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From live to interactive electronics.
Symbiosis: a study on sonic human-computer synergy.

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Masterarbeit

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Abstract

Human-computer interaction in live electronics is – in most cases still today – a *reflection* of the instrumental model. The electronics, like a musical instrument, must react to the performer's orders as precisely as possible. The frequent use of control devices, such as musical interfaces, reinforces the instrumental character of live electronics, leading to an action-reaction performance model, derived from instrumental performance (*performative electronics*).

A detachment from the instrumental model in live electronic music can be achieved through the design of human-computer interaction not as a *reflective*, but as a *formative condition*. Instead of taking the action-reaction model for granted, the relationship between the performer and the electronics can be re-examined and redefined. A design of human-computer interaction from a compositional point of view enables the transformation of the musical work into a sonic process, as the result of a reciprocal sonic interaction between man and machine (*interactive electronics*).

This thesis attempts a systematization of live electronics on the basis of (human or software) agency and describes the author's personal approach to the design of interactive sonic systems in a piece for double bass and interactive electronics.

Kurzfassung

Mensch-Computer-Interaktion in der Live-Elektronik ist – meistens heute noch – eine *Reflexion* des instrumentalen Modells. Die Elektronik, wie ein musikalisches Instrument, soll möglichst genau auf die Anweisungen des Performers reagieren. Die Verwendung von Steuereinheiten, wie musikalische Interfaces, unterstützt den instrumentalen Charakter von Live-Elektronik und führt zu einem Aktion-Reaktion-Aufführungsmodell, welches sich von der instrumentalen Aufführung herleitet (*performative Elektronik*).

Eine Abweichung vom instrumentalen Modell in der Live-Elektronik wäre durch die Gestaltung von Mensch-Computer Interaktion als *formative*, statt als *reflektive Bedingung* möglich. Anstatt des herkömmlichen Aktion-Reaktion-Modells, könnte das Verhältnis zwischen Performer und Elektronik neu betrachtet und neu definiert werden. Die Gestaltung von Mensch-Computer-Interaktion aus kompositorisher Sicht ermöglicht die Transformation des musikalischen Werkes in einem klanglichen Prozess, als Ergebnis der reziproken klanglichen Interaktion zwischen Mensch und Maschine (*interaktive Elektronik*).

Diese Masterarbeit unternimmt den Versuch, eine Systematisierung von Live-Elektronik auf der Basis eines menschlichen oder Softwareagenten vorzunehmen und beschreibt eine persönliche Herangehensweise an die Gestaltung von interaktiven Klangsystemen anhand eines Stückes für Kontrabass und interaktive Elektronik.

Contents

1. From live to interactive electronics

1.1. Agency in live electronics

Although live manipulation of sound by electronic means has been an established practice for more than fifty years, the term "live electronics" is one of the most ambiguous terms in today's western art music. The practice of live electronic sound manipulation includes a vast number of possibilities concerning techniques, sound material and (human or software) agency, all summarized under the term "live electronics".

The ambiguity of the term becomes evident when it is placed in an electro-instrumental context: e.g.: "piano and live electronics". While an acoustic instrument, such as the piano, is clearly defined through its intrinsic (e.g. sound production, spectral characteristics) and extrinsic properties (e.g. historical repertoire), "live electronics" is a vague, technical indication that contains no information about the type of electronic manipulations applied or the resulting sound output.

Regarding sound material in works for acoustic instruments and live electronics this can vary from pre-produced sounds (e.g. samples, pre-recorded and processed or synthesized material) to sounds generated in real-time and from computer-generated, purely electronic sounds to the transformation of an input signal in real-time. Techniques employed in live electronics include playback of pre-produced or live-recorded material, sound synthesis, signal processing and several audio effects, to name but a few.

However, while the material and techniques used in live electronics do not differ significantly from those employed in fixed media pieces, what is genre-specific to live electronics is *agency*. "Liveness" suggests the *presence* – *physical* or *psychological* (Emmerson, 2007) – of an agent, adjusting some kind of *run-time control data* (Di Scipio, 2003). The agent can be either *human* (one or more performers) or *virtual* (software agent) and its role can vary from a triggering function to a *reciprocal interaction* (Nake, 2008) within a dynamic sonic system.

In computer science, an agent is defined as follows:

> *An autonomous agent is a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to effect what it senses in the future*.
>
> (Franklin and Graesser 1996, p. 4)

According to Wooldridge and Jennings (1995), the agent is a hardware or software-based computer system characterized by *autonomy*, *social ability*, *reactivity* and *pro-activeness* ("the ability to exhibit goal-directed behavior by taking the initiative").

In philosophy, the agent is generally an entity able to *act intentionally* within a certain environment. This definition is the most applicable in live electronic music, since it encompasses all types of agency. *Intention-driven action*, whether initiated by a human or a software agent, is a prerequisite for "liveness" in electronic music.

For the purposes of this thesis, the type (human or virtual) and role of the agent in live electronic systems is regarded as the main criterion for further differentiation within the field of live electronics.

1.2. Human-Computer Interaction

Agency, as the key aspect of live electronic music, goes hand in hand with the concept of *Interaction,* a term as vague and ambiguous as "live electronics".

For the moment, let's restrict our discussion of Interaction to Human-Computer Interaction. Human-computer interaction, as an interdisciplinary research field between computer science, psychology and media theory among other disciplines, focuses on the development of interfaces for the improvement of human-computer communication.

