Watchers – Directionality as Metaphor for Interaction with a Generative Installation
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Abstract
Watchers is an interactive multi-channel audio installation that experiments with different compositional approaches of incorporating the loudspeakers' directionality as central functional and aesthetic element. The directional properties of the custom developed loudspeakers are not only defined by the characteristics of their sound radiation but also integrate a light-based line of sight and orientation sensing mechanism. It is through this latter mechanism that the configuration of the installation affects the algorithmic creation of the musical content. And its also through this mechanism that the musical content is rendered responsive to the visitors' physical manipulation of the installation. The realisation of the installation forms part of a research strand that addresses the issue of rendering the algorithmic principles of a compositional work experienceable not only through its sonic manifestation but also via spatial and tangible representations. These representations can provide affordances for interaction and thereby offer the possibility for visitors to engage through embodied actions with a musical work.

Exhibition of Watchers at the NeMe Arts Centre, Limassol, Cyprus

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Key words: Sound Installation, Algorithmic Music, Interaction

Main References:
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Watchers
Directionality as Metaphor for Interaction with a Generative Installation

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Premise

Watchers is an interactive multi-channel audio installation that experiments with different compositional approaches of incorporating the loudspeakers' directionality as a central functional and aesthetic element. The directional properties of the custom developed loudspeakers are not only defined by the characteristics of their sound radiation but also integrate a light-based line of sight and orientation sensing mechanism. It is through this latter mechanism that the configuration of the installation affects the algorithmic creation of the musical content. And it is also through this mechanism that the musical content is rendered responsive to the visitors' physical manipulation of the installation. The realization of the installation forms part of a research strand that addresses the issue of rendering the algorithmic principles of a compositional work experienceable not only through its sonic manifestation but also via spatial and tangible representations. These representations can provide affordances for interaction and thereby offer the possibility for visitors to engage through embodied actions with a musical work.

1. Introduction

The installation *Watchers* consists of six custom-designed loudspeakers each of which is mounted with a rotational hinge on top of a stand. Visitors can interact with the installation by manually changing the orientation of the loudspeakers. This interaction alters the directionality of the emitted sounds and also affects the generative processes that generate the musical output. Accordingly, the loudspeakers not only serve as acoustic devices but also provide tangible affordances for interaction with the generative musical works.

This publication describes the installation and the musical works that have been specifically created for it. The description includes an overview over the motivation and conceptual background that informed the realization of the installation, a description of the generative sound producing principles of each musical work, an overview of the hard- and software implementation, a description of the exhibition and interaction situation, and a conclusion and outlook for possible future research directions.

Additional information about some aspects of the installation that are only superficially addressed in this paper is available in another publication [1]. This previous publication complements the current publication in that it is more exhaustive in its description of the conceptual background that informed the realization of the installation and also places a stronger focus on a single musical realization. Instead, the current publication focuses on the description and juxtaposition of the different compositional approaches that led to the realization of multiple musical works.

2. Background

The motivation for realising *Watchers* is based on the authors' interest in developing interaction principles that could be particularly suitable for generative sound installations. These developments are guided by the hypothesis that for an audience to creatively engage and interact with generative music, the processes underlying the music need to be exposed on two perceptual levels: Not only through the musical output but also through specific physical affordances for interaction that are clearly correlated with these processes. The authors believe that by establishing a close correspondence between generative principles and affordances for interaction, the audience gains not only an aesthetic appreciation of the musical work but is also encouraged to obtain an intellectual understanding for its underlying formal structure and functioning.

The approach that has been chosen for the realization of *Watchers* is inspired by the field of tangible computing. According to this field, an interface is considered tangible if it establishes a close relationship between physical elements for interaction and the characteristics of the computational system that is being interacted with. The tangible interface elements constitute embodied representations of digital data and at the same time provide the means for their manipulation [2]. It has been shown that tangible interfaces can contribute to the legibility and learnability of a computational system in that the interface's tangible elements leverage the connection of body and cognition and thereby facilitate tangible thinking [3]. Concerning the characteristics of the correspondences between physical and digital objects, Boriana et al. propose a framework that is based on the degree of coherence between physical and digital objects [4]. The strongest form of correlation results from aligning the mutual ontological status of digital and physical objects. This level of alignment is also known as 'full metaphor' [5] or 'natural mapping' [6].

