Contingency and Synchronization: Conceptual Framework, Artistic Experiments and Speculative Syn-theses

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Introduction

One of the strongest motivations for working with algorithms in any artistic practice is the desire to be surprised, to initiate processes that can give rise to something that can develop, react, and transform in an indeterminate, open, and at least partially autonomous way. Self-organizing systems, machine learning, and stochastic processes may serve as examples of distinct branches of generative procedures that artists explore in order to achieve unexpected aesthetic results, inexhaustible variation, and non-teleological development. At the same time, these concepts and technologies are also used, in the arts and beyond, due to their potential to make behaviors and developments more predictable, stable, calculable, and controllable. Hence, there is an inherent tension between openness and predictability. This paper discusses the practice-based research project *Contingency and Synchronization*, which revolves around this tension and which deals with the question of how algorithms can produce something new and unpredictable, in other words, with the contingency of computational processes. At first glance, contingency and synchronization seem to be diametrically opposed notions, one pointing towards surprising indeterminacy and the other to the deterministic leveling out of differences. However, this project practically works through how one can be expressed through the other.

Contingency and Synchronization is an ongoing series of works that began in 2019 that makes use of distributed multi-agent networks that explore computational synchronization phenomena, while always reflecting on the ways in which these computational processes are rooted in and interconnected within material conditions, such as acoustics, spaces, listeners, computing machines, and objects.

The series has an iterative character. Each iteration repeats initial questions and constitutes a new step so that the whole series can be seen as a computational process. Each iteration renegotiates the relation of contingency and synchronization and attempts to connect computation, site, and listening in ways that are specific to its material format. The formats include spatial and web-based installations, visualizations, and fixed media renderings. In doing so, we transform the nature and role of

Musica/Tecnologia, 17 (2023), ISSN online 1974-0050, ISSN print 1974-0042, pp. 95-116
DOI: 10.36253/music_tec-15198 – http://www.fupress.com/mt

synchronization and the way in which contingency emerges and intervenes in deterministic processes, pointing to ways in which algorithms and different types of materiality are entangled. On the one hand, contingency is essential to the explorative production process, the unexpectedness encountered while developing the work. We aim to be sensitive to the ways in which our material exceeds our conceptualizations. On the other hand we seek to expose a type of contingency in the aesthetic experience of the artistic results; the artistic outcomes seek to create a potential for experiencing contingency.

The central concepts of contingency and synchronization allow us to articulate, compare and pursue the aesthetic specificities of the physical setups and computational dynamics. Each work creates a different relation between contingency and synchronization. Rather than attempting to implement or illustrate certain pre-existing ideas, however, we seek to discover aesthetico-conceptual constellations that result from the experimental and practical entanglement of computation, sound, site, and collective artistic decision making. This paper is thus a reflective documentation that aims to account for the central conceptual and artistic repercussions of this series of works.

We can describe the practice we have developed during this project as a careful choreography of situations that have the potential of discovery. In other words, we have aimed to develop a method for guiding the conception and staging of our works; that is a method to construct situations that may reveal something previously unthought, un-sensed, or something we had not or could not foresee or foresense. Our method is one of eliciting *the unexpected*. What we mean with the unexpected are aesthetico-conceptual patterns that feed back into our thinking and in turn require a change in our ways of engaging with them. *The unexpected* is therefore less an arrival point or a conclusion in our work. Rather it is the origin of a novel perspective allowing for a different reading of our works and therefore also allowing for the development of new artifacts that would, in turn, have the potential of unexpected outcomes.

Iteration is thus at the very core of the project we have followed: not only in the generative processes we have composed, but also in the way we have choreographed our working, thinking, and perceiving. Simply put, *Contingency and Synchronization* has developed into a sort of aesthetic laboratory where we engage in an aesthetic experimental practice. Crucially, it is a pretext to put our assumptions (about sound, space, perception, computation, etc.) to the very test while imbuing them with a materiality capable of producing perceivable consequences. Ultimately, with *Contingency and Synchronization* we want to push further our practice in computer music and hopefully, by exposing this project publicly, the practice of others.

In what follows, we will first outline the central concepts of synchronization and contingency and how we conceive their relation in this series of works. This is followed by a discussion of the artistic practice, the different works, or "iterations" that this series consists of. This separation between "theory" and "practice" is made here due to the necessary linearity of the paper format. Actually, the conceptual work and the artistic experiments are entangled, even if they retain a certain degree of autonomy. We discuss three practical works: initial visualizations, an on-site sound installation and an online installation. Apart from the two central concepts and their relation, we will deal with

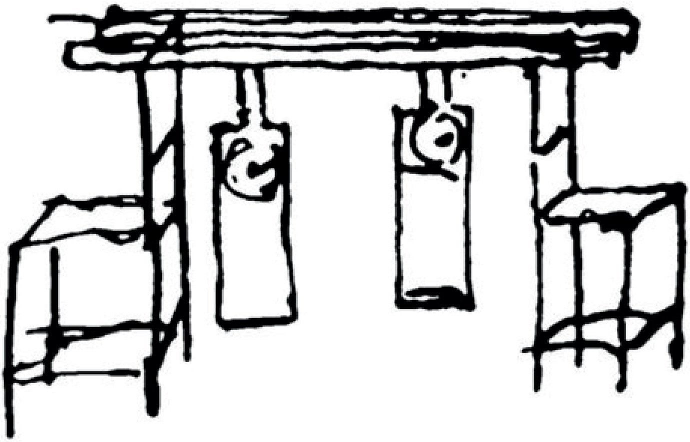


Figure 1. Drawing by Huygens of his 1665 experiment.

the role of listening, emergence, computation, space, and performance on the basis of these works. The discussions of the conceptual framework and the artistic experiments feed into the following section, which sketches a number of speculative theses, that aim to articulate central yet possibly tentative findings and positions that have characterized this project. These theses are speculative, because they are not condensed insights gained within the project, but rather vectors pointing beyond what we have done in the project so far. We will conclude with an outlook that sketches how *Contingency and Synchronization* will feed into a larger upcoming three-year research project[1].