However, human-computer interaction is – from a philosophical point of view – a paradox. Interaction, as a series of actions connected through causal relationships, is only possible between two parts that are able not only to *react*, but also to *act*. A prerequisite for *action* is *intention*: there can be no action without intention and therefore, since machines have no intention, they cannot act. A machine can only react to the user's orders. It is *operated* by the user, but does not *interact* with him/her. Interaction in its literal sense is only possible among humans.

> *The miracle of human-computer interaction is that it is impossible as interaction in the true sense of the word. [...] The miracle is that humans were bold and intelligent enough to establish this. The miracle is not that machines were so intelligent to do it.*
>
> (Nake 2008, p. 107)

1.2.1. Human agency: performative electronics

Any type of agency in live electronic systems requires some kind of man-machine communication.

In the case of a human agent, the performer (either the instrumentalist or a second performer, or sometimes even the composer) operates some software by setting control variables. The role of the human agent can vary from triggering presets to providing data streams in real-time. For this task the performer can either use general purpose interfaces (mouse, keyboard etc.) or specialized musical interfaces (MIDI-pedals, sensor-based interfaces etc.).

Miranda and Wanderley (2006) classify musical interfaces as: *augmented musical instruments, instrument-like gestural controllers, instrument-inspired gestural controllers and alternate gestural controllers*. The instrument analogy that is prominent in Miranda and Wanderley's classification reflects a common opinion, according to which interface design should imitate musical instruments, enabling a learning process that is similar to learning an instrument (McDermott et al., 2013; Ryan, 1991). This analogy is not only the by-product of a well-established music tradition (Brent, 2012), but also the result of a task oriented interface design, developed for problem solving in custom human-computer interaction. The human-computer interface is "an emergent event in the development of computers" (Card, Moran and Newell, 1983), dictated by the need for information exchange between the user and the machine. The musical interface, like any other interface, is also a control device, used to operate a machine (computer) while performing a specific task (playing music).

Despite all efforts for an instrument-oriented design of musical interfaces (with the exception of bio-sensor based interfaces, which will not be discussed in this thesis), the latter have been criticized for lack of musicality in communicating virtuosity and emotion (McDermott et al., 2013). Furthermore, the *"instrument" metaphor* is often considered as a rather debatable approach when used in the context of interactive music systems (Di Scipio, 2003).

An instrument (whether musical or not) is designed to be operated, to be controlled. The instrument has no intention: it is designed to react and not to act. Consequently, the instrumental condition excludes any kind of interactivity. The control device is only used to “translate” the user’s orders, so that they can be executed by the computer.

Human agency in live electronics is a synonym of the instrumental condition: the electronics react to the agent’s orders according to the instrumental model, they are *performed* by the agent (*performative electronics*). In the communication between the agent (performer) and the software the distinction between subject and object is clear. The subject (agent) acts and the object (software) reacts. The subject-object communication is restricted to a one-way reaction, excluding human-computer reciprocity.

1.2.2. Software agency: reactive and interactive electronics

Reactive electronics

A reciprocal interaction between human and computer in live electronic systems is only possible in the context of software agency.

In this type of agency, the run-time control data required for the live electronics is provided by the software itself. This requires decisions made by the computer either randomly or based on the analysis of current input data, or in most cases both.

In a piece for acoustic instruments and live electronics the input data can be provided by the instrumental sound. The signal of the acoustic instrument(s) undergoes various analyses (FFT, Amplitude Tracking, Onset detection etc.) in real-time and is used as a source for control data for the electronics algorithm. The algorithm then adapts its output to the current input, constantly adjusting to changing external conditions. Electronics of this type are *reactive*.

In *reactive electronics*, the subject-object communication (performer-software) is replaced by an object-object interaction (sound-software). The system is reactive but not interactive. Although the live electronics react and adapt to the input data provided by the instrumentalist, the performer does not adapt his/her reactions to the output of the electronics.

Interactive electronics

Interactive electronics require mutual adaptation among system components (in this case the performer and the algorithm). Such a reciprocal interaction between the performer and the electronics can only be achieved through the use of some kind of algorithmic score, allowing the performer to *react* to the electronics in the same way that the electronics react to the performer.

In interactive electronics, both system components analyze each other's actions and react correspondingly. The object-object interaction is transformed into a subject-subject interaction. The computer is able to analyze human actions, make decisions and act upon intention. In other words, the software is turned into a subject able to interact with the human user in an equal and reciprocal interaction.

According to Nake (2008), the interface is the coupling of surface and subface, surface being the intentional interpretant (e.g. computer screen) and subface the causal interpretant (e.g. display buffer). According to this definition, the communication between the two system components in *interactive electronics* is shifted from the *surface* to the *subface*. The interface – or any other control unit – is replaced by a direct and unmediated interaction, based exclusively on sound. The relationship between the performer and the computer is not a mere translation of the performer's intention, but a causal chain of reciprocating actions between the performer and the computer: the mediation is not *intentional*, but *causal*.

1.3. Systemic Composition: Interaction as a compositional approach

The transition from intentional to causal mediation in live electronics can be the starting point for an expansion of the scope of the compositional process in general.

A human-computer interaction that is based on intentional interpretation limits live electronics to an instrumental behavior. The computer simply "translates" the user's *intention* into a sound output. In this *action-sound relationship* (Brent, 2012) there is a clear distinction between intention and action on the one hand and interpretation and reaction on the other hand. The first two belong to the human agent and the second two to the computer. This approach restricts live electronics to a performative character, requiring a human agent that operates the system, but does not interact with it (*performative electronics*).

