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Indice

Questo numero

Giulia Vismara

Il concetto di "musical assemblage"[1] proposto da Georgina Born mette in luce l'interconnessione e la molteplicità di mediazioni nel dominio musicale. Questa prospettiva sottolinea che la musica non ha un'essenza materiale fissa, ma piuttosto una materialità distribuita che si manifesta attraverso diverse forme di esistenza contemporanea tra cui la traccia sonora, l'esegesi discorsiva, la partitura, la protesi tecnologica, la performance sociale e corporea. Questa complessità richiede di concepire l'oggetto musicale come una costellazione di mediazioni, stimolando associazioni tra una vasta gamma di soggetti e oggetti e offrendo un quadro per comprendere la varietà e l'evoluzione della creatività musicale.

Il diciassettesimo numero della rivista "Musica/Tecnologia" esplora il tema dell'interazione tra spazio e suono, interpretando la relazione tra di essi come una molteplicità interconnessa che definisce la sua esistenza attraverso mediazioni in continua evoluzione. La rivista funge da spazio temporaneo in cui intricati assemblaggi tra oggetti musicali, soggetti umani e vari elementi come pratiche, spazi, tecnologie, rappresentazioni, prospettive e pratiche si intrecciano nell'utilizzo delle tecnologie di spazializzazione 3D. In questo contesto, l'assemblaggio è un processo senza un ordine o punto di vista predeterminato che consente la proliferazione di materiali eterogenei.

Nonostante l'analisi e la teorizzazione delle interazioni tra spazio, suono e corpo siano state a lungo oggetto di studio nel campo della musica, si è sentita la necessità di esplorare più approfonditamente il tema, vista la crescente diffusione e il conseguente utilizzo di queste tecnologie. Contestualmente, è emersa la necessità di dare forma ad una teorizzazione basata sulla pratica artistica, estetica e sui processi compositivi suggeriti dall'uso della spazializzazione 3D. La domanda di fondo, "In che modo il suono materializza lo spazio?", guida i cinque articoli, che evidenziano come le tecnologie 3D siano parte integrante del processo compositivo/creativo.

Nel primo articolo MacArthur mette in relazione la particolare esperienza percettiva supportata dallo speaker compatto icosaedrico, IKO, con l'esperienza fenomeno-

[1] See Born, G. Music and the materialisation of identities, *Journal of Material Culture*, *16*(4), 2011.

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logica di trovarsi sott'acqua per esplorare l'aspetto estetico e quello pratico del suono spaziale. In *Artistic approach to the WFS system,* Ji Youn Kang analizza attraverso la sua esperienza come compositrice le peculiarità e le sfide proposte dall'utilizzo del sistema di spazializzazione Wave Field Synthesis. Nell' articolo *The aesthetic implications of 3D technologies on the spatial conceptualizations, configurations, and articulations of my compositional process*, esploro alcuni dei cambiamenti e delle riflessioni che l'adozione della spazializzazione 3D ha apportato alla mia pratica compositiva. Brona Martin, presentando le sue composizioni e i diversi sistemi di spazializzazione di volta in volta impiegate porta una riflessione su come diverse tecnologie, flussi di lavoro e scenari performativi informino e influenzino l'approccio compositivo nel campo della composizione elettroacustica. Luc Döbereiner David Pirrò indagano con il loro progetto *Contingency and Synchronization* l'interazione tra apertura e prevedibilità nell'ambito dell'arte computazionale. Nel loro articolo esaminano l'impatto concettuale e artistico del progetto, esplorando la relazione tra contingenza e sincronizzazione e affrontando le ripercussioni su concetti di ascolto, emergenza, computazione, spazio e performance.

Swimming in space: exploring spatial sound through underwater experience

Angela McArthur

Working with the IKO icosahedral loudspeaker changes one's spatial sound composition practice. Upon first hearing the IKO at ZKM[1] in 2017, I was instantly beguiled. I developed a myopic focus. I attended courses and a summer school, in order to work with it. I had the good fortune that the lead of my then research centre[2] secured funds to buy an IKO, knowing of my ongoing obsession. I'm still grateful for that. Despite years of working with it, it eludes me in many ways. I sense it always will, and that is in large part why I'm captivated.

One of the ways in which it escapes my grappling, is with a certain nullifying effect on my ability to articulate the impact it has, on both practice and listening (mine and other people's). I've definitely tried. My best efforts have led me into abstractions and analogies which approach expression, yet remain elusive, somehow always substantially out of reach.

Snorkelling recently, I considered how submersion in the ocean transforms and reconfigures my experience of the world: my multi-modal perception of the underwater environment; awareness of my body through my sensoria; the trajectories available to my body, as well as the trajectories of the other-than-human life around me; the very way I move, and am moved. It struck me that this experience could be explored to help articulate the spatial experience of working with and listening to, the IKO. This text explores water as a milieu through which a persistently abstract theorisation of spatiality can become entangled with a persistently concrete approach to spatial sound practice. This mixing up of mediums – water and sound – opens up non-terrestrial ways of conceptualising and articulating space.

> *Perhaps more than any other element, water is a complete poetic reality*
> Bachelard (1983, p. 15)

Watery poetic reality might help us to think about sound as space, due to its ability to traverse the embodied and the metaphoric. Poems work on us in ways which are

1 Center for Art and Media Karlsruhe https://zkm.de/en/zkm-digital

2 SOUND/IMAGE Research Centre https://www.gre.ac.uk/research/groups/sound-image

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true to subjective experience and yet remain mysterious, ripe with possibility. These potentials, rather than seeming discrete or disordered, cohere. They retain depth in their illumination, as well as diversity and directness in the ways they reach out to speak to us. They are often experienced with an interiority which belies their origins. Poetic reality indeed.

Underwater, I enter a much deeper three-dimensionality than the kind which is terrestrially available. Above water, I am constrained by gravity and a medium (air) that cannot hold and support me. I am bound to a limited range of movement. Below water, I am tangibly resisted and carried by the medium. It holds me up, particularly in highly saline water, like that in Greece where I recently found myself suspended. Held. Connected to water in a way that blurred the boundaries of the structure that is me – my surfaces and substances – and a structure that is not me, the water. My interiority is heightened. In part because my usually dominant vision as well as my hearing, are compromised. This creates a presence of body which can be either serene or disturbing, depending on both context and one's state of mind.

Such interiority does not, however, engender isolation. I am connected to other structures, also held by the water. other-than-human life forms of various shapes and sizes, carried and moved around, as am I. In this hydrological choreography, I consider the kinds of 'others' I want to move towards or away from. Those that could leak into my inner cavities, viscera and liquids: microorganisms; effluent; sediment. Some benign, some undoubtedly not. Those that provide interest to me: kelp gardens; shoreline rocks; schools of fish. Some accessible, some resolutely not. These structures, these others which are not me, can easily circumnavigate my field of view. Yet I inevitably consider their presence. Why? Not being the choreographer myself, I am inescapably part of a movement within which I have limited agency. Considering the trajectories of others is an act inherent in the dance. Do I do the same for my habitual medium, air?

Generally, no. Is it because I move in substantially different ways in air? As with waking as opposed to dream states, my airy movements are generally immediate and relatively precise, whilst my watery movements are temporally delayed and more approximate. There is a temporal distinction between air and water which allows me to quickly change my trajectory in relation to others, who may in turn change their trajectories. Air that would bring exhaust fumes or hyacinth scent to me, can just as quickly dissipate them. If I need to catch something, or avoid being hit by someone, I can quickly predict my odds of success, and move accordingly. The familiarity of weightedness in air aids this predictive ability, and frees us from much of the physical effort of movement, associated with being underwater. As humans, our predictive success increases our agency, and consequently reduces the salience of events. Unfortunately by doing so, it also reduces our conscious engagement with the medium. Our agency inadvertently permits us to disregard others, and ignore the interconnectedness of a system, in which the medium is both conduit and participant. Air does have the capacity to move us, but water has far more capacity for many involved in the dance. Part of this capacity is a subjective movement from the cognitive to the affective.

In water, both the presence of body and sense of touch are heightened. Audition, relatively compromised, undergoes a shift in character. The vibrations of sound are

transferred through the water, into me. Water holds both the sounds and me, in an act of transduction. This in turn allows me to sink into a relaxed state.

This article tackles two strands of thought. In the first, spatial sound in its practical, conceptual and aesthetic dimensions, is considered. In the second, the bodily experience of submersion into water is explored. These strands are not woven together in a prematurely tight arrangement. This is in order to preserve the liminal possibilities currently between them; the relations which emerge when they are considered as distinct, and yet placed on the page together, in a montage of sorts. This text seeks to be generative, not to define or identify solid, causal relations. Indeed to do so would be absurd, given the mutable nature of water, and the spatially complex nature of the IKO.

What is the IKO?

The IKO is a loudspeaker array, comprising 20 highly engineered beam-forming speaker drivers. These work via direct and reflected sound. Unlike most 'outside in' loudspeaker rigs, which tend to be fixed in position to walls and ceilings, the IKO is an 'inside-out' array, and can travel. This is one of the things which makes it unique, as it can be taken into diverse settings, bringing to life the distinct material properties of each space. The reflected sound bounces off ceilings, floors, wall surfaces, and so on. It can be further aided with the use of reflector panels.

> *The way* [the IKO] *actively engages the acoustics of the room seamlessly blends physical and sonic spaces. You don't feel that you're playing back music in a space. The space itself becomes part of the music.*
> Knight-Hill (2021, online)

The spatial sound reproduction of the IKO is distinctive, and impressive. It has to be heard to be believed (no, really, it does). It delivers defined spatial automation and gestures. It offers distance gradients in its spatialisation (not just in one's source materials, but in the phantom sound sources in the room). It creates a physically arresting, visceral experience. Sound space penetrates us.

As such, the IKO is a distinct figure within the world of spatial sound. And uncommon, with only a handful of IKOs in existence worldwide at present. However, in spite of the time I've spent with it at the centre, and during a 5 month artistic residency in Graz (its birthplace) I am still confounded when I try to describe its ways. Sometimes, as in the previous paragraph, I stumble back into language which takes the IKO's precision engineering as referent. I don't want to take these elements as syntactical foundations, however. They are glaringly incomplete, though have the assumed gravity of objectivity, of definitive totality. The subjective experience, the affective impact of the IKO to which I wish to give voice meanwhile, remains fecund but frustratingly abstract. Communication (between practitioners or with publics) is challenging. How then to balance out the limits of precision with the (at times unrealised) promises of inexactitude? How to balance such convergence and divergence in a way which does not ossify at the speed of sound? A way which does not become an aural anecdote, with progressively less life between story and storyteller? The liquid world of submersion provides this possibility. Not only as a medium of articulation, but of thought. The phenomenologically watery is familiar enough, yet uncommon enough, to balance these apparently competing impulses. At the very least, it contributes to a field which is under-theorised. So too, can it elicit flushes of ideas, associations and imaginings for other fields. We all have corporeal, lived connections to water. A thesis which does not define and claim authority over a rigid domain of knowledge, can instead precipitate onto-epistemological movement in those to whom it flows. That is the kind of fluid, dynamic theory which can reach around, between and within us, in transformative waves.

The theorisation of spatial sound phenomena

Spatial phenomena has of course been variously described by scholars and practitioners in an assortment of contextual frames, some more material (physicists range from Newton to Mach) and some more immaterial[3] (for example, Lefebvre's (1991) socially produced spaces or Massey's (2008, 2013) idealisations of, communities of, ethical questions about, and perceptions of space and place).

There are challenges in presenting ideas about complex, often abstracted, phenomena. Whilst these phenomena are experienced sensorily (we after all necessarily navigate space as bodies in the world), they somehow also defy our ability to grasp them. No doubt the multi-temporal nature of spatial phenomena[4] which leads into every direction at once, is not best dealt with by our culturally and historically contingent (but taken-for-granted) framing of time. This framing essentialises time as sequential, as proceeding in one direction (irrespective of quantum physics, which tells us otherwise). Our framing discretises space, placing the temporal into a position of relative privilege. To consider spatial phenomena, their movements and relations, we must freeze the frame. We cannot logically process multiple relations (the objects, the relations between objects, the movements in these, and so on) in parallel. Multi-processing is a seductive myth. Better to impose consequential lines across isolated components and have some chance of prediction. Except, spatial phenomena do not concede to our desire for perceptual congruence. At best we have a Gestalt 'gist' of spatiality. We fill in the gaps. It's more efficient, and lets us progress, in some sense. Even if such progression is based upon a coherence which is – at best – partially true. Emphatic assertions of the objective qualities and properties of space, may be proportionate reactions against the unavoidable *subjectivity* of space. That said, where does this conflict of interests get us, as practitioners?

Based upon the literature, and upon the conversations I have had with practitioners (as well as my own direct experience) a dearth of practically coherent, yet conceptually and aesthetically generative, expositions is evident, concerning the aesthetics of spatial sound. Cartesian conceptions of space do not assist us so much in this

[3] The term 'immaterial' here doesn't suggest a separation between the concrete and abstract, nor that the description of more immaterial spaces aren't also tangible. The distinction here serves to underline the pragmatic needs of spatial sound practitioners, in physically realising their artistic ideas with digital, acoustic and electronic means.

[4] In 'singular' time we can follow a particular trajectory of phenomena through space. This privileges the temporal. If we instead privilege space, there is a simultaneity of trajectories and phenomena which outpace our temporal processing, making us able to consider the spatial only if we 'freeze' time. Really, space is 'multi-temporal'. It is our tendency to sequentially process our experience that makes it seem otherwise.

task. Undoubtedly they do make certain things achievable. However, aesthetics are (presumably) part of the tacit knowledge which sound practitioners embody, yet can struggle to articulate.

Immaterial articulations of space, as political, social, ethnographic or anthropogenic – whilst hugely valuable – do not help practitioners move forward with the tangible demands of working to spatialise sound in their work. Conceptually, such ideas may act to underpin one's context, yet the ways in which these are translated to plugin interfaces and loudspeaker decoders, remain tangential. Perhaps that is as it should be. Perhaps though, a closer relationship could be formed, to advance the practice of spatial sound aesthetics. Certainly, one of the obstacles to this closer coupling is the allure of immateriality – where we can 'deal' with spatiality whilst remaining untethered to its material realisation. But this leaves us without agency, according to Barrett –

> *…in composition, if we are to successfully embody these ideas [of agency] we need an accurate spatial recreation rather than an interpretation.*
> Barrett (2010, p. 7)

However our concepts of the real are built around expectation, individual and shared. Therefore they need not be built around what is 'objectively' realistic. If those working in spatial sound establish a kind of 'virtual realism'[5], through setting our expectations about sound, possibilities unfold. We can become untethered (at least in part) from realism. Perhaps more importantly, such an approach extends agency and affords plurality of voices.

A question now arises – how do practitioners free themselves of their own conditioned, habitual expectations, in order to stretch into the aesthetic possibilities of the medium which is spatial sound? Could watery experience help expand practitioner expectations into wider possibilities? Could it do this by emulsifying the immaterial and material, the subjective and objective qualities of space, and contribute to a de-polarisation between them? Certainly, the relative absence of theories which are of practical benefit, calls for such contributions, and for quixotic responses. So why think through water, towards such a theory?

Earthy articulations are inadequate for describing phenomena which are not simply earthy in nature – those such as spatial sound. Whilst sound is certainly material and affective (Voegelin, 2014), it also exceeds these dimensions, as illustrated by the disparate attempts to find ways of describing its spatial qualities in both empirical work (e.g. Rumsey 2002; Berg, 2006) and practitioner (subjective) accounts (e.g. Truax 2012; Normandeau 2009; Stankievech 2007). The interplay of its multiple aspects is by nature beyond empiricism, with its narrow field of vision. And yet when making work, we need a certain groundedness in the material reality of our experience. Somehow space and spatiality ask that we transcend this material, encumbering weight. That we

[5] by instantiating a self-contained integrity (consistency) to a piece of work, a virtually real world can be established. The internal integrity of the work ('virtual realism') can be more or less differentiated from 'external' objective experience.

feel and think in substantially different ways. The very specialisms which increase our expertise in one field or another, limit our ability to deal with spatiality. And so, memories of the medium of water enter my awareness when I strive to outpace my weighted, material experience. The lived experience of being in my body (not in my studio, on my digital audio workstation, nor at my screen) and *being* in my body (in the manner water affords) enables a grappling with spatiality which circumvents existing perspectives and opens up a world of possibilities. These feel freer, more interesting, and somehow coherent despite the diversity of their potentials. As Bachelard notes –

> *A poetics of water, despite the variety of ways in which it is presented to our eyes, is bound to have unity. Water should suggest to the poet a new obligation: the unity of the element. Lacking this unity of the element, material imagination remains unsatisfied, and formal imagination is insufficient for drawing together dissimilar features. The work lacks life because it lacks substance.*
> Bachelard (1983, p15-16)

The substances we encounter, and the ways in which we conceptualise them, suffer from terrestrial biases. Thus we bind sound to the earth more than to the air, because it reflects our own experience. As bodies on the land, we are subjected to certain physical forces, forces which sound is free from to a far greater degree (such as gravity, a fundamental aspect of our existence). Our naming conventions reflect these biases. Jue cites the name 'sea-cucumber' or expressions such as "I'm feeling down" as obvious examples of this (Jue 2022, 29:38). What would a creature buoyed up by the ocean make of such expressions and associations (Jue, 2022, 30:00)? Hall's (1966) fourspheres of social distance (the intimate being the closest, followed by the personal, the conversational and finally the public sphere, see Brown 2001), is an example of this terrestrial bias. This doesn't make terrestrial thinking redundant, just limited when we want to think *sonically*. Further, terrestrial life, unlike underwater life, is more reliant on visual perception, which tends to dominate discussions relative to the sonic. As Idhe points out in discussing auditory experience, we use –

> *…an abundance of (visually) spatial terms. Sounds are "movements," there is "up" or "high" and "down" or "low," and so forth […] in musical theory and musical training the conceptual scheme is again one dominated by visual metaphor.*
> Idhe (2007, p. 219)

Idhe claims that "the field space of visual imagination is similar in structure to the field space of auditory perceptionand not to the field space of visual perception" (2007, p208). In his illustration of this point, he describes how he can visually imagine a horse galloping behind him, but cannot visually perceive the horse behind him. Thus, the visual imagination can take auditory perception as its spatial correlate more than visual perception. So auditory space is imaginatively rich in visual realms too. Idhe's real point is that our imagination exceeds the structural foundations of what we perceive – it extends beyond them into subjectivities which are richer than metaphors, at least visual metaphors. Such phenomenological metaphors, are deficient relative to the phenomena themselves. Water, like sound, moves in waves. Its inherent instability is what elevates it above the frames of visual thought and metaphor.

