saxophone and the computer was more clear than ever. This is the kind of material that Adrià would have needed to sit down and write a traditional-style score.¹⁰⁵ However in listening to the recordings, we also noticed that there were often key moments during the experimentation process that we missed in the moment. By going back and

¹⁰⁵ It is likely that we will come back to this approach in future projects together.

listening to the separated audio recordings, we were often able to identify interesting material that we would have otherwise missed. At this point we discovered a key method of recording an exploratory improvisation and then immediately listening back to it together. In this way we were re-experiencing the event, but from a different, shared point of view. Working in this way, we rarely had any disagreement about which moments should make it into the final piece.

At this point we had found the means to reach a significant degree of agreement between us about what material should make up the movements of *aubiome*, however it remained problematic to reproduce the results. The recordings provided us the chance to identify and re-listen to our material, and it also allowed us to separate the saxophone sound, so I could always recall what I had played to elicit particular responses from the computer. However it did not give us detailed information about the computer's configuration at that moment. During these exploratory improvisations Adrià was also an active participant, adjusting system parameters, so at this point we realized that we could add in another recorded track of Adrià narrating the process to describe what was happening at each moment.

Our final working process was to make narrated, multi-channel recordings of each improvisation, to listen back to it together immediately in order to recall the peak moments and the corresponding conditions, and then the audio files were organized, commented and saved. During the last few weeks of the project leading up to our video recording session, we also tried to add video to the process. The added visual element made recall easier, but this did not play a major role in our working process. As we continue the collaboration into the future, we plan to incorporate both video and screen capture, to more precisely document what is happening moment to moment.

4.11 Shared Terminology

As we began to realize the central role that capturing shared experiences would play in our working process, another consideration appeared: how to communicate about them. We were able to draw on existing musical terminology when it meaningfully described the material we were working with; eg. 'microtonal', 'climax', 'tension/release', 'agitato', 'misterioso', etc. Of course we could also rely on saxophone-related terminology, for example “let's start at the moment when I end the multiphonic and begin playing slap tongue notes”. These terms allowed us a general way of talking about the music, but we needed a more specific way to discuss the actual behavior of the computer. We needed to somehow

define the individual links between the saxophone and computer, a problem described by Joel Ryan:

The need for 'hands on' in performance forces the composer to confront the abstractness of the computer head on. Each link between performer and computer has to be invented before anything can be played. But these 'handles' are just as useful for the development or discovery of the piece as for the performance itself. In fact the physicality of the performance interface helps give definition to the modeling process itself. The physical relation to a model stimulates the imagination and enables the elaboration of the model using spatial and physical metaphors. The image with which the artist works to realize his or her idea is no longer a phantom; it can be touched, navigated and negotiated with.¹⁰⁶

Ryan refers to 'handles' as a way for the performer to relate to the computer, giving a kind of physicality to something that would otherwise remain entirely abstract. These handles are necessary to understand how to perform with an instrument, but critically they are also part of the “development or discovery of the piece”. As we were listening back to our rehearsal recordings, we needed to find concrete ways of talking about these abstract ideas. We could only capture and develop musical ideas if we could find a way to talk about them.

Adrià was much more proactive with this than me, as the idea of a common terminology is not too far from the idea of notation. For example when experimenting with new computer configurations, he took the initiative to label them with descriptive terms, which allowed us to return to particular states more easily. These handles had to define completely abstract relationships, so they were descriptive or sometimes just arbitrary words that Adrià came up with in the moment. Some colorful examples that we ended up using in *aubiome* are 'synapse', 'subharmonics', 'digi mofo' and 'cytoplasm'. This is an area where further work is clearly needed, and it will be a primary topic of concern for our future collaborations.

106 Ryan. (1991). pg. 2, 3.

Chapter 5

Aubiome for saxophone and live electronics (2017)

This chapter is meant to accompany a viewing of the video documentation of *aubiome* (2017) for soprano saxophone and live electronics. The videos were recorded over a period of four days in May 2017 and took place at the Institute for Electronic Music and Acoustic in Graz, Austria. It is recommended to watch the video first, as it assumed that the reader is familiar with the piece of music.