In a human-computer interaction based on causal mediation on the other hand, the action-sound relationship is transformed into an action-action relationship, through the replacement of intention with causality. The computer does not simply "translate" the user's intention into a sound output. The actions of both the performer and the computer are in a causal and reciprocal relationship with each other, forming a network of interrelations.

This transition from *control* to *interactivity* enables the creation of self-organizing sonic systems, the sound output of which is the result of mutual dependencies between the performer and the electronics. The concept and practice of *interactive electronics* inevitably leads to a redefinition of the compositional process. The composer's task is shifted from composing sounds to *composing sonic interactions*. The creation of a network of sonic interrelations between the musician and the electronics becomes part of the compositional process, resulting in a new understanding of composition as a practice and of the musical work itself.

> *By delegating some of the creative responsibility to the performers and a computer program, the composer pushes composition up (to a meta-level captured in the processes executed by the computer) and out (to the human performers improvising within the logic of the work).*
>
> (Rowe 1999, p. 87)

At this point, an important distinction needs to be made. A music system cannot be called interactive, unless *every action* performed within it is in a causal relationship to the previous one. This is the main difference between *interactive* and *reactive systems*, in which only *every second action* is in a causal relationship to the previous one.

Having said that, most definitions of interactive music systems seem to be problematic. According to Rowe, "interactive music systems are those whose behavior changes in response to musical input. Such responsiveness allows these systems to participate in live performances, of both notated and improvised music" (Rowe 1993, p.

1). Rowe's definition clearly refers to *reactive systems,* confusing *responsiveness* with *reciprocity*.

> *Rowe presents an image of a computer music system listening to, and in turn responding to, a performer. The emphasis in Rowe's definition is on the response of the system; the effect the system has on the human performer is secondary.*
>
> (Drummond 2009, p. 126)

The same can be argued for Chadabe's definition of *interactive composing*.

> *Interactive composing is a two-stage process that consists of (1) creating an interactive composing system and (2) simultaneously composing and performing by interacting with the system as it functions.*
>
> (Chadabe 1984, p. 23)

Chadabe regards interaction as an improvisational and not as a compositional approach. His model is composed of a *performance interpretation algorithm* and a *response algorithm* (consisting of a *composition* and a *sound algorithm*), both regulating the response of the computer to the performer. In Chadabe's model there is no algorithm determining the performer's response.

Similar efforts have been made in the field of Artificial Intelligence, aiming at stylistic imitation through machine learning. Projects like *PAPAGEI* (by S. Bakht and C. Barlow), *OMax* (developed at IRCAM among others by G. Assayag) and *Voyager* (by G. E. Lewis) try to reproduce musical improvisations based on a real-time statistical analysis. Of course, this one-sided imitation is far from being a reciprocal interaction. The computer simply imitates the musician, by generating variations of the material played by him/her. The system may have *intelligence*, but it has no *intention*. Moreover, the pitch-based approach that is followed in these approaches is a huge limitation of the possibilities of electronic sound manipulation.

An interesting compositional approach in a neighboring – if not overlapping - field to *interactive electronics* are Di Scipio's *audible ecosystems*. Nevertheless, in *audible ecosystems* the focus of interaction lies in the triangular connection between the human agent, a DSP unit and the sonic ambience (Di Scipio, 2003) and not in human-computer reciprocity. Another important difference between *interactive electronics* and *audible ecosystems* is that, in the latter, the object of human-machine communication is not necessarily sound. The human agent can control the electronics via control devices, resulting in a mediated (interface-based) and not sound-based interaction, a condition that has been described here as *performative electronics*.

Interaction as a compositional approach is generally a rather new approach to live electronics that remains to be explored further, not only compositionally, but also in a conceptual and theoretical basis. A reassignment of roles and a redefinition of the relationship between man and machine in live electronic systems can be the starting point for a new understanding of *composition*, that regards technology as a *formative* and not as a *reflective* condition.

In the following chapter I describe personal work that illustrates a compositional approach to sonic human-computer interaction.

2. *Symbiosis* (2015), for double bass and interactive electronics

Symbiosis, for double bass and interactive electronics, is a study on live electronics as sonic human-computer interaction. The piece is an autonomous *sonic system*, the output of which is determined by the reciprocal interaction between the double bass performer and the computer.

As a composed system, *Symbiosis* cannot be regarded – and thus notated – as a linear sequence of sound events. The score of the piece consists partly of conventional notation and partly of abstract and improvisational notation, while the electronics run independently during the performance, based on self-regulating processes and do not require a second performer.

In *Symbiosis*, the changing interrelations between the performer and the software agent are the focus of the compositional process and the piece itself is considered as a *sonic process*. Instead of temporal sonic structures, the work is composed of a non-temporal, abstract interaction model, the output of which is the result of sonic human-computer synergy. This model undergoes several modifications during the piece, leading to various stages of interaction and reciprocating control. The interaction model of the piece is explained in detail below.

2.1. Interaction Model

The interaction model of *Symbiosis* consists of two discrete algorithms, which are responsible for the action-reaction cycle between the acoustic instrument (*real sound object*) and the electronics (*virtual sound object*). The *electronics algorithm* adjusts the output of the electronics to the live input, while the *score algorithm* is responsible for the performer's reaction to the electronics, providing abstract models as possible continuations of the score. The two algorithms correspond to different structural levels, the electronics algorithm determining the parameters of single sound events (microstructure) and the score algorithm being responsible for larger sections of the piece (macrostructure). Combined, the electronics and score algorithm, enable a reciprocal communication between the performer and the computer based on an action-analysis-reaction feedback loop.