Notions of space also suffer from assumed objectivity, which disembodies us and displaces affect. Who experiences space like this? We may view it in a (presumed to be neutral) technology: a spatial sound software GUI presents us with Cartesian or Euclidean constructs. Similarly to the historical contingency of materials (Ingold, 2007), those of space (Shields, 2013) and its idealisation (Blomberg and Thiering 2017) are largely unaccounted for. Without recognition of these necessarily reductive frames of reference, we may essentialise space, accept needless limitations on our ideas, and further propagate historically hierarchical knowledge structures. We may also continue to reproduce gendered epistemes centred around isolationist (versus ecological) approaches, as well as to devalue the body's place in knowledge-production. We could rather translate a lived experience of space, to the graphical representation of space. Not the other way around. Space begins –

> *…from meas the zero point or degree zero of spatiality. I do not see it according to itsexterior envelope, I live in it from the inside; I am immersed in it. After allthe world is all around me, not in front of me."*
> (Merleau-Ponty 1964, p. 178)

In this way, Merleau-Pontypoints out that one is not *in* space, but that space combines with, and includes, them. Each is deeply co-constitutive. So too with sound. These two topics (interconnected as they are) are well suited as means of exploring one another. Yet each compounds the complexity of the other. Considering them together is a challenging task. We need some way of propping open the poetics of this undertaking, whilst attending to the pragmatics of the sensible. Given that "psychic life is founded upon corporeity" (Husserl 1970, p. 271) we must attend to matter, if we wish to advance engagement with spatial sound.

> *Reception [of acousmatic music] can behampered by an inability to enter acousmatic space-form as a tangible construct*
> Barrett (2010, p. 1)

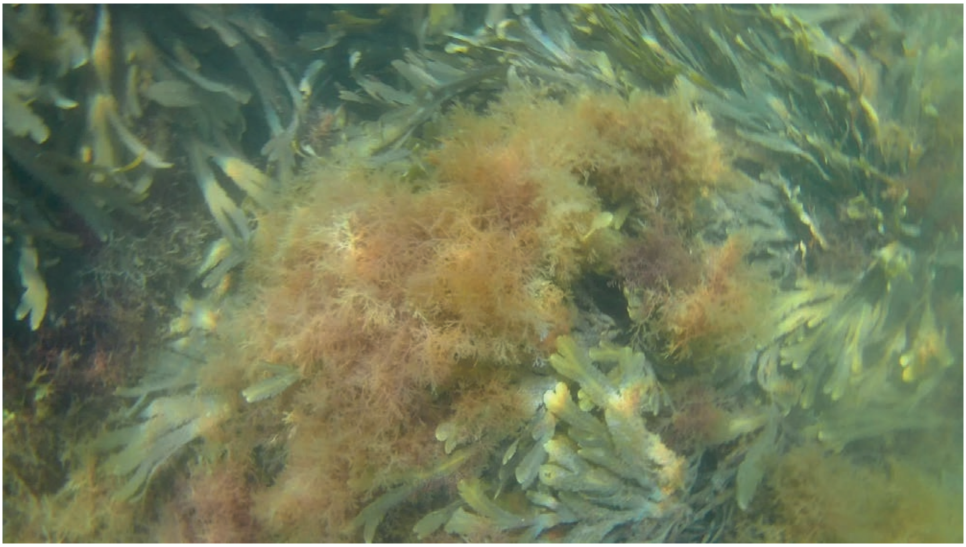
Watery approaches to theorising phenomena

> *…the ocean is not just another space*
> Jue (2022, 27:46)

Jue asserts that oceanic spaces are characterised by a "whole other level of affect" (Jue 2022, 30:44). Why wouldn't we then extend the affectivity of water to sound – both are three-dimensional spaces of ephemerality. Gibson (1979) described a 'medium' as one of the three components of inhabited environments (the other two being substances and surfaces). As terrestrial creatures, humans usually encounter the medium of air, not water. Our ways of expressing ideas, including those about our embodied experience, derive from milieu-specific habits (Jue, 2020). Consequently, these are where our language (and thus our ways of articulating and conceptualising phenomena) are drawn from. There are material (not to mention ethical) limitations to milieu-specific thinking. Any specificity in thinking, by definition focuses us in a certain direction, thereby excluding others. If, as Gibson suggests, a medium affords us movement and perception, changing the medium through which we interact and thus think, affords changed movements and perceptions. For sound, this frees our experience from a mental cul-de-sac, where thinking too often leads our sense of material reality, and instead allows us to enter the materiality of sound directly, through our bodies. As felt. In water. This offers up ways of thinking. We don't impose our preexistent notions onto watery thoughts (thoughts which, like the medium itself, struggle to maintain fixed forms). We avoid the "*premise that as the embodiments of mental representations, or as stable elements in systems of signification, things have already solidified or precipitated out from the generative fluxes of the medium that gave birth to them*" (Ingold 2007, p. 5). Might water help free us from the relative fixity of material cultures, so that we may approach sound (perhaps even more solid material realities) with more responsiveness, with fewer preconceptions? Though Ingold discusses the terrestrial medium of air, his ideas are easily transferred into liquid worlds –

> *…materials* […] *are the active constituents of a world-in-formation. Wherever life is going on, they are relentlessly on the move – flowing, scraping, mixing and mutating. The existence of all living organisms is caught up in this ceaseless respiratory and metabolic interchange between their bodily substances and the fluxes of the medium*
> Ingold (2011, p. 28)

Water is a material medium in perpetual flux. It is unfamiliar enough to focus our attention on the present. It is not the only medium which can affect this. A recent flurry of snow in London changed adults into children, tobogganing down hills



in Greenwich park and constructing gargantuan snowmen. Eye contact among park visitors palpably increased. The novel (and undeniably fun) medium of snow, freed people from the habitual, into the re-creational.

Water also affords a bodily experience of being at once interior (my body, my breath, my movement) and exterior (the medium surrounding me, the horizon where water meets air, the horizon where water meets land). This quality is shared by sound –

> *…the indefiniteness of auditory space proceeds inboth directions – it extends indefinitely from me but it also "invades" mybeing*
> Idhe (2007, p. 207)

Almost outer space-like, water calls for three-dimensional movement, and grants a certain weightlessness. Is there something in my corporeality that recognises the water as life-giving? As threatening? As a pre-birth memory or a present-moment assemblage of interchange?

Bachelard argues that our abilities to express ideas are founded upon materiality, upon embodied experience, and being in the world. He links language to water as a form of such materiality –

> *the voices of water are hardly metaphoric at all; that the language of the waters is a direct poetic reality […] human language has a liquid quality, a flow in its overall effect, water in its consonants. I shall show that this liquidity causes a special psychic excitement that, in itself, evokes images of water.*
> Bachelard (1983, p. 15)

Metaphors are allies in our expressive efforts, even when – as Bachelard asserts – water is more direct than metaphoric. This is because it carries in it powerful symbolism and a “varied repertoire of emotional, cultural, and sensual associations” (MacLeod 2013, p1). Water, suggest Chen, MacLeod, and Neimanis, is a “particularly potent linguistic ingredient” (2013, p. 10). Our memories – including pre and post-birth, as well as individual and collective memories – of water can help us harness a certain linguistic imagination surrounding these personal and cultural associations –

> *Language emerges from corporeal experience.* […] *Waters add very particular nuances and associations to the concepts they help to signify, and symbolic meanings of waters accumulate from both personal and collective experiences.*
> Chen, MacLeod and Neimanis (2013, p. 10)

Fluid spatiality is both metaphor and analogy. Such conceptual-linguistic devices provide scaffolding for our attention, thinking, actions and interactions, thus “dictating what is perceived and what remains invisible” (Chen, MacLeod and Neimanis 2013, p. 11). The authors suggest that it also acknowledges the other-than-human, material influence on human thinking and languaging. Water thus potentially rebalances the ecological as well as the corporeal. Its metaphoric and direct qualities contribute a lot here because –

> … *metaphor is a phenomenon of the poetic soul. It is also a phenomenon of nature, a projection of human nature on universal nature.*
> Bachelard (1983, p.183)

Our watery bodies often respond to water in ways which attest to its restorative powers. There is a certain catharsis, cleansing and presence of being brought about by being in contact with water (even limited contact, such as washing one’s hands or feet). Can we translate some of this power to the medium of sound, which has similarly restorative, cathartic and emotionally resonant affects?

Our bodies, being largely composed of water (somewhere in the range of 60 – 90%) serve as material media (Neimanis 2012). When we place these bodies into a larger watery body we form a correspondence between them, much in the way that we form correspondences in sounding bodies, when we place our bodies into an environment with the IKO. Our bodies are sensitive to sound. They produce their own soundings. They contain air, materials and resonant cavities which amplify, absorb and respond to sound.

Barrett discusses personal agency in spatial sound practice, that is “the imaginer’s own involvement in what is being imagined” (2010, p6). Describing how listeners connect to spatial sound through various cues including the acoustic, psychoacoustic, material and social, Barrett asserts that these cues act as basis for a projection of the self into the time-space experience of spatial sound. An act of creative consciousness, this demonstrates listener agency. Watery movement requires even more assertive projection. Water is more resistant than air, it slows us down and suspends us (Jue, 2021). As a result, we become more aware of the passing of time and events, and move ourselves with more energy, intensity of effort, and presence of mind. Such effects are well placed to cultivate a sense of spatiality, distinct from the one we experience on land.

Concerns with watery approaches

Watery approaches have been critiqued, and brief mention of that here is appropriate, lest we imagine there are no concerns with their forms seeping into shared idioms. The use of watery terminology can act to legitimise nefarious practices, systems and structures. We hear of the 'flow of capital', of 'liquidity' and the 'trickle-down effect' – phrases which belie exploitation, domination and inequities of the human and other-than-human kind (MacLeod, 2013). Important then to keep in mind that a medium, even one of inherent flux, is not neutral in its application.

My underwater experience

In the water, I am freed from habitus. I am connected to my limbs and my breath and the medium of water, as material. As moving. As multiple. These aspects act on me – and I on them – simultaneously. Where does the me that is watery, and the watery medium which is not me, locate its fissures of distinction? I press against the saline buoyancy of the ocean, and it presses against me. Our fluid bodies meet in ways which feel overwhelming at times. I doubt my ability to surface whilst freediving in an enclosed space. I lose sense of time whilst clumsily following marine creatures, and latently realise: I should breathe. Some part of me reacts – I am not in my native world. Yet I too am multiple. Some parts of me feel an abiding peacefulness. There are depths within me which respond to the water as if a heavy aching, some old longing, has been met. I feel viscerally held, and therefore at home, in this underwater world. The pressure of the water like viscous swaddlingI forget my need to breathe *because* of these relationships to the water. Its pluralities meeting my own. My pluralities meeting one another with intimacy, immanence, vulnerability and an innocent joy borne of play.

Playfulness is key in my underwater experience. I dive and swim for my own pleasure of course. This maintains said playful disposition. But so too the novelty of the medium (relative to the terrestrial) and the embodiment if offers, combine to create a sense of freedom in exploration. This is a kind of freedom unavailable to me, even in my best moments, on land. Land is where I have dwelled perpetually since birth. It's where my thinking, moving and knowing originates. I cannot shake myself free of a lifetime of such references, try as I might (and I don't always try). Water's playfulness meanwhile, reawakens a childlike curiosity in me.

The comparatively alien range of underwater life fuels this curiosity. I am enchanted. What world have I entered? Why is no-one else here, no-one who looks like me? I am suspended in a world which is clearly ill-suited for my abilities, one in which the inhabitants effortlessly escape my attentions. Clumsy as a child, I accept my lack of efficacy without expectation or indignance. My expertise is absent. My wonder is ignited.

I prefer to dive and snorkel alone, in order to further foster this secret other-worldliness. Being a solo 'other' in this world affords me respite from above-water acoustic stress. To underline – this is due to my being 'other'. Acoustic pollution for marine inhabitants is a very real and increasingly problematic concern, and one which is – as with other underwater environmental concerns – given scant attention.

As I move around to discover and interact with the inhabitants of this world, to feel seaweed fronds against my skin, to approach fish (keen to avoid my lumbering mass), I begin to dance. The unified orchestration of movement created by the medium itself, connects my movement to the wider environment, to currents, to the effects of these on underwater flora and fauna. Dance is variously defined as rhythmic movement of the body, expressive of ideas or emotions (such as delight). A release of energy. Being underwater is all of those things. The pace is legato. I move more slowly in liquid worlds than earthbound ones. Yet the slowness of watery experience prevents

my mental rapidity from disconnecting from my sensual actuality. I notice that the qualities of dance are present. Tidal environments are by nature rhythmic. The waters move me as I move in them. Boundaries blurred, we move in unified ways and waves. Synchronised undulation. My navigation, my exploration of this world is expressive in ways which are unlike my corporeal expressions on land. The expression is affective as a result, consciously experienced and felt. How could this *not* be dance?

Linking underwater experience with spatial sound

Spatial sound as created by the IKO, is freed from habitus. No loudspeaker array has been created like the IKO. No array sounds like the IKO. It appeared in the spatial sound ecosystem without precedent (this is not strictly true, many arrays based on similar principles have been prototyped, but none developed into a commercially available system). The IKO was developed over many years inside the lab, whilst simultaneously and iteratively being toured for installations, concerts and performances. In this way, ecologically valid design-input was accounted for, as part of its evolution. This makes it unique. The novelty of the medium (spatial sound, specifically from the IKO) means that the world it creates is non-native to all (at least, at the present time). This begets a freedom of discovery and sense of wonder, an enchantment (in that one gives oneself permission to be enchanted). Such aspects are not usually available in the highly codified spatial sound systems of academia. We may talk of 'playing' our compositions in conventional settings, but the 'play' is ironically serious. Perhaps such academic systems are an equivalent of the terrestrial domain.

If worlds are always "intersubjective, the shared space of ahistorical community with a particular culture that uses a common languageand a common description of reality" (Heelan 1989, p. 10) does the IKO place us into a void? The world one enters with the IKO is alien. Without history, community, dialect and convention. Yet rather than confound us, it enlivens.

In the IKO, there exists a comparatively foreign range of spatial sound affordances. The 'secret' other-worldliness created by this instrument, rare and new as it is, has not yet been colonised. Similarly, water remains largely uncolonised. Both are more emergent, more personally vital, as a result. With both the water and the IKO, my relationship to time fades as my relationship to space is foregrounded.

Add to this the lack of efficacy one faces when working with the IKO in varied environments (there is uncertainty and risk involved in creating work in one space to perform it in another, due to the way the IKO interacts with the material characteristics of spaces) and the heightening of the emergent is clear. The futility of control in such circumstances induces humility; one accepts ones limits as would a child. Or an adult, underwater. Expertise absent, it is possible to be awed by the medium, and its ability to orchestrate all around and within in. This has correlation with the pulsing movement of the ocean. Such naivety, and its de-centring of the human subject as the site of onto-epistemology, into a melee of conceptual polysemy, is not only appropriate for sound and for space (see Blomberg and Thiering, 2017), but is utterly enlivening.

> *Materials shift from the traditional and expected to something that requires attention*
> Kelly (2018, online)

The heightened embodiment of sound as reproduced by the IKO in combination with an environment's material structures, surfaces and occupiers (human or other-than-human) feels watery. My sensoria tell me I am in relation to all things in the environment, through the medium of sound. These heterogenous elements emerge temporarily as subjective unity. I am connected, a relation which is affected by, and affects other elements within the assemblage, as I am with the medium of water.

> *Thinking with water encourages relational thinking* […] *Water is a matter of relation and connection. Waters literally flow between and within bodies, across space and through time, in a planetary circulation system that challenges pretensions to discrete individuality [..] water is a deep source of plurality and potential, as bodies share and connect through their common waters.*
> Chen, MacLeod and Neimanis (2013, p. 12)

This relational quality pervades my experience with the IKO. Where does the sound have its edge with me? Where is the separation? If my body absorbs and occludes, it is part of the composition as experienced by me, and as somewhat distinctly experienced by other listening bodies. The IKO activates elements in the environment – of which I am one. Its multitudes meet my own with an intimacy that places me into direct contact with the sound, and the environment. Such pluralities remain distinct, yet subjectively unified.

I move around to discover the medium, its world and inhabitants. This connects my rhythms and bodily gestures to those created by the medium itself. I enter into a unified orchestration of movement created by the medium itself. Energy is released, reflected, absorbed and met with more energy. The IKO's sound acts on me as I act on it. Its impact is felt. Its imaging is perceived by my sensoria as *in direct relationship* to the body that is me.

Godøy (2010, 2006)describes how human mental activity is intimately linked with sensations of movement. The orchestrated movements of the IKO and its relations, provoke thoughts via affect in me. Like the water, it acts on me, and consequently awakens my imagination.

Water as transducer

Being held, supported, resisted and met by the pressure of water is a kind of transduction. Is there a distinction between sounds which penetrate viscera, and water which presses against it? The idea of a watery 'transductive ethnography' has been discussed by Helmreich as a way of making "explicit the technical structures and social practices of sounding, hearing, and listening …" (Helmreich, 2007, p. 1). The value for such an approach is borne of the way in which –

> *…for humans, underwater sound is largely registered by bones in the skull, which allow enough resistance – impedance, to use the technical term – for vibrational motion to be rendered into residences in the body.*
> Helmreich (2007, p. 4)

These embodied residencies are transductions – the altering or converting of a signal from one medium to another structure, says Helmreich. These transductions creates matter and meaning, simultaneously. As the IKO acts on me and I on it, its affect is meaningful. My pulse is slowed, my presence heightened, and I am returned to my body, to the environment, to the sound.

Transduction follows movement in the water. As I swim close to a fish, it moves. I occlude the sun. I create bubbles and small vortexes. This agency and the medium of water as a continuous signal, produces affective transduction. Helmreich asks whether an "anthropology of such a transducer sensing can make explicit the conditions that permit immersion" (Helmreich, 2007 p2). What might it mean, that our perception of a spatial field is felt underwater, unlike vision which doesn't extend outside of its range of sight? What might movement underwater contribute towards phenomenological literacy? Jue urges that we pay attention to the conditions through which we are theorising, and how different forms of objectivity are constructed. She suggests that the water, as an environment, affords unique orientations and unique conditions of interpretation. Consequently, one needs to experience it, something you can't realise when looking at someone else's images in a mediated manner (Jue 2020 p163). She also describes how water's pressure re-characterises one's experiences. Such embodiment-reliant intimacy with watery worlds is helpful for navigating the nuance of spatial sound in general, and the IKO in particular. You need to hear the IKO, you need to be with it, not just hear a binaural render of someone else's work. As "the ocean can help us have humility in how we characterise [our] objectivity" (Jue 2022, 38:06, see also Jue 2020 p22) so the IKO can help us have humility in spatial sound theorising and practice.