5.1 Piece Overview

The piece itself was written during a roughly five-month period from January 2017 until May 2017. As described in the previous chapter, this was done as a collaboration between myself and composer Adrià Artacho. We had identified several years earlier in 2014 that the primary challenge we were facing was to design the electronics to have a feeling of liveness in proportion to the saxophone, but it was only with *aubiome* that we started to have some success toward that goal. During our rehearsals in 2016 it would have been common for us to describe a desirable computer response as 'organic', for example. It was this way of thinking that eventually lead to the concept and title of the piece.

The work is not meant as an exhaustive catalog of electronics techniques, but rather one example of what can be achieved by employing a performer-centric approach. It is the result of our specific working process, system design, and joint artistic goals. We do not offer *aubiome* as any kind of definitive work, but rather a 'proof of concept' for what could be possible by rethinking the usual roles for performer and composer.

5.2 Formal Structure

We did not approach writing *aubiome* with any kind of a traditional formal structure in mind. In January 2017, we only knew that it should be a substantial work connected to the current artistic research project. This was a highly contended decision to not begin with an overarching formal idea from which the piece would be derived, but rather to focus on developing material from the saxophone-electronics system instead. If the piece had been written in another context, we probably would not have adopted this approach.

Joel Ryan described it all the way back in 1991:

Contrary to the beliefs of some there is no crisis of formal thinking in contemporary music. We live in a structural paradise where the formalisms of a hundred different disciplines are waiting only for the novel application. Certainly in computer music the problem is not lack of form it is the immense mediating distance which confronts each composer when encountering the computer. Despite twenty years of programming for music, the territory gained seems quite small compared with the empire of musical aspiration. Many composers long to regain some sort of musical spontaneity.¹⁰⁷

Aubiome is an attempt at closing the mediating distances not only between composer and computer, but also between computer and performer and finally between composer and performer. This search for musical spontaneity became the central focus, and the work's formal structure emerged from that working process. The evolution of the piece can be traced through three structural levels: small, medium and large scale.

5.3 Levels of System Behavior

At the lowest structural level, we are concerned with the immediate system behavior in conjunction with the material played by the saxophone. This was where John Croft's comments about liveness and instrumentality are relevant. Material that ultimately made it into the piece meant striking the right balance between simplistic, one-dimensional sound treatments and overly complex systems that lose the sense of live response. Most of the computer behaviors we used in *aubiome* used some kind of interactive elements on this level. We learned how to design the electronics so that the general texture or musical effect would be similar between performances, but the immediate behavior was somehow unpredictable. This adds variability to each performance while confronting the performer with an engaging musical environment.

5.4 Individual Movement Structure

To turn this experimentation into coherent musical structures, we decided to use multiple extended instruments in each movement. Of course this is not the only way to employ extended instruments. It

¹⁰⁷ Ryan (1991). pg. 1.

could be possible to use a single configuration that remains for an entire piece. Another related approach would be to begin with a single configuration, but then to vary the system's behavior by adjusting the parameter over the course of the piece. We tried experimenting with this approach, but we ultimately decided to juxtapose multiple configurations in each movement to create a more dynamic result. In the case of *aubiome* it was a primary goal to show a range of what could be achieved using our approach, so this ultimately made the most sense.

This progression of extensions is controlled in real time by Adrià, whose role is something like steering a ship. He is responsible that the movement proceeds as planned, and he can make adjustments at any moment, but he does not initiate individual gestures except for a few exceptions. We experimented with automating some of this job, but it turned out to be difficult to preprogram actions that might need to happen slightly different between performances. In the final version we found it preferable to give Adrià the responsibility for striking the appropriate balance between the saxophone and computer sound, as well as managing smooth transitions between sections.