For *Watchers*, two different levels of correspondence have been chosen. On the first level, each loudspeaker corresponds to an individual sound producing unit within the generative system. The loudspeaker not only renders the musical output of that unit audible but also provides the unit with a position within physical space. As a result, the generative system becomes accessible for spatial forms of exploration for instance by approaching a loudspeaker in order to closely listen to the activity of it's corresponding unit in isolation, or by retreating from it in order to perceive the activity of the entire generative system. This correspondence follows the principle of natural mapping. On the second level, the relationship between the relative direction of the loudspeakers and the generative system establishes another correspondence. Whenever the loudspeakers are oriented in such a way that they face towards each other, the corresponding sound generating units increase their level of mutual correlation. Vice versa, when the loudspeakers are facing away from each other, the corresponding sound generating units decrease their level of correlation. This *visibility* among loudspeakers exposes additional aspects of the underlying generative system in a spatial manner. But in addition to this, it also invites tangible and embodied forms of interaction in that visitors can manipulate the generative system through the physical proxies of the loudspeakers, and in that the visitors' bodies through their occluding effects alter the *visibility* among the loudspeakers. This relationship between the *visibility* among loudspeakers and the correlation between sound generating units represents a weaker metaphor of correspondence. By combining the same two types of mapping, the relationship between the tangible properties of the installation and the generative musical processes is made consistent across the different musical works. Moreover, as the second mapping incorporates a weaker metaphor of correspondence, a certain level of flexibility is granted for different compositional approaches.

3. Compositional Approaches

Each of the three authors of this publication has created an individual musical work for the *Watchers* installation. This section describes the different compositional approaches that have been chosen to connect tangible interaction and generative processes.

3.1 Recurrence

This work employs a time-delayed recurrent network as sound generating mechanism (see figure 1). Nodes in such a network exchange signals among each other via directed connections. The signals can be delayed in time as they travel along these connections and some of the connections can even form loops. Such networks are musically interesting for several reasons: the activity of the network can be rendered audible through direct audification [7], they permit the creation of musical structures across a large range of temporal scales, and they exhibit rich and self-organized behaviours. The authors have previously published their findings concerning musical applications of such networks [1, 8, 9].

For this particular musical work, the network consists of six nodes. Each of these nodes possesses a permanent recurrent connection with itself. The connections among different nodes are sparse and their existence changes over time. Each node produces its own unique signal in the form of a sine wave to which it adds all the incoming signals. The summed signal is then passed through a sigmoid wave shaping function which distorts the signal. The slope of the function is automatically adjusted to maintain a stable signal amplitude. The distorted signal propagates across the network connections. These connections process the signal in the following ways: a gain attenuates the signal, a high pass filter removes a DC offset, a low pass filter removes high frequency content that has been introduced by fast changes of the wave shaping function, a delay line delays the signal, and an output gain attenuates the signal before it arrives at the receiving node.

The correspondence between the generative system and the tangible properties of the installation is as follows. The output signal of each node is rendered audible and emitted from the loudspeaker that corresponds to this node. The directionality of the loudspeakers controls the presence and absence of connections in the signal processing network. Whenever loudspeakers are facing each other, a connection between the corresponding nodes is established. The changes in connectivity strongly affect the diversity of signals that propagate through the network. The signals of mutually connected nodes increase in similarity due to the fact that the nodes combine their respective signals and suppress their own sine oscillators. The signals of nodes that are not connected gradually return to their own unique characteristics.

