Process and Form
in Feedback Systems

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Declaration

I hereby declare and confirm that this thesis is entirely the result of my own original work. Where other sources of information have been used, they have been indicated as such and properly acknowledged. I further declare that this or similar work has not been submitted for credit elsewhere.

Graz, June 11, 2019

Daniele Pozzi

Contents

List of Figures

Kurzfassung

Diese Abhandlung stellt ein Modell für die Komposition und Performance von Computermusik vor - Musik, die während der Aufführung auf der Grundlage gespeicherter Programme und von Aufführungs- und Umgebungsinformationen instanziiert wird. Das Modell wird vor dem Hintergrund der Musikkomposition als experimentelle Aktivität vorgeschlagen, deren Ergebnisse aus den vielfältigen Wechselwirkungen zwischen den verschiedenen an ihrer Entwicklung beteiligten Kräften resultieren.

Bei einer retrospektiven Analyse der Spuren und Knotenpunkte, die zur Entstehung eines der neuesten Werke des Autors geführt haben (eine Live-Elektronik-Performance mit dem Titel CK91), wird versucht, das zugrundeliegende Gewebe aus Strängen zu entfalten, das seine Entwicklung und die auf dem Weg getroffen Entscheidungen motivierte die Entscheidungen auf dem Weg getroffen. Einige Themen, die als relevant für ihre ästhetischen und künstlerischen Implikationen angesehen werden, werden ebenfalls aus dem experimentellen Prozess herausgelöst und aus einer kritischen Perspektive diskutiert.

Abstract

This thesis presents a model for computer music composition and performance - music instantiated during performance on the basis of stored programs and performance and environmental information. The model is proposed on a view of music composition as an experimental activity, whose results are the consequence of the manifold interactions happening amongst the various agencies involved in its development.

In performing a retrospective analysis of one of the author's most recent works (a live electronics performance entitled *CK91*) an attempt will be made at unfolding the underlying tapestry of strands and nodes that motivated its development and the choices taken along the way. Some threads and traces, which are considered relevant for their aesthetic and artistic implications, will also be pulled out of the experimental process and discussed from a critical perspective.

Chapter 1

A View of Music

This thesis presents a model for computer music composition and performance - music instantiated during performance on the basis of stored programs and performance and environmental information. The model is proposed on a view of music composition as an experimental activity, whose results are the consequence of the manifold interactions happening amongst the various agencies involved in its development. Music is understood as a dynamical complex of interacting situated embodied behaviours, as described by Jonathan Impett in his article *Interaction, Simulation and Invention* (Impett, 2001).

> Each event on the musical surface is the trace of a unique node in a tapestry of threads – structural, cultural, personal and technological. The balance of this distribution might be said to characterise a particular style, cultural context or kind of experience. These strands aggregate hierarchically into structures, materials, works and practices, adapting individually and forming the context for each others evolution. New constructs at any level are the emergent result of their interaction. Their tendency to interaction and self-organisation is the motor of musical activity and experience, and is further constrained by the more slowly evolving nature of human cognition and action, technology and cultural practice.

In performing a retrospective analysis of one of the author's most recent works (a live electronics performance entitled *CK91*) an attempt will be made at unfolding the underlying tapestry of strands and nodes that motivated its development and the choices taken along the way. Some threads and traces, which are considered relevant for their aesthetic and artistic implications, will also be pulled out of the experimental process and discussed from a critical perspective.

1.1 Experimentalism

"Experimental is an act the outcome of which is unknown" is a famous definition by John Cage, first appeared in his article *Experimental Music* in *The Score* and *I.M.A. Magazine*, London, issue of June 1955. In this text, the experimental attitude is proposed as an alternative to a more traditional approach to composition (Cage cites serialism as an example), where the focus is on making things "upon the boundaries, structures, and expressions on which attention is focused". Experimentation, on the contrary, requires an inclusive, rather than exclusive, attention, an observation and audition of many things at once.

> Where attention [...] becomes inclusive rather than exclusive no question of making, in the sense of forming understandable structures, can arise (one is a tourist), and here the word "experimental" is apt, providing it is understood not as descriptive of an act to be later judged in terms of success and failure, but simply as an act the outcome of which is unknown (Cage, 1955).

As such, experimentation involves inclusive attention and it requires action. In 1955 defining a musical work as an experiment might have seemed puzzling or perhaps even objectionable, since it implies an emphasis upon the process of composing rather than its final result. Shouldn't a composer have the end clearly in sight? Yet working without preconceived notions about how music should sound creates an inclusive, rather than an exclusive aesthetic attitude allowing for virtually unlimited possibilities. This openness to new sounds allowed composers to forge a unique musical identity recognised today as the experimentalist tradition. But such inclusive attitude was not bounded to the realm of sounds and timbres. That artistic composition, whatever the domain or discipline, can involve anything and everything triggered a tremendous period of experimentation with the ontology of music itself (Kuivila, 2019). These ontologies may focus on material (as was Cage's focus) or the corporeality of performance (as was Tudor's) or time (in the case of Morton Feldman). Indeed, one of the most significant achievements of experimentalism was liberating music from its status of being *sound organised in time*, opening up to *experimental aesthetics*.