Conceptual Framework

Synchronization

Historically, the study of synchronization phenomena started with the work of the Dutch researcher Christiaan Huygens who, in 1665, observed how two clocks lock their rhythms (Huygens & Blackwell, 1986). The clocks were suspended from the same wooden beam and independently from the starting conditions they would consistently and precisely synchronize their ticking after some time. After Huygens' experiment, it is however only in the nineteenth century, when similar phenomena were observed in diverse fields, that scientific interest in synchronization grew stronger leading to more systematic studies. For instance, in his treatise "The Theory of Sound", Lord Rayleigh observed how synchronization between neighboring organ pipes may even lead to tones disappearing (Rayleigh, 1896). A few years later B. van der Pol discovered how synchronization might be used to stabilize frequency genera-

[1] More information about the Speculative Sound Synthesis project can be found here https://speculativesoundsynthesis.iem.sh/

tors (van der Pol, 1927). Since then synchronization has become a highly active field of mathematical, physical and technological research. Synchronization (sometimes also termed entrainment or locking) now appears as the basis for studying ubiquitous phenomena in nature on different temporal and spatial scales from very large (e.g. planets and satellites synchronize their orbits, like the earth and the moon) to very small (atoms synchronizing their oscillations, for instance in lasers), in biology (insects synchronizing to each other) or medicine (such as the human heart beat and respiration patterns as well as synchronization phenomena between neurons). Formulating, modeling and understanding synchronization might therefore lead to a better understanding of many systems.

As a research topic, synchronization can be placed in the context of the study of dynamical systems, in particular in the field of nonlinear dynamics. In this context, the term synchronization identifies the mathematical formulation and modeling of mutually interacting systems and the study of the patterns that emerge from the temporal unfolding of that interaction. Due to the nonlinearity of interactions, the temporal behavior that synchronizing entities might produce are not just limited to the convergence to a common rhythm (as in Huygens' case): on the contrary, patterns might exhibit a variety of qualitatively different behaviors, ranging from regular to chaotic processes following unpredictable trajectories (Pikovskij et al., 2007, pp. 91, 213).

Apart from their clear importance for science and technology, the essential aspect that attracted us to synchronization systems is that they are oscillatory processes that are *open* and exposed to disturbances, be they internal or external. For the sake of simplicity, the mathematical and physical study of temporal evolution, i.e. of dynamical systems, always departs from approximate systems that are *closed* and *autonomous*. Among these systems, synchronizing systems stand out as they are per definition systems that are open to external influences. In fact, there is no synchronization at all without interaction or without disturbances effectively entering into each part of a system, causing sensible deviations. In physics, the part of the mathematical formulation that describes this interaction is called *coupling*. In general mathematical terms, synchronization systems maybe written in this form:

$$\frac{dx}{dt} = f(x) + p(x,t)$$

This equation describes the temporal evolution of a system x, depending on its own internal dynamics $f(x)$, but also influenced by an *external* perturbation $p(x,t)$ which changes in time t. The strength with which this external influence causes deviations in the system's own dynamics is determined by the value of the factor ε, called *coupling.*

In particular, for the computational processes we consider, the so-called *Kuramoto Model* (Kuramoto, 1975). It is still one of the most studied synchronization systems, and is our starting point. The model gives an elegant, compact and simple mathematical formulation of a system of mutually interacting oscillators:

$$\frac{d\phi_i}{dt} = \omega_i + \varepsilon\sum_{i=0}^{N} sin(\phi_k - \phi_i)$$

This formula has a similar form as the previous one: it describes a system which has a simple internal dynamics (the constant phase increase ω_i) and that is disturbed by some other dynamics (the $\sum_{i=0}^{N} sin(\phi_k - \phi_i)$ term). The Kuramoto model formulates the temporal evolution, i.e. the dynamics of a set of N oscillators ($i=1..N$), identified by their phases ϕ_i. These oscillators follow their internal dynamics, which is a constant frequency ω_i and are also influenced by all other oscillators through the nonlinear interaction term $\Sigma sin(\phi_k - \phi_i)$ whose strength is controlled by the coupling strength.

In this form, the Kuramoto system formulates the synchronization behavior of an ensemble of mutually interacting oscillators. In this model, the disturbance for each of the elements comes from within the system, rather than from a completely unknown "outside". Despite its formal nature, it has proven to serve as a good model for more general systems. Further, it was particularly interesting for us as this is a very concise model, involving only one variable (the oscillators' phases) and essentially only two free parameters: frequency and the strength of coupling between oscillators. However, when computed numerically, by choosing different parameter sets, this model may already generate a great variety of qualitatively different behaviors, as we will see further below.

It is important to emphasize the difference between synchronization and the concept of *resonance* as the terms seem to apply to very similar situations. Resonance applies mostly to linear systems, i.e. systems that have a linear coupling with others, as in, for instance, linear time invariant systems. Resonance is thus the behavior of a system as it reacts to an external stimulus. A good example is a pendulum on which a periodic force is applied: the pendulum's behavior may exhibit resonances depending on the frequency of the forcing oscillation. Synchronization, however, refers to a behavior that appears when two (or more) systems that are in some way *active,* possessing an *internal* rhythm or behavior are interacting with each other (Pikovskij et al., 2007, p. 15). Thus, while resonance deals with systems that are passive (e.g. filters in signal processing), synchronization looks at systems that are not just falling into one specific mode, but are open to *continuously adapting* each moment of their interaction, engaging in an ongoing negotiation.

The aspect of *opening* is for us a fundamentally aesthetic one: the inherent affordance these systems have towards being linked, interconnected, of "being with" something that is external, is not merely a formal acknowledgement of a fact. We take it as formulation of an essential trait of how we, as sound artists, understand action and perception, sounding and listening and their relationship. For us, it is more than just a causal unidirectional connection: rather, we see it as a reciprocal interaction or as mutual influence between the involved actors, perceiving or acting. In a synchronizing system, all agents establish a tight connection between what is "heard" and their action, a connection that is both internal – what is listened to affects the inner rhythms –, and external – one agent's actions affect what others' perceive. Eventually this means that what sounds changes with respect to how the environment in which it is situated reacts and what listens changes in dependence of what sounds. In a sense, our work's pivot is this specific, active and consequential way of listening.

The synchronizing systems we used in *Contingency and Synchronization*, with their inherent coupling to the outside, allows us not only to take this aesthetic perspective, but also to put it to “work” concretely by making it the very core of the generative sound processes we compose. Thus, the core of our artistic practice transforms into a kind of choreography of interactions, into a composition of relations between all involved elements we can distinguish in a particular setting and that are contingent on that space: the sound synthesis algorithms we devise, the particular technological setup we use, the acoustic environment we are in, the audience’s behaviors etc. When all these elements, these multiple agents of disparate materiality have to be regarded as mutually affecting actors, we are composing an ecology rather than “just” a sound or visual installation. When all these actors interact, what we hear and experience is the behavior emerging from that particular complex ecology of contingent relations.