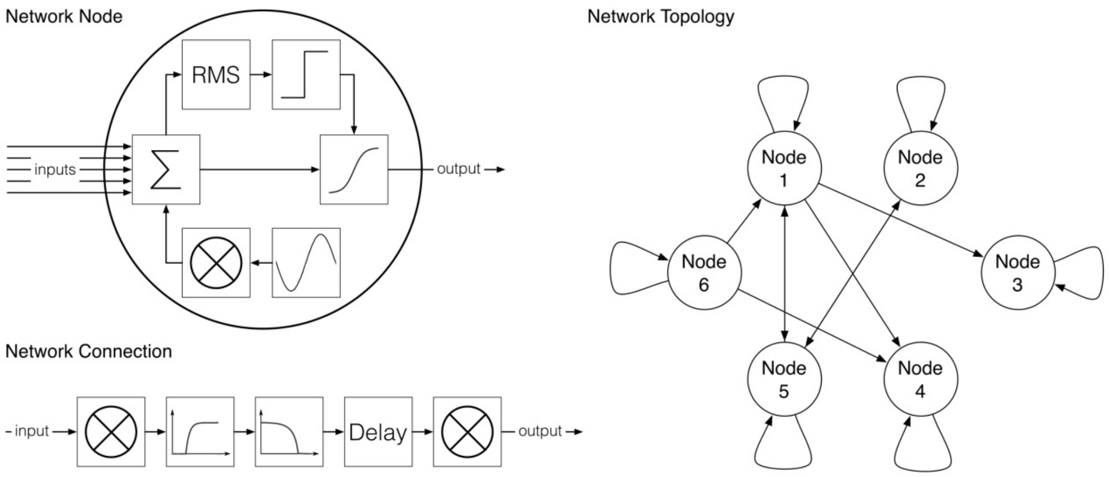

*Fig 1: Schematic depiction of the network employed for the work Recurrence. Shown on the top left are the characteristics of a network node. The symbols are (in clockwise order): signal summation, root mean square of summed signal, threshold function, wave shaping function, wavetable oscillator, gain function. Shown on the bottom left are the characteristics of a network connection. The symbols are (from left to right): input gain, high pass filter, low pass filter, delay line, output gain. Shown on the right side is a possible connectivity in a network of six nodes.*3.2 Synchronization

This work employs Van der Pol oscillators as audio signal generators (see figure 2). The non-linear characteristics of these oscillators gives rise to a sonic output whose spectrum is rich in overtones. The oscillators are inherently stable and therefore do not require external control for stabilization. If certain non-linear oscillators are coupled in a network they can mutually synchronize their frequencies [10]. The frequencies can be identical or related to each other by simple proportions [11]. Synchronization is achieved mathematically by adding to the differential equation describing a single oscillator the state value of another oscillator multiplied by a coupling constant. The size of the coupling constant controls the amount of synchronization that occurs between two oscillators. The larger the difference in the frequencies among the respective oscillators, the higher the coupling value that is required to achieve synchronization.

For this particular musical work, the network consists of twelve Van der Pol oscillators. The output of six oscillators is directly rendered audible. The remaining six oscillators modulate the amplitude of the audible oscillators. The audible and modulating oscillators are organized in pairs in that one modulating oscillator controls the amplitude of one corresponding audible oscillator. All the audible oscillators can potentially be synchronized among each other. The same also applies for all the modulating oscillators.

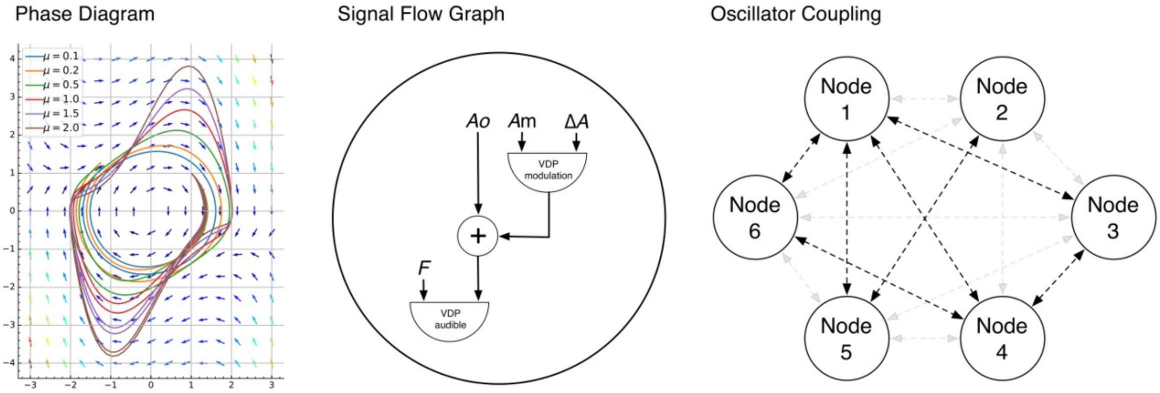

Fig. 2: Schematic depiction of the oscillator architecture employed for the work Synchronization. Shown on left is a phase diagram of a Van der Pol oscillator exhibiting different limit cycles for different values of the μ parameter. Shown in the middle is a node containing the signal graph between a pair of Van der Pol oscillators. The amplitude of an audible oscillator (VDP audible) is controlled (solid arrows) by a second oscillator (VDP modulation). The labels are: reference frequency (F) of the audible oscillator, reference frequency (Am) of the modulating oscillator, width of the amplitude modulation (ΔA), amplitude offset (Ao) to which the output of the modulating oscillator is added. Shown on the right are possible couplings (dashed arrows) among six nodes. They affect either strongly (black) or weakly (grey) the synchronization of the frequencies among the oscillators.