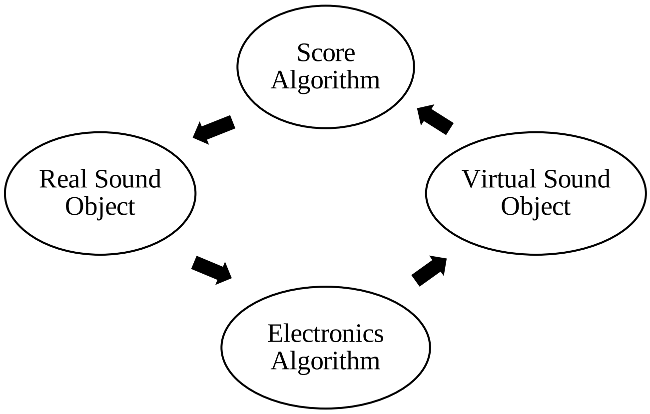

Figure 1: The interaction model of *Symbiosis*

2.1.1. Electronics Algorithm

The electronics algorithm is an adaptive algorithm, consisting of an analysis, a mapping and a sound generation stage. In the first stage, the input signal of the double bass is being analyzed. Data derived from FFT analysis and amplitude tracking is then being mapped, in order to provide the parameters for the virtual (electronic) sound. The algorithm constantly adapts to current input, changing its output correspondingly. The choice of a mapping strategy is therefore decisive for the behavior of the system, as it determines the interconnections between its components and, consequently, its output.

Another characteristic of the electronics algorithm is its non-linearity. The electronics algorithm can be described as a *live algorithm*, meaning that it does not relate input to output in a linear way. The complex dependencies between the components create a system which is highly sensitive to initial conditions and, thus, non-deterministic.

2.1.2. Score Algorithm

Based on the output of the electronics, the performer follows a set of rules on how to proceed with the score reading (algorithmic score). The score provides the performer with an open form, the interpretation of which is based partly on the non-deterministic output of the electronics and partly on decisions made by the performer in real-time. The algorithmic score model was used in the last part of the piece and marks the transition from *reaction* to *interaction*. As the behavior of the virtual sound object becomes more complex and less predictable, the performer's role is shifted from *action* to *interaction*, allowing reciprocity and mutual adaptation.

Modifications of variables (e.g. input signal) or processes (e.g. mapping) within the above-mentioned interaction model affect the behavior of the system, resulting in different control levels and interaction stages. Such variations were applied in a macro-structural level and are responsible for the formal development of the piece.

Symbiosis can be divided in three parts, each illustrating a different stage of interaction between the two system components (performer-computer). The transition from reaction to interaction is thematized as a formal process and is reflected not only in the changing interdependencies of the system, but also in its sonic properties. The strictly reactive and relatively predictable behavior of the electronics in the first part of the piece is replaced by a much more complex and less transparent mapping process in the second part, until the virtual sound object is transformed into an autonomous entity (third part).

2.2. Sound Material

The electronics part of *Symbiosis* is based on real-time Convolution of the input signal (double bass) with artificial, pre-composed Impulse Responses (IRs). The Impulse Responses used in the piece are transformations of a real Room Impulse Response (RIR), measured in *György-Ligeti-Saal* of the *Haus für Musik und Musiktheater* (MUMUTH) in Graz (Eckel and Rumori, 2014). The Impulse Response of the concert hall was only used as a reference. The resulting IRs were derived from abstract processes and do not correspond to the spatial properties of the concert hall or any other existing physical space.

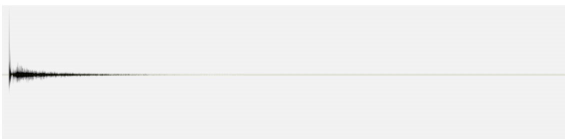

Figure 2: Model Impulse Response (MUMUTH)

The composed Impulse Responses were based on the superposition of delayed and reverted copies of the initial IR and have a rather gestural, than spatial character.

The delay time and number of superimposed copies are gradually increased during the piece, leading to an escalation of the temporal and spectral autonomy of the virtual sound object. The artificial IRs used in *Symbiosis* are depicted below.