5.5 Overall Structure

Aubiome is divided into several shorter pieces, each of which explores a different way that musical sound could be organized. We did not approach any of the pieces from a formal point of view in the traditional sense, but rather we started each one with a saxophone-computer configuration and built up the structure from there. As described in Chapter 4, there was an exploratory phase during which I was primarily responsible for experimenting with new instrumental extensions. Then we would meet to rehearse and try to develop material together. In the end we had much more material than went into the final piece, so we decided that *aubiome* would be an ongoing project, which would continue to evolve and develop with each performance. The individual pieces make up a pool, from which a unique version can be assembled for each performance. We plan to continue adding new pieces to the pool, while modifying or even eliminating old ones, thereby extending the work-in-progress approach that we have used over the past five years.

5.6 Public

One final mediating distance to consider is that between the performer and the audience. The audience's perception of liveness is ultimately as important as my experience on stage, so this was

always a consideration. Before devising *aubiome* we had already performed in various configurations, with and without foot pedals, with Adrià on stage with me or at the mixing board, with or without a click track, and with or without monitor speakers. We decided for this piece, that the only interface between the saxophone and the computer would be the saxophone's sound itself. Instead of adding sensors or using a foot pedal to control the computer, we wanted *aubiome* to be performed with the most transparent interface possible in the hope of reducing the mediating distance between performer and audience.

Toward this same goal, we finally decided that all of the sounds generated by the computer would be generated in real-time, in reaction to the saxophone sound. We had thought for a long time about including some fixed material to compliment the saxophone-based material, but in the end we decided that it would be more interesting to try to produce the entire piece in real-time.

5.7 Video Recording

A final note about the video recording itself. Online video is a fantastic way to share artistic work, but the mediating distance of watching through the computer, dislocated from the original performance in both time and space, results in a completely different experience than attending a performance. Instead of filming with a fixed camera position in an attempt to imitate the view of an audience member at a performance, we decided to shoot a video intended to be watched online. This meant using different types of camera movement and lighting corresponding to the musical content of each movement. With this approach we hoped to recapture some of the feeling of being physical present in the space.

5.8 *Aubiome* Movements

5.8.1 Sonocatalysis

The piece begins with a strong example of how the electronics system can be used to dynamically add layers to the monophonic saxophone sound. The saxophone sound is routed through a type of granulation, creating a 'cloud' of sound behind it. By rapidly varying the types of sound produced on the saxophone, multiple textures can be layered on top of one another. This layering strategy works particularly well with the saxophone, because of the instrument's ability to quickly change between completely different modes of play. In this case we chose to use sharp air sounds, key clicks, slap

tongue, and short scale fragments.

From the opening section there is a transitional section where the saxophone material is reduced to mostly key clicks and some slaps, which are treated by an amplitude-modulated feedback delay. Since the delay reacts differently depending on amplitude of the input, we found that it was again possible to create multiple layers. Very short notes produce only a faint echo in the electronics, but even slightly longer notes produce a distinct 'squeaky' sound. These types of extensions to the saxophone are an important part of *aubiome*, because it is possible to produce interesting and varied textures within a single configuration.

The movement ends with a more melodic section, comprised of short and medium length notes which are shifted down by a pulsing pitch shifter. The pitch level of the computer sound is modulated in a way that is jumps around somewhat unpredictably. The parameters of the pitch shifting are controlled by the second musician, so that the movement ends with a single, low repeating note in the electronics.

5.8.2 Synnecrosis

The second movement is an example of how we created the illusion of agency in the computer. The movement begins with a single note in the saxophone, which then splits off into a second voice that slowly slides up or down about a step above or below the initial pitch. This initiates a kind of 'musical chase', where the saxophonist listens to and attempts to follow the wandering note. As this chase continues, additional elements are added, the velocity increases, and the notes multiply.

While this kind of chase is not a complicated musical idea, it was a challenge to program. It was important that the computer produce a tone with the same characteristics as the saxophone tone, so that they would blend seamlessly. When the computer and saxophone sounds are properly balanced, the listener should lose track of which voice was produced by which source. However in order to produce a true 'chase', the computer also needed to produce an unpredictable path for the saxophonist to follow. This was accomplished using a variable time delay with a modulated delay time. When we found the correct parameters through trial and error, the computer sound seemed to 'come alive'. In fact, this movement is an example of one of the more 'organic'-sounding movements: an outcome that we considered desirable during the writing of *aubiome*.