More than fifty years later, experimental music has explored many different paths within an extended range of fields and areas. While no attempt is made to condense the richness of such experimentation into one definition, Bob Gilmore, for example, provides a useful coordinate system (Gilmore, 2014), highlighting that experimental music, more than being merely a historical period or an ideological distinction (Nyman), focuses on asking new questions about methods, materials, and working practices, and even producing the possibility for composers to iterate and continue the experiments of others (Tenney). This thesis is developed in the context of the so-called *experimental computer music* [1] and explores some issues related to the use of computers in music composition and performance.

1.2 Computers as Experimental Machines

Computers, and computational media in general, are an ideal playground to set up experimental processes and to observe the emergence of unexpected results, or to study phenomena which are otherwise difficult to understand or predict. Since their early developments, scientists became interested in the potentialities of the electronic computing machine for heuristic work, where in absence of closed analytic solutions experimental work on a computing machine would perhaps contribute to the understanding of properties of solutions of specific problems. Particularly fruitful for problems involving the asymptotic long time or in the large behaviour of non-linear physical systems, the field of numerical simulation was arguably one of the first examples of the experimental use of computers, often observing that the behaviour of the systems they were studying were quite different from what intuition would have led them to expect (Fermi, Pasta, and Ulam, 2014).

It was not long after that artists began to explore this territory. In the early 60s, visual artists like George Nees, Frieder Nake or Manfred Mohr made use of simple iterative algorithms that were able to produce emergent visual forms and geometries. The term *generative art* came up when the first exhibition of algorithmic art was staged in 1965, featuring works of Georg Nees and Frieder Nake. On that occasion, Max Bense started to use the term to characterise the surprising and unintended results of such computer graphics programs (Terranova and Nake, 2014). In an interview with Charissa Terranova, Frieder Nake describes the unfolding of these unintended characteristics, drawing a parallelism between generative thinking and the contemporary discourse on emergence:

> When you write a program of modest complexity, let alone high complexity, and you now run it, and observe its results - let's assume they are visual - then you will be surprised. Something is emerging there that you, as the author of the program, were not aware of when you were writing the program (Terranova and Nake, 2014).

In the field of music, similar results are usually achieved through bottom-up strategies. In such approaches, that favour "emergent properties" or second-order sonorities, sound objects emerge from a composer's manipulation of microstructural processes (Di Scipio, 2001). An example is Xenakis' stochastic concatenation of dynamic stochastic synthesis: it is a technique

[1] For a contextualisation of the term, see https://almat.iem.at/questions.html

that preserves the timbral quality and liveliness of single stochastic synthesis processes, while at the same time incorporating them into textures and composite sounds. This sound synthesis technique is economical and automated, to use Xenakis' own terms. When creating sounds or small sections, parameter values are only needed at the beginning "in order to give the initial impulse and a few premises (Xenakis, 1992)". While most combinations of parameters yield continuous sounds, others can create sounds that exhibit interesting behaviours over time and give the illusion of organicity. *Tendency Masks* and *Sequences of Second Order Random Walks* are the selection procedures that more frequently display this type of behaviours (Luque, 2009).

1.3 Experimental Aesthetics

All the afore mentioned examples point out a crucial characteristic of computational media. They demonstrate how, in the different fields of science, visual arts and music, computers can be used to surpass, or even contradict, intuitions and expectations. To put it in other terms, a sort of *gap* is observed between the outcome of an algorithmic process and its formalised structure. Indeed, this gap becomes especially evident when the execution of the process generates results which are not implied in its formulation, nor inferable from a direct analysis of its functioning. This excess, which is produced by the machines' own operation and becomes accessible only when the machine is computing, could be an evidence that the complexity an algorithm produces overwhelms the simplicity and clarity of algorithmic thinking itself - as suggested, for example, by Yuk Hui (Hui, 2015). In relation to algorithms, Parisi's (Parisi, 2013) analysis points to a similar direction: instead of generative aesthetics based on prediction and probabilities, she argues that there is a speculative tendency intrinsic to computation, producing genuine novelty that cannot be explained by external forces or initial conditions.

These evidences suggest that algorithms, and computation in general, may possess a peculiar *performative* quality that generates outcomes which are impossible to predict a priori. In order to approach these unknown possibilities, it is necessary to set the process in motion, to engage with its mechanical function, making this kind of processes an ideal playground for the development of experimental aesthetics. Indeed, another important aspect becomes the interface between the artist and his or her apparatus. As noted by Rutz in his text *Agency and Algorithms*:

> The critical agency that produces the contours of the epistemic thing is situated at this interface, as another instance of grafting or boundary crossing to the inside, i.e. the incursion of the machine into the researcher and vice versa. This partial revocation

> of boundaries between human and machine is what Rheinberger calls *extimacy*, and what Barad calls *intra-action*, the idea that knowing requires proximity and entanglement (Rutz, 2016)

We may define *experimental aesthetics* as those practices that have strong focus on this entanglement and on the excess which is produced in the course of experimentation and artistic practice. This attitude privileges the process itself over its final outcomes and is characterised by an inclusive approach towards the contingent results of experimental actions. The performative qualities of the algorithmic and the fissure between outcomes and formulations are a stimulating area of artistic inquiry, and a major focus of the present work.