Coda

Water is not in utilitarian service to us, something to be exploited as if entirely separate. It is part of an assemblage, with its own affective agency. Any such isolationism points to out-of-date thinking. It is not that we should *use* water to derive value from it (as if taking from it isn't also always taking from ourselves). We can (and of course should) acknowledge our deep connection to, dependence on, and symbiosis with, water. Besides, it remains in excess of any grasping –

> *Water, like space has "a remarkable capacity to resist containments of all kinds – be they the language we use to capture water's materiality, or the dams and dikes we deploy to keep its surges at bay*
> Chen, MacLeod and Neimanis (2013, p. 12)

Instead, we can think *through* water, as we move through it, to find ways to understand our experience of the medium of spatial sound. Whether linguistically, corporeally, or otherwise: this can help us understand spatial sound phenomena, as diverse and complex as they are, with a sense of unity. Rather than being overwhelmed, we can surrender into the overflows of spatiality and simultaneity. We can resist the impulse to temporally or spatially freeze things, so as to form sequential, predictive patterns in our terrestrial minds. Fixations of this nature are by definition limiting. We need not think about mind and matter as in polarity. Water helps us know this. As a medium it is always both mind and matter; complete in itself, offering complete absorption for us. Thinking through the qualities of water we –

> *…can begin to think relationality in increasingly sophisticated ways. We can (cautiously) voice the subtleties of relations that may previously have been ignored, invisible, under-articulated, or unintelligible, at the same time as we realize that full fluency in these languages is beyond our grasp.*
> Chen, MacLeod and Neimanis (2013, p. 13)

Perhaps water uniquely ensures we are 'true to the materials' in "respecting its properties rather than riding roughshod over them" (Ingold 2011, p. 29). In flux, beyond mastery, beyond adherence, water mirrors the qualities of sound as a medium. Water's character changes – at times more salty and buoyant to bodies, at times more visible and lucent to eyes. It presents us with new shades of colours, new depths, new ways of feeling temperature. It filters light, it filters sound. It is peaceful. It is foreboding. It pulls us away from our intended destination, or pushes us along a trajectory that we do desire. There is something about the way it brings me into present, embodied awareness of the environment which makes me feel as though the ocean exists only for me, in this spatio-temporal experience, when I am in it.

The IKO can be installed to be more or less visible (I have experimented with both polarities during performances). It too presents new depths, new ways of sensing sound (yes, really) and new trajectories for our artistry and explorations. It changes the way we create and compose work. It requires us to substantially re-think our process, and this break from habit vivifies our ways of working and thus our work. It is peaceful – its affective character has a calming quality. It is foreboding – there is something about its singularity and unfamiliarity which feels imposing and somewhat threatening, as if it may challenge us in unpredictable or sonically uncomfortable ways. There is something about the deeply relational sound it produces which makes me feel as if it exists just for me, in the moment.

These shared qualities abound, and are not dealt with exhaustively here. The qualities of water and sound, unlike their apparently objective cousins 'properties', are subjective. They exist within us, they exist between us and the medium, as "part of that private view of the world which artists each have within them" (Pye 1968, p. 47). These interior affordances are processual, intimate and generative. The relational affordances communicate shared meaning, whilst preserving the interior affordances. Water's affective materiality grounds such diverse subjectivities and their shared context in the pragmatics of the here/ now/ body. Being phenomenologically unfamiliar (and not a medium through which we have preconceptions about sounding), water is germane for exploring the (somehow still nascent) aesthetic aspects of spatial sound, in particular the unfamiliar, affective IKO.

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Artistic approach to the WFS system

Ji Youn Kang

1. Introduction

During the last few decades, a number of different multichannel speaker systems and spatialization technologies have been introduced. Not only have different configurations of loudspeakers in concert situations evolved, but also headphone listening situations. Wherever we go, a nice pair of headphones with 3D technologies can allow us to listen to various spatial music. These ever-evolving technologies allow composers to approach the use of space, acoustics, and spatial concepts in their compositions in various ways. They also need to aim for the right listening situations, whether the music is heard at a concert or via headphones (Otondo, 2007). The distinction between multichannel systems for live sound diffusion following the Bayle's Acousmonium tradition and for sound spatialization following Chowning's studio panning tradition has blurred too. The overwhelming technologies ask for in-depth research, consideration, and experiences in dealing with spatialization in music because each different speaker configuration comes with unique attributes, which can vary depending on the panning technique chosen. It is certainly important for composers to find a way to integrate their compositional ideas into the technologies and the listening situations and 'the music has to be adapted to suit the particular performance situation' (Austin & Smalley, 2000).

A primary consideration for composers when approaching a multichannel system is to consider the individual channels as instruments within the context of the greater meta-instrument configuration (Fielder, 2016). Similar to composing for instruments such as violin and flute, composing with a multichannel system requires a close examination of what the system has to offer musically. This includes not only the spatialization possibilities, such as moving trajectories and the possible number of static sources at different distances, but also its timbral characteristics. However, it is crucial to consider that as the timbral quality does not depend solely on the hardware, but also on the choice of spatial audio technologies and the room acoustics.

Despite the availability of various technologies for spatializing sound, there are general problems in acousmatic listening, in which we immerse ourselves in the expe-

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rience of the sound and listen differently (Beard, 2019). A well-known problem with conventional multichannel systems is the broken spatiality outside of the sweet spot. Typically, compositions are mastered in a studio, and it is rare for composers to spend most of their time at a concert venue or to have access to the same number of speakers. Composers carefully calibrate the spatial movements of sounds, their positions and harmonies, and their changes in time when composing their music pieces. However, at the concert, the audience is generally situated all over the place, among whom only a very small area has the desired spatial image.

Another concern is that the sonic space and the listening space are often divided in many acousmatic listening situations. Speakers are frequently placed in one part of the concert space, and the performers in another part, resulting in a detachment of sound sources (Otondo, 2007). This does not prevent us from appreciating the music, but it can be seen as a hierarchy in which the audience remains as observers. In most cases, the audience is seated and cannot move to another side of the listening location. Similarly, being surrounded by a number of loudspeakers gives a center-oriented experience that is not representative of the physical world. Hearing sound without seeing its causes happens every day (Kim, 2011), and those sounds do not circulate around us being centered. Unlike a sound installation where the audience is allowed to walk around the sounding space, the audience in an acousmatic listening situation is physically passive while being asked to actively listen. The reason why I see this as a concern is not about the limitations of physical variability of the audience, but about the inability to fully immerse oneself in the space where events are happening.

The first listening experience of the Wave Field Synthesis (WFS) system in 2006 made me think about these limitations because it changed the way I listen to acousmatic music. This was not because of the accuracy of moving sound sources, nor the number of loudspeakers overwhelmingly surrounding us, but of the immersion, the sense of sounds – not only through our ears but also on our skin by the air pressure moving throughout our body. We are literally situated together with the sounds. With the WFS system, it was truly possible to make sounds right in front of me, passing by my head.

Since then, I have worked intensely with the system for about eight years until 2013, and since 2018, I have been teaching spatialization with the WFS system to students at the Institute of Sonology, The Royal Conservatoire in The Hague. In this paper, I would like to first introduce the WFS system and then share a few important aspects that I have discovered and learned.

2. Wave Field Synthesis (WFS) System

Wave Field Synthesis is a spatial sound-field reproduction based on the Huigens principle (Berkhout, 1988). Unlike common spatial audio techniques such as Stereophonic panning, Vector Based Amplitude panning (VBAP) and Ambisonics where an impression of sound moving from one side to the other is achieved as a psychoacoustic phantom image and requires for the audience to sit at a sweet spot in order to perceive

Figure 1. Game of Life WFS System.

the trajectory, WFS enables sounds to be physically reconstructed within loudspeaker arrays as a wave field. It offers a larger sweet zone for the audience to observe the spatial images relative from where they are seated. WFS offers improved localization and movement perception compared to other spatial audio techniques, but it does not fully replicate the way we perceive sound in reality. A sound of an object arrives to our ears after going through a number of obstacles in the surrounding environment. The direction of the sound is heard together throughout our auditory system and we recognize and judge the localisation of the sound. The WFS offers an omni-directional sound, allowing the audience to locate sound sources from kilometers away or right in front of them. However, the system is located in a hall with its own acoustics, leading to some mismatches with how we perceive sound in our everyday lives. Nevertheless, the system offers various possible ways to spatialize sound sources.

The *Game of Life*[1] WFS system (Figure 1) in The Hague, The Netherlands is a mobile system with 192 loudspeakers and is operated using an open-source software *WFSCollider*[2] (Figure 2).

The WFSCollider is capable of spatializing sounds individually using UChain, and each UChain is located in a UScore with a timeline view. It resembles DAW software,

1 *The Game of Life* foundation https://gameoflife.nl/en

2 *WFSCollider* https://sourceforge.net/projects/wfscollider/

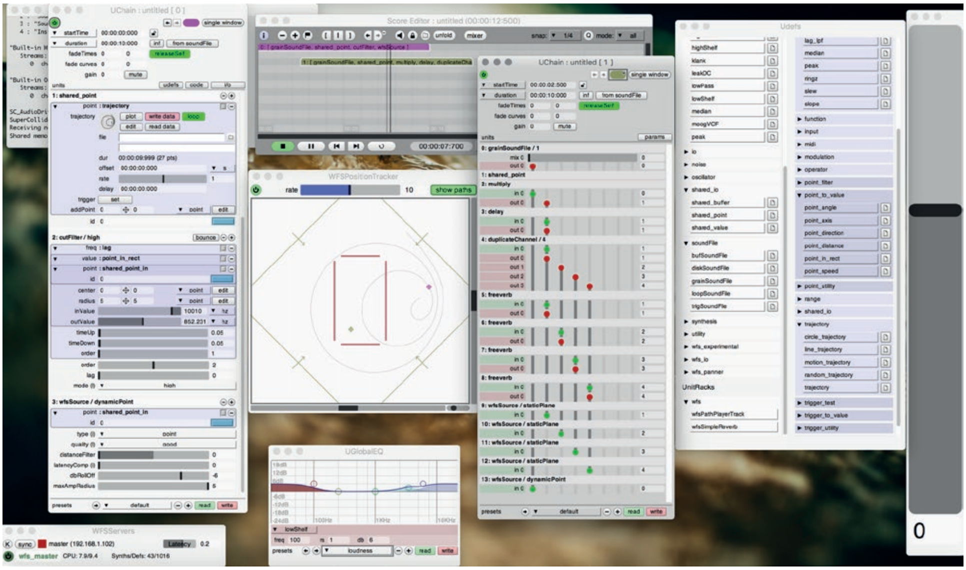

Figure 2. *WFSCollider* (https://sourceforge.net/projects/wfscollider/).

where one can arrange sounds in a timeline and edit them. However, the UChain is unique as it offers time information (e.g., starting and ending time, duration, etc.), a type of sound source (e.g., oscillator, synthesis, or sound file), and a type of spatialization, such as point source (Figure 3), plane wave (Figure 4), and static/moving sources of point source and plane waves, as well as an index source, which skips the WFS calculation and allows a sound to be located at a single loudspeaker. The trajectory interface shows the configuration of the speaker arrays as a square, which is also reconfigurable depending on the system setup and the number of loudspeakers. The user can intuitively move the location of the sound or draw a trajectory using a mouse. It also comes with a number of additional functions, such as creating a pattern or using a function written in SuperCollider, the programming language the WFSCollider is built on. The integration of additional functionalities is limitless. However, an advantage of using the WFSCollider is not limited to its extendibility but rather its accessibility without requiring programming skills. Anyone who has sound materials and spatial ideas can easily learn the software and compose spatial music. The resulting sounds are specific to the design of the software, and accordingly, there cannot be a generalization to what every WFS system technically offers.

The WFS system comes with limitations too; due to the closely located small loudspeakers, spatial-aliasing happens above certain frequencies. (Baalman, 2010) Also when the sounds are moving inside the speaker arrays, the constructions of the wave fields are reversed (Figure 5). This is clearly an interesting artifact. When I was using the system for the first time, I was advised not to make too many sounds inside the speaker arrays because the localization of the sound inside is not as accurate as sounds being outside of the speaker arrays. However, it is not unclear as to perceive them being out of the trajectory when we are listening; one can clearly feel the sound

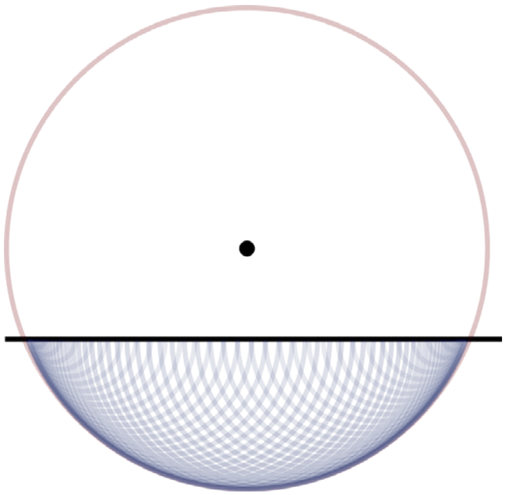

Figure 3. A point source outside of the speaker array.

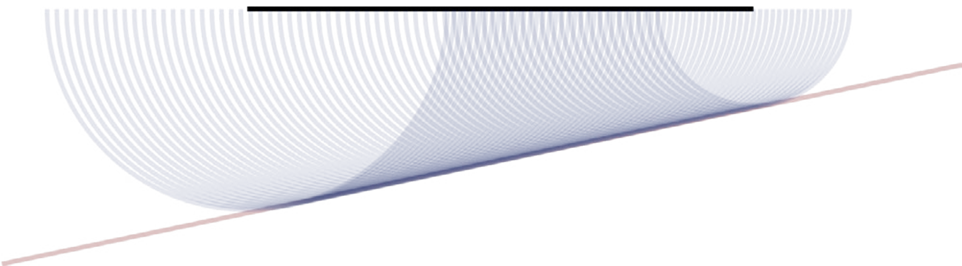

Figure 4. A plane wave source.

moving around, and it even adds physical sensations of the sound pressure as mentioned earlier. More about this character will be discussed in the next subchapter. Another disadvantage is that the system is not easily accessible, and is expensive to build. The opportunities to compose a piece for the system is therefore limited, and to work with the system on location can also be limited. However, the number of the system is growing. Also, if one finds a chance to compose for the system, it is also not necessary to compose always 'with' the system. On the other hand, I encourage my students to spend more time working without the system but with the WFSCollider stereo simulation. When one works with the system, their creativity could be bound to which they just have listened and it is difficult to go beyond what is heard, while working with imagination can open up more possibilities and be extremely powerful. It is also questionable whether or not the piece will be replayed in another situation, as electroacoustic music can be performed again on another occasion. Indeed, it always requires a WFS system to listen to the piece exactly how it is composed, but the WFSCollider offers a possibility to render into a version with various types of multichannel systems. When it renders, the new version does not use the WFS calculation but VBAP. The spatial images are therefore not experienced exactly the same, but one

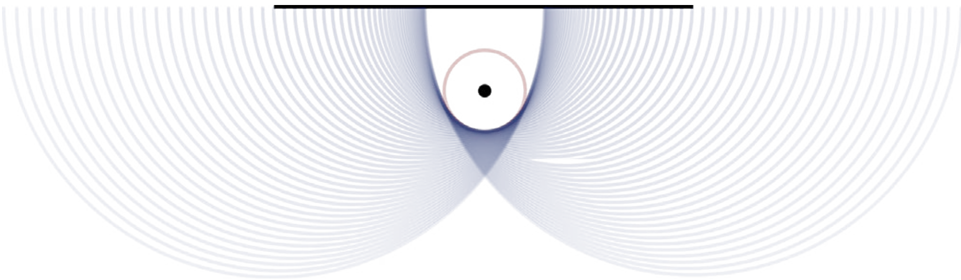

Figure 5. A point source in front of the speaker array with "inverse time" wavefield calculation.

can re-master the piece using another multichannel system, as the preview setting is available in order to listen with the other systems.

Despite all the limitations, it is worth trying out the system. Among many reasons it gives an opportunity to deeply think about the connection between your musical ideas with space. Every single sound that goes into the timeline on your score must have its physical location or a spatial behavior, which comes with distance, speed, and variations of those. They require decisions based on one's artistic approach to how their music should be heard. I would like to address a few critical points that the WFS system offers and artistic aspects of those attributes with examples from my own pieces and experiments.

2.1 Physical experience of sounds and sense of distance

As mentioned earlier the WFS system gives a unique experience of listening to acousmatic music; it gives a physical sensation that the sound is present or approaching so close to the audience, penetrating our bodies, and sometimes right on our heads. This is due to the fact that the WFS system reproduces sounds based on physics and the air pressure of the sound can be felt when the sounds are moving inside the speaker arrays and passing by closely or through the audience. The audience can feel as if they are situated with the sounds coming and going, different from being surrounded by it. Often it feels so embodied and intimate that the audience gives a physical reaction such as turning their heads when sounds are quickly approaching them. Such a unique experience of listening is what the WFS system distinctively offers, and it opens up a number of creative ideas because the performing and listening space are no longer separate, but we are in the same musical space. This attribute raises questions to composers how to utilize it in an artistically meaningful way.

The feeling of nearness or being unified with sounds offers a possibility to work on the variation of dynamics without raising their level but by moving them far or close to the inner location of the speaker arrays. Natasha Barrett talks about this when she describes compositional considerations in a 3D virtual sound field; the composer can work with more intimate sound proximities and also enlarge the spatial difference between distant and near sound materials (Barrett, 2002). The relationship with a close and far sound can be emphasized by differentiating their distance, and accordingly the amount of the intimacy as its perception is not bound to one being softer than the other; rather one being more physically closer than the other.

2.2 Clear(er) distinction between juxtaposed sounds

When trying to juxtapose various sounds at the same time, either to create a sound mass, or to depict individual sound with its own musical path, the WFS system gives more clarity in listening to each sound source than conventional multichannel setup in which they may mask each other due to lack of channel required to contain and distribute many sound sources simultaneously. A different spatial depth is provided by spreading many sound sources extensively, using both moving and static sources. Not only the density of the sound-space can therefore be heavier, but also can be organized into an extensive sonic field. Such a possibility allows us to come up with diverse approaches toward distinctive acousmatic landscapes.