5.8.3 Pulse Interval

The material for *Pulse Interval* originally showed up in a previous movement called *CRISPR/Sax9*, which Adrià and I performed in June 2016 in Graz. I had been experimenting since the beginning of the research project with rhythmic delays, but *pulse intervals* is the only movement that uses any kind of persistent elements of groove. This particular delay is slightly different from a typical feedback delay, because it uses a fixed number of repeats, each of which is manipulated individually. Each note repeat can have a different gain level and filter applied, which allows a more syncopated feel. The type of sound reminded me of EDM artist Autechre's 1993 track titled *Bike*, so our movement is inspired by that sound world.

5.8.4 Homeostasis

This movement uses two granulators to create a long trail behind the saxophone melody. When experimenting with one trail, I first noticed that it produced an interesting, eerie sound in response to a low, airy note in the saxophone. I improvised a legato melody using quarter tones in the lower fifth of the saxophone register, and the resulting harmonies with the electronics trail were the seed for the movement. After further experimentation we added a second, parallel granulator tuned to a different interval and trail length. The resulting texture is a dialogue between the saxophone and its two trailing 'ghosts', resulting in a kind of 'haunted choir'. The saxophone line is a fixed pattern of only six notes, each held for a variable length, but the saxophonist should be aware of the constantly shifting harmonies between the three voices as they slip between equal-tempered intervals and microtonal ones.

5.8.5 Oxides

Oxides makes use of an unusual microphone technique in order to emphasize two extended techniques of the saxophone: key clicks and air sounds. The key clicks are picked up by a contact microphone placed on the body of the saxophone, while the air sounds are picked up by a headset microphone. This strategy provides nearly perfect separation between the two types of sounds, allowing them to be manipulated independently without bleed between microphones.

Air sounds and key clicks are often used by composers, but unfortunately the natural sound of a key click on the saxophone is quite soft compared to a normally-produced tone, and the same is true for air sounds to some extent. Therefore there is a benefit to amplifying these sounds to create the effect of an

auditory 'zoom in'. By bringing the volume of both types of sound to the same level, it is possible to have an interesting interplay between the two.

The movement begins with a 'glitchy' texture, which is created by treating the air sounds with a kind of gated reverb and some delay. As the movement progresses, key clicks are added, eventually taking over the texture and replacing the air sounds. The key clicks then pass through several different types of sound manipulations applied to the unpitched percussive sounds picked up by the contact microphone. The movement ends dramatically with five, increasingly powerful key clicks, which produce a pitched sound in the electronics. This is achieved with a feedback delay line with a very short delay time and a long feedback trail.

This movement is performed without the saxophone mouthpiece on the instrument, which has been used here and there in the saxophone repertoire. However here the idea is taken a few steps further by independently manipulating the two sources of sound. *Oxides* only shows a glimpse of what could be possible with this strategy.

5.8.6 Metabolic Pathways

Metabolic Pathways uses another type of delay, which essentially records and repeats a small slice of the saxophone sound. Like the processing used in *Pulse Interval*, the character of this 'repeater' is different from a feedback delay, because of the ways the repeat can be shaped. We found that long notes on the saxophone could produce an interesting, 'choppy' response from the computer. By playing long notes that were as long or longer than the repeater's response time, a layering effect could be achieved that adds a texture to the saxophone's otherwise smooth sound. By moving more quickly between notes, the trails of each note begin to overlap.

In this movement, while the system behavior is relatively transparent, the slices are not triggered in an entirely predictable way. When we experimented with a more regular trigger interval, the result was much less interesting because there was less variability in the types of overlaps that would occur. The system configuration of *Metabolic Pathways* required a lot of fine-tuning in order to achieve the desired result, but it is one of the best examples in *aubiome* of an 'extended instrument'. It is at once control intimate and interactive, and the computer behavior is simple enough to be transparent to the listener. This type of computer configuration is pleasurable to play with as a performer, because it

blends seamlessly with the saxophone sound and opens the doors to layered melodies that could not be achieved with the saxophone alone.