1.4 Non Standard Synthesis

In the field of sound synthesis, significant examples of experimental aesthetics may be found in the works of composers like Iannis Xenakis, Gottfried Michael Koenig and Herbert Brün. These approaches are in fact characterised by a close connection between sound synthesis and strongly articulated artistic positions. Their experiments from the 1970s are usually grouped under the umbrella term of *nonstandard synthesis*, a formulation coined by Steven R. Holtzman to discern approaches that "given a set of instructions, relate them one to another in terms of a system which makes no reference to some super-ordinated model [...] the relationships formed are themselves the description of the sound (Holtzman, 1978)". The nonstandard methods are based on compositional ideas of sound and musical organisation rather than on physics, acoustics and psychoacoustics (as in *standard* synthesis methods). The nonstandard systems are rooted in the belief that electronic and digital means allow "the composition of timbre, instead of with timbre (Brün, 2004)", and that sound production in itself can be considered a compositional activity. As a consequence, timbre and the processes related to its production acquired a change in ontological status, enhancing a speculative approach as the composer is forced to invent new ways of describing sound. We witness also a fundamental change in the conception of technology itself, as noted by Luc Döbereiner:

> A perspective in which technology and its function are not accepted as pre-given or as immutable; not as merely a means for realising a preconceived objective, but as something to be explored, to be determined, to be defined. The question is not so much which desires one can satisfy with a given technology, but rather which (old and new) desires emerge from it (Döbereiner, 2011).

As such, the computer can also be intended as an expansion of the field of experience: through its capability of deviating in unexpected ways and then find its way back, the composer can encounter musical situations which would never have occurred to him otherwise (König, 2018).

1.5 Process, Form and Emergence

A peculiarity of electronic music is that compositional ideas can hardly be separated from material ideas, which relate on the one hand to the sound as such, and on the other to the ways and means sound is generated.

The more radical form of nonstandard thinking pushes this relation to its extreme, where the materials, the processes that generate them and the forms they compose become indistinguishable from one another. In some cases, for example in the electronic works of Gottfried Michael Koenig, the concept of musical material itself ceases to exist, and the form coincides precisely with the process which generates it.

> Sound forms, interrelated through the specific mode of production, would be created without reference to a preconceived form. The conjoining of sounds then offered a certain guarantee that a form would successfully emerge. I could therefore try to replace the question of form by a report on my approach in the studio - not chronologically, of course, since the sounds were generated from the standpoint of technical rationality, rather than in any order they could ever actually occupy an aesthetic context (König, 2001).

This coincidence between process and form, where sound becomes the epiphenomenom of implemented relationships, plays also an important role in the works of composers like Xenakis and Brün. This was noted, for example, by Di Scipio when analysing *Infraudible*, *Dust* (Brün) or *Gendy3* (Xenakis) (Di Scipio, 2002). Introducing the concept of *byproduct* in music composition, he writes that:

> In Brün's computer-generated pieces and in most of Xenakis's, the object of composing is a system or mechanism whose operations leave traces that are the music as finally heard. A mechanical process like sawing wood follows a precise design, and the sawdust is a side effect, or a byproduct. Brün put this byproduct at the center: the music is a side effect of composing, just as dust is a residual phenomenon of some process. As a byproduct, this residual is "noise".

And again, when analysing Xenakis's hypothesis (Xenakis, 1992) of an (auto-)creation of "higher order sonorities" in Analogique A et B, Di Scipio makes a small shift in Xenakis's concept: "Today cognitive scientists and epistemologists would probably describe the hypothesis of 2nd-order sonorities as a question of emergent properties of sound structure (Di Scipio, 2001)".

The concept of emergence, that appears to be central (wether intentionally or not) in many of the approaches considered so far, is well suited for experimentation in computer music practice (and, in a wider sense, in computational media in general - computer simulations etc.). Although a univocal and exhaustive definition for the term doesn't exist, the notion of emergence is strictly related to that of complexity, the first defining the quality of unexpectedness of the results, the second defining the structural organisation of the process. As noted by Dario Sanfilippo and Andre Valle (Sanfilippo and Valle, 2013), emergence can refer to organisational levels (Lewels, 1879), to self organization (Varela, Thompson, and Rosch, 1991), to entropy variation (Kauffman, 1990), to nonlinearity (Langton, 1990), or exclusively to complexity (Cariani, 1991) or synergy (Corning, 2002). From a qualitative and holistic point of view, emergence is the rise of global properties coming from the interactions of lower level components, where the global properties are not related to those of the components (Mitchell, 2006). In these cases, the synergy between the interacting components gives birth to an entity which is different from the sum of its parts (Corning, 2002).

1.6 Feedback Systems

A field in which the entangled concepts of process, form, self organisation, emergence and complexity are brought together in a coherent way is that of feedback systems. Indeed, feedback is an interesting case of a simple behaviour that leads to unexpected results (due to nonlinearity) through iteration. In this sense, it can be described in the framework of complexity (Sanfilippo and Valle, 2013). A minimal definition of feedback takes into account the configuration of a system, provided with input and output, in which some kind of transformation occurs, where the output is connected (fed back) to the input after a delay (Rosnay, 1997). A feedback process is characterised by circular causality (Gershenson, 2007). In such a configuration, effects are also causes (Heylighen and Joslyn, 2001), and there is a mutual relation between them.