I have worked on implementing various types of sound mass with the WFS system. My very first WFS piece *Hu-tn Gut*[3] shows this approach clearly. *I am very interested in understanding how the imagery and spatial articulation proper to the Korean ritual tradition dialogues with technology in spatial organization. For example: what are the difficulties, if and how do they influence each other? I mean not from a factual point of view, which is already established, but more from a perceptual, aesthetic and space concept perspective. I hope it is clear what I mean. I would like to start a post doc research about this... Hu-tn Gut* is the first process of *Nae-Rim Gut,* which is one of the most commonly performed Korean traditional rituals. Before the main ritual starts, all kinds of -lame- Gods are first invited – so that the main ritual does not have any disturbance from them – by playing metallic instruments and holding the branches of trees, then serve food, play music, and dance to please them. Gods and demons come into the space, have food, and enjoy music for a while, and shamans take them away by playing the last part of music (Kang 2008). *'Hu-tn'* means 'nonsensical.' The ritual has a clear structure; *invitation – party – farewell*. The locations vary: it begins in the front yard, moves into the living room for the party, and finishes at a far enough place where one cannot hear the sound of music any longer.

The sound mass movement is used in three different manners in order to reflect on the process of invitation of Gods, their party, and their departure. Processed percussion sounds call them in, and slowly each God, represented by differently textures synthetic sounds, enters the space and starts *dancing*. Figure 6 shows an example of the amount of juxtaposition in the piece, as well as a rough metaphorical image of how each layer is a combination of different streams of rhythmic electronic sounds.

The spatialization of each layer in the first part (invitation) moves in the same direction at the same speed (Figure 8 left) The movement of the mass accordingly is uni-

[3] Audio/Video materials related to this article are available at the following DOI: https://doi.org/10.5281/zenodo.10252898

Figure 6. Structure of the third part in 'Hu-tn Gut' and a snapshot of inner structure of a sound stream of figure.

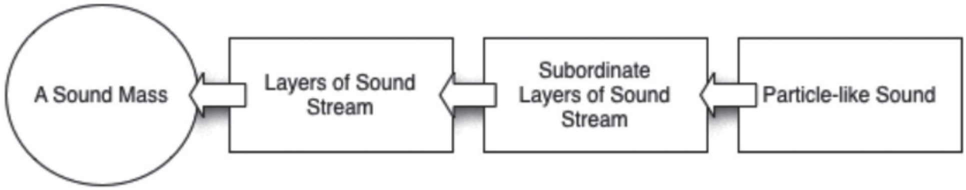

Figure 7. The progress of a sound mass in Hu-tn Gut.

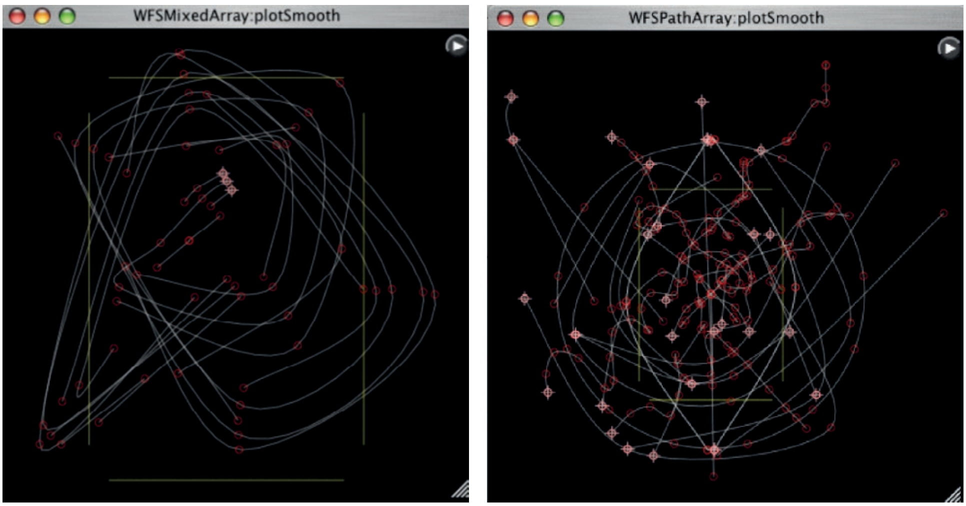

Figure 8. Two different mass movements for the second and the third parts of *Hu-Tn Gut.*

fied as well as its speed. However, those layers are still clearly heard individually rather than one single mass, but a group of distinctive layers. In the third part (farewell) each layer is moving away toward the front after its individual wandering (Figure 8 right). One can hear quite clearly their own unorganised 'dancing' motion, and after some time they all move away to one direction. This clear distinction in the spatialization of sound masses in each section helps to give each part a clear structural character.

2.3 Hearing Doppler effect in moving sound sources

One of the most frequent complaints from composers who work with the WFS system is that they constantly hear the frequency shift that the doppler effect causes. The moving sources of the WFS system cause two different kinds of doppler shift; the first is a simulation of the natural doppler shift by distance between a sound source and a reference point – a listener –, and the second is one per speaker caused by distance between a sound source and individual speakers. These effects are unavoidable as they are part of physics happening when sounds are moving through the air – and when we think for a moment, we don't experience that many sound objects moving so quickly around in our daily lives other than cars, motorcycles, mosquitos, and sometimes airplanes for which we lived with those sounds for a long time. The WFSCollider includes the doppler effect by default accordingly, and one cannot remove it from the source. Sound is heard via a speaker system, and the system comes with its colors due to the way it is built and works, and therefore this phenomenon is inescapable. When sounds move slowly, the effect is logically not very observable, but when they move fast enough, the frequency shift is clearly heard, shifting the frequency of the source materials. It is therefore understandable to hear the complaints because composers carefully sculpt their sounds or bring carefully recorded sound materials. Nevertheless, when the doppler effects become a bother, it gives an opportunity to think of the reasons why we try to move specific sounds at a specific speed and what we expect to hear as a whole. When the speedy movement is used, it must be chosen for its musical role and expression.

This character makes us think of the system as an instrument too; composers research on all the possibilities an instrument can contribute and approach it with the most suitable musical choices. The same principle applies to composing with the system; when one embraces the sounding characters and what the system offers us to do musically, the choice of the sounds and their gestures are carefully made for it. Then such an effect can become a strong character that can be utilized in order to reveal a specific musical gesture that is unique to the system. It certainly influences the choices of sound materials, the choice of musical gestures, and thus the spatial imagery to be created.

2.4 Spatial granulation by extremely speedy moving sources

When sounds are moving faster and faster, they start sounding not as moving continuously anymore, but jumping. The doppler effect causes such a *spatial modulation* that the original sound quality and gesture are entirely broken, and are becoming granulated. For example, a slowly moving sawtooth wave with 500-700 Hz frequency – a mosquito-like sound – will turn into the sound of falling stones on concrete ground. The sense of 'moving sound' disappears as well. Depending on the characteristics of the source material, the granulated sound will also vary in time. By modulating further, the speed of the moving source together with other parameters of the sound such as frequency, spectral modulations, etc, a number of different results can come out. This characteristic of the system can be seen as a good example that the spectral components of sound and its transformation are strongly dependent on and bound to the spatial parameters, where the speed becomes a fundamental parameter for such a radical and unpredictable morph of sound.

2.5 Simulation of various acoustics and coexisting different spatial properties and acoustics

The WFSCollider comes with a number of effects (Figure 9) that make it possible to process the sound source in real-time. Convolution reverb is a useful one among those that can be used in order to vary the acoustic properties of the sound source, and it is possible to modulate its parameters over time and to use your own impulse responses. Plane wave (Figure 4) sources can be a great tool to simulate an acoustic

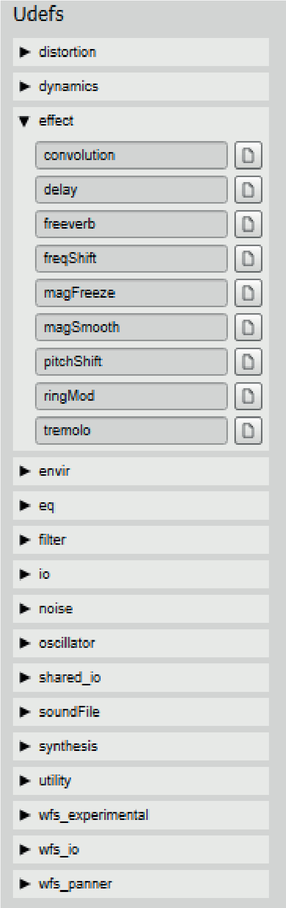

Figure 9. Various effect in *Udefs*. 'Udefs' is a list of unit definitions, and a unit is used to define a type of sound and spatialization in *WFSCollider*.

quality. For example, one sound without much of its own spatial cue can have its own position or movement, and can also be duplicated with a plane wave without having a fixed localization where a convolution reverb is applied.

I have applied this to many of my compositions, resulting from the separation between the reflected space and the sounding space. It is true that whichever reverberation is applied to a sound, it collides with the acoustics of the listening space. When there are more than one objects with their own spatial cues, then they would create a conflict, but it is also possible for many spatial illusions to collide into one total spatial illusion (Barret, 2002). The goals of applying different spatial cues are to reveal altered spectral quality by unique and different spatial cues, (re)contextualization of an environment, and/or unidentified reference to the current listening environment.

Another example that I implement often is that I place the same sound source into three different locations: 1) locating a sound being completely dry and far from the centre; 2) applying a reverberation but moving from one point to the other, while wet/dry rate changes over time by its distance, and 3) locating it at the opposite position with a few millisecond (1-20ms) delay. The sound material for this is normally one with a dynamic gesture rather than a long static one – although this does not sound uninteresting – so that the sound quality does not vary too much by the accumulating reflections. The result is interesting; the ever-changing number of artificial reflections gives strange room quality and the delayed layer gives a sense of being in a 'closed' location; imagine that you are walking on a street surrounded by buildings, the opposite side there is a load construction with a drilling machine, and then you hear the reflection of that machine in your side.

Dennis Smally talks about 'placing a room of a certain dimension inside another room' in the interview with Larry Austin (Austin & Smalley, 2000). I have implemented this in the last piece of *Nae-Rim Gut*, *Madang*.[4]

Madang comes from '*Madang-Gut*' a compound word of *yard* and *ritual* that is a traditional festive event. It can happen as an independent event or the last process of rituals where all the participants celebrate the rituals at the front yard or the square in town. It consists of various cultural events including music performance, theatre plays, and dance.

As the last piece of the project, the important aspect of this composition was to reflect the entire ritual, the characteristics of such a complicated process, to release the tension of the heaviness the ritual carries, and to give a festive atmosphere. The found approach was to juxtapose the first four compositions on top of each other. Each composition – two live electronics pieces and two WFS compositions – is rendered into a quadraphonic piece, and then juxtaposed both in music and in space. The parameters that shape the pieces as a single entity was to consider each piece as one square sonic field and by placing and moving them in different distances the dynamics of the piece was decided. Figure 10 shows the first sketch of the graphic score; the black square is the inner space of the WFS speaker arrays, and blue, red, green and yellow ones refer

[4] Audio/Video materials related to this article are available at the following DOI: https://doi.org/10.5281/zenodo.10252898

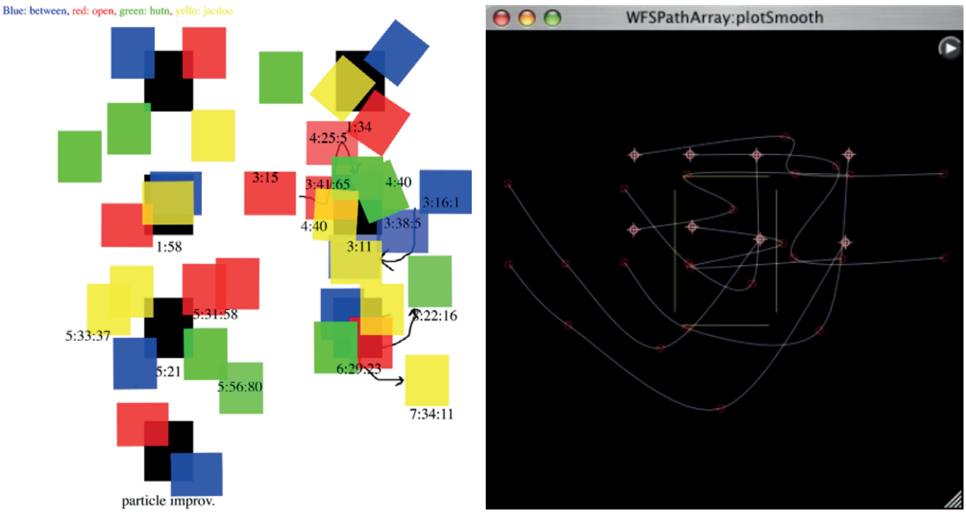

Figure 10. Spatial score of *Madang* and an example of the movements of 4 pieces.

to four pieces. There are time codes written in order to trace where and how far and long the squares have to move.

The decision has been made purely to reveal different complexities at a moment. Such complexities are not only revealed by the juxtaposition of differently sounding pieces, but also the spatial properties of each piece caused by 4 different performing spaces combined in one space. Natasha Barret talks about a state of conflict arising when the spatial information inherent to each sound-object is conflicting with their 3D spatial dispositions. Then the original spatial properties disappear due to the juxtapositions of different sonic fields (Barret, 2002), but there emerge new properties. Complexity could be one way to describe it; the four rooms become one in time and space with its own context and orientation. What is happening in between, before four rooms gather at a place, is probably rather more complicated in its musical figure and sonic phenomenon.

Each composition (each room) in *Madang* has different characters; the first two pieces involve instruments such as cello, recorder and Jing (a Korean gong), and the last two with electronic sounds. The first two pieces were recorded in two different concert spaces. In this piece, the original roles of sounds in the original pieces are re-organized simply by their momental superimpositions caused by moving them in the same space. The original quadraphonics spatial characters in the pieces do not share anymore their original spatialities. Both the unfolding sonorities and spatialities are creating a new musical context.

2.6 Diffusion and spatialization

When talking about sound spatialization in Electroacoustic music, we can come up with two different traditions: one is to apply spatial algorithms into the number of channels while creating sounds or composing the piece. When performing such pieces one can adjust the levels of each channel in order to reveal the composed, pre-designed sound sources in balance, but the spatial images are not altered. Another approach is a sound diffusion of a mono or a stereo music composition to multiple loudspeakers using a diffusion desk. While the composition is fixed, it is distributed to multiple, and often different types of loudspeakers – loudspeaker orchestra – in real-time in order to articulate, expand, and isolate certain gestures in music and to reveal timbrel characters by sending them to a specific set of loudspeakers. Moving sound around in space is not the main concern, but rather the articulation of the music through performing different passages through differently sounding arrays of speakers (Zvonar, 1999).

Although one of the significant differences is in the deterministic character of the two traditions, they require completely different practices. Sound diffusions do not use spatialization algorithms. Moving sound sources are possible but limited to the motion of the fingers on the mixing desk. Therefore, composing for a sound diffusion needs a particular strategy. Spatializations rendered in multichannel have more possibilities to generate and pre-program various geometric shapes and trajectories. Above all, it makes it possible for each sound source to have its own gesture when they are distributed in time. As mentioned in the chapter 2.2, the WFS system maximizes such a complexity of polyphonic spatiality and its clarity; a more vividly structured sound mass can be realized. The number of layers simply depends on the capacity of the servers and the complexity of each movement, yet it normally exceeds 25 moving – possibly lengthy – sound sources. Then an ambiguity of the localization of the sound can also be considered if one tries to merge those layers into a cloudy total mass. Plane waves can be used solely or together with point sources in order to achieve that as they make it possible to simulate PA loudspeaker simulation. Comparing the point sources with clear locations and gestures, the plane waves only work with a direction and a distance. It can also move, and when it does, its movement feels more massive than the one of point sources. This does not offer the same impact as sound diffusion in practice, but the sound results of diffusion can be simulated, or co-exist with various spatializations.

2.7 The 3rd dimension

The WFS system suggests 2-dimensional hearing experience of sound. Ideally the best experience of spatiality can be achieved when the listener is seated in the same height as the speaker arrays. The WFS system at Institute of Sonology (Figure 11) is set up in such a way – probably one of the most transparent environments as the studio has a proper acoustics aided by the acoustic panels and the height of the system matching our ear level –, and the Game of Life system is set up slightly higher than that. This is because the WFS in Sonology is for studio mastering while the Game of Life WFS is for concerts. When it is set up higher than our ear level, it prevents the other people from blocking the moving sounds. Regardless, the system is generally located in a concert hall with its acoustic condition. The reflections of the hall are therefore unavoidable. This means that it is difficult to observe the transparency of the sound journey.

This can be seen as a problem as the desired sonic images cannot be fully achieved. However, such an issue does not belong only to working with the WFS system and it does not seem to come across as a disadvantage. The concert space can help the composition to shine, to resonate with itself, and to even reveal undiscovered areas of sonic exploration (Kang, 2021). Students in Sonology work in this studio over the year, and at the end of the school year the Game of Life system is installed in a bigger concert space. Their impression of the experience in two different environments tell that the help of the room acoustics make their pieces truly resonating – although the WFS system in the studio has a higher resolution with many more loudspeakers than the Game of Life system. The sonic environment sizes they feel in both locations vary as well, yet the core of the spatiality of the entire music remains the same.

These 'sizes' do not only mean the horizontal plane, but it certainly extends to the vertical dimension. Together with the work of the room acoustics, our psycho-acoustics help to feel the height of sound as if they are flying above our heads. Such an impression is hard to be formulated due to the complexities in each different acoustics, but it can be learned and integrated to a certain extent by experiences and experiments.

2.8 Live possibilities

The WFSCollider offers possibilities to perform live electronic music with the WFS system. The number of input channels for the system is depending on the num-

Figure 11. Wave Field Synthesis Studio at Institute of Sonology (http://sonology.org/).

ber of input channels in the main audio interface. The Game of Life system has 8 analogue inputs and 8 ADAT inputs, but they cannot be used together. Accordingly, the total input is limited to 8, which can be seen as a limitation. Composing for the WFS system requires its justification; one could ask themselves if their musical and spatial ideas can better be achieved using other types of speaker configurations. Hopefully I elaborate on the reasons why I am addressing such a question. There is no fixed answer to what the right strategies would be in such a wide range of spatial music approaches. Nonetheless it is important to think about the limited number of the input sources and what each input will consist of, and how to spatialize them. An important point to be considered is that each input does not necessarily occupy one location nor move alone. Each channel can also be processed, re-created, or modulated by using various effects available in WFSCollider. This aspect can open up creative solutions to the limited input channels.