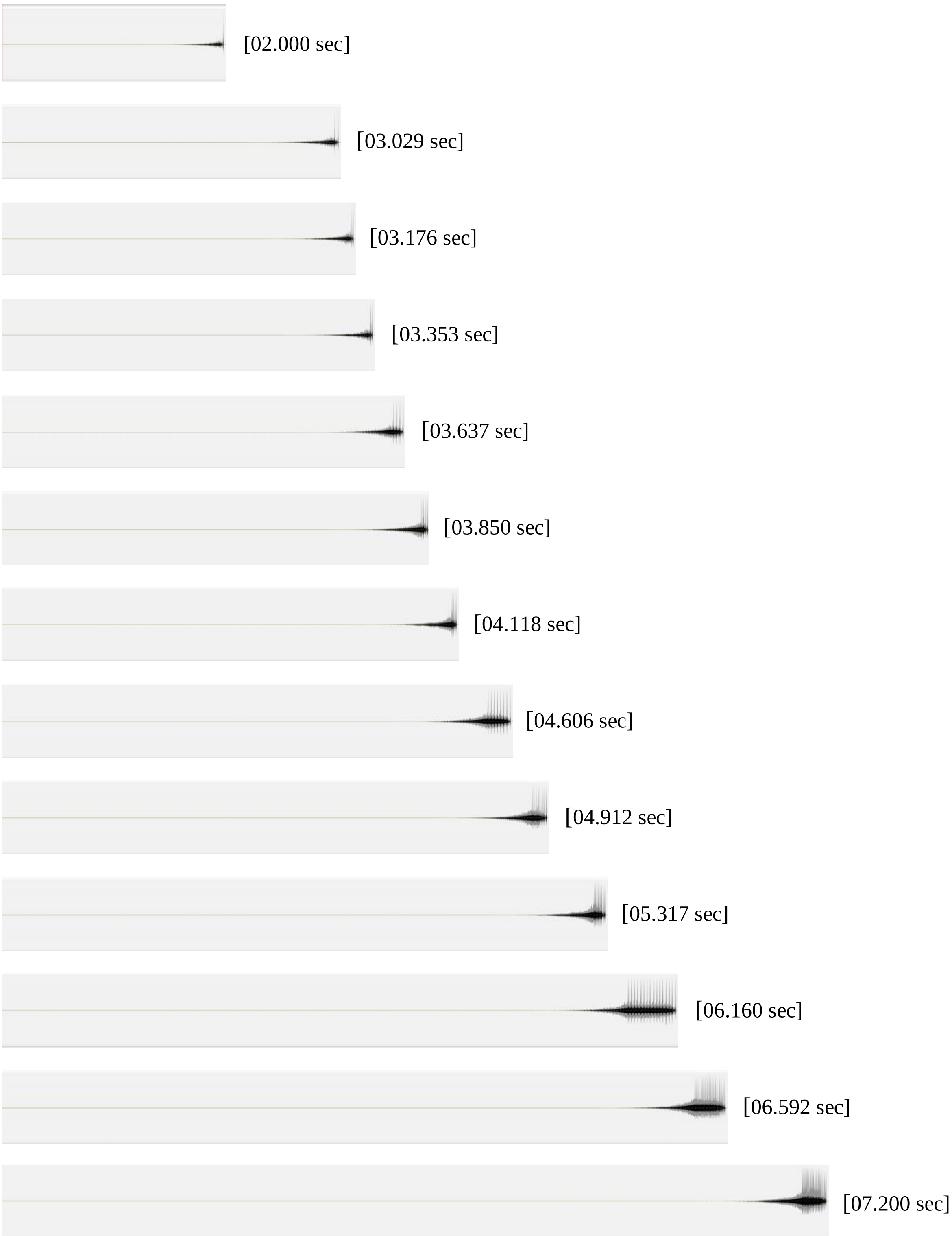

Figure 3: Composed Impulse Responses

2.3. Formal development

2.3.1. Adaptive signal processing

In the first part of the piece, data derived from FFT analysis of the input signal is used in order to control an adaptive signal processing algorithm.

As shown in the signal flow chart (fig. 4), the input signal is analyzed in order to extract the spectral centroid. The value of the centroid is then mapped to an amplitude value, determining the amount of signal that is sent to the convolution. If the centroid value is lower than a certain threshold, then no signal is sent to the signal processing algorithm. This means that the input signal is processed selectively and dynamically, according to its spectral characteristics.

The spectral centroid is a measure for the energy distribution within a spectrum. Therefore, not only pitch, but also playing techniques can affect its value, by determining how “pure” or “noisy” a sound is. The value of the spectral centroid is highly unpredictable, partly because the energy in the higher frequencies is more than in the lower frequencies (meaning that the choice of a less or more “noisy” playing technique can be decisive) and partly because of its dependency on the type of microphone, its distance from the instrument and several other factors.

The sound material of the instrumental part points to the non-deterministic character of the analysis stage. The material for the double bass was chosen based on spectral content. Contrasting sound spectra and playing techniques that enable transient overtone accentuation were used in order to ensure variability. The score in this part of the piece consists of long durations and playing techniques that enable subtle spectral variations, subject to non-deterministic dynamics.

The panning of the output signal to the four output channels is controlled by its amplitude.

In this part of the piece, the sonic system consists of an acting (performer) and a reacting component (electronics), both following deterministic instructions (score and mapping process respectively) and yet resulting in a non-deterministic sonic synergy.