Feedback systems pertain to the more general field of dynamical systems, thus inheriting the concept of phase space. In dynamical system theory, a phase space is a space in which all possible states of a system are represented, with each possible state corresponding to one unique point in the phase space. The notion of space implies that one cannot deliberately jump, for example, from a point A to a point B: it is necessary to cross a trajectory, which is then traced over time. From this perspective, composing a feedback system coincides precisely with composing its phase space. By defining the relations among the elements that compose the system, one is also creating the phase space which embeds in itself all the musical possibilities, plus the distances between them - which, in a musical context, get translated into time. Form is not something preexisting the process, it emerges through relations, thereby giving rise to new orders of magnitudes, new forms, new ideas. This coincidence between process, materials and form is quite resonant with that described in Section 1.5. Feedback systems can thus be inscribed in the field of nonstandard thinking.

This act of composition cannot be separated from a direct experience of the system itself. Given the unpredictability which is characteristic of feedback networks, it is impossible to compose the system a priori. From this point of view, the computer and its processes are seen as a crucial agency, with which one has to establish a strict entanglement, a form of intra-action (Section 1.3). This entanglement takes the form of a feedback loop between the artists and his or her processes, as shown in Figure A.2. Within this circle of experience, speculation and actualisation it is inescapable to confront with the fissure between formulation and outcomes (described in Section 1.2) and with the performative qualities of computation. Indeed, in my work, feedback systems are thought as experimental systems whose outcomes one could call instances of experimental aesthetics.

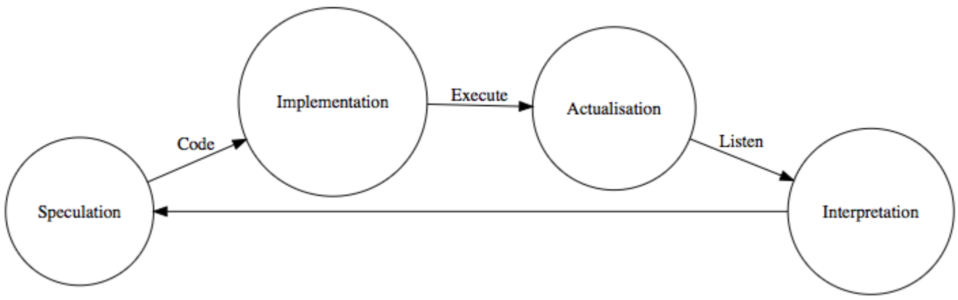

Figure 1.1: Scheme of the interaction between artist and process.

1.7 Feedback Systems and Contingency

The conception of music presented so far put an emphasis on the agency of the materials at use in artistic production (in this case, the processuality and performativity of computational media) and proposed a model of interaction between artist and process. In the scheme depicted in Figure A.2 the most crucial steps are represented by those of *interpretation* and *speculation*: indeed, the decisions made at these stages will have the greatest influence not only in terms of the final results, but also in shaping the overall dynamics of the creative ecosystem itself. These choices are largely dependent on the context, which typical for my compositional method.

In more general terms, Figure A.2 describes a systematic method for investigating, and confronting with, the contingency of the materials. Indeed, the type of feedback networks that are analysed in this work can give rise to certain possibilities that can be used as bases for interactions and dynamic processes; but they can equally bring forth adverse possibilities resistant to such interactions, or no possibilities at all. The practice of many artists who choose to confront with the contingency of the materials is often rooted in a search for surprise, for the encounter with the unexpected - as described for example by Nake in Section 1.2. Of course surprise can be understood also as an end in itself, but this conception doesn't completely match the approach presented here. Here surprise is rather intended as a form of *perturbation*, that is capable of provoking a movement of adaptation in the subject, an expansion of the field of empirical experience that stimulates the emergence of alternative points of view and divergent approaches. In some sense contingency, through surprise, plays with identity.

From my point of view, the mechanism of this interplay is related to the discrepancy between intentions and outcomes and, in the case of the feedback systems I tend to work with, I believe it is associated with the fissure between formulation (intention) and process (results) described in Section 1.3. The articulation of these discrepancies in time is what punctuates my relation with these systems, and what shapes my interaction with the processes I use. This relationship can thus be understood as a form of *complicity*, as described by Reza Negarestani (Negarestani, 2011):

> Complicity can be understood as an involvement and collusion but one without any emphasis on commonalities [...] The contingency inherent to artist's materials does not entail any commonality with the artist's intentions; if anything, such contingency bends, hijacks and punctures such schemes, sensibilities and intentions. In reality, the work is not created based on commonalities but on patterns of intrusion, twisting and suspension determined by contingent materials (during the movement from the so-called ideas to physical materials), in the process of artistic production. If we consider the effectuations of contingency as traumas, the work can be said to be a regional or focused gradient of traumas that simoulataneously shape it and mediate it with the cosmic exteriority in alternative - or more accurately, contingent - ways.

Accepting, rather than refusing or confining, these intrusions as structural elements of the artistic process can be thought as a declination of the inclusive approach which is characteristic of experimentalism (Section 1.1). In my case, this desired mutual influence is motivated by the importance I give to this moments of twisting and bending that such contingencies can provoke.