5.8.7 Organic Decay

This movement grew from the idea of 'fattening up' the sound of the soprano saxophone by shifting down the saxophone pitch by an octave. Experimenting with this simple configuration, we realized that the computer's response was nearly synchronous with the saxophone, giving the effect of a shadow or undertone to the saxophone sound. However since there is no time-delay aspect to the computer's response, it turned out to make sense for me to play long, continuous lines with only short breaks in between, and we decided to use fast trills and staccato notes to make up the beginning of the movement.

As the movement goes on, a cloud of distortion begins to compete with the saxophone line, eventually leading to a climax and fragmentation of the opening material. As the pieces continue to break down into smaller fragments, the energy of the system returns to baseline. We titled this movement *Organic Decay* to indicate this breaking-down process over time, leading to smaller and more elemental pieces. This material then becomes the basis for the final movement that follows.

5.8.8 Charge Saturation

The piece ends with a noisy mass of sound, which is meant to contrast much of the more 'organic' material found earlier in *aubiome*. While previous movements largely showcase various ways that the saxophone sound can be augmented or complemented by the computer, *Charge Saturation* is based on the idea of pitting the instrument and computer against one another.

The movement begins where the previous movement left off: with a mass of small, elemental 'particles' of sound. Out of this material, some saxophone notes begin to emerge, which are sharply rebuked by an aggressive distortion in the electronics, eventually leading to a violent clash of the two sound worlds: the acoustic and the digital. The movement ends with one final breath from the saxophonist, which is extended into a long, glitchy tail by the computer.

Conclusion

This study has investigated the idea of a performer-centric approach to developing live electronics systems. As an artistic research project, this took place primarily through practice, working both alone and in collaboration with composers, centered around the five year collaboration with Adrià Artacho and the resulting work, *aubiome* (2017). Our collaboration evolved during the research project, and passed through several iterations, during which we designed and re-designed our system several times. This hands-on process required us to address overarching questions at many levels of the music-making process, such as those related to instrumentality, performativity, the composition-improvisation divide, as well as issues around performer/composer voices, authorship and notation. As our thinking on these topics changed over time, the resulting series of music we produced provides a series of 'snapshots' of that working process. The final work is submitted here as a kind of final snapshot of the project as it stands now in 2018.

This collaboration and work are not meant to suggest any kind of general or universal model, but rather to offer one possible way of using a 'performer-centric' approach to electronics design in order to bridge the gap between composer and performer. I am convinced that the music in *aubiome* would never have been produced by a traditional, composer-based approach. To whatever extent that this is true, the piece serves as a 'proof of concept' that points to an unexplored area that deserves further investigation.

The ideas about extended instrument design in Chapter 3, as well as Chapter 2's look at how these instruments might be situated in the social networks that surround new music making, may help orient other performers who are interested in expanding their performance practice. As we get to be more proficient at working hands-on with live electronics systems, I would also hope to see the development of a pedagogy around this practice, which could be integrated with either existing contemporary music study programs, or specialized courses in electronics for performers.

Finally this research project is meant to be equally inspiring to composers who are willing to work together with instrumentalists in collaborations that go beyond the normal 'consultative' working model. Despite the increasing number of 'composer-performers' who choose to work alone, I would

argue that there is still interesting work to be done through collaboration if we are willing to re-think our long-held ideas of authorship and virtuosity.

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Video Recording Links

aubiome (2017)

Sonocatalysis: <https://youtu.be/BZWUx5KyGXI>

Synnecrosis: <https://youtu.be/IpkjPtCD-ds>

Pulse Interval: <https://youtu.be/xw5BftIHL4k>

Homeostasis: <https://youtu.be/7GEPHWChU4s>

Oxides: <https://youtu.be/VUCBG0NgGFQ>

Metabolic Pathways: <https://youtu.be/50fg-oBnHLA>

Organic Decay: <https://youtu.be/OgiA06pJIoY>

Charge Saturation: <https://youtu.be/js23-4S9sOo>

May 2017 rehearsal extract

<https://youtu.be/RJCoZ3mSY1k>

Labyrinth (2015)

<https://youtu.be/0SjTjDpgE04>

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