A challenge in live electronics for the WFS is to come up with performance strategies based on what WFSCollider and the system can do specifically. Normally performances of live electronic music involve performative aspects such as changing parameters in real-time using controllers and performing with instruments played by the composer or other instrumentalists. Also, the pieces can be fully composed, or be improvised. Then there come parameters that have to be controlled in real-time: spatializations. Mentioned earlier, spatialization does not come only with a location and movement, but with distance, speed, and acoustic properties. In case of improvised music where the performers cannot anticipate fully how the music will flow in time, then it is questionable how the spatialization will be achieved without knowing the sonic properties and the relationships with other sounds. Localization in the WFS system is made in a cartesian coordinate plane with (x,y) – or possibly in a polar coordinate system (distance and angle)-. In order to move a sound source in space, it requires two parameters controlled at the same time as a pair, which is difficult to control with a linear controller like a fader or knob. Also, there could be variations of speed that do not depend too much on the way our finger moves. In case of already composed music pieces, especially with a live performer with an instrument, it is also questionable where the performer should be located – inside the speaker arrays, or outside? if outside, then which side and how far? – what the instrument is and how loud it is, and whether or not the instrumentalist has to listen clearly to the electronic sounds. Not having a clear stage, or rather to say, no division between the audience and the sonic space could become a question to solve in order for the music to meet a desired sound result.

Another significant issue is that the live input is supposedly and preferably received without any latency especially when one is processing it in real-time, or to perform in duo with demanding accurate time cues. The general latency level is not high for rendering a score, but when there is a live input source, the latency, even being minimized, is audible. A solution to reduce the problem of latency happening with live input is to link the source always to an index source, preferably close to the desired WFS sources. This means that the input signal is reaching at least one speaker first by skipping the WFS calculation before it goes into its desired location or moves.

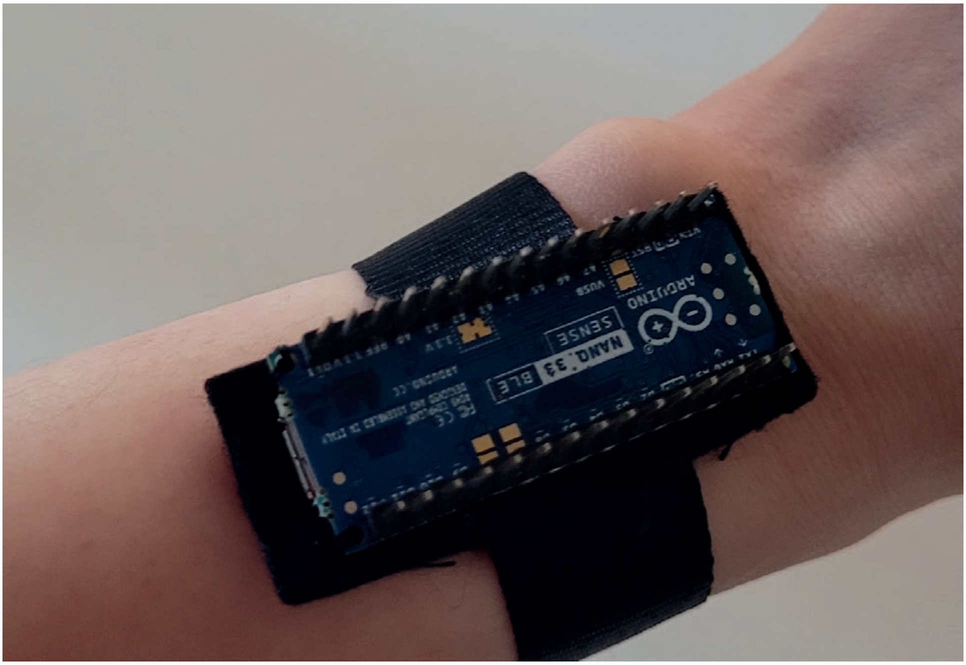

Figure 12. Arduino nano 33 BLE on a wrist.

As mentioned earlier, the latency is long enough to be noticed, but short enough to be masked in this way. The index source used in this context is probably not desired artistically, but it works as a bridge to its desired position or movement. In this way multiple performers are able to synchronize with each other without any latency.

With all those restrictions and challenges, there are still a number of possibilities to perform it in real-time, some of which can be out of the 'conventional' ways to approach a live electronic music composition.

One example of live control with a sensor where the cartesian coordinate system is mapped already. This can be done with an accelerometer, gyroscope, or magnetometer sensor, or a combination with them where they can also be controlling the other parameters in sound processing. In 2020-2021, I have experimented with *Arduino nano 33BLE* (Figure 12), a small sized microcontroller. The sensor is connected to the *WFSCollider* via Bluetooth, and communicating via Open Sound Control (OSC) signal. There are three different mappings made: 1) drawing a spatial trajectory in real-time; 2) changing the speed of multiple, pre-designed spatial trajectories; and 3) a conditional decision-making point for on-going sound processing. (Kang, 2021)

In this experiment, it was important to limit the drawing function with the sensor to a specific moment in order not to make unified motions being created in multiple trajectories. Rather it is better to be used for a distinctive moment of the music where there is a space for the sound to be traveling within an improvisation situation. In my

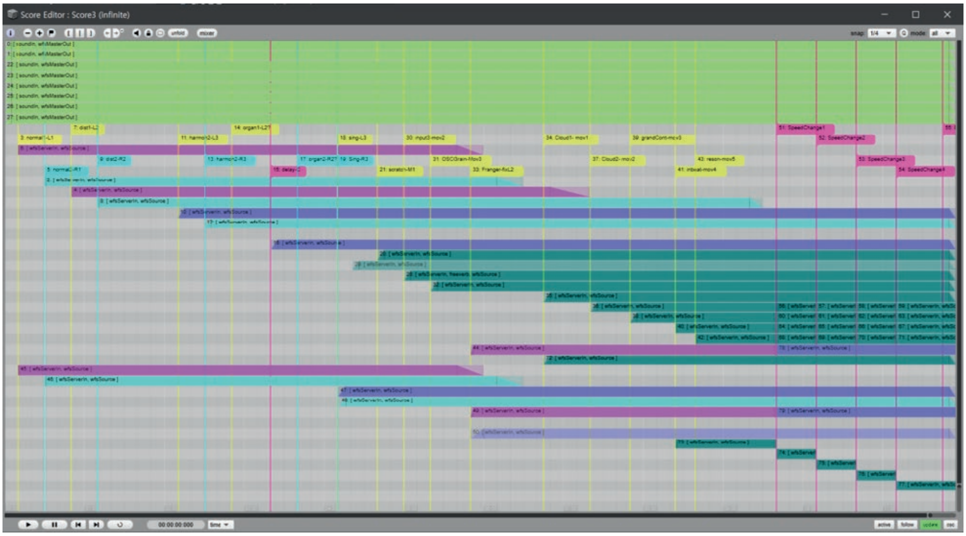

Figure 13. The UScore of The Voice (2021).

experiment for the piece *The Voice*[5] in 2021, this function was used at one event, the light green-blue event in the middle layer of the score in Figure 13.

Another possibility is that either the control for the spatialization or for the processing can already be composed, and work as a 'score' for the other to fit in. It is not uninteresting to have a fixed time and gesture already composed, and the other musical elements follow them. Mapping between musical parameters and spatial parameters can also be implemented in this platform. By doing so, one does not think of the music and space separately but together.

WFSCollider also opens up a unique possibility to generate a score file using *SuperCollider*. One can skip the graphical user interface (GUI) and directly code the score and execute it in real-time. This surely requires knowledge in *SuperCollider* programming. An Icelandic composer Bjarni Gunnarsson presented in 2022 his live electronic music 'Wildfires' where he generated 22 scores that are activated in real-time but in no particular order (Gunnarsson, 2022). In each score, he created events with 'infinite' duration, so that each score is composed without a fixed duration. The sequence of the orders depends on his execution, not necessarily one after the other. This can be compared to having 22 different instruments in front of the performer, who decides how to play them in time.

3. Conclusions

The WFS system opens up the possibilities to think deeply about the use of space in music in such a way that spatialization is strongly connected to the evolution of

[5] Audio/Video materials related to this article are available at the following DOI: https://doi.org/10.5281/zenodo.10252898

sound and music. Various approaches and aspects are introduced, and I hope them to be an inspiring opinion rather than a guideline; there is no absolute answer to how we must use an instrument, but we can always be open to how others compose with it.

When discussing sound spatialization, it is crucial to think firstly about the sound source materials such as synthetic sounds, synthesisers, field recordings, and studio recordings, which call for in-depth listening in order to discover their *spatiality*. Therefore different approaches are required. This is probably the most important practice when approaching the WFS system as well. I hope to have another opportunity to write specifically about this in the future.

A spatial audio system such as the WFS system is an instrument with a unique voice and it broadens our thoughts toward the implementations of musical space; it is not only a tool for sounds to move and locate somewhere, but also to shape, alter, and transform the sounds together with their spatial gesture. The WFS system does not give you the most realistic sonic image like in reality, – as a number of critiques are based on – and even if so, it might not be an interesting musical instrument to compose with. The differences make it unique, and give a room for composers to utilise them. It also does not solve every issue on spatialization in electroacoustic music. Nevertheless, it forces us to use every single parameter in sound spatialization, not in a single manner but with choices of variations, and integration and utilisation of real and virtual acoustics. This is an invaluable practice that one can carry on in daily musical practice.

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Institute of Sonology http://sonology.org/

The aesthetic implications of 3D technologies on the spatial conceptualizations, configurations, and articulations of my compositional process

Giulia Vismara

For all new conceptions there must be new means.[1]
Varese E.

Each art practice is inscribed in its own time, materializing a true 'media ecology', a set of mediations and mediators of various kinds, explicit (technical, institutional) and non-explicit (cognitive, cultural, symbolic).[2]
Di Scipio A.

The rapid development and widespread adoption of immersive audio technologies, such as Dolby Atmos, Ambisonics and Wave Field Synthesis, has given rise to several sonic practices in which spatial experience plays a crucial role. The use of these technologies present a notion of space as a quantifiable and predetermined object designed to replicate a 360-degree sound field that closely mimics human auditory perception. However, this stance does not sufficiently contemplate the complexities[3] of their reciprocal influence from an aesthetic and perceptual perspective. Intrinsically, sound has the ability to provide us with immediate spatial awareness and, the implementation of 3D audio technology, emphasizes this interconnection. Because 3D recorded sound holds spatial coordinates, the link between these two elements appears to be more clearer when the attributes are already entangled within the spatialization algorithms. Independently of visual cues, the ability to seamlessly incorporate spatial and auditory

[1] E. Varese, Varèse, *La mécanisation de la musique*, 1930, quoted in *Varèse*, 1983, pp. 58–63 and in *Composing Electronic Music, A New Aesthetic*, *Composing Electronic Music: A New Aesthetic,* Oxford University Press, 2015, XXIV.

[2] "Ogni prassi d'arte s'inscrive nel proprio tempo materializzando una vera e propria 'ecologia dei media', un insieme di mediazioni e mediatori di vario tipo, espliciti (tecnici, istituzionali) e non (cognitivi, culturali, simbolici). " in A. Di Scipio, *Circuiti del Tempo. Un percorso storico-critico nella creatività musicale elettroacustica e informatica*, Libreria Musicale Italiana, 2021, XVII

[3] Where "complexity" for Edgar Morin is a *complexus*, that is, what is woven together, made up of inseparably associated heterogeneous constituents and poses the paradox of the one and the multiple. E. Morin, *Introduzione al pensiero complesso. Gli strumenti per affrontare la sfida della complessità*, Sperling & Kupfer, 1993, p. 20

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attributes immediately establishes a connection between the concept of space and the experience domain. Hence, composers and sound artists can intentionally mold the perception of auditory spatial awareness by attuning themselves to the medium they are employing. The process of expanding spatial perception necessitates specific compositional considerations and unique listening approaches that directly involve the 3D sound system environment as essential elements within different setups.

Natasha Barrett, discussing her approach to spatial audio, describes her interest in realistic movement behavior and how the coupling of spatial tangibility and sound identity can influence our perception of spatial characteristics.

Whereas:

> *Although some answers can be found in mathematical models, these models are not designed to capture our perceptual experiences, nor can they address the context of musical materials. The complexity of the problem is such, however, that solutions can also be revealed through compositional investigation.*[4]

The integration of 3D spatialization technologies into my practice gave me the opportunity to contemplate a multifaceted perspective on how sound can reshape and expand our perception of space. The article investigates the implications of diverse methods, techniques, and 3D spatialization tools on my compositional approach. It provides a glimpse into my creative process, encompassing conceptualizations, configurations, and articulations illustrated through the presentation of two projects and future endeavors.

Correspondence and Transposition

As my comprehension of space evolved beyond acousmatic music, I began to envision different relationships between the elements involved in the construction of space and construct a transdisciplinary conceptual framework. I draw on the concepts of *correspondence*[5], as proposed by Tim Ingold to refer to how separate components interact with one another in various spatialization configurations and how, occasionally, these interactions inform a particular conception of space. And *transposition*[6], as dis-

[4] Carpentier T., Barrett N., Gottfried R., Noisternig M.. *Holophonic Sound in IRCAM's Concert Hall: Technological and Aesthetic Practices.* Computer Music Journal, Massachusetts, Institute of Technology Press (MIT Press), 2017, 40 (4), pp.14-34.

[5] Ingold T., *Correspondences, Knowing from the inside,* University of Aberdeen, 2017

[6] Braidotti R., *Transpositions On Nomadic Ethics,* Cambridge and Malden, MA: Polity, 2006, p.6. figurations.p.28 In the introduction to *Transpositions, Aesthetico-epistemic operators in Artistic research*, M. Schwab describes the concept: "*The logic of representation is singular, remaining the same in different instances, while the logic of transposition is multiple, because it requires attention to the differential aspects of the relations between the positions, having to be transposed from instance to instance. Such transpositional operations require a particular emphasis on the differential aspects of the relationships enacted between positions. The positional specificity that is part of transposition – be it in space, time or otherwise determined – explains why it has been so difficult to deal philosophically with transpositional operations and why artistic research, which is sensitive*

cussed by Rosi Braidotti, creating an interexchange between diverse disciplines dealing with the notion of space. This exploration leads to extra-musical ideas, approaches and perceptual categories provided by other fields. The notion of correspondence encapsulates the dynamic nature of the interconnections and interactions between various elements, such as 3D audio technologies, the composer's spatial intention, the sound source's attributes, and the listener's experience. To investigate this complexity, I developed a network that is based on the concept of *correspondence-thought*, which reflects the ever-changing nature of configurations and relationships. A network based on the dynamic process, known as *ontogenesis* where the principle of openness is central because it recognises the fluidity and malleability of interconnections and enables possibilities to evolve. This perspective highlights that space undergoes constant transformation through interactions between its components. Consequently, the transient configurations represent an ongoing series of processes in which human and nonhuman elements organize, assemble, and gather the space formation.

As accurately presented by Rosi Braidotti:

> *Transposition is a scientific theory that stresses the experience of creative insight in engendering other, alternative ways of knowing*[7]

M. Schwab[8], describe transposition as the fluid movement and cross-referencing between different disciplines and levels of discourse within artistic research. Through deconstruction, it gives rise to new methods of knowledge exchange that encompass aesthetic qualities. Transposable concepts, often described as *nomadic notions*, form a network that bridges philosophy with societal realities, theoretical pondering with practical strategies, and abstract concepts with creative potentials. In developing my conceptual framework I relied on interdisciplinary interactions that integrated insights and concepts from various fields including architecture, psychology, anthropology, media philosophy, sound and digital studies. The mutual exchange of concepts and practices from several disciplines deepened my understanding of space and its implications towards sound.

Ultimately, this mapping helped me to envision a multidimensional and complex outlook on space, one that could assume various forms contingent upon the interactions between sound, technology, spatial conceptualization, and the listeners.

3D Spatialization

There are two main sound spatialization systems: the acousmonium, which is a loudspeaker orchestra where the signal level is routed to several loudspeakers, and the

to the specificities of what is at hand, can present new options not only for a bottom-up rather than a top-down approach, but also for an approach for which there is no 'up', but only positions that result from movement."

[7] Braidotti, R., *Transpositions: On Nomadic Ethics,* Polity Press, 2006. p.6

[8] Schwab, M., *Transpositions: Aesthetico-Epistemic Operators in Artistic Research,* Leuven University Press, pp. 7-19.

soundfield, which employs an abstract arrangement that allows working with virtual sources. Although both systems aim to replicate a sense of spatial dimension, they provide distinct affordances and agencies. Drawing from my personal experience, composers can actively shape the perception, conceptualization, and overall sound experience within the spatial domain by understanding and harnessing these affordances and their agency. This gives them the ability to emphasise specific emotions related to spatial relationships, and even challenge conventional notions of space and spatiality.

In the case of the acousmonium, the composer has the ability to manipulate and control the movement of sound within the physical space. This system offers a more direct and tangible means of working with spatialization, allowing the composer to position sounds in specific locations and orchestrate their movement between speakers. On the other hand, the sound field approach takes a more abstract perspective, employing algorithms to simulate virtual sources within a virtual space. This method offers a different set of tools and possibilities for shaping the perception of space. Ambisonics is a technique used to encode and reproduce sound fields by capturing and representing their directional attributes. Unlike traditional multi-channel audio systems that assign specific channels to individual speakers, it uses channels that contain information about various physical properties of the sound field, such as pressure or acoustic speed. In doing so, it allows the creation of a more immersive and realistic sound field, offering a faithful representation of the spatial attributes of the original sound source. Employing a spherical coordinate system to capture the spatial characteristics of sound, Ambisonics allows the creation of a three-dimensional audio experience that can be enjoyed through an appropriate arrangement of speakers or headphones. It provides flexibility in sound reproduction, facilitating accurate location/ positioning and movement of sound sources within a virtual or physical space.

During the passage from a multi-channel system to virtual sources, my compositional methodology encountered a significant transformation. This shift has initiated a reconsideration of space, as the absence of physical speakers resulted in a fragmented understanding focused on the movement of sound among speakers. Instead, I embraced a more abstract notion where space is perceived as a unified and continuous flow, accompanied by a contingent sense of time.

Moreover, the process of encoding and decoding played a crucial role in this transformation. By integrating spatial information directly into sound, the intrinsic spatial quality of sound itself was revealed, highlighting that sound inherently possesses spatial characteristics. As a result, the interaction between space and sound, including their respective properties, occurred even before the compositional phase. These distinct characteristics of the ambisonic method led me to reconsider various aspects such as sound material selection, space pre-compositional conceptualization, and the resulting spatial experience perception. The composer's agency here is manifested through the manipulation of parameters and algorithms that determine the spatial characteristics of the sound field. The choice between these systems can significantly impact the conceptualization and creative process related to spatialization (in music composition).