These twists and intrusions will influence precisely the interpretative and speculative aspects of the compositional loop in Figure A.2, which must then be reflected in meaningful interventions on the structure of the process (König, 2018). The final system, which embodies a certain coherence that has to be accepted or rejected as a whole, is thus the result of a process of stratification of adjustments, suspensions, collisions and divergences between the system and myself.

Chapter 2

CK91

CK91 is a live electronics performance which embodies many of the ideas described in the first chapter of this thesis. It is a piece for two microphones, laptop and two or more loudspeakers where the performer acts on the physical configuration of the system in order to alter its internal dynamics, therefore catalysing the emergence of different sonic forms. The system is composed of two interdependent feedback networks: an acoustic one is formed by the coupling of microphones to loudspeakers, and the environment in which the performance takes place. The second one is a digital feedback network, consisting of recursive signal processing functions that both generate and modify audio. The component which is central in the coupling of the two networks, converting signals from the analog to the digital domain and viceversa, is the audio interface. The two networks are coupled, meaning that digital transformations integrate microphones signals as part of their signal flow (the digital network is *open* to the environment); they have different sensitivities to these inputs and their internal processes are dependent on the sounds which are picked up by the microphones. The result of these transformations is eventually sent to the loudspeakers, bringing about the Larsen effect and thereby creating the conditions for circular causality. The causes are fed back to themselves through their effects, and the effects are the result of their combination with the causes, thus breaking the input–output linear proportion.

The interrelation of these sub systems creates an aural phase space which is always different, depending on the environment, on the spatial configuration of its physical elements and on the choice of its components (different kinds of microphones or loudspeakers affect the resulting sound quality). This phase space is considered as a territory that the performer navigates by executing various actions in the performance space. Different behaviours are achieved by exploring the room resonances, different angles and distances of the microphones from the loudspeakers, and low-level sonic interactions. The performance is articulated in three parts, each exploring different equilibria between the digital, the analog and the acoustic components.

2.1 DSP Structure

The basic structure of the work consists of two interrelated DSP networks that interface with the environment through microphones and loudspeakers. One is specifically composed to treat the audio feedback loop between microphones and loudspeakers, articulating Larsen tones and regulating their amplitude and spectral content through negative feedback dynamics. The main features of this network are described in Section 2.2.1. This first network is also responsible for generating control values (mainly through a rough analysis of its DSP chain) that reshape the internal dynamics of a second network, which synthesises sounds through non-standard digital feedback techniques. This reshaping process happens by altering the topology of the feedback network through a variation of the amplitude of the recirculating signals and changing the relations between the components by modifying their parameters. This network is discussed in Section 2.3. Since the second network works at the smallest delay possible - when the control period is equal to one sample - the two networks run on two different SuperCollider servers to avoid CPU load. The first one executes on a server having a control period of sixty four samples, while the second runs on another server with block size one. The two exchange audio through a shared Jack server, as illustrated in the figure below.

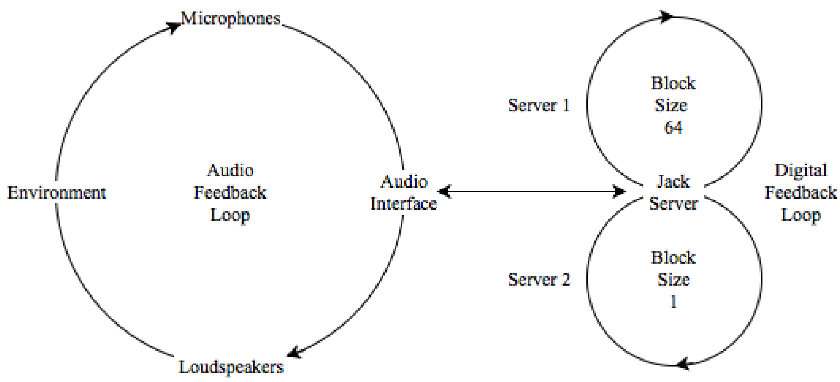

Figure 2.1: CK91: acoustic and digital feedback structure.

2.2 Acoustic Network

The acoustic network consists of a common audio feedback loop comprising (2) microphones and (2 or more) loudspeakers. The Larsen effect happens when - given sufficient amplification - the sound captured from a microphone connected to a speaker is reproduced and again captured, recursively, resulting in a positive feedback that produces pitched tones from the iterated amplification of a signal (Boner, 1966). When speakers are at fixed positions, moving a microphone will result in a modulation of the perceived pitch.

The microphones used in the performance consist of AKG CK91 small condenser capsules mounted on AKG SE300 B microphone pre-amplifiers. This specific model was chosen both for its cardioid polar pattern and its modular structure (during the piece, sometimes pre-amplifiers are used without their capsules). The work was originally sketched out using a pair of Klipsch KP-301 3 way speakers, but in different occasions was performed with other systems. The ideal spatial arrangement is with the two loudspeakers placed quite close to each other, facing the same direction, as illustrated in Figure 2.2.

Figure 2.2: Spatial configuration for CK91 in Neue Galerie Graz.