Contingency

The philosophical concept of contingency is commonly defined as the opposite of necessity (Blackburn, 2005, p. 248), as that which may but does not need to happen. The domain of this necessity, or lack thereof, may be physical, logical, or metaphysical. A contingent sound event, for example, can be understood as one that may emerge or die away, may occur or not occur, have certain timbral characteristics or others without contradicting its context of creation, be this context a musical composition, an algorithm, the instrument that produces it, or any sonic environment more generally. Contingency, however, does not refer to the lack of knowledge of the reasons for the occurrence of a sound event; it rather denotes the positive knowledge that it may not have occurred or that its timbre or duration may have been different (Meillassoux, 2008, pp. 53–54). In a sense, contingency forms the basis for a strong form of indeterminacy, an openness, such as in the sensitivity to initial conditions or external disturbances of a generative process. Contingency points to an opening beyond commonly attributed values and meanings, an aesthetic shift that disrupts the way in which we make sense of the world as it reveals a potential for things to be different. Contingency can thus be understood as the intrusion of a present but rarely acknowledged dimension into the realm of human sense making, which seeks the orienting stability of the appearance of necessity. For the works discussed in this text, this dimension is primarily constituted by relations among diverse processes, materialities, and time scales. We are trying to render perceptible how external disturbances and conditions determined by such relations affect the emergence of form and thus connect the human listener to their environment.

Contingency may be thought of in terms of ‘possibility’, however it is precisely not a possibility that can be captured by a probability. A contingent sound does not pre-exist as part of a set of possible states, selected by chance due to a certain probability, or at least it is not contingent because of its stochastic selection. This distinguishes contingency, as we aim to conceive it in this project, from methods of introducing indeterminacy into musical composition that rely, for example, on pseudo-random number generators or on the performer’s selection from a set of possible actions. Such strategies try to open the artistic work up to the indeterminate, but on the condition of making it predictable, of capturing it in representational terms. Thinking in terms of possible states relies on an attempt to represent, control, and circumscribe contingency, it is made compatible and "affordable," a "domesticated contingency" as Reza Negarestani puts it (Negarestani, 2015, p. 13). Contingency is not the choice of one state from a set of possible states. The distinction between contingency and possibility, as we practice it in this series of works, is perhaps akin to Deleuze's famous critique of the concept of the possible vis-à-vis his concept of the virtual: "The possible is opposed to the real; the process undergone by the possible is therefore a 'realisation'. By contrast, the virtual is not opposed to the real; it possesses a full reality by itself" (Deleuze, 2001, p. 211). The possible has no existence prior to its 'realization' and is based on a representative relation to the real; it is "an image of the real" (Deleuze, 2001, p. 212), as Deleuze writes. The works described here aim to explore forms of contingency that are always actual. It is the actual interaction, the *con-tingere*, the encounter of actual entities, such as computational processes, the physical technological setups, the listener, the space, and the changing sonic environment that give rise to indeterminacy. Indeterminacy thus does not derive from the statistical representation and prediction of processes, but from their connections and sensitivity to be influenced. Even if we design and develop systems with regard to their potentials and thus shape processes with certain circumscribed identities, limits, and boundaries, these potentials are not sets of possible states to be realized, but behaviors that produce contingent situations as a result of their interconnections.

However, contingency cannot simply be exposed directly. The contingent interaction of entities is ephemeral and inconsequential if it does not leave traces. It needs to be inscribed into a medium and thus paradoxically be turned into a kind of necessity. The biological evolution of life forms is a good example for this process: Biological form is the product of retaining effects of contingent environmental changes, genetic mutations, encounters, and disturbances. The synchronization algorithms we employ in this series of works allow for ephemeral contingent events to have consequences, to *take shape*. These algorithms are deterministic and even follow a form of inner telos, a tendency that can be regarded as a kind of necessity. Due to this telos, the synchronization processes can be affected and coupled to other processes. Disturbances can unsettle synchronization, propagate through a topology of connected oscillators and thus have lasting consequences. Synchronization acts as a form of interface that is sensitive to contingent outside disturbances, events which synchronization transforms into its own morphogenetic dynamics. The telos of coupled synchronization allows for contingently emergent forms. We thus experience the openness of contingency through deterministic synchronization. The different instances of this series of works renegotiate the interior and exterior of the work and in doing so, they expose different forms of contingency, both internal and external, both perceptual and ontological, both computational and material. Each iteration of the work redraws the borders between inside and outside, between event and emergent form.

The notion of emergence informs this series of works, in particular because it opens a way to overcome the static opposition of form and material. Emergence allows for the conception of form as the result of the interaction of material processes. Form can thus be understood as a product of a material process instead of being imposed onto material. Moreover, it is particularly the agent-based conception of emergence that informs our works. As John Holland writes, "Emergence occurs in systems that are generated. The systems are composed of copies of a relatively small number of components that obey simple laws." (Holland, 2000, p. 225)

While emergence produces irreducible strata beyond its constituent elements, it is not necessarily contingent, surprising, unpredictable or indeterminate. Technology, for example, relies on the predictable capacity of material encounters to give rise to emergent forms. Emergence thus describes a type of stability. Moreover, the emergence of new organizational levels, and the ideas of upward and downward causation imply an idea of hierarchy, as Holland writes, it is "much coming from little" (Holland, 2000, p. 1). Life and consciousness, the paradigmatic examples of hierarchical emergence, constitute the irreducible peak of an ever more complex ascent from matter to thought. In contrast, we seek a transverse non-hierarchical form of emergence, a "transmergence". Instead of an ascent there is a constellation of connected materialities and orders of magnitude that give rise to each other. Much comes from much, little from little, little from much, and much from little. Form is not the higher-level product of lower-level interactions. It comes into existence due to the interactions of diverse processes, objects, spaces and sound, from their boundaries, limits, and interfaces. Hence, for us a central compositional criterion for developing systems and forms of interaction is their capacity to allow for conditions and disturbances to be able to take effect. This sensitivity, or capacity to be affected, is a prerequisite for contingency to produce new forms.

Artistic Experiments[2]

Visualizations

As part of the first encounter with phenomena of synchronization, we have developed a series of small visualizations which have helped us gain a better understanding of the behavior the systems we developed could produce. The simplicity of the mathematical formulation of the Kuramoto system seems counterintuitive when contrasted with the sheer multiplicity of qualitatively different behaviors it is capable of producing. This is especially true when the synchronization system comprises multiple synchronizing entities or agents: In fact, some forms of evolution appear only when the system's complexity, i.e. the number of interconnected interacting elements, exceeds a threshold. Given that our specific interest lies not in eliciting complex behavior, but rather in searching for the "minimal" thresholds at which new structures emerge, the "phase transitions" in the patterns of evolution, we wanted to be able to observe how systems composed of a great number of elements evolve. While working on our first

[2] Recordings, videos, code, and further texts on the artistic experiments can be found at: https://www.researchcatalogue.net/view/1825188/1825189

sonifications of smaller systems, we therefore decided to devise visualizations of larger systems and explore their parameter space.

The terms 'understanding' and 'observing' are here used less with a mathematical or scientific meaning, and rather in an aesthetic sense. It is not our principal interest to be able to formulate in a mathematical language what we observe, but to explore, open and re-compose the space of material possibilities of which an in itself closed mathematical form might be the origin.