At first I thought of sound as a vital source with a generative potential for materializing the spatial dimension. Then, with the addition of 3D technologies, I began to superimpose ideas and concepts of physical, virtual and imaginary spaces to my practice.

Sonorous substance

> *The philosophy of organized sound places great emphasis on the initial stage of composition—the construction and selection of the sound materials. Just as the molecular properties of mud, thatch, wood, stone, steel, glass, and concrete determine the architectural structures that one can construct with them, sonic morphology inevitably shapes the higher layers of musical structure. These interrelationships confirm what musicians have known all along: Material, transformation, and organization work together to construct a musical code. It is through this context that a given sound accrues meaning.*[9]
> Curtis Roads

Through my experimentation with 3D spatialization, I've realized more and more the potential of sound as a means to shape the morphology and morphogenesis of the spatial configuration. Identifying sound as a material entity for the construction of a space prompted inquiries into the notion of materiality and the distinctive qualities of sound. Initially attempting to associate sound with the notion of materiality defined by the qualities of physical substances, I conceived of sound objects as fragments extracted from a specific spatiotemporal environment, subsequently inheriting and preserving those environment-specific characteristics. Although extrapolated from their original context when diffused in a multichannel setup, they evoke expectations regarding their location. This leads to a dynamic interaction between the listener's preconceived spatial expectations and the compositional intention.

Later, influenced by Tim Ingold's perspective on materiality, which suggests that a deeper understanding of materiality requires moving away from a narrow focus on physical materials[10]. I shifted my interest to how interactions among materials shape the overall experience, highlighting the importance of experiential aspects over the physical properties of the materials themselves. Sound is inherently intertwined with space and thus possesses its own spatial attributes, while remaining connected to an intangible idea of it. Considering the transition from matter as a potential for expression to materiality as a catalyst for effects and experiences, we can assert that the materiality of sound has the ability to activate spatial experiences. In this sense, sound has the capacity to materialize or bring life to a space, making it tangible through our perceptual experience. This quality makes sound a powerful tool for embodying and exploring various possibilities of inhabiting space through listening.

[9] Roads, C., *Composing Electronic Music: A New Aesthetic,* Oxford University Press, 2015, p.17

[10] Ingold, T. *Materials against materiality,* in Archaeological Dialogues 14 (1) 1–16, Cambridge University Press, 2007, p. 2 '*To understand materiality, it seems, we have to get as far away from materials as possible*'.

The utilization of 3D technology is akin to a means of questioning and rearticulating the connection between space and sound and investigating their materiality.

Ubiquitous feeling

Sound localization is a complex phenomenon involving the processing of multisensory information, synaptic plasticity dependent on previous auditory information, spatial experience, and movement. Our brain has learnt to associate specific characteristics of sound with certain spatial positions or movements.[11] To improve sound localization accuracy, the brain can integrate sensory observations with sensorimotor information based on previous experiences. By leveraging this information, the brain can make inferences about where sounds are more likely to occur. For example, the increase in volume and change in spectral content when sounds approach from a distance is a well-known perceptual cue derived from our real-world experiences. By manipulating these cues and challenging the expected spectral changes, composers can generate a sense of surprise, disorientation or work with spatial associations and tap into the listeners' preconceived expectations, creating a sense of familiarity. Kendall examines the behavior of perceptual activity of the spatial dimension during spatialization in a multichannel system of electroacoustic music, emphasizing how a fully embodied understanding of space and spatial movement is the basis of the listener's feelings and thoughts as they experience listening to sound in space[12]:

> *Listeners experience electroacoustic music as full of significance and meaning, and experience spatiality as one of the factors contributing to its significance. Perceived sound is always spatial, and spatiality is an integral part of any auditory experience. Sometimes spatiality is in the foreground of attention and is a primary carrier of meaning. Other times, it slips into the background. If we want to understand spatiality in electroacoustic music, we need to understand how the listener's mental processes give rise to the experience of meaning. The feelings and thoughts that the listener associates with the experience of sound in space seem to spring from a deeply embodied knowledge of space and movement spatial. This space knowledge is acquired through sensory experience that presumably begins at the beginning of life and continues through interactions with the everyday world. Notions of space, acquired and understood through bodily experience, at the heart of much of our everyday thinking. Spatial analogies and spatial metaphors traverse our language and reasoning. It is no wonder that space can be a powerful component of meaning in electroacoustic music.*

[11] Francl, A., McDermott, J.H. Deep neural network models of sound localization reveal how perception is adapted to real-world environments. *Nat Hum Behav* 6, 111–133 (2022).

[12] Kendall G., Spatial Perception and Cognition in Multichannel Audio for Electroacoustic Music in Organized sound, Cambridge Press 2010, p.228.238, p-228, Kendall G., *The feeling blend: feeling and emotions in electroacoustic music*, Organised Sound 19(2): 192–202 & Cambridge University Press, 2014.

In my current approach to composition, I am actively exploring the use of sound sources that gradually lose their recognizable qualities, becoming forms that traverse space, occupy it and evoke it. In this passage I experimented with the concept of the quantum of sound that holds significance from a psychoacoustic standpoint as an indivisible unit of information. In the time domain, it exhibits reversibility without altering the quality of perception.

By manipulating micro temporal relationships and micro intervals, the distribution of the sound spectrum in space is affected, consequently influencing its articulation within that space. The notion of grains arises from the process of discretization, where matter is atomized and divided into particles. From the concept of sound object to the adoption of particles has radically altered the framework of spatio-temporal references in my compositional approach. Completely detached from the sound sources, I can focus on shaping a material that contains an understanding of space that I define pre-morphological. This approach allows me to emphasize the inherent immanence of sound[13], its characteristics and behavior within spatial contexts. The utilization of 3D sound as a case study provides an opportunity to examine its impact on various aspects of human experience within immersive environments, such as perception and cognition. Through this investigation, we can delve into how 3D sound spatialization shapes our understanding of space, time, presence, and narrative. Additionally, it prompts us to consider how sound influences our sense of reality, identity, and agency.

Coefficient of space generator

Continuing to reflect on the specific materiality of sound, I employed my body as a means of vibration and imagination, serving as the vehicle for the materialization of the spaces invoked by it. This brings with it the idea of a body that is not merely a passive entity in space but an active agent that participates in the production and experience of it. The relationship between the body and space becomes a fundamental aspect in understanding how space is constructed, perceived, and inhabited, and how individuals shape their sense of self within spatial and temporal contexts. Gødoy'[14]s research on motor mimetic musical cognition suggests that listeners engage in a range of responses to music, including the generation of images or imitations of sounds. These responses can involve gestures that accompany sonic or emotional expressions, or trace the movement of a sound. Since movements give rise to sounds and sound is fundamentally the movement of air, he considers gesture as an integral element of

[13] Wanke R. Santarcangelo V., *Memory as the Aspatial Domain for the Perception of Certain Genres of Contemporary Art Music*, Music & Science, Volume 4: 1–18, 2021, p. 6.

[14] Gødoy R. I., *Gestural-Sonorous Objects: embodied extensions of Schaeffer's conceptual apparatus,* in *Organised Sound* 11, Cambridge University, 2007, p. 149–157.

Godøy, R. I., *Gestural Affordances of Musical Sound*, *in* Godøy R.I. & Leman M. (eds.), *Musical Gestures: Sound, Movement, and Meaning*, Routledge, New York, 2010, pp. 103-125.

sound itself. According to Gødoy, the construction of imagery and space in relation to auditory perception goes beyond the immediate perception of sound. It involves the memory and imagination of sound itself. In this context, the musicologist introduces the concept of the gestural sound object, expanding upon the traditional notion of a sound object. The gestural sound object is associated with embodied cognition, emphasizing the connection between sound and bodily movements. Sound opens up other perceptual dimensions, allowing us to explore the spatial realm from a unique perspective. It offers a rich and immersive medium through which we can engage with spatial environments, enabling us to perceive and navigate them in ways that transcend traditional visual perceptions.

> *The goal of spatial audio in electroacoustic music should be to evoke experiences in the listener with artistic meaning: in particular, meaning emerging from the spatiality of the perceived sound. Therefore, the goal of a multichannel audio system should be to deliver acoustic signals to the ears of the listener that provide the stimulus for such artistic spatial experiences and understandings. The more that we understand about the complex relationship between spatial sound systems and the listener's spatial thinking, the better we will be able to harness the capacities of such systems for artistic purposes.*[15]

In the process of constructing a space, while seeking correspondences and transpositions across various disciplines, the concept of space is envisioned as a dynamic and continuously evolving entity. It has the capacity to assume diverse forms or articulations according to the interactions among its constituent elements. In this perspective, space and sound are regarded as essential components of the overall experiential process, inseparable from the individuals engaged in the act of listening.[16] From the listener's perspective, which is inherently tied to the body's experience, engaging with a composition aimed at evoking a sense of spatiality involves a coefficient of spatial generation. When Di Scipio discusses the relational dimension of sound, he introduces the notion of the *coefficient of sound generation* in relation to the act of listening. This departs from the idea of sound as object and instead recognizes that sound takes shape not only within the creator but also within those who anticipate or receive it. Similarly, we can also discuss the concept of a space generation coefficient, highlighting how the experience of space is actively co-created by those who engage with it. This coefficient represents the listener's active participation in shaping and perceiving spatial cues within the auditory environment. It underscores the mutually dependent relationship between the listener and the spatial experience.

[15] G. Kendall, *Spatial Perception and Cognition in Multichannel Audio for Electroacoustic Music,* Organised Sound 15, Cambridge University Press, 2010, p. 228–238, p.229.

[16] A. Di Scipio, *Sulla dimensione relazionale del suono,* https://static1.squarespace.com/static/53161999e4b0ebfb9eceb115/t/534c50ede4b03c03e07b0c95/1397510381974/Di+Scipio+-+Sulla+dimensione+relazionale+del+suono.pdf, consulted on 10 June 2023.

Spatiotemporal heterogeneous components

The Lefebvre's[17] perspective on the production of space highlights how bodily practices contribute to the production of socially constructed spaces and times, and concurrently shape individuality that becomes internalized within the body. Lefebvre argues that space and time are intricately linked, and they both hold the same ontological significance. While they can be distinguished, they cannot be entirely separated, as they manifest themselves as distinct yet inseparable entities. His argument that space and time share ontological significance, intertwined and inseparable, echoes the dynamic relationship we've explored between the body and space. These discoveries highlight the delicate interaction of the body, space, and time, exposing a diverse range of perception, experience, and uniqueness within the constantly shifting landscape of human existence.

Through an immersive listening mode supported by 3D audio technologies, the listener has the opportunity to experience space-time coordinates from a perspective that is not only linear and geometric, but strongly interconnected with a phenomenological approach. At the same time from a composer perspective, with the support of these technological means the compositional approach can move beyond the articulation of spatial information in the space of projection and immediately interconnect to the *spatiotemporal* dimension.

Eleni Ikoniadou, in *The Rhythmic event*, *Art, Media and the Sonic*, investigates affective modes of perception, temporality, and experience enabled by experimental new media sonic art, with the aim of providing a new perspective to the speculative philosophy of media that focuses on the creative unpredictability of the event, refers to the perception of a sound event beyond what is actually heard.

> *Digital sound art introduces interesting mutations as new rules of form, time and space, treating them as complementary heterogeneous layers of the event rather than as dimensions subordinate to each other.*[18]

In an attempt to probe the presence of the artwork of sound as a set of sensations that transcend space, time and the bodies that compose and experience it, takes into account what remains, involuntary, non-nominal and unknowable forces along the periphery of sound. The final challenge proposed in the text is to think of rhythm as discrete continuity, as a center of uncertainty between real and virtual. Ikoniadou's exploration of rhythm and affective perception within the realm of digital sound art

[17] H. LeFebvre, *The production of space,* Blackwell, Oxford e Cambridge,1991, p. 407

[18] Ikonadiou E., *The Rhythmic event, Art, Media and the Sonic,* The MIT Press, Cambridge, 2014, p. 233. Eleni Ikoniadou with the aim of providing a new perspective to the speculative philosophy of media focuses on the creative unpredictability of the event, refers to the perception of a sound event beyond what is actually heard. In an attempt to probe the presence of the artwork of sound as a set of sensations that transcend space, time and the bodies that compose it and experience, takes into account what remains, involuntary, non-nominal and unknowable forces along the periphery of sound. The final challenge proposed in the text is to think of rhythm as discrete continuity, as a center of uncertainty between real and virtual.

aligns with Lefebvre's rhythmanalysis and his strong emphasis on the significance of the lived experiences of individuals engaging with a particular environment.

Dust variations

Interstellar dust is thought to be produced by supernova explosions or by the nuclear fusion of stars. The different materials that make up the dust, the shapes and sizes of the particles, the evolution of the properties of the grains and their history all contribute to its variance. Space is not uniformly distributed among the particles, but they grow, occupy and move through it according to their unique properties.

Inspired by the interplanetary dust continuous cycle of life and death, *Dust Variations* is a three-part project. The aim of the project is to suggest to the listener a spatial experience and a reflection on the formation of space in a broad sense, but particularly the cosmic one. Each project variant explores different spatialization strategies, configurations, and approaches. Similarly, the data related to dust is gathered through varying methods on each occasion, serving as the foundational element for shaping the spatial, temporal, and spectral organization within the musical composition. These variations provide multiple cues, enabling the audience to immerse themselves in and experience the subject in various ways. The first variation originates from

Figure 1. Interstellar dust.

a speculative notion concerning the creation of cosmic space and the behavior of interstellar dust, following a conversation with astrophysicist Riccardo Gualtieri. The second variation involves the sonification of data related to the composition of the dust particles and their movement, achieved through the development of an agent-based model. The third one will be an interactive installation, enabling the audience to engage with sound spatialization through their movements where the sound material will be taken from the previous Dust Variations I and II.

Dust Variations I

Dust Variations I, a 5th order Ambisonic composition combined with other spatialization formats, such as 8 channels and stereo. The piece was created in 2020 during a residency as a Guest Artist, at ZKM, the Centre for Art and Media, Karlsruhe.

Sound material

Interstellar dust appears as a mixture of grains with a maximum diameter of 1 um micron. These grains are actually simple assemblies of molecules that become increasingly complex and, depending on their interactions, can form aggregates of various sizes. For the creation of the sound material, I focused on the properties of the dust, such as the mass and density of the different elements that form the compounds, and hypothesized their impact in the formation of the aggregates, finally arriving at a hypothesis on their spatial behavior. In fact, I created correspondences between these properties and the spatial attributes of the individual grains, working on the mass of the sounds at the frequency band level. I used granular synthesis and identified three basic types of dust grains, each grain has a specific sound mass, density and timbre that determine the specific speed of movement, distribution in space (Sound Example 1; Sound Example 2; Sound Example 3).[19]

These grains can grow by agglomerating with each other (Sound Example 4),[20] taking on different shapes from time to time, and can last over time or become extinct due to various factors, such as the magnetic force of attraction or repulsion between the elements. The composition incorporated two singers, Nadia Cunillera, a soprano, and Matthias Horn, a baritone. The vocal elements serve to symbolize the notion that we share the same fundamental components as interstellar dust. Their purpose is to accentuate a sense of unity and connection with the entirety of existence, emphasizing our interconnectedness rather than division from the surrounding world. The voices fulfill a role acting as triggers, initiating a change in the grain behavior linked to their

[19] Audio materials related to this article are available at the following DOI: https://doi.org/10.5281/zenodo.10646848

[20] Audio materials related to this article are available at the following DOI: https://doi.org/10.5281/zenodo.10646848

movement and evolution and in this way contributing to the formation of sound aggregates. The initial phase of the creative process involves exploring parallels and harmonies between various states of matter present in both cosmic dust and the human body, as expressed through vocalization. Consequently, qualities associated with liquid, gaseous, solid, and plasma states are translated into the vocal realm, manifesting as liquid-like timbres, breath-like articulations, sustained tones, glissandos, and punctiform sounds (Sound Example 5; Sound Exemple 6).[21] Depending on the state of matter these sounds interact in distinct ways with other sonic elements and the space image, giving rise to a specific form of intra-action.

Spatialization

The sound dome, which consists of a configuration of 43 Meyersound loudspeakers suspended three-dimensionally in space on an elliptical ring system and additional four speakers placed on the floor, was employed to create the piece. This configuration can be controlled by the free software Zirkonium, which the ZKM | IMA has been developing since 2004. For *Dust Variation I*, I used the Reaper software to create my own decoder from the speaker layout json file, using the IEM AIIRA plug-in and encoding stereo and multichannel files with IEM plug-ins.

The possibility of using this loudspeaker array and the ambisonic method favored the idea of a cosmic space in which to immerse the listener by exploiting the vertical plane in particular and working with the sense of upward expansion, which is usually not possible with non three-dimensional configurations. The sounds move, generating a space thought of as energy, and this is reinforced by the distribution in all directions x,y,z, and w, enabled by the ambisonics method. Indeed, I have taken great care to meticulously shape the composition's structure to convey the specific impressions I intend. However, recognizing that the foundational concept of space may not always be immediately apparent to the listener's ear, I have deliberately integrated elements that introduce a level of suggestion. This helps to bridge the gap between composer's intention and perception in the listener's experience. The emphasis on proximity, distance, and depth effects in the selection of sound materials is noteworthy. For instance, the choice of using three grains, as the foundational elements of the initial work, alludes to something organic, often falling within the medium to low-frequency range, which can evoke a sense of familiarity. Similarly, the nearly imperceptible vocal interventions follow a similar pattern. On the other hand, the agglomerations formed at times feature a somewhat ominous high-pitched quality, compelling the listener's perception to expand upwards and creating a desire to push these elements into the distance.