2.2.1 Tuning and Self Balancing

Frequency shifting tunes the acoustic network to the desired frequency range. This was preferred over pitch shifting for its metallic, inharmonic character that radically alters the sonic qualities of the signal, as well as to limit aliasing by compressing the spectrum in a more contained frequency range. The network is tuned between 13 and 15 kHz, in order to accentuate the directionality of the Larsen tones. In the time domain, the shift is achieved through single-sideband complex modulation. As described in (Wardle, 1998), the positive and negative frequencies of the input can be isolated from each other by calculating the Hilbert Transform (designed as FIR filters) of the signal. When applying ring modulation to the transformed signal, the frequency shifter is equivalent to a single-sideband modulator. The signal is then routed to an automated gain controller which is in inverse relation to the input amplitude. Therefore, as the input gets louder, the shifted signal is scaled down to avoid clipping. When there is little input, the feedback gain is larger to make way to Larsen tones and other byproducts; as Larsen tones and other sound materials get louder, however, the gain decreases enough to preventing too strong howling distorted sounds (Di Scipio, 2006). When a correct balance is found, the process gives way to the emergence of Larsen tones, keeps them at a rather constant amplitude, and eventually lets them fade out at a rate that is dependent on the desired ramp time (see Figure 2.3).

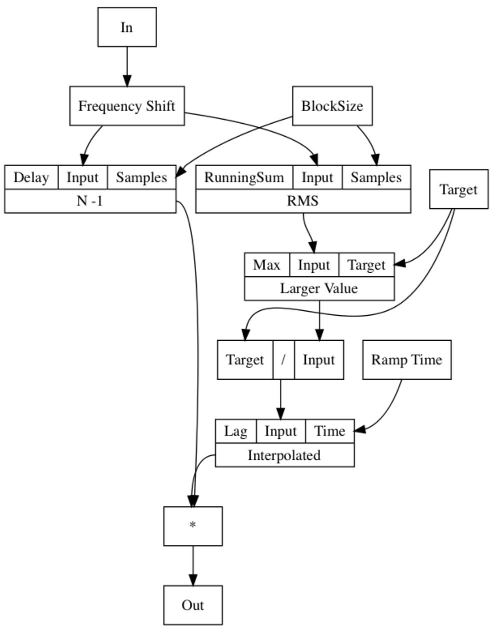

Figure 2.3: Self balancing mechanism scheme.

2.2.2 Self Analysis

Simple analysis methods are also implemented that allow to estimate some features of the sounds produced by the network. An example is an efficient algorithm for the time-domain estimation of the spectral tendency that works by using a crossover to divide the input spectrum into two parts whose energy is measured through the RMS. The imbalance between the two spectra is what creates a negative feedback loop by shifting the cutoff of the crossover towards the predominant side. As a result, the system will gradually oscillate around the point of equal energy providing a rather accurate estimation of the spectral tendency. As proposed by Dario Sanfilippo (Sanfilippo, 2018), this algorithm can be extended by inserting a low pass filter on top of the chain, whose cutoff frequency is also piloted by the spectral imbalance (see Figure 2.4). This provokes a recursive process of spectral attenuation that ends when no components are left on the lower side of the spectrum. If we apply the same process to the upper side of the spectrum we can determine the bandwidth of the signal. By combining this information with the previously derived value of the point of equal energy it is possible to roughly estimate the flatness of the signal. The network running on the block size one server receives these values in the form of audio signals and adapts its behaviour accordingly - for example, the flatness is coupled inversely with the modulation index of a recursive frequency modulation process, keeping the system in a state of dynamical equilibrium between noise and tone.

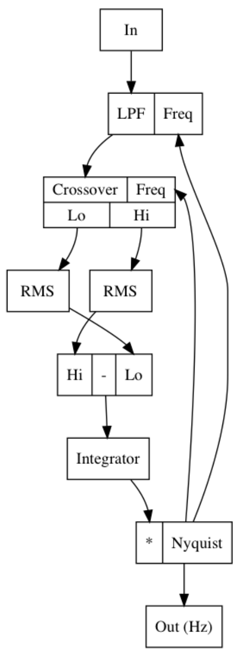

Figure 2.4: Scheme of the lowest partial estimation algorithm.

2.3 Digital Network

The core of the single sample feedback network consists of two oscillators that cross-modulate each other. At each new sample the phase of the two oscillators is computed by adding the actual phase of each oscillator to the one sample old output of the two oscillators, as follows:

$$x(t) = cos(wt + Ax(t-1) + By(t-1))$$
$$y(t) = cos(wt + Cx(t-1) + Dy(t-1))$$

In frequency modulation synthesis A, B, C and D are usually called *modulation indexes* and their value determines the amount of modulation that is applied to the signal. As described in the previous section, these indexes are dependent on the analysis performed by the first network. In particular, they are in an inverse relation with each other: modulation indexes increase when the output is soft, and decrease when this is louder or more noisy.

Other major components of the network are an adaptive comb filter, a zero crossing frequency estimator and a square wave generator. All these elements are organised in a feedback loop whose recirculating signals are reorganised through a 8x4 feedback matrix. This matrix is responsible for combining different sources and rescaling the amount of signal that is fed back to the process in the successive iteration. A simplified representation of the network is in Figure 2.5.