The first work, *Iteration 1*[3], consists in a web application developed with the *elm* programming language[4,5], that computes a synchronization system to generate grayscale images (see table 1). The model the application is based on is a simple Kuramoto model of a one dimensional "chain" of multiple coupled oscillators. Each row of the resulting image consists of a series of square boxes, one for each of the oscillators in the model; the gray color of each box relates to one oscillator's phase, ranging from black to white[6].

The first row of boxes from the top left to the top right of the image is a representation of the initial state of the oscillators. Each subsequent row in the image is associated with the oscillator's state after one step of the process: the model's evolution may thus be read observing the relative gray scale changes between neighboring boxes and from top to bottom.

The application allows to set the number of oscillators in the model and the number of steps that should be computed, the distribution of the random initial conditions as well as the distribution of their intrinsic frequency and coupling strengths. Further, it is possible to switch between two different coupling models: in "neighbors diff" only the nearest neighbors in the chain are coupled (see figure 2), while in the "all diff" version all oscillators are coupled (see figure 3). All the images below (see table 1) were generated using 300 oscillators and various parametrizations of the model.

In the second visual iteration, *Iteration 1b*, again a Kuramoto model is used to compute the behavior of a large set of interacting oscillators. In this case, however, the oscillators are organized spatially on a two-dimensional plane: each oscillator is coupled only with its four nearest neighbors, two along each spatial axis (see figure 4). In this iteration a synchronization process with a great number of oscillators is computed, 192 times 192: In this case the phase state of each oscillator maps to the gray scale value of a square box on a canvas. The spatial distribution of the oscillators in the computational model thus corresponds to the placement of each square. Therefore, for each step of the process, one single image is drawn and the temporal evolution of the whole system may be experienced observing how phase changes from one image to the next. While in the previous iteration the work has no temporal axis, i.e. one still image is generated, this second work generates a *stream* of images.

[3] Accessible at https://almat.iem.at/assets/kuramoto/main.html

[4] https://elm-lang.org/

[5] The application's code is openly accessible here: https://git.iem.at/almat/almat-ld/-/tree/master/elm

[6] In order to avoid discontinuities in the visualization a mapping based in the sine of the phase of each oscillator has been used e.g.: $g = (\sin(\theta) + 1) / 2$, where g is the gray value of the box and the phase value of the associated oscillator.

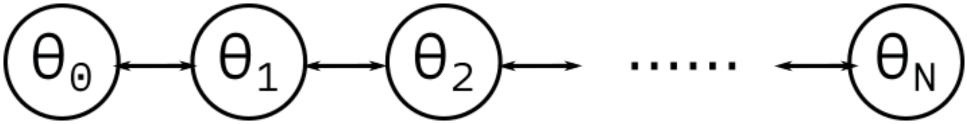


Figure 2. Coupling oscillators with nearest neighbors.

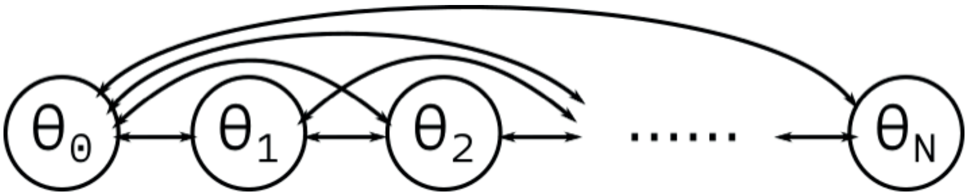
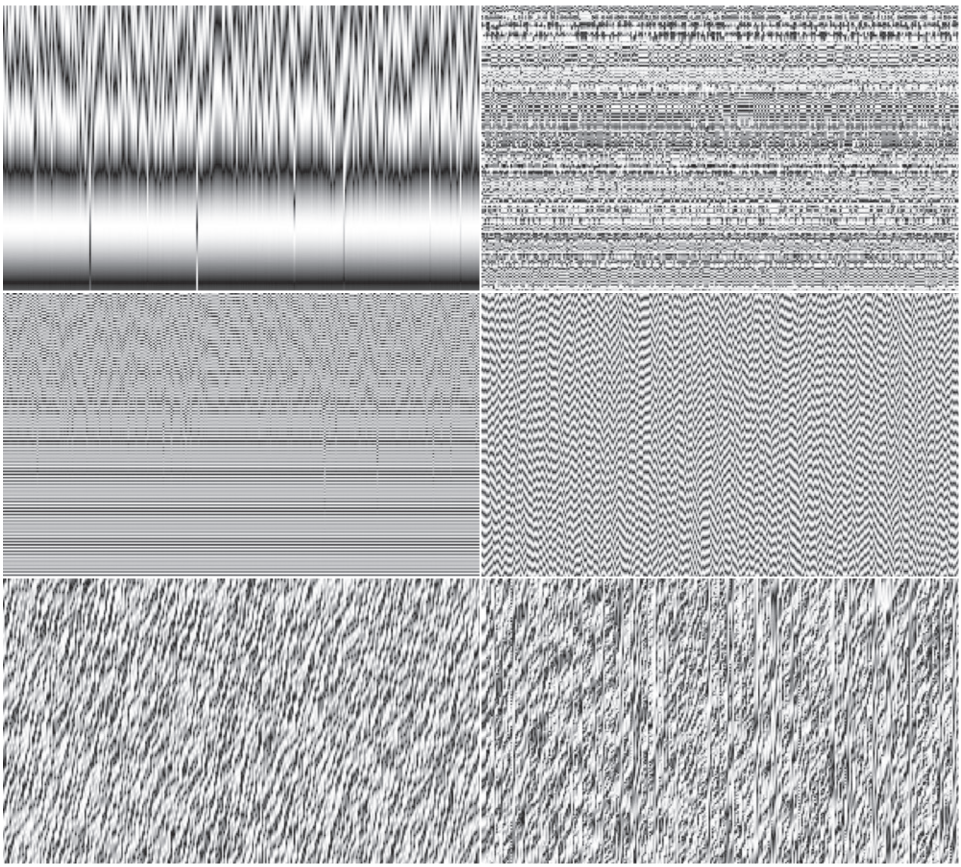


Figure 3. Coupling of all oscillators with all other oscillators.

Table 1. Visualizations of different parameter settings of the one-dimensional Kuramoto model.