The correspondence between the generative mechanism and the tangible properties of the sound installation is as follows. Each of the audible oscillator emits its sound via a corresponding loudspeaker. The directionality of the loudspeakers controls the value of the coupling constant among the audible and modulating oscillators and also affects their amplitude level.

3.3 Interpolation

This work uses six monophonic synthesizers each of which consists of a resonating filter excited by an impulse generator, an oscillator to modulate the amplitude of the signal, as well as of a white noise generator whose signal is bandpass filtered and mixed to the output signal in varying amounts. The sound quality of these synthesizers can be modified in three ways. First, the attack time of each sound can be changed to lend it a more or less percussive quality. Second, the frequency of the amplitude modulation can be adjusted to control the amount of distortion. Third, the synthesizer's state can be switched to 'inactive' which lowers the volume and adds the bandpass filtered noise to achieve a quieter, noisier and less saturated timbre (see figure 3).

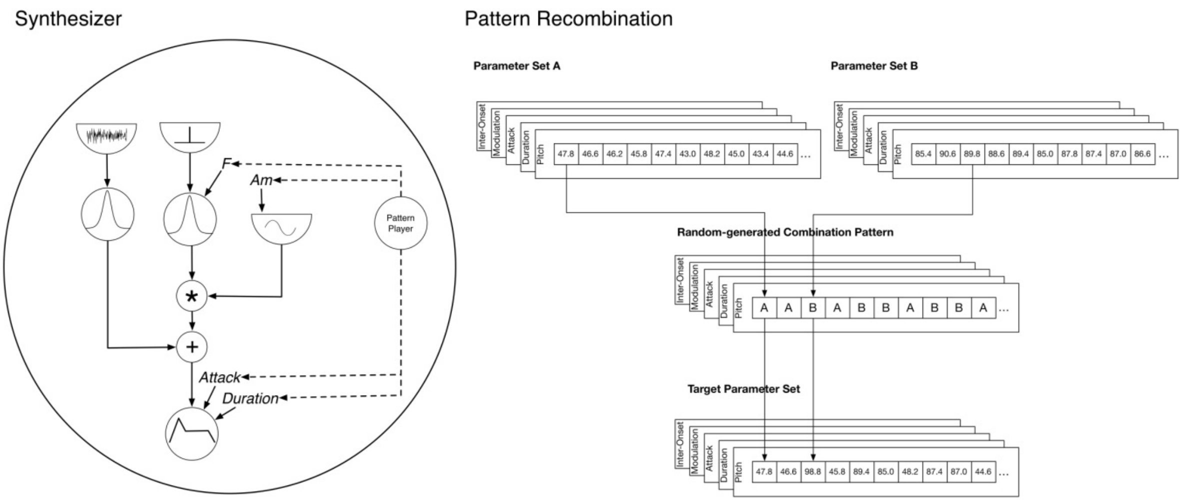

Fig 3: Schematic depiction of the sound generating mechanisms for the work Interpolation. Shown on the left is an instance of the monophonic synthesizer. The symbols are (from left to right and top to bottom): a white noise generator, an impulse generator, two bandpass filters, a low frequency sine oscillator, and an amplitude envelope. The labels are: resonant bandpass frequency (F), amplitude modulation frequency (Am), attack duration (Attack), and amplitude envelope duration (Duration). Show on the right is the pattern recombination mechanism. For each parameter, the two pattern sequences of the two correlated instances A and B are combined into a new target pattern sequence by randomly choosing the values at each sequence position either from pattern A or pattern B.

Each synthesizer is controlled by a generative algorithm named 'pattern player'. This algorithm iterates through a set of five lists all of which contain 15 values. Four of these lists hold the sound synthesis parameters pitch, duration, attack time and amplitude modulation frequency. One list contains the inter-onset intervals, i.e. the times to wait before the next note is played. The pattern player reads these five parameter lists synchronously in a loop to generate a repeating musical pattern of 15 notes. Each loudspeaker's output is individual due to the fact that every pattern player runs through a unique set of lists.

The correspondence between the generative mechanism and the tangible properties of the installation is as follows. When one loudspeaker faces another one, its synthesizer's state is toggled from 'inactive' to 'active'. As a result, the music becomes louder and the noisy sound quality changes to a clean timbre. At the same time, a new set of parameter lists is generated by randomly combining the values of both loudspeaker's parameter lists. This new set of parameters contains half of the original values and half of the other loudspeaker's values. Subsequently, this new set becomes the target for an interpolation process. During this process, the current parameter values are gradually replaced by the values of the target set. As an effect, the musical pattern slowly changes and it becomes audible how the two loudspeakers exchange their musical properties. When a loudspeaker is isolated, its music becomes soft and noisy again. And, after a while, all parameter lists regress to their initial state.