In terms of spatial organization, I have focused both on the distribution of sound sources based on their intrinsic characteristics of frequency and therefore on their spatial attributes, e.g. mass, density, speed, both on listening in terms of expectations about

[21] Audio materials related to this article are available at the following DOI: https://doi.org/10.5281/zenodo.10646848

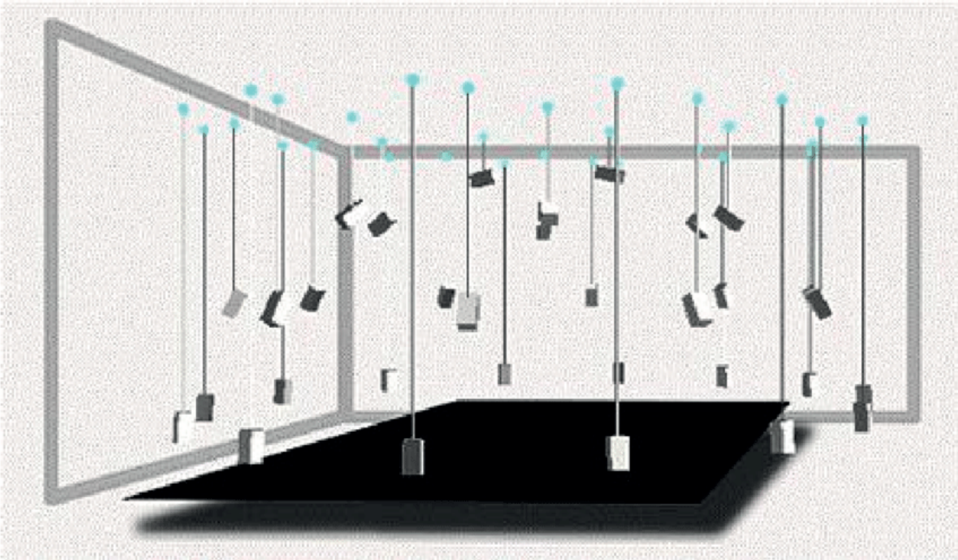

Figure 2. A graphic representation of speaker's position in the klangdom, Center for art and media, ZKM, Karlsruhe.

their position in space as mentioned in the previous paragraph. The spatial domain is strongly intertwined within the materiality of each sound source and the specificity of technology. The sound field aims to recreate the way in which dust particles move and change over time, e.g. from their rarefaction to a high density of dots covering all angles and distances in space, or from a saturated mass to an unbridgeable void.

To get a more complete spatial image, I used a hybrid approach that combines different techniques. This involved overlapping a full range spatial field created with a high-density speaker array, which aimed to blur the boundaries between sound and space using virtual speakers. Simultaneously, I incorporated a space built using localized and distributed points through 2D stereo panning. Using this combination, I tried to create a multi-dimensional sound environment.

Every spot is sweet

The Ambisonics method interprets an audio scene as a complete 360-degree sphere wherein sounds originating from diverse directions converge toward a central point. This central point represents the microphone's location during recording and/or the listener's designated sweet spot during playback. However, despite matching to the requirements defined by mathematical calculations, the notion of a singular point from which to listen does not accurately reflect the physical world. As a result, I have consistently viewed the concept of the sweet spot as a limitation. It not only perpetuates a hierarchical perception of our spatial orientation but also implies that our bodies must remain stationary in a fixed position to fully engage with sound. In

2018 during a Summer School hosted by the Technische Universität, Berlin, I had the opportunity to test a new speaker, IKO. This speaker, which can be defined as an instrument, employs via a 20-sided, 20-channel array of 20 speakers in the shape of a regular, convex icosahedron. The first prototype was created by Dr. Franz Zotter in 2006 at the Institute of Electronic Music and Acoustics (IEM) of the University of Music and Performing Arts in Graz, Austria, and was initially intended to holographically simulate the typical sound diffusion of musical instruments.

The IKO, as a compact array of acoustic loudspeakers with ambisonically regulated radiation patterns that project sound outwards, opposes the otherwise inwardly oriented ambisonic surround reproduction. Although the Ambisonics method is usually associated with speakers surrounding the audience, in this case it is used to control directional beams radiated outwards from the compact Iko spherical array. For example, within a room, the beam direction can be set to predominantly excite reflections

Figure 3. Iko speaker.

from selected walls or combinations of reflections, causing interesting effects in the perceived localization. This means that you can model the perception of directional sound sources in reverberant environments. We could imagine a centripetal force, in which many loudspeakers from predetermined points in space converge towards a fictitious ideal central listening point, available to a few and a centrifugal force, in which a single loudspeaker diffuse sound outwards from a center that varies from time to time, dismantling the sweet spot concept and rearticulating it towards an open multiple perspective. The possibility to create music with this instrument allowed me to develop a new perspective on the potential of 3D spatialization envisioning new sound trajectories and perceiving sound sources in unprecedented ways, thereby challenging the conventional sweet spot paradigm.

One distinctive characteristic of the compact speaker, in contrast to other 3D spatialization systems that demand a fixed arrangement of multiple speakers within the physical space, necessitating subsequent acoustic adjustments (e.g., domes, cubes), is that the IKO is a mobile and easily transportable device. It engages in a continuous dialogue with the surrounding architecture in which it is positioned. (the compositional process, and public perception.) In rooms and architecture with natural acoustic reflections, the iKO, dismantles the concept of the sweet spot and leaves the field open to a surprise effect that, with an unfixed dialogue and an unenclosed space, is able to bring out unforeseen resonances and shapes. In spaces and architectural environments characterized by natural acoustic reflections, the IKO dismantles the traditional notion of a sweet spot and engages in a dynamic interaction with the given space itself, revealing unforeseen resonances and forms. This allows the audience to select their preferred position within the spatial context. The capabilities of this compact speaker consequently introduce additional compositional possibilities that have yet to be fully explored.

Easily broken

Easily Broken is a composition designed for IKO and was featured in the Loudspeaker Orchestra series of concerts held in 2022. These concerts are organized by the Sound/Image research Group.[22] Easily Broken was performed during the concert on May 11th, as part of the Constructs event at St Alfege's Church in Greenwich.[23]

[22] https://www.gre.ac.uk/research/activity/las/loudspeaker-orchestra

[23] The body of the church – the first of eight in the fifty churches scheme in which Hawksmoore was involved – was built up against the medieval square tower, which survives inside the Portland casing which John James added, with the steeple above, in 1730. This view from across Greenwich High Road is practically the same today as far as the church and churchyard are concerned, with part of Church Street on the right. The church no longer has a flag mast and the roof and most of the interior dates from the 1950s, when it was sensitively rebuilt by Professor Sir Albert Richardson after being gutted by incendiary bombing during World War II. The victor of Quebec, 1759, Major-General James Wolfe, is buried in the vault as is John Julius Angerstein, founder of the National Gallery: both were local residents and have visible memorials in the church, as does Sir George Airy, 7th Astronomer Royal, though not buried there.

The composition takes inspiration from the concept of fragility, understood as the quality and condition of what is fragile, encompassing both its literal and metaphorical interpretations. It is composed in the 3rd-order Ambisonic format.

Sound material

The sound sources are sounds of organic and human materials and AI generated voices to create textures that blend, cross and create space. The voices are discussing the various meanings of human and nonhuman fragility throughout the composition. Fragility is defined as the quality of being easily damaged or broken. To give the voices a sense of movement and a specific role as if they were part of a choir I used mostly the elevation and in contrast to this instead the other sound sources moved mainly around the azimuth.

Attuning with the architectural space

One aspect of particular interest to me is the contrast between the compositional process that took place in the studio and the subsequent performance in a different venue, specifically St Alfege's Church. As the concert rehearsal commenced, I found

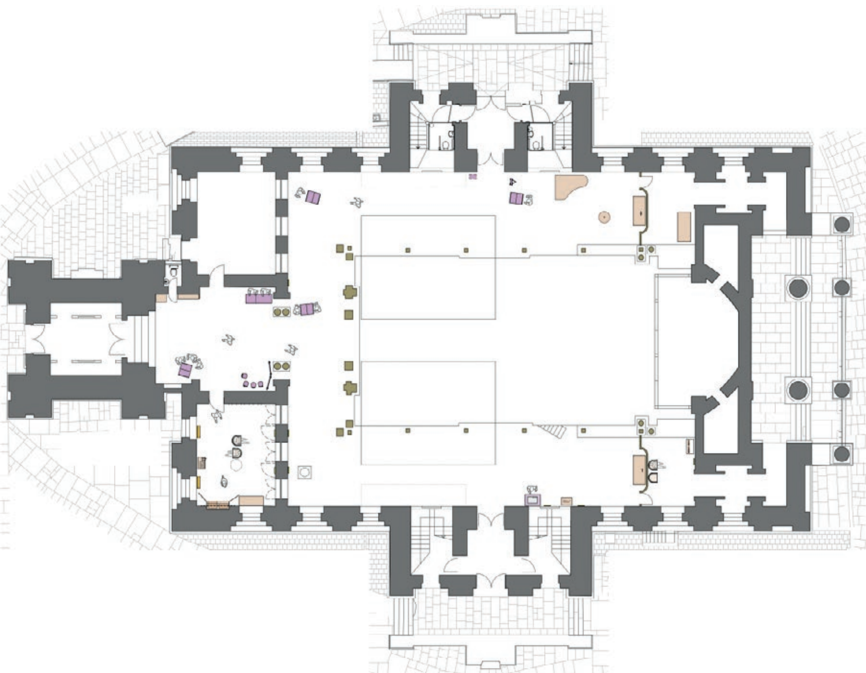

Figure 4. Plan of St. Alfege's Church.

Figure 5. IKO speaker at St. Alfege's Church.

myself concerned that the intended spatial concept of the piece would be completely transformed by the unique acoustics of the church.

Upon my arrival at the venue, I discovered that the Iko instrument had already been strategically positioned in the most suitable and logical location for the concert – at the far end of the entrance, just before the apse, after the seats. This placement was chosen to optimize the overall listening experience and create a comfortable sonic environment for the audience. Upon my arrival at the venue, I discovered that the Iko instrument had already been strategically positioned in the most suitable and logical location for the concert – at the far end of the entrance, just before the apse, after the seats. This placement was chosen to optimize the overall listening experience and create a comfortable sonic environment for the audience.

The studio's controlled environment and the church's unpredictable acoustics were in contrast. I wondered if the desired spatial qualities that I had meticulously achieved while in the studio would be faithfully transmitted in this new setting.

Could the unique reverberations and resonances of the church significantly alter the perception of the composition?

The surprise came when the speaker placed just before the apse entered into dialogue with the structure, making the voices flow exactly in the dome, creating an incredible choral effect. The term comes from the Latin chorus and the Greek χορός. This term is also used in architecture to indicate the apse area usually occupied by singers during liturgical functions in the church, or the place where the singers' places, known as stalls, or 'benches' were placed; the term chorus also indicates a musical composition written for such a chorus. the unexpected. Note how the apse is also called a chorus. However, as the performance unfolded and the sounds interacted with the architectural space, my initial concerns began to subside. The reverberations and resonances of space added layers of depth and complexity, transforming the piece into a living, breathing entity within the church's unique sound environment.

The composition has taken on surprising meanings thinking about the fragility of the concept of sweet spot, the effect of surprise and dismay that technologies can still bring, the relationship between human voices and the fragility that becomes the power and expansion of architecture and voices generated by algorithms, IKO has become a multifaceted narrator.

The compact speaker, with its disposition of establishing a reciprocal dialogue with the physical space it occupies, brings forth relational dynamics that differ from the traditional configuration of speakers placed in a fixed position all around the listener. Instead of adhering to the conventional speakers arrangement, IKO activates a new set of relational dynamics by engaging with the specific characteristics and qualities of the physical space. By transcending the constraints of a fixed speaker setup, it opens up possibilities for a more dynamic and responsive spatial experience.

Another reflection on this specific experience with IKO is on the concept of authorship.

The dynamic nature of the spatial environment and the interaction between sound and space invite the listener to actively engage and shape their perceptual and emotional responses. As a result, the traditional notion of the composer as sole author and authority over the sound narrative becomes blurred. The boundaries between the composer's intentions and the listener's authority become porous, as the immersive and interactive nature of the experience allows for multiple interpretations and perspectives.

This confrontation with the illusion of authorship opens up new possibilities for collaboration and co-creation between composer and listener. It challenges us to rethink the hierarchical relationship between creator and audience and to embrace a more inclusive and participatory approach to artistic expression.

The discussion of the authorship of algorithms and artificial intelligences when they contribute to composition is also brought up by this contemplation, but it needs its own dedicated *space* in another context.

Unimaginable sound architectures

Moving into the virtual dimension allows for the exploration of sound and spatial synthesis in ways that are not yet possible in the physical world. In virtual environments, creators have the freedom to exaggerate, reinvent, and redefine spatial dimensions, leading to novel and expanded auditory experiences.

Archimusic

> *While I have used cyberspace as a thought-tool, I want to emphasize at this point that what is most important is not the technological expansion that cyberspace represents, but*

> *the conceptual space opened up to imaginative examination. Once we have a firm grasp on archimusic, we will be able to apply our findings to both virtual and actual worlds.*[24]

The integration of technology has played a unifying role, bridging design practices and processes, particularly between architecture and sound. This convergence has opened up an additional (neutral) creative space where sound, space, and the body can intersect and establish different connections. Through this research, I have become increasingly intrigued by the potential for space to take on forms and configurations that are not yet fully comprehended or explored. By embracing technology and pushing the boundaries of traditional compositional approaches, I aim to uncover novel sonic and spatial possibilities.

Starting from the 90s the experiments belonging to Digital Architecture have often met those related to electronic music.[25] Markus Novak theorizes the concept of cyberspace, which defines as a new wild nature, a virtual world that becomes visible and within which music and Architecture can merge into a single discipline: *archimusic*.

> *When we look at music, architecture and calculus, we can ask ourselves what is shared and what is different in the inner and outer worlds they investigate, where are their boundaries, and in which direction lies the boundary of the known world, so that we can go in that direction, cross the line in the darkness and enlarge our universe.*

The concept of archimusic informs the idea of a virtual space where to reshape the relationships between space and sound and where you can freely play with non existing and impossible forms.

Contagiousness

A transposition of particular relevance regarding the impact of 3D spatialization technologies can be associated with Luciana Parisi's reflection on digital architecture. According to Parisi, algorithms are responsible for constructing spatiotemporal actualities, implying that digital architecture is involved in the creation of instances of spatial thought. The crucial point here is not whether this construction process is physical or not, but rather the acknowledgment that digital architecture, and in this case, 3D sound spatialization, is already actively engaged in shaping our conceptions of space and time.

[24] Novak M., *The music of architecture Computation and composition,* Media Arts and Technology University of California, Santa Barbara, 2007, p.13.

[25] Cyberspace is a completely spatialized visualization of all information in global information processing systems, along pathways provided by present and future communication networks, enabling full co-presence and interaction of multiple users, allowing input and output from and to the full human sensorium, permitting simulations of real and virtual realities, remote data collection and control through telepresence, and total integration and intercommunication with the full range of intelligent products and environments in real space."In Marcos Novak, *Liquid Architectures in Cyberspace, in Cyberspace:First Steps,* Michael Benedikt, editor, MIT Press, 1991.

Algorithms allow the integration of space and sound and can no longer be considered abstract formalizations. Especially when generated through artistic experimentation and practice, they are intertwined in the mechanisms that create space and time.[26]

Temporary Sound architecture

At the MAxLab research group of the Royal Academy of Antwerp[27] and the Institute for Psychoacoustics and Electronic Music[28], Ipem, at the ASIL laboratory I am developing the project *Temporary Sonic Architecture*. The project lasts two years and is still in its early stages. I'm following two lines, a speculative approach that compares the acoustic characteristics of a physical space and its virtual reproduction. They are looking for a fracture between the acoustics of real space and its perception virtually rebuilt, also through the intervention of algorithms that approximate and generate acoustic models through auralization. And at the same time the development of a methodology to compose temporary sound architectures.

Conclusions

With this article I wanted to provide an initial, albeit not exhaustive, aesthetic-theoretical recognition of my personal path in the field of spatial composition, highlighting the basin and the areas of contact from which emerge the trajectories of research that I have explored and continue to explore and the main concept from where I develop a theoretical network. Unveiling the skein of insights I've gathered so far opens up new avenues and I hope it will inspire others interested in spatial composition. The changes that I am integrating into my practice concern the convergence of spatial information in the sound source and how this affects the perception of acoustic space and compositional modes.

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[26] Luciana Parisi & Steve Goodman, *Extensive Continuum Towards a rhythmic anarchitecture*, Journal INFLeXions No. 2 – Rhythmic Nexus: the Felt Togetherness of Movement and Thought (Jan. 2009).

[27] https://www.ap-arts.be/en/researchgroup/maxlab

[28] https://www.ugent.be/lw/kunstwetenschappen/ipem/en

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3D Spatialisation Technologies and aesthetic practice within electroacoustic composition: A journey through Listening, Composition and Performance

Brona Martin

1. Introduction

Spatial audio is used within a variety of media such as electroacoustic composition, gaming, virtual reality and film. Within the contexts of film and gaming this practice is well documented with many artists sharing their knowledge and tools disseminated through the use of podcasts, YouTube videos and journal publications. However, there is little documentation on spatial audio workflows and how this technology influences creative outcomes within the genres of electroacoustic music and sound art. How do these technologies affect the way we compose and listen? How do we use these tools as both instruments and compositional tools? As composers what do we learn as we work with these technologies?

2. Channel-based audio spatialisation

As an electroacoustic composer I have created multi-channel compositions which have been composed for 5.1 and 8.0 (a ring of 8 loudspeakers) to create immersive listening experiences.

A Bit Closer to Home (Martin, 2014) is an 8-channel soundscape composition composed at NOVARS Research Centre, University of Manchester. The piece focuses on the soundscape of my hometown, Banagher located in the middle Ireland on the River Shannon, combining field recordings from the area and interview excerpts which discuss sounds from the past. The piece explores the listening experience of the composer while reflecting on sounds from the past that no longer exist which are discussed in the interview. For this work, field recordings were made using an H4n Zoom recording device and DPA 4060 omnidirectional condenser microphones. These highly sensitive microphones capture the fidelity of sounds and sense of space acting as a microscope between the ear and soundscape. A variety of field recordings were captured including birdsong, a thunderstorm, water lapping and machine noise from the local mill.

In order to replicate the original listening experience of the composer and the environmental context, an 8-channel loudspeaker configuration facilitated a realistic version of the original sound environment.

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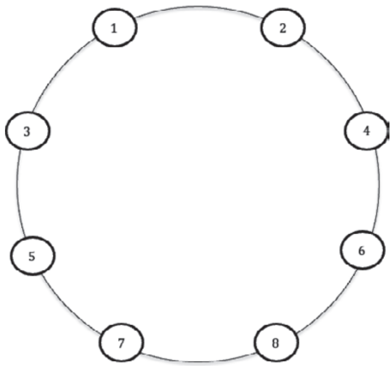

Figure 1. SEQ Figure * ARABIC 1 8-Channel loudspeaker layout.