This iteration was generated with a program written in the *Fortran90* language and is based on a slightly extended version of the Kuramoto model. In this version the interaction term contains higher-order interaction components (Hansel et al., 1993)

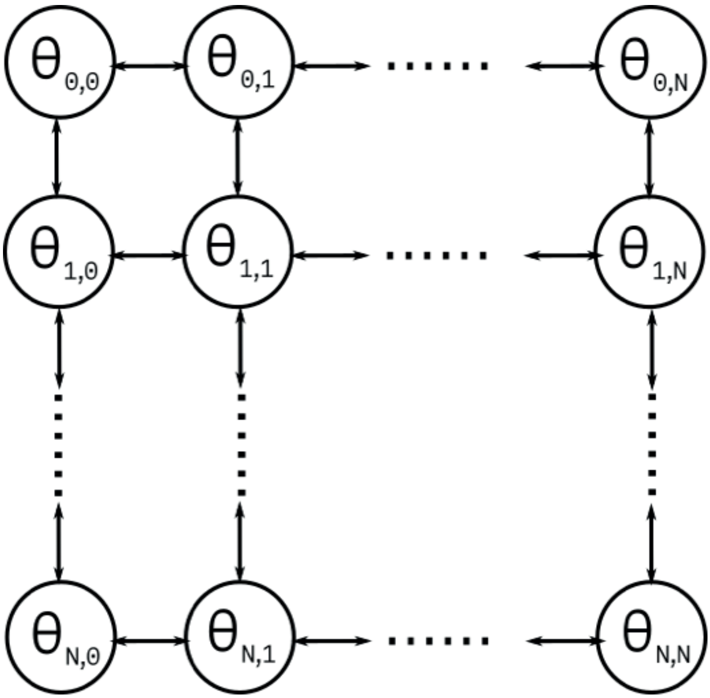


Figure 4. Two-dimensional coupling with a set of nearest neighbors.

(the original Kuramoto model approximates the coupling to the first term of a Fourier expansion).

$$\frac{d\phi_i}{dt} = \omega_i + \alpha sin(\phi_i - \phi_j - \beta) + \gamma sin(2(\phi_i - \phi_j))$$

The images below (see table 2) collect some of the different spatial and temporal types of behavior that this computational process generates. Always departing from a random distribution of phases, already simply modulating the relation between the oscillator's frequency and the coupling strength the model may produce a variety of global patterns *emerging* from the local interactions between oscillators. Especially activating the higher-order interaction components produces interesting interferences and superimpositions of two different pattern or behavior "phases" coexisting at the same time. These spatio-temporal structures cannot be read or be foreseen only from the mathematical formulation of the model or its computation implementation.

Some of those patterns undoubtedly arise solely from the properties of the numerical process: the inherent approximation of numerical integration, the time and and magnitude scales chosen, and the size of model that can be computed within an acceptable time frame are some of the factors that have a qualitative effect on the generated behavior. On the one hand, in most computation related practices, technical, scientific, and artistic alike, such approximations or numerically induced limitations are considered errors to be corrected or to be minimized in an attempt to fulfill external predefined expectations. On the other hand, there are artistic practices, as for instance in so-called *glitch art*, that make such errors or unwanted artifacts their very aesthetic and generative core. In our work, we follow neither of those approaches. We are aware and accept that these are aspects proper to the computational process we develop; we are interested in how mathematical forms and their computational implementation, both with their specific qualities and forms, encounter each other. This is not an encounter without friction, it is more a collision than a smooth transition. However, this encounter opens up a space of material spatio-temporal structures. By disregarding computational artifacts as mere errors or by dismissing mathematical formulation as abstract forms incapable of dealing with the material this space would remain unreachable. We consider the unforeseeable and computationally specific material forms we find while exploring this space aesthetically a form of *computational contingency*, which is especially true in the case of the visual iterations we are presenting here, as these generative processes are not influenced by external factors.

Considering such computational processes and mathematical forms as independent and at the same time deeply related, entangled in a mutual interaction, we carefully choose, devise, and compose each of them. It is part of our aesthetic work to experiment with and choose a dynamical system to work with as well as trying out and picking the numerical integration algorithm generating the most interesting artifacts. Therefore, in the collection of images below, we may find patterns for many so-called *reaction-diffusion dynamical systems,* also called *Turing patterns* (Turing, Alan Alan Mathison, 1952), the so-called "waves", "pinwheels" or "chimeras", but also patterns clearly generated by purely computational artifacts, as well as a mixture of both.