4. Implementation

The hard- and software components that constitute the basic infrastructure of the installation have been custom designed by one of the authors. The software that implements the generative sound producing mechanisms pertinent for each musical work have been developed by each of the three authors individually.

4.1 Hardware

The hardware of the installation consists of a loudspeaker casing that houses a broad band speaker driver, a mono audio amplifier board an infrared light emitter, an infrared light detector, a gyroscope module, and a microcontroller (see figure 4). The infrared emitting and detecting components form the basis for the capability of the loudspeakers to detect and identify each other. The gyroscope module measures the angular acceleration of a loudspeaker. Each loudspeaker is attached to a rotational joint that also houses a slip ring. This joint is mounted on top of a microphone stand. The audio signal, wired communication and power supply pass through the slip ring. Located at the bottom of the loudspeaker stand is a wooden box that contains a Wi-Fi enabled microcontroller and a hum suppression transformer. The Wi-Fi microcontroller serves as interface between the wired communication and a wireless network. A master computer is connected to a Wi-Fi router, an audio interface. The screen is used to show visitors textual information about the currently playing musical work and a visual representation of the *visibility* among the loudspeakers. A schematic representation of this setup is shown in figure 5.

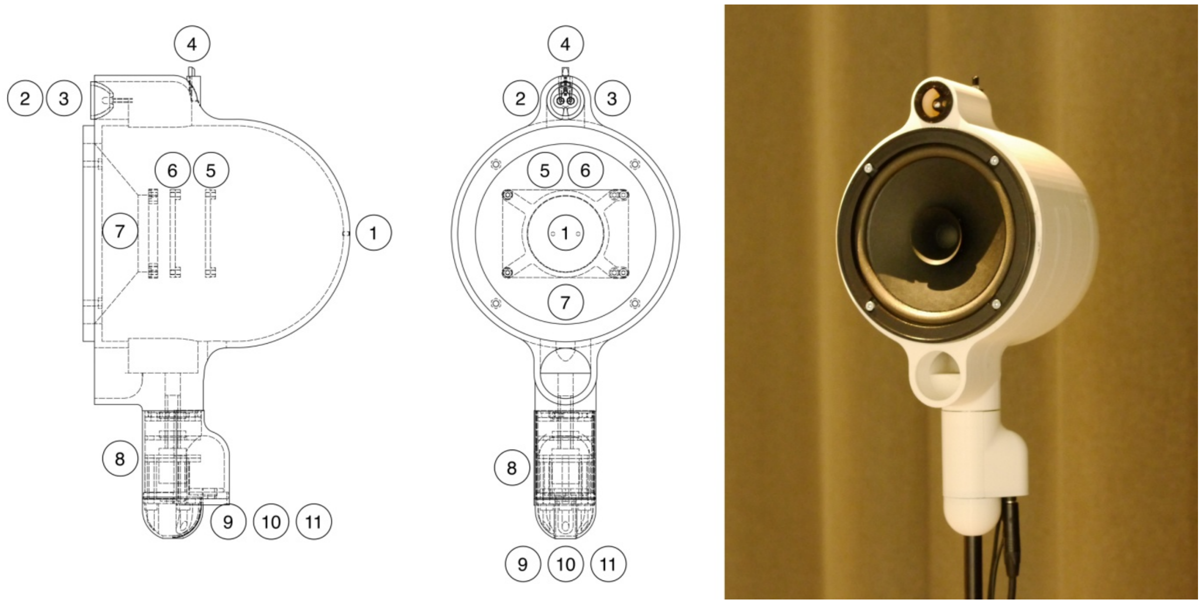

Fig 4: Watchers loudspeaker housing. The schematic depiction indicates several hardware components that have been integrated into the housing. The numbered labels correspond to the following components: 1: status LEDs, 2: white light emitting LED, 3: infrared light emitting LED, 4: infrared light receiver, 5: microcontroller board, 6: audio amplifier board, 7: speaker driver, 8: slip ring, 9: audio connector, 10: I2C connector, 11: power connector.