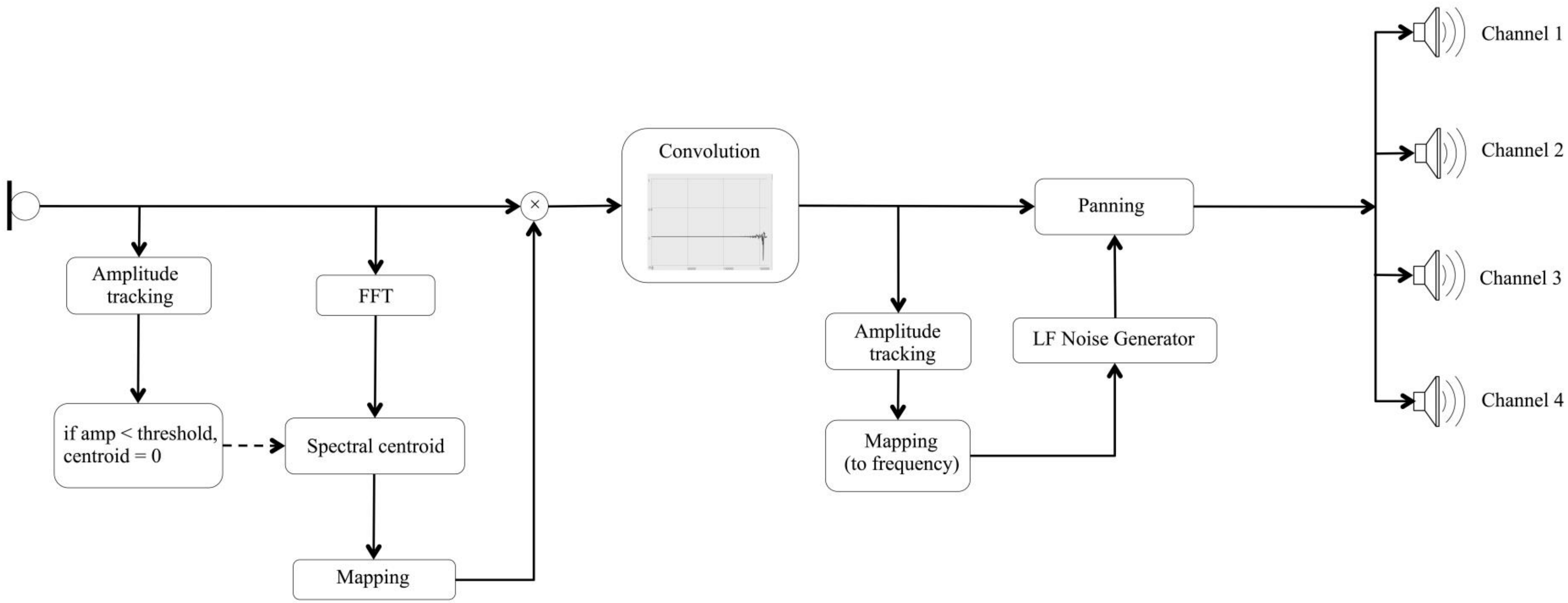

Figure 4: Signal flow chart (part 1)

2.3.2. Increasing system complexity

In the second part, the complexity of the system is increased through less transparent mapping processes and a non-deterministic system behavior. More than one (from three to six) Impulse Responses are used simultaneously and the algorithm cross-fades among them based on spectral information.

Another characteristic of the electronics algorithm in the second part of the piece is the introduction of feedback as a self-regulating structural process. This feedback is not electroacoustic (between the loudspeakers and the microphone), but algorithmic (implemented in the signal processing algorithm). The output of each convolution is fed back to all the others and to itself, forming a complex feedback matrix. The feedback matrix is the first step in the transformation of the virtual sound object into an autonomous sound organism, providing additional input to that of the acoustic instrument and, thus, increasing system autonomy.

Another aspect of feedback that plays a decisive role in the detachment of the virtual sound object from the real is its non-deterministic character. A self-organizing and self-controlling process, such as a feedback loop, is extremely sensitive to initial conditions and cannot be controlled externally.

Interaction between the real sound object and the feedback matrix of the electronics lies in a rather non-transparent mapping between the spectral centroid and amplitude values within the matrix. However, the values of the spectral centroid are not mapped directly to amplitude values. A cumulative sum of the centroid values is calculated by adding each new value to the stored one, after weighting them with different factors. By giving greater weight to past information the weighted sum value changes slower than the actual centroid values, resulting in slow amplitude fluctuations within the matrix. The performer’s control over the electronics algorithm has become mediated, indirect and deferred in time.

While the mapping process increases in complexity, enabling indeterminacy, the instructions in the score remain deterministic. The musician is asked to play a thoroughly notated, pointilistic texture, while the electronics are becoming less and less responsive and are gradually transformed into an autonomous system. The interaction paradox of the second part points to the necessity of a reciprocating communication between the performer and the software agent, which takes place in the third part of the piece.