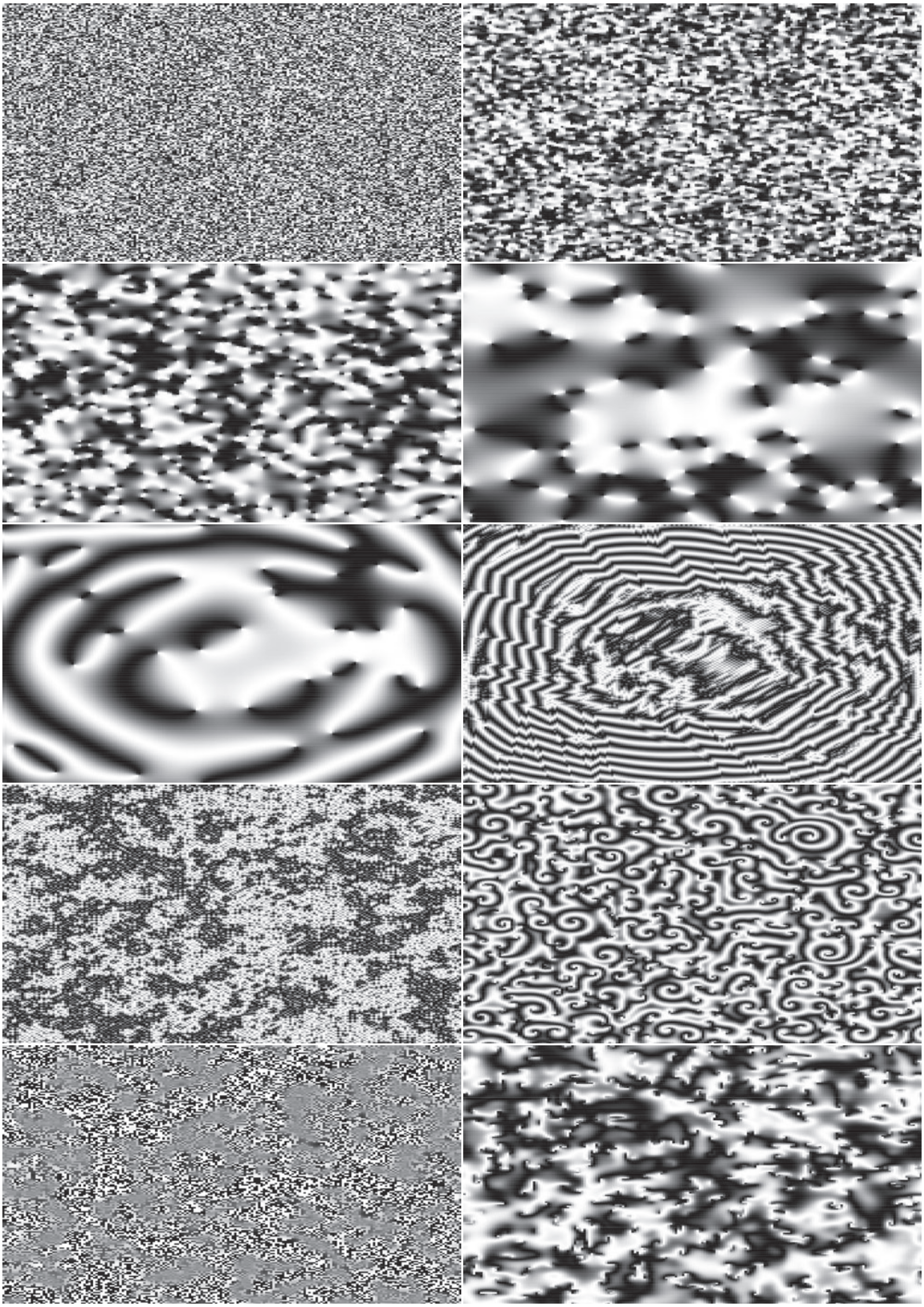
On-Site Installation

The second iteration is a sound installation premiered at the Orpheus Institute in Ghent in March 2019 as part of the *Simulation and Computer Experimentation in Music and Sound Art Seminar*[7]. It consists of a network of six coupled oscillators. It is the first iteration that transposes a purely computational idea into a physical space, thereby opening algorithmic synchronization towards a material external to the computational process. It stages synchronization by distributing the network in physical space and it also introduces new forms of contingency. In doing so, it explores ways in which computation and the acoustics and environmental place can be entangled.

There are six adaptive dynamical sound synthesis systems which are each played back over one of six loudspeakers. There are also six small-diaphragm condenser microphones placed in the room each of which serve as the input to one of the six systems. The systems themselves consist of two components: a frequency adaptive Hopf oscillator (Righetti et al., 2009) and a band-limited impulse generator whose output is played back over a loudspeaker. The frequency of the generator depends on that of

[7] https://orpheusinstituut.be/en/news-and-events/simulation-and-computer-experimentation-in-music-and-sound-art

Table 2. Patterns produced by a two-dimensional spatio-temporal Kuramoto model.



the adaptive process. This creates six spatially distributed pairs of input and output that interfere with each other, attempting to synchronize while constantly failing and continuously giving rise to new musical situations. Such situations are characterized by a polyphony of partially locking rhythms, zones of synchronization that form temporary areas of emergent coherence. However, their coherence is unstable and may be disrupted leading to new situations.

The differential equations describing the frequency adaptive Hopf oscillator are:

$$\frac{dx}{dt} = (\rho - x^2 - y^2)x - \omega y + \varepsilon p(t)$$

$$\frac{dy}{dt} = (\rho - x^2 - y^2)y - \omega x$$

$$\frac{d\omega}{dt} = -\, \varepsilon p(t) \frac{y}{\sqrt{x^2 + y^2}}$$

Differently to the equations we introduced earlier, where we used polar coordinates, in this case, the oscillator is given in terms of cartesian coordinates. As in the previous equations, stands for the oscillator's internal frequency, represents a time-variable external influence and the strength of coupling. Additionally, stands for the radius of a *stable limit cycle,* which is a fixed attractive periodic orbit in the systems' phase space (Strogatz, 2018, p. 196). The third differential equation is governing the adaptation behavior of the oscillator's frequency.

The placement of the loudspeakers and microphones is crucial as it determines the degree of coupling of the six systems as well as the time delays between them. We placed the microphones of each system relatively far away from the respective loudspeaker in order to attenuate internal feedback and allow for stronger coupling to other influences. This creates a spatio-temporal topography of coupling. The setup in the space is part of the piece's design; it is a determining compositional decision that establishes conditions for the possible audible dynamics, forms, and rhythms emerging as a result of this setup. Further realizations in different spaces have explored the importance of this topography. The frequencies generated by the Hopf oscillators are differently weighted in order to couple activities in different registers. In addition to the spatially determined coupling, this creates synchronization across different temporal scales. Moreover, the input is biased by using filters that emphasize particular frequency regions. It is a defining quality of complex systems that they are based on the interaction of diverse and interdependent agents that adapt to each other and their environment to give rise to emergent patterns that range from repetition to chaos. The biases and frequency divisions of the adaptive systems increase the diversity of agents in the system, each having their own particular sensibility to be affected by certain frequency regions.

The visitors of *Iteration 2* can be said to navigate the interior space of a connected graph of nonlinear oscillators. In this sense, there is no inside and no outside, but an entanglement of computation and physical space. The visitor is situated within the system and thus always experiences it from a particular listening perspective. In contrast to a purely computational rendering, there is no absolute position, in the sense that there is no *ab-solved*, no detached way of experiencing its totality from the outside. Every possible experience is involved in its object. Žižek describes the notion of the "parallax" as materialist entanglement of subject and object that defines materialism: "Materialism means that the reality I see is never "whole"–not because a large part of it eludes me, but because it contains a stain, a blind spot, which indicates my inclusion in it." (Žižek, 2009, p. 17) In *Iteration 2*, the visitor experiences the installation by listening to their own distortions of it, their own inclusion. This inclusion leads to two different forms of contingency at play in *Iteration 2*. On the one hand, there is the contingency of the acoustic environment and the physical technological setup, including background noise, the characteristics of the loudspeakers and microphones as well as the noises made by the audience. The materiality of the site thus becomes a source of contingency. On the other hand, there is the computational contingency of the network of oscillators that are at the verge of chaos, at times creating spatial regions determined by temporal, rhythmic patterns and at times exhibiting symmetry breaking behavior that lets the network spiral into quasi-random states. However, it is only the attractive and determinist pull of the adaptive Hopf oscillators, their drive towards synchronization, that allows for both forms of contingency to have lasting perceptible effects. The material disturbances throw off stable patterns and lead to new ones. These effects are the emergent aesthetic object itself, which is always in a state of becoming.