4.2 Software

A software infrastructure that is required of the installation's basic operation comprises two components: a program that runs on each microcontroller and a program that runs on the master computer. The programs running on the microcontrollers have been programmed in C. These programs control the infrared-based communication among the loudspeakers, the acquisition of the loudspeakers respective identifiers and their transfer via I2C and Wi-Fi to the master computer. The program running on the master computer has been programmed in Processing. It handles the start-up of the installation, the timing of the infrared-based communication, the derivation of the visibility among loudspeakers based on the acquired loudspeaker ids, the communication of this visibility to the currently running musical work, and the switching between different musical works.

The three musical works have been developed in different musical programming environments. The work *Recurrence* has been implemented in the Processing programming environment and makes use of the Beads library. The work *Synchronization* has been implemented using Java within the Max programming environment. The work *Interpolation* has been implemented in the SuperCollider programming environment. All these works communicate with the basic installation software via the Open Sound Control communication protocol.

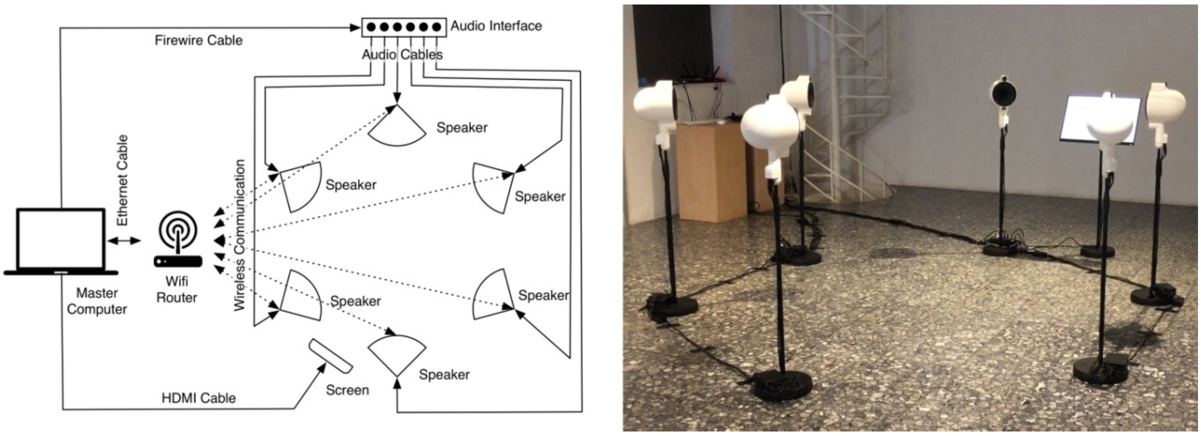

Fig 5: Watchers installation setup. The setup consists of six loudspeakers mounted on microphone stands and arranged in a ring configuration, a screen mounted on a stand, a master computer connected to an audio interface, and a Wi-Fi router.

5. Exhibition

The *Watchers* installation has been shown in 2017 as part of a group exhibition entitled See you hear in the NeMe gallery in Limassol, Cyprus [12]. This exhibition took place in the context of the Sound and Music Computing conference. For this exhibition, the installation consisted of six loudspeakers that were arranged in a circular setup with a diameter of about three meters. The information screen was mounted on a stand and placed outside of this ring setup. A 3D rendering of the exhibition situation is shown on the left side of figure 6. A photograph taken during the opening of the exhibition is shown on the right side of figure 6.

The ring configuration was chosen for two reasons. In this setup, none of the loudspeakers can be oriented in such a way that they see more than two other loudspeakers. As a result, the alignments among the loudspeakers is always partial. The correspondence of the loudspeaker alignment with the sound producing generative processes gives rise to the appearance of multiple musical clusters that differ from each other both spatially and sonically. The sonic changes within each of these small clusters and their correlation with the alignment of the loudspeakers are easier for the visitors to comprehend and control than would be the case for a singular large cluster. Also, this setup permits visitors to interact in two fundamentally different ways with the installation. Visitors can decide to stand either inside or outside of the loudspeaker ring. From an outside position, a visitor is able to carefully align the orientation of individual loudspeakers and then observe from this external listening perspective the resulting changes in the sonic output. This mode of interaction permits a precise exploration of each musical work and fosters an analytic understanding of its generative principles. If, on the other hand, a visitor enters the installation, his or her mode of interaction is much more disruptive with respect to the behaviour of the installation. In this situation, the occluding effects of the visitor's body have a profound effect on the visibility among the loudspeakers. As a result, the spatial aspects of a visitor's movements and the physical extension of his or her body become themselves tangible aspects in the mapping between the installation's physical properties and the sound producing processes. The following subsections describe the relationship between interaction and musical output for each work.