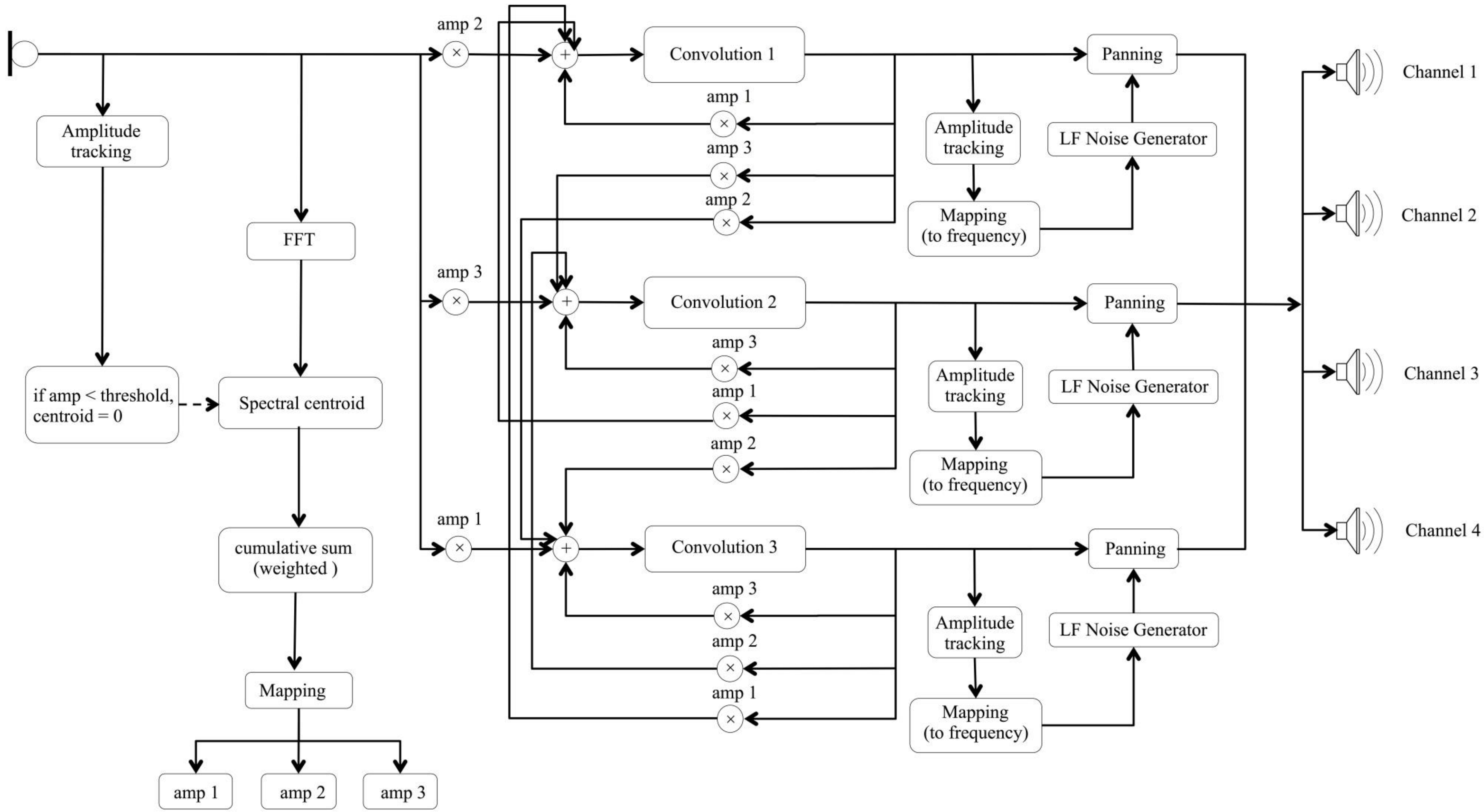

Figure 4: Signal flow chart (part 2)

2.3.3. Human Computer reciprocity

In the third part of *Symbiosis*, the signal processing chain is interrupted and for the first time the input material is provided by the computer and not the double bass. Through the replacement of the input signal with an impulse generator, the computer is turned into an acting component, able not only to *process*, but also to *generate* sound. The impulses are controlled by a noise generator and fed into the convolution and feedback matrix. The amplitude values for the matrix are no longer controlled externally (by the double bass signal), but internally. The algorithm sets an amplitude value for the feedback matrix, which in this way evolves into an autonomous, self-regulating system. As in the first and second part, the panning of the output signal is controlled by its amplitude.

Since both input and control data required for the electronics algorithm are provided by the computer, every direct dependency on the instrumental sound is cut off. The third part of *Symbiosis* is the last stage in the development of a *reactive* into a *self-organizing* system.

The changed status of the virtual sound object is facilitated by a new interaction model and a redefinition of the roles of the two interacting components (performer-electronics). Instead of providing run-time control data for the electronics algorithm, the performer can only intervene in the system and force it to respond. More specifically, if the weighted cumulative sum of the spectral centroid is higher than a threshold value, then the output of the electronics is set to zero. When the amplitude of the electronics recovers its initial value, the same process is repeated, this time with different weighting factors, resulting in a stronger smoothing of the analysis data.

The score in this part of the piece is based on an abstract notation that allows the performer to adapt to the electronics, by adjusting his/her reactions in real-time. No pitch or duration is notated, while the form is open, meaning that the notated actions can be performed in any order, one or more times. The performer tries to eliminate the continuously accumulating feedback by playing material that will raise the centroid sum. Every time that he/she succeeds, the weighting factors are reset making the next effort more difficult. When the performer's efforts fail to meet the criteria established by the algorithm, the piece is terminated.