In *Iteration 2,* listening does not only disclose space as a ubiquitous yet rarely perceived background, as in Lucier's *I am Sitting in a Room*, but it rather gives rise to a space that results from the relations between human listeners, acoustic site, and computational algorithm. These relations are articulated in sound and make it possible for subjective phenomenological auditory experience to encounter computation, for both to be affected by each other and to *co-exist*. Pauline Oliveros describes how what she calls "inclusive listening" treats "many places at once [...] as one rather than many." (LaBelle, 2006, p. 158) The relational nature of *Iteration 2* affords an inclusive listening that highlights the capacity of computational and human agents to be affected. One doesn't listen to an external source, a sound object, but to a continuous unfolding of related oscillations that include the human listener as well as the algorithmic processes. One listens to oneself listening, but also to the computation listening to itself and being transformed as a result of this experience. This points to what Beatrice Fazi terms an "aesthetics of contingent computation", that is the potential for the indeterminate self-actualisation of computational processes. Indeterminacy is thus not the privilege of lived experience and computation is not an abstracting reduction; computation is capable of producing something new, there is an "aisthesis of the digital." (Fazi, 2018) Aesthetic experience, listening, does not only reside in the relation of the embodied human listener to the digital, but the computational itself is capable of being affected, of self-actualizing through its relations to others, and thus in a certain sense capable of listening. The six oscillators in *Iteration 2*, can thus be said to experience the work. They are capable of being affected by form, which emerges, but remains precarious; audible form is the ephemeral coherence of temporal patterns, a contingent synchronization.

Online Installation

The third iteration of this project was initially intended to be a translation of the on-site installation into a web-based format. The first online installation, *Iteration 3*, constructs a virtual space in which the oscillators and the listeners are located and through which they are connected. This, however, is not a simulated acoustic space, but a computational meshwork of linked adaptive processes. We understand this network as spatial because we conceive of it in terms of distance and perspective. The sound generating nodes are located, their mutual influence depends on their proximity, while the listeners are situated in this meshwork as well. The experience of each listener, and the audio stream they receive, is different due to their location within this space. We aim to transport the phenomenological notion of intentional, lived spatiality as an existential foundation of subjective perception and aesthetic experience into the computational realm. However, we try to do so without attempting to simulate a habitual corporeality as many immersive VR environments do. We don't try to abstract bodily experience, that is, we don't try to reductively determine it in terms of a computer program. We rather try to express an immanent abstractness of lived spatial experience[8]. At the same, this computational realm is spatial in order to differentiate the component processes. Their interaction can only lead to emergent complexity if there are boundaries between the individual agents, that is if they are individuated and if there is a degree of separation.

Similar to the onsite installation, the online installation is made up of connected Hopf oscillators. However in the online installation there are sixteen such oscillators instead of six. The installation is limited to a maximum number of sixteen simultaneous visitors, since each listener corresponds to one node in the meshwork. Each Hopf oscillator aims to synchronize to the frequency of the microphone input of one listener, if there are enough listeners present, and to its neighboring oscillators. The frequencies produced by the Hopf oscillators are sonified using simple phase modulation sound synthesis. This creates an additional non-linearity translation leading the oscillators to track resultant partials and thus also introduces a source of instability and oscillation in the overall dynamics of the system[9]. The cross-correlation value of connected oscillators controls their modulation index, leading highly correlated sources to drift further apart, and the network delays between the listeners and the server controls the distance of the nodes to each other. Each listener hears the three closest oscillators. These connections and the distances between the oscillators are also represented in the visualization (see figure 5). The system also operates without microphone input but listening disturbs the system leading to changing connections and new visual and sonic forms.

[8] See (Fazi, 2018, p.47)

[9] Sound synthesis and the state of the meshwork are implemented in SuperCollider, websocket-based audio streaming is written in Rust and JavaScript and the web frontend is written in elm.

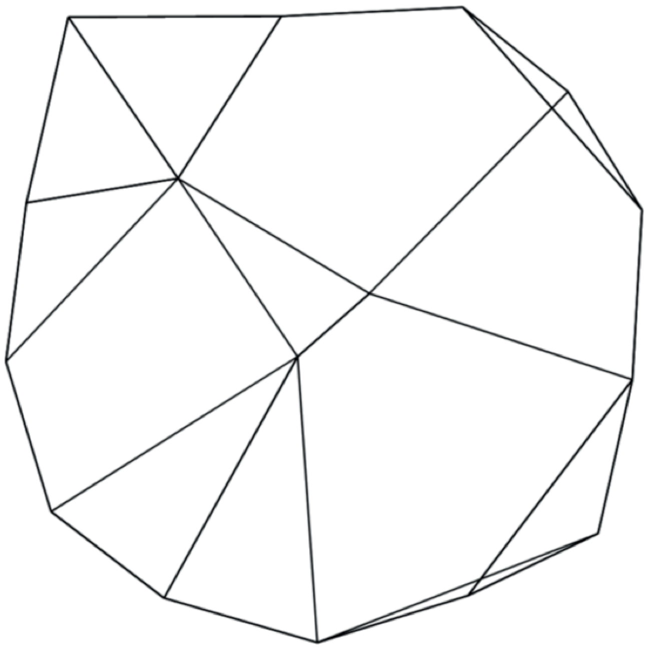


Figure 5. Visualization of the connections between oscillators in Iteration 3.

Speculative Syn-theses

The ongoing series *Contingency & Synchronization* has served as a nexus for the practical engagement with and articulation of wide ranging questions related to e.g. computational materiality, aesthetic experience, ecology, listening, spatiality, temporality, and musical form. By way of conclusion, we want to highlight a few of these aspects that have been most transformative and insightful for our own development. In particular, we try to formulate how we conceive of the relations of these aspects and ideas. Understanding how these relationships can be articulated serves to expose aspects of our work which would otherwise remain hidden. We call these ideas "syn-theses" (as opposed to "postulates" or "fundamentals") to underline that we do not expect these statements to hold or carry the construction of the project as a whole. These theses retain a tentative character as we expect to refine, falsify, overcome, or exceed them in the future. These statements do not necessarily "come after" the development of the conceptual framework and the realization of the artistic works. They do not necessarily represent results or concluded thought processes, but serve as pointers towards further concepts and artistic experiments. We regard them as a part of the artistic process as well as of the reflection process between works and they are therefore part of the experimental process described in this paper.

Listening is con-tingere

Philosopher Alva Noë argues that perception is not something that "happens," rather it is something we do (Noë, 2006). Perception is thus not just an external stimulus or even the result of some information "extraction" process performed by our senses: perception is an action in itself. Especially with regards to visual perception, Alva Noë writes "seeing is like touching" (Noë, 2006, p. 72), thus involving a reciprocity of perceiver and perceived. Similarly we want to understand listening as a way of touching, of *tangere*. Listening is a material and bodily action that departs from a fundamental gesture of "reaching out", extending outwards towards sound. The haptic metaphor serves us well to highlight how the act of listening departs from a disposition of being touched, or being affected: it is the openness to offer a surface on which traces can be left. But touching also affects what is being touched: it is an act of manipulation that leaves a trace on what it touches. Thus, listening is an encounter of mutual touching, a *con-tingere* affecting and leaving traces on both involved entities, on both the listener and what is sounding. Still, the border where touching takes place remains: the end result of this reciprocity of effects is not the disappearance of identities into one system. The border on which the touching takes place remains, keeping one part well separated from the other: in fact it is this insurmountable confines, this skin, that makes interaction possible at all.