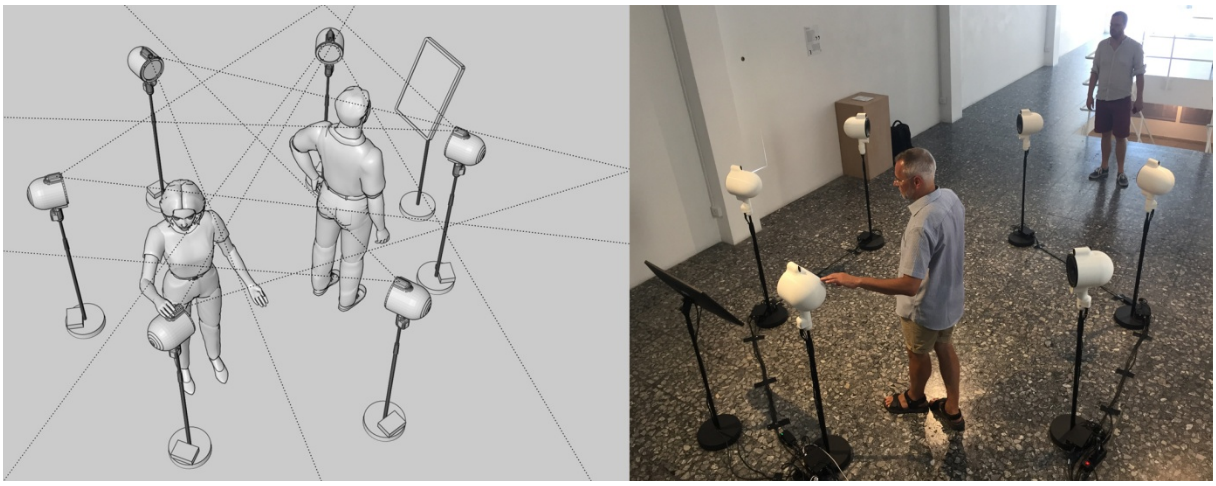

Fig 6: Exhibition situation. Shown on the left side is a 3D rendering of the installation setup including two visitors. The right side shows as photograph of the installation in an exhibition situation. In the rendering, the dashed lines emanating from the loudspeakers indicate visibility cones within which a loudspeaker can perceive other loudspeakers.

5.1 Recurrence

When this work starts, the sound synthesis parameters associated which each node and its own recurrent connection are randomly assigned different values. As a result, each loudspeaker initially exhibits its own unique acoustic signature. This signature helps to highlight the musical consequences of interaction. The acceleration that results from a manual rotation of a loudspeaker is correlated with a change in the delay time of the corresponding node's own recurrent connection. This change triggers a quick, localized and clearly audible perturbation of the loudspeaker's acoustic output. Whenever a change in orientation of a loudspeaker causes it to see other loudspeakers, the resulting establishment of network connections causes the formerly isolated acoustic signal to propagate through the network. As a result, other loudspeakers start to combine their own acoustic signal with that of the propagating signal. This effect is particularly well perceivable when the propagating signals are being affected by the previously described acceleration-based perturbation. And it is also particularly well perceivable when the propagating signal bounces back and forth between nodes via recurrent connections. This eventually leads to a harmonization of the sonic output of all nodes involved. Rotating a loudspeaker into an orientation in which it can no longer see other loudspeakers will cause the output signal of its corresponding node to gradually re-acquire its original sonic characteristics.

5.2 Synchronization

Upon initialization, the frequencies of all Van der Pol oscillators are assigned random values and their coupling constants are set to zero. As long as the oscillators remain in a non-synchronized state, each of them produces a unique acoustic output. When loudspeakers are manually rotated to face each other, the coupling constant of the corresponding oscillators increases rapidly, causing their respective frequencies to quickly settle into a harmonic relationship. This sonic effect is further accentuated by an equally quick increase in the amplitude level of the corresponding oscillators. As a result, synchronized oscillators are sonically clearly distinct from their non-synchronized counterparts and dominate the overall musical result. When loudspeakers are turned away from each other, the coupling constant and the amplitude slowly decreases towards their initial values. Accordingly, the acoustic output of these oscillators gradually fades back and merges with the background of non-harmonic sounds.