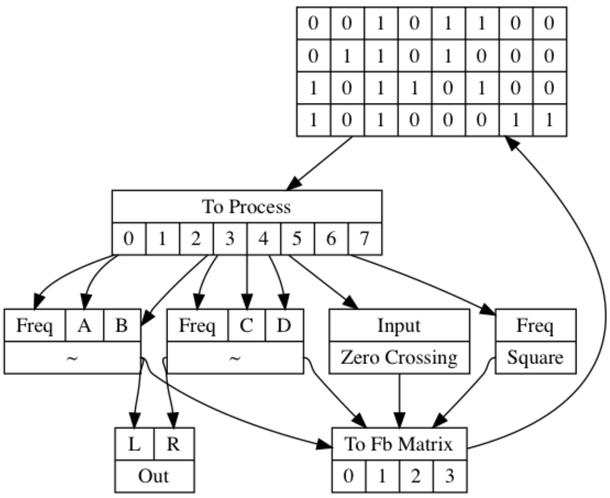

Figure 2.5: Single sample feedback network scheme.

The structure of this system was inherited from another digital network that was previously used in a series of laptop solo improvisation, generally under the title of *Else*. This network was iteratively composed through a non standard synthesis approach that is useful to outline here, since the structure of the network itself is crucial for the emergence of many sonic features of *CK91*, and because some implications of its development are relevant for the discourse of this thesis. As a practical example, the development of the Zero Crossing frequency estimator will be described in detail in the next sections.

2.3.1 Abstraction - Approximation

In *Else*, my original aim was to explore the conditions for and the extent to which the gap between an algorithmic formulation and its computational actualisation (as described in Section 1.3) could emerge as a perceptible quality of aural form. The strategy I adopted to explore this gap was to maintain the complexity of a specific process (i.e. the aesthetic qualities of a feedback network), while at the same time abstracting its algorithmic formulation. Here, the term *abstraction* is not used in its informatics meaning. Instead, it might be understood from a pictorial perspective: in the visual arts abstraction is a movement from figurative to non-figurative painting. Relating the term to the structure of a feedback system, an abstraction is a reformulation of a certain process in which the resulting formulation exists with a degree of independence from its initial reference. It is a form *approximation* in which the initial reference is substituted by a less identifiable version of itself. The language in which the digital network is implemented (SuperCollider) provides many high level DSP units (UGens) which are easily identifiable due to their specific functionalities - waveform generators, filters, compressors and so on. These high level units - or compounds of multiple units - can be replaced by an approximated replica by combining other more generic components that emulate the original behaviour. Through approximation, these functionalities get less specific and more prone to deviation. An example is the reformulation of a rudimental analysis unit - composed of a Zero Crossing and a SinOsc Ugen - that synchronises with the instantaneous frequency of an input signal. As shown in Appendix A this unit can be reconstructed using a sign operator and a circular buffer. A change in the input signal from negative to positive will cause the segment between two successive zero crossings to be repeated until the next negative to positive jump. Through the removal of the SinOsc Ugen the process is made more abstract, meaning that its behaviour becomes less specific and identifiable (see Figure 2.6).

2.3.2 Deviation - Intention

This movements towards abstraction has a twofold effect. By reiterating this act of abstraction the original behaviour is gradually shaded, and the process becomes more open to deviations. As Figure 2.6 demonstrates, the

ZeroCrossing Ugen could originally only output a sinusoidal signal. After its reformulation, the sinusoid becomes a *possibility*: sinusoidal segments can be observed in the waveform, but they are exceptions within a richer articulation. Nevertheless, the output maintains a general similarity with its initial reference. In particular, the frequency of the signal remains completely unaffected. Indeed, in the process of abstraction, a crucial step is deciding which characteristic are to be preserved and which others can be opened up for divergence. These are compositional decisions which depend upon the system's dynamics, and that are often devised after empirical evaluation.

A second effect is that of shading the original intention that was embodied in the initial implementation. The more a process is abstracted, the more aesthetic results appear which were not contained in the former formulation. Moreover, these byproducts are ofter not inferable nor predictable from a direct analysis of the functioning of the process. This excess could be understood as the byproduct of the interplay between a compositional intention and its algorithmic formulation. The genuine novelty which is produced needs to be understood from an inclusive perspective (as found in experimentalism, see Section 1.3) and often requires a movement of adaptation in the composer who, in the next algorithmic interaction, needs to react in order to balance his aesthetic intentions and desires with the mechanics of the system he is developing, as depicted in Figure A.2. This reciprocal influence recalls the twists and intrusions between artist and materials discussed in Section 1.7. In composing a feedback system through a non standard approach, the articulation and stratification in time of the little adjustments, suspensions, collisions and divergences between myself and the system, punctuated by the desires (old and new) that emerge out of these interactions, is what shapes the overall artistic work.