This understanding of *con-tingere* is the paradigm for our understanding of the relation between listening and sound. This relation is an ongoing, mutually affecting, but identity preserving interaction between all actors: humans, computational processes, technical apparatuses, acoustic spaces, etc.

Material and form are reversible

Adorno famously described artistic material as, "all that the artist is confronted by, all that he must make a decision about and that includes forms as well." (Adorno et al., 1984, p. 213) By including form in the description of material, Adorno points to a dialectics of material and form in artistic thought. Neither term is ever fixed, but both are involved in an ever changing relation of mutual determination. In the works presented in this paper, we are confronted by formal elements, such as mathematical formulations and algorithmic processes, as well as material objects, acoustic spaces and sensuous experiences. We explore the "plasticity" (Malabou, 2012) of these elements, that is their capacities to give and take form. At different stages in the compositional process and from different perspectives on the work, material and form exchange positions. However, this reversibility does not imply equality or identity. The works explore the shifting border between form and material. In doing so, form is materially produced while contributing to the constitution of its own material.

Variation establishes difference retrospectively

Variation, as a process of change, can be found on different levels in the presented series of works. From an overarching perspective, it is inherent to the serial nature of the works itself, but it can also be found in the musical development of the individual works. Musical situations, made up of the audible relations of different sound generators, stabilize and destabilize to form new ones. Different sound producing streams coalesce, momentarily sync up and then diverge to form new relations. This level of musical phenomena is tied to the level of computational processes that iteratively produce new states as variations of previous states. Variation thus creates differences that do not preexist this process.

Form is the product of non-hierarchical emergence

Form is the product of interacting layers that include mathematical, computational, sonorous and experiential elements. This project explores how form emerges from their interfaces, boundaries, gaps and limitations. This kind of emergence, however, is not hierarchical in the sense of creating lower level and higher level strata of organization. There is no ascend from material to form but a constellation of incomplete and unstable identities. This "transmergence" creates connected zones of organization that have some formal closure but that can never be fully self-sufficient.

Reduction heightens sensitivity

In general, we have followed a path of *reduction* or simplification. As for the concise form of the Kuramoto system, for our works we aim to develop the most compact formulations that would employ the most reduced parameter space. When developing the numerical processes, their sonic or visual appearance, as well as while composing the interaction and reaction channels, we tried to minimize the complexity of all these single elements. This leads to artifacts that are in a sense more "readable": but this is not our main concern. When taken separately, the behavior space of each of those elements might seem small, even uninteresting. Instead, however, when arranged to interact with each other, all those elements might become entangled in a network of interactions that is complex *as a whole.* This is the complexity we are interested in: a complexity that, rather than being determined by the internal properties of the network's nodes, arises from the temporal evolution of interaction between them. This is a complexity then that is even more so a trace of the materiality and of the *contingency* of a particular aggregate of interacting elements. Hence, this reduction is not an attempt to strive for purity, but rather to increase the system's potential to be affected by what is different and to be more sensitive to the complexity emerging from its interactions within the contingent ecology in which it is situated: in other words, by reducing the complexity of each node we heighten our sensitivity to the contingent properties of the network.

Computation generates new aesthetic openings

Computational aesthetics and aesthetic computing are commonly understood as sub-branches of computer science or artificial intelligence aiming at developing methods for the evaluation of artistic content. The aim of such research is to solve the problem of how computers could generate "aesthetic expressions". In other words: "Computational Aesthetics is the research of computational methods that can make applicable aesthetic decisions in a similar fashion as humans can." (Hoenig, 2005)

When we state that *computation generates aesthetics* we take up a different position. Instead of adapting or mimicking human judgements, we understand computational processes as developing an aesthetic that is their own proper, non-human or post-human (Hayles, 2017). We place the origin of such aesthetic roots in the iterativity of computational processes, in the fundamentally discrete nature of their unfolding, in the gaps that these discrete steps leave, as well as in the incompressible difference between the mathematical formulations that form the basis of programs and their implementations, and in the constrained precision of the numerical operations they perform. We do not see these properties of computation as shortcomings of computation; these steps, gaps, voids, approximations and limitations (from our perspective) form a system that allows for new relations to emerge. That is, we ascribe to computational processes the capability to make sense and thus re-construct and materialize connections between objects that are novel, "unthought" from our human perspective. Our position resonates with that of Beatrice Fazi (Fazi, 2018) in that for us computation is capable of novelty: from processes of computation new forms and materials may emerge which cannot be predicted or formulated a priori by those who develop and write the algorithms and cannot be inferred prior to the actual unfolding of the program: materials that are contingent on computation.

Staging Wormholes

The physicist and science-fiction writer Arthur C. Clarke described space as "what stops everything from being in the same place" (Clarke, 2013). Space is what allows us to distribute things which otherwise would remain indivisible and unrecognizable. While taking care not to break their connections, by placing them too far apart, space is that "device" that allows us to fan systems out, spreading them, reading into and through them. The works are spread out allowing for a spatial experience of their inner dynamics. Here, space is not merely something we deal with as a given, but also a proper "tool" we employ in our explorations.

Space takes on different roles and forms in this project: There are the spaces of bodily movement, spaces spun by mathematical formulations, phase spaces, spaces of possibilities, acoustic spaces, and spaces of experience. All these spaces enlarge radically different material aspects of what we research: there's not just one space. However these spaces are also not orthogonal to each other: they "touch" at specific positions, producing "tunnels" for traveling from one kind of space to the next. We could say that part of our artistic work could be understood as staging those "wormholes".

Outlook

The ideas and practices developed in this project have fed into the three-year research project titled *Speculative Sound Synthesis*[10]taking place at the Institute of Electronic Music and Acoustics Graz. The project seeks to artistically question and investigate digital sound synthesis by destabilizing technological standards. The idea of speculation is central to the project, both methodologically as well as aesthetically. For us, speculation does not refer to unfounded conjecture or purely theoretical thought removed from concrete practice or experience. As we attempted with the speculative syn-theses in the previous section, speculation can be understood as an oscillation between experience and imagination that is characteristic of processes that bring forth new forms of knowledge. *Contingency and Synchronization* has been an exercise in developing a sensitivity to the ways in which our material exceeds our conceptualizations. The project *Speculative Sound Synthesis* carrie this approach further and seeks to release contingent aesthetic potentials of computation and technology.

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[10] The Speculative Sound Synthesis Project is funded by the Austrian Science Fund (FWF PEEK AR713-G). More information about the Speculative Sound Synthesis project can be found here https://speculativesoundsynthesis.iem.sh/

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