5.3 Interpolation

When this work starts, all six loudspeakers emit an individual musical pattern as their parameter lists are in their initial state. The initial parameter lists are designed to make these six musical patterns clearly distinguishable. Their values are each in a narrow range, hence, each loudspeaker plays notes in its own pitch range and in its own rhythm. When two loudspeakers are aligned, they start to influence each other. They randomly exchange some of their parameter values and new musical patterns emerge. When loudspeakers are turned away from each other, they return to their initial pattern. This process, however, takes some time. Thus, if these loudspeakers are aligned soon enough with yet another loudspeaker, they pass on some of their inherited properties. This is particularly perceivable for those parameters that stick out: high pitches, sharp attacks, short durations. By constantly aligning new pairs of loudspeakers, the visitors can control how several musical features spread among the whole installation.

6. Discussion

The following section compares the different compositional approaches. The comparison distinguishes between aspects that are predetermined by the chosen interaction affordances and metaphorical mappings and aspects that have been freely chosen.

The following compositional aspects are predetermined:

- the generative systems are organized in a modular manner. Each module represents an individual sound generating unit whose output is rendered perceivable through a corresponding loudspeaker.
- the visibility among loudspeakers affects the amount of correlation that is established among the generative units.
- the binary state of the loudspeaker’s visibility (loudspeakers are either visible or invisible to each other) is correlated to a binary change in the generative sys-tem (addition or removal of network connections, high or low coupling values, permutation or preservation of musical patterns).

The following compositional aspects are not predetermined are shared by all works:

- all sounds are synthetic rather than pre-recorded.
- the interaction affects the balance between a musical foreground and a musical background as the acoustic outputs of correlated units are more clearly perceivable than those of the uncorrelated units.
- the generative processes cause the musical output of correlated units to become increasingly similar to each other.

The commonality of these non-predetermined aspects is interesting since it is based on voluntary decisions made by the three authors. These existence of these commonalities can shed some light on how strategies derived from tangible computing can inform and inspire compositional ideation. The choice of using synthetic rather than pre-recorded sounds is likely owed to the fact that sound synthesis allows for a precise control of the characteristics of a musical output. This level of precision is a prerequisite for realising a gradual assimilation of the musical output of correlated generative units. The choice to relate the alignment of loudspeakers to an increase in musical correlation is at the same time straight forward and arbitrary. For future compositions, it would be interesting to experiment with the opposite approach of relating loudspeaker alignment to musical differentiation. The acoustic dominance of correlated units which is common to all three musical works leads to a reinforcement of the physical affordance that is already given through spatial alignment. As such, the compositional approaches employ musical strategies that integrate into themselves some of the interaction concepts from tangible computing.

Lastly and most importantly, the differences among the three compositional approaches are to be mentioned. These differences highlight the breadth of creative possibilities that are available to composers even if they adhere to the constraints imposed by specific interaction and mapping principles. The three musical works differ with respect to the following aspects:

- the work *Recurrence* employs a signal processing approach in which the coupling among generative units is achieved by passing audio signals through connections.
- the work *Synchronization* controls the coupling among generative units by changing the parameter values for an oscillator-based sound synthesis.
- the work *Interpolation* exchanges and permutes parameter patterns among generative units as part of its coupling mechanism. These patterns can be likened to musical symbols that operate on note level.

These differences are the result of the application of three fundamentally different compositional strategies. The work *Recurrence* is representative of approaches that directly operate through routing and mixing of audio signals. The work *Synchronization* is representative of musical systems that directly link interaction to changes in sound synthesis parameters. The work *Interpolation* is representative of algorithmic compositional approaches that generate 'musical scores' in real time.

7. Conclusion and Outlook

The creation of several generative compositions for the *Watchers* installation illustrates how design principles from tangible computing can serve both as inspiration for coming up with new musical ideas and as means to foster an audience's understanding and appreciation of the aesthetic and formal aspects of a musical work.

This installation represents one particular example of relating affordances for interaction with the generative aspects of musical works. It is clear, that many other approaches exist that are at least equally valid and promising for the creation of interactive and generative sound installations. But in order start this research into the potential that tangible computing possess for interactive generative music, the authors deemed it useful to focus on a small number of interaction and mapping strategies only. The fact that this research led to the emergence of musical works that are on hand commonly grounded in the interaction scenario provided by the installation and on the other hand represent a wide diversity of compositional approaches lends credence to the usefulness and validity of this approach.

To continue along this research trajectory, the authors plan to develop additional interactive installations as platforms for exploring new compositional approaches for creating generative music. Each of these installations will establish a different type of tangible affordance and mapping metaphor and render them available for the composers to work with. By doing so, the authors hope to contribute to a systematic assessment of the creative and educational potential that tangible computing possesses for the field of generative music.

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