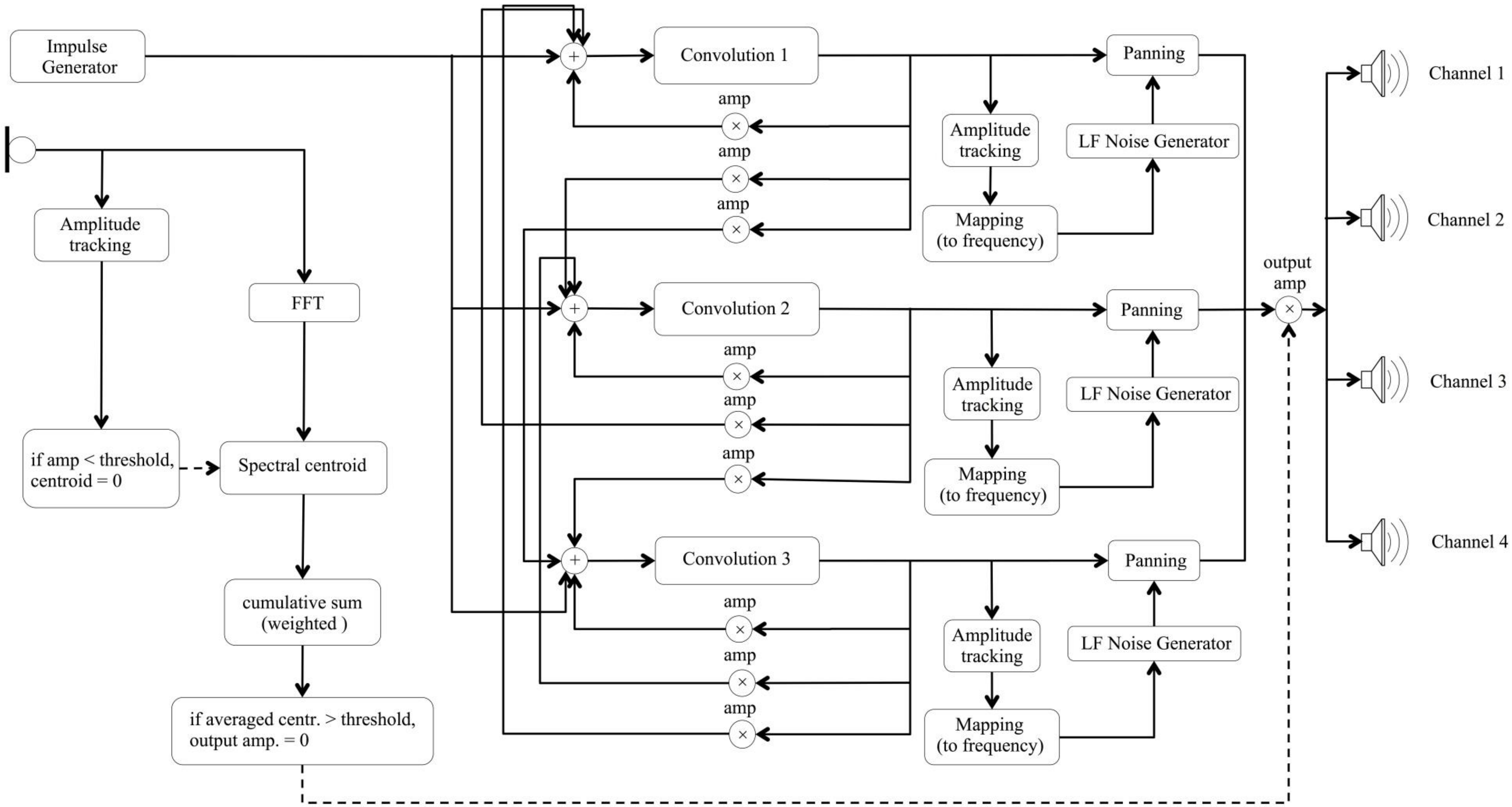

Figure 5: Signal flow chart (part 3)

2.4. Macro-structural processes

The transition from *reactive* to *interactive* and finally *unresponsive* human-computer communication in *Symbiosis* is the result of changing interrelations between system components. Changes in the input and control data of the system, as well as in the mapping process, affect the level of human control over the electronic system and, consequently, the type of human-computer interaction. The following table is an overview of macro-structural processes in *Symbiosis*, concerning input, control data, mapping processes, interaction stage and level of (human) control.

	Part 1	**Part 2**	**Part 3**
Input data	Double bass signal	Double bass signal	Impulse generator
Control data	Derived from double bass signal	Derived from double bass signal	Computer-generated
Data mapping	Direct	After data smoothing	After data smoothing
Interaction stage	Reaction	Reaction (with higher system complexity)	Interaction
Control	Direct	Mediated	Limited to a reset function

Figure 6: Macro-structural processes in *Symbiosis*

2.5. Conclusion

Symbiosis (from Greek σύν, "with", "together" and βίος, "life") illustrates a shift in control from man to machine. The performer (subject) gradually loses control over the computer (object), until human-computer communication becomes unresponsive. Starting from a direct control over the electronics which gradually becomes mediated, the performer's role is finally restricted to a reset function, until he/she loses every influence upon the system.

The electronics, on the other hand, evolve from a mere reflection of the instrumental sound into an independent, self-organizing sonic system. This shift in control is reflected not only in the interaction model and the transition from reaction to reciprocal interaction, but also in the input and control data of the system. The live input of the double bass and the control data derived from FFT analysis and mapping is gradually replaced by computer generated impulses and decisions made by the software agent.

The mapping process is also modified, in order to facilitate the transition among different control levels and interaction stages. The use of the cumulative sum as a data smoothing process is an example of a mapping strategy that enables *causal* instead of *intentional* interpretation. A direct mapping of input to control data is a simple translation of an input into an output. With the introduction of a data smoothing process, however, the input data – and together with it the user's intention – is *filtered*. The output of the system is in a causal relation to the user's actions, but it is not a direct translation of his/her intentions. The user's intention is filtered through the intention of the system: the computer interprets input data according to its own "will".

A software agent that acts upon intention is a prerequisite for reciprocal human-computer interaction. Interaction can only take place among interacting parts of the same status (subject-subject). Therefore, a passive reaction of the system to the user's orders establishes it as an object and restricts man-machine communication to a control relationship. *Intentional agency*, on the other hand, transforms the object (computer) into a subject and brings human-computer communication to the stage of reciprocal interaction. In this stage, both system components are capable of analyzing each other's actions, making decisions and expressing intention through action. The distinction between subject and object is lifted.

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