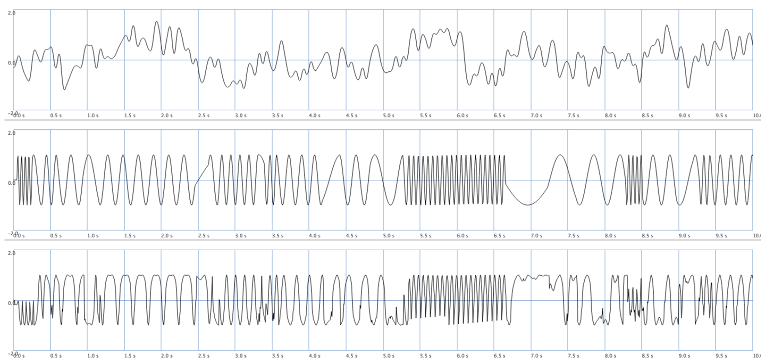

Figure 2.6: Comparison of the zero crossing and its reformulation. First wave: input signal. Second: initial reference output. Third: reformulation output.

Chapter 3

Conclusions

This thesis discussed several aesthetic and artistic implications related to the use of feedback system in music composition and performance practice. Feedback systems were analysed from a non standard perspective and their application in music was contextualised in the field of experimentalism. The intertwinement of process, form and emergence was discussed both in its theoretical aspects and through concrete examples drawn from one of the author's most recent works. A special focus was on the interplay between artist and process. Their mutual influence, described as a form of complicity that manifests through reiterated gestures of perturbation and adaptation, could be understood as a model of co-creation between man and machine that explores the intrinsic speculative aspects of computers as experimental machines and their performative qualities. These distinctive traits of feedback systems makes them a fertile field of artistic inquiry, fostering a critical approach that considers technology and its function not as pre-given or immutable, but as something to be explored, to be determined and to be defined.

Appendix A

Zero Crossing Abstraction

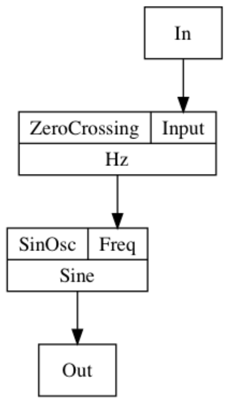

Figure A.1: The initial reference consists of a ZeroCrossing Ugen combined with a sine wave, whose frequency is dependent on the ZeroCrossing output. The two compose a rudimental analysis unit that synchronises with the instantaneous frequency of an input signal.

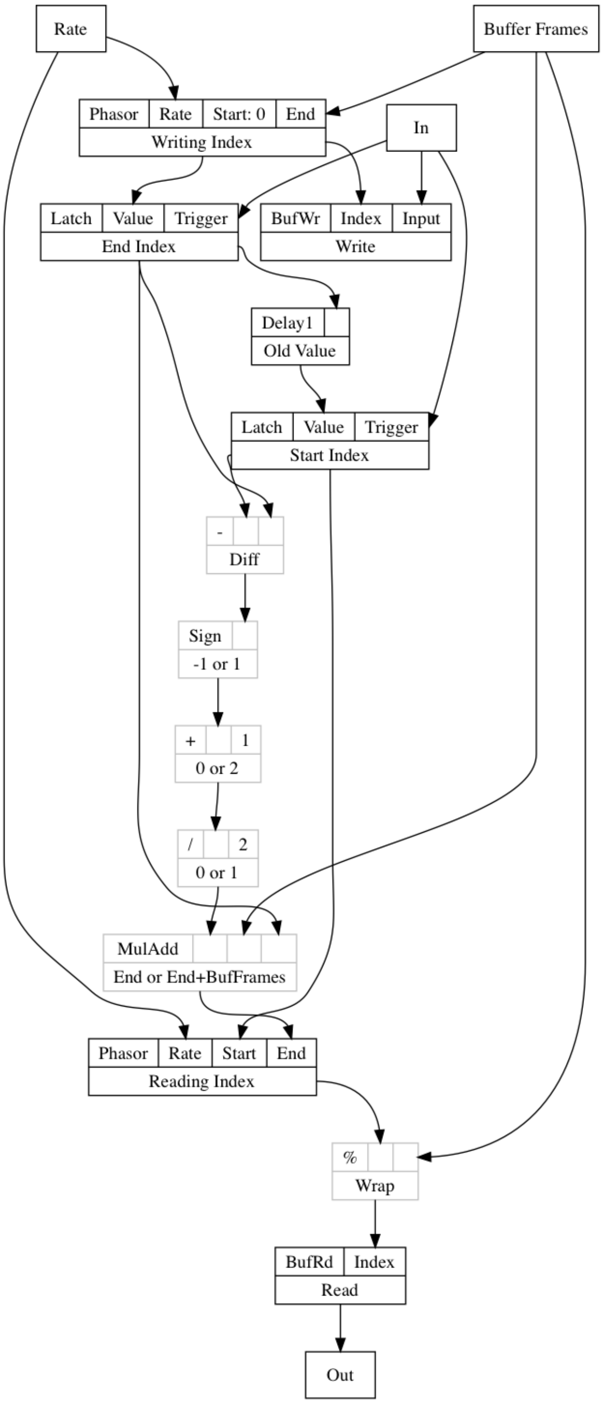

Figure A.2: The unit is reformulated using a sign operator and a circular buffer. A change in the input signal from positive to negative will cause the segment between two successive zero crossings to be repeated until the next zero crossing. Operators in grey compose the wrap around function to avoid discontinuities when reading the buffer.

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