Even just eight channels of discrete source material create a convincing soundscape where composed sounds can be localised in the manner experienced in acoustic environments. (Truax, 2008, p.105)

Discrete localisation of sounds such as birdsong and people's voices combined with layers of ambient field recordings are effective in creating a realistic immersive soundscape, where the 8-channel setup is treated as eight mono speakers, four pairs and an 8-channel ring.

Within this composition I worked with stereo sound files. Spatialisation was achieved by layering sound materials across the 4 pairs of loudspeakers i.e. (1+2, 3+4, 5+6, 7+8). Panning occurred between these pairs, moving sounds from left to right and vice versa. Some tracks were also routed to 4 auxiliary sends, where each send was assigned to a pair of loudspeakers. This made it easier to send a copy of one sound source to other speakers using send automation so sounds could easily be moved from front to back.

Granular processing of some of the field recordings in Cecilia[1] resulted in the creation of textural sounds, dividing the sound into much smaller segments known as grains. The use of this processed material can be heard in the beginning of the piece where traffic sounds on a wet day are panned left and right on the front speakers. The distinct sounds of water drops falling from a drain on to concrete begin to emerge at 00'25 (Sound Example 1)[2] seconds and can be heard in the foreground. Once the cars pass at 00'54, granulated water drops emerge and are spatialised across the ring of 8 loudspeakers enveloping the listener within these delicate sounds.

To replicate discrete localised birdsong, these recordings were panned to one speaker. The spoken word within the piece was placed on the front loudspeakers 1 and 2 to create the illusion that the narrator is sitting in front of the audience. Additional layers of field recordings were added and spatialized. For example, at 2'46 a rain/

1 http://ajaxsoundstudio.com/software/cecilia/

2 Audio materials related to this article are available at the following DOI: https://doi.org/10.5281/zenodo.10252743

thunder scene begins (Sound Example 2).[3] The sound of closely recorded water drops from a drain return and are placed in one speaker with the gradual addition of rain and thunder recordings. Changes in perspective are created by using EQ to gradually enhance the bass frequencies so that the thunder appears louder and closer while increasing overall amplitude resulting in distant thunder rumbles coming closer to the listener, enveloping them within the soundworld.

In this example, composing for a ring of 8 loudspeakers allows the composer to enhance, intensify and embellish the field recordings resulting in an immersive listening environment where the listener can localise various sound events weaving between elements of real and imaginary soundscapes. It also allows the composers to keep various elements of the soundscape separate, placing the listener in the centre e.g. the traffic remains in the front, birdsong is placed in single loudspeakers while the rain is placed all around the listener.

As mentioned above the spatialisation for this piece was implemented by layering sounds across different pairs of speakers in combination with send and panning automation. For this piece I didn't use a panner and the spatialisation of materials occurred after I had organised my sound materials. Therefore, the creation of space within the work came afterwards. However, in later works listed below the use of a panner such as SpatGris to spatialise materials throughout the ring of 8 loudspeakers was much easier and resulted in the space being composed within the work simultaneous to the organisation of sonic materials.

3. Object based audio approaches

> When working with object-based audio system mono and stereo sounds can be defined as objects. These objects can then be panned throughout the 3D space. When working with object-based audio "all sounds are distributed independently, which are mixed only during reproduction."[4]

3.1 SpatGRIS – VST Panner

In 2018, I composed an 8-channel soundscape piece, *NightEscape.* This piece explores a night-time field recording, from Atlantic Center for the Arts, New Smyrna Beach, Florida recorded during a residency with composer Jonty Harrison in 2014. The piece was composed at EMS Stockholm in March 2018. For this piece I explored some new spatialisation and sound processing tools. SpatGRIS[5] (Université de Montréal) was used to spatialise the audio in 2D on a ring of 8 loudspeakers.

[3] Audio materials related to this article are available at the following DOI: https://doi.org/10.5281/zenodo.10252743

[4] Fonseca, N. 2020. *All you need to know about 3D Audio*. Sound Particles Lda, p. 10.

[5] https://sourceforge.net/projects/spatgris/

> The *SpatGRIS* is a plugin (Mac AU/VST and VST Windows format) designed to compose multichannel space. It allows the user to spatialize the sound in 2D (up to 16 speakers) or in 3D (up to 128 speakers) under a dome of speakers with the ServerGRIS (Normandeau et al. 2018, p. 291).

Working with this panner made it much easier to spatialise the audio with a choice of movements and different trajectory systems while there are also different ways of linking sound sources together. This resulted in a broader range of spatial movements within the piece. SpatGRIS facilitated the movement of a single sound source through the space, 'dissociating sound source's localisation from the loudspeakers position" (Ledoux and Normandeau, 2018, p. 3).

> The composition of space must be concurrent with the composition of time in the general process of development of the work. The space is not an added flavor, a color sprinkled at the end of the course when the work is already finished on the temporal plane. It is an integral part of the electroacoustic work of the 21st century, it is even the most original and exclusive component. For these two reasons, we decided to develop not a new sound spatialization software – there are already many – but rather a plug-in that integrates with the daily work tool of composers (Normandeau et al., 2018, p. 291).

For this composition each track had 8 channels and the SpatGRIS VST plugin. Within the plugin the input mode and output modes were determined e.g. 2 in 8 out.

As a result of the SpatGRIS panner I began to see the ring of 8 loudspeakers as a complete spatial image where sound objects could move through the space and beyond the speaker periphery no longer restricted to loudspeaker position.

8-channel spatialisation also facilitated the division of the night-time cricket

Figure 2. SpatGRIS VST with a stereo sound source.

sounds into different frequency bands (Sound Example 3).[6] These bands were placed in different locations within the space rather than being mapped to a specific pair of loudspeakers. As a result, it is a combination of all of the speakers which are producing the sound. Barreiro calls this spectral diffusion:

> Spectral diffusion happens when the spectrum of a mono or stereo sound is sliced in several frequency bands (called bins), which are then spread over the several channels. One interesting aspect of this technique, at least in conceptual terms, is that the resulting sound is produced by all loudspeakers working together. The sound is not placed in one loudspeaker or between two loudspeakers, but scattered all over the multichannel array. The result (although this depends on the spectral characteristics of the original sound) is that the listener is enveloped by the multichannel sound (Barreiro, 2010, p. 291).

Within this piece I also worked with 8-channel sound files. BEASTtools[7] was used to process and transform stereo sound sources into 8-channel files. For example, Granul8 facilitated 8-channel granulation where stereo sound sources were granulated and spatialised across the 8 loudspeakers. Similar to most granular processing software the user has control over grain position, grain duration, envelope type and pitch. It also includes octave and fifth harmonisation. This type of processing facilitated the diffusion of the sound across the loudspeaker array enhancing the sense of immersion as micro divisions of the sound source enveloped the listener.

> The granulation of sampled sounds in multichannel systems produces multichannel sounds through the placement of several grains among the loudspeakers. The results obtained with such a technique are largely dependent on the characteristics of the sound being granulated and the parameters used in the granulation process. In general terms, however, the results tend to be diffused, although localised, sonic images that can move in the space or be static (Barreiro, 2010, p. 291).

As a result of working with these new technologies the 8-channel workflow was easier and much more intuitive. It had an impact on how I composed space within my music working with the space has a whole rather than being restricted by the position of the loudspeakers. The composition of space develops along with the composition. This was also the first time where I used sound processing tools, where the processed output was an 8-channel sound file specifically spatialised for a ring of 8 loudspeakers. The use of BEASTtools resulted in the composition of space being included at the sound processing stage, whereas previously I had always worked with stereo processed sounds.

[6] Audio materials related to this article are available at the following DOI: https://doi.org/10.5281/zenodo.10252743

[7] https://www.birmingham.ac.uk/facilities/ea-studios/research/beasttools.aspx

3.2 L-ISA Studio (L-Acoustics) and the Ocean Loudspeaker System

In 2019 I composed *Frogland* commissioned by the University of Greenwich with funding from the (HEIF) Higher Education Innovation Fund. This was a collaboration between the University of Greenwich and L-ISA (Immersive Sound Art) technology designed by L-Acoustics, led by Dr. Andrew Knight-Hill.

Frogland explores the soundworld of Frogs recorded in Florida, USA and Brisbane, Australia. Some of these field recordings were recorded around New Smyrna Beach during the residency at Atlantic Center for the Arts. Composer Rick Nance[8] also attended the residency and kindly allowed me to use some of his frog recordings within the piece.

I used the L-ISA object based panning system to spatialise the audio on the Ocean Loudspeaker System located in their Immersive Sound Art studio in Highgate, London. This 18.1.12 loudspeaker system consisted of "18 Syva scene and surround speakers and 12 Syva Sub speakers."[9] L-ISA have developed their own software, L-ISA Studio which features a 3D controller interface:

> With L-ISA Studio, interaction designers can design and test their interactive environments at the earliest stages of a project simply by connecting the L-ISA Controller to game engines, tracking systems, or other creative solutions via the Open Sound Control (OSC) protocol. The entire design can be tested and presented on a laptop.[10]

L-ISA Studio software included source control plugins and their L-ISA controller application. This allowed us to set up the panning for our work which we would later refine in the studio.

Frogland was mixed in Reaper, where each track had the L-ISA VST plugin. Each of the L-ISA plugins has a source ID which is mapped to a source within the L-ISA controller. The plugin allows you to control 3D spatial audio parameters such as Pan, Width, Distance and Elevation. You can also write this automation to the reaper project by moving the sound objects within the L-ISA controller. The L-ISA plugin within Reaper communicates with the L-ISA controller application using OSC. I used mono and stereo recordings within the work where sound sources were placed on fixed points within the space or spread across multiple loudspeakers. 360 degrees panning further facilitated and enhanced movement and gestures within the work.

Once I got to the L-ISA studio I was able to load my saved L-ISA controller session on to their studio computer where I could then refine the spatial mix. A L-ISA technician assisted with the setup where the L-ISA controller was on a touch screen. This of course meant I could move objects through the space with my fingers rather than using a mouse.

[8] Rick Nance Bandcamp Page https://acousmaticart.bandcamp.com/album/inquiet

[9] L-ISA Ocean Sound Spaces specification sheet, https://creations.l-acoustics.com/uploads/2022/07/Ocean_SPS_EN_1.4.pdf (Accessed 29th November 2022).

[10] https://l-isa.l-acoustics.com/create/studio/ (Accessed 29th November 2022).

Similar to working with SpatGris, the affordances of working with object-based audio resulted in a detachment from a specific loudspeaker layout. With channel-based audio I was mainly thinking about how much of the sound signal should go to one or more speakers. With object-based audio, the focus became more about the placement of sound objects within the space. I started to think about the division of the overall soundscape in terms of smaller sonic events perhaps influenced by the L-ISA interface and the movement of sound objects.

Since I knew that the audience would be moving through the space during the performance the spatialisation of the materials was not symmetrical i.e. working with layers of stereo pairs, with the listener in the centre. This had a direct influence on the spatialisation of the work. I focused on composing smaller soundscapes within the piece which were spread throughout the room, which merged together to create the overall soundscape.

The performance of *Frogland* was featured in a concert of works at the L-Acoustics Studio in High Gate, London. The concert featured works by Dr. Andrew Knight Hill, Paula Fairfield and University of Greenwich students. There was no seating and the audience moved freely through the space, experiencing my composition perhaps as they would a real-world natural environment – free to walk about and listen to the soundscape. Others stood still and closed their eyes. I enjoyed walking through the space during the performance positioning myself within different parts of the virtual soundscape, no longer tied to the mixing/playback console which was in a studio next door. As I moved through the space, I felt I was stepping into different smaller soundscapes made up of multiple sound objects within the overall space. This was considerably influenced by the use of L-ISA's object based panning software and the ability to visualise sound objects within the space thanks to the specific interface.

Back in 2019 L-ISA Studio software would only work with hardware such as the L-ISA processor II[11] which was required to create immersive playback, capable of rendering up to 128 outputs in a 2D or 3D layout.[12] Therefore, the performance of *Frogland* was restricted to the L-ISA studio which had the processor. Due to this restriction, in September 2019 during a residency at EMS Stockholm I remixed the piece using ambisonics so that the piece could easily be adapted to different loudspeaker configurations without using L-ISA Studio software.

4. Ambisonic workflows and aesthetic

> The basic approach of Ambisonics is to treat an audio scene as a full 360-degree sphere of sound coming from different directions around a center point. The center point is

[11] This has changed now, and the L-ISA studio will work without the processor. A very recent review of L-ISA studio can be found here: https://www.mixonline.com/technology/l-acoustics-l-isa-studio-review

[12] L-Acoustics L-ISA Studio 2.4 – A Real- World Review, Part 1 - mixonline.com/technology/l-acoustics-l-isa-studio-review (Accessed 6th December 2022).

> where the microphone is placed while recording, or where the listener's 'sweet spot' is located while playing back.[13]

> Ambisonics is a system of sound reproduction based on the spherical harmonics of the sound field. The more spherical harmonics, or in other words the higher the order of representation (high order ambisonics, or HOA), the greater the spatial resolution over a larger listening area (Barrett, 2010, p. 3).

My journey into ambisonics began in 2016 when I was an artist in residence at Atlantic Center for the Arts,[14] Florida where I had the opportunity to work with composer Natasha Barrett.[15] During these three weeks we explored ambisonic formats and tools, composition workflows and sound field recording. Much of my knowledge and research about ambisonics has come from Barrett who has been working with ambisonics since 2020 and has published extensively about her practice. Over the years I have heard Barrett's work diffused over different loudspeaker arrays and I was always impressed with how she composed and performed with three-dimensional soundfields.

> The simulation and recreation of three-dimensional sound fields (with ambisonic or wavefield synthesis) results in spatial clarification doing away with the ambiguous phantom imaging and allows the direct transmission, without performance interpretation, of spatial information to the listener (Barrett, 2007, p. 245).

During my residency at EMS in 2019, I had the opportunity to revisit ambisonics and everything I had learned from Barrett at ACA. For me the first step was to understand ambisonic workflows in order to create an ambisonic version of *Frogland*. This involved duplicating the *Frogland* reaper session and then replacing L-ISA Source control plugins with IEM[16] ambisonic stereo encoder plugins on each track. Each track was then set to 16 channels as I decided to work in 3rd order ambisonics. All tracks were routed to an Ambisonic Bus which was then routed to 2 different tracks. 1 track had the IEM binaural decoder which facilitated headphone mixing. The 2nd track had the IEM ALLRADecoder which decoded the mix to a specific loudspeaker layout. Since I was working in Studio 2[17] at EMS, the mix was decoded to a 15 genelec loudspeaker array with 9 loudspeakers at listening level, 5 in the ceiling and 1 subwoofer. EMS supplied the JSON file which had the azimuth and elevation co-ordinates for the loudspeakers. This file was imported into the ALLRADecoder which then uses this file to calculate the decoder. ALLRAD can be used to decode any ambisonic order. Now that I had an ambisonic mix of *Frogland* I could use the ALLRADecoder to decode the mix for any loudspeaker layout once I had the coordinates of that loudspeaker array.

13 https://www.waves.com/ambisonics-explained-guide-for-sound-engineers

14 https://atlanticcenterforthearts.org/

15 https://www.natashabarrett.org/

16 https://plugins.iem.at/

17 https://www.elektronmusikstudion.se/work/studio-equipment

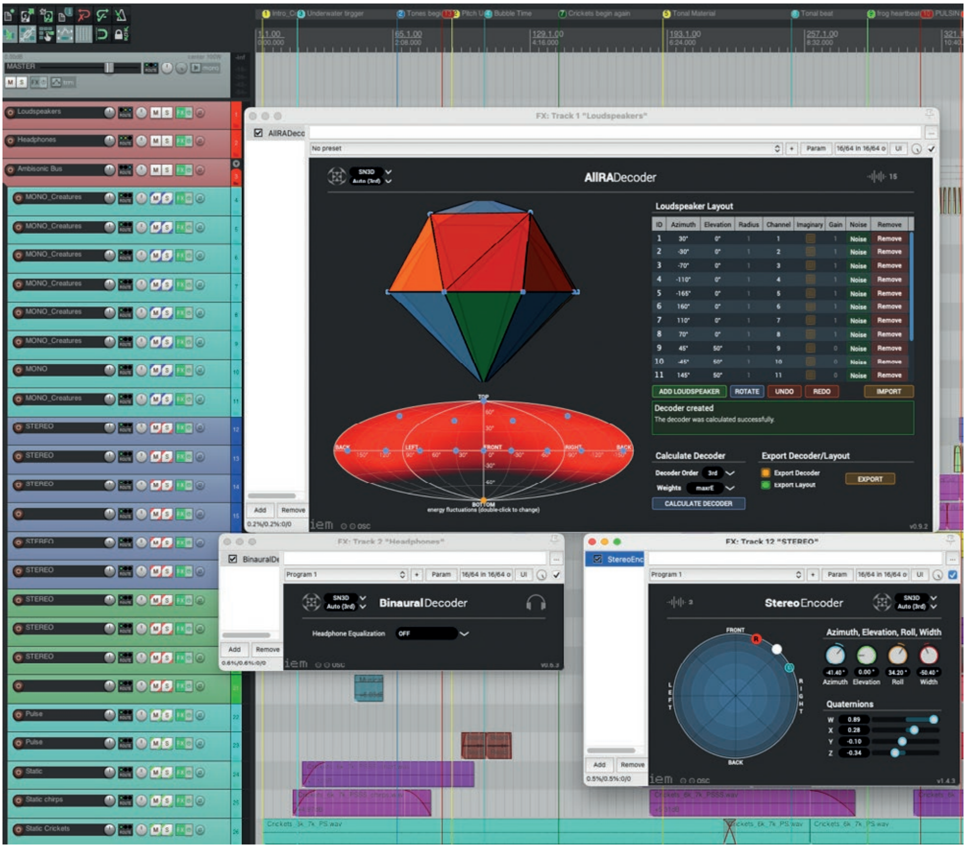

Figure 3. 3rd Order Ambisonic workflow in reaper using IEM Plugins for encoding and decoding.

While I was composing space within a 2D loudspeaker configuration such as a ring of 8 loudspeakers I always thought about space in terms of distance and amplitude. I have previously divided sound materials into different frequency bands where these bands are gradually layered back together slowly enveloping the listener in the original sound. By starting with the higher frequency content and gradually introducing the other layers, ending with the lower frequencies the soundscape is brought closer to listener. However, composing 3D space using ambisonics offers a more realistic interpretation and recreation of specific soundscape. We now have the ability to spread the layers of the soundscape vertically as well as horizontally. We can spatialise the spectrum of sounds within the soundscape vertically along the loudspeaker array i.e. low frequency content on the lower speakers and high frequency content on the higher speakers. This allows us to create a sense of height and depth within our works.

4.1 Performance and Adaptability of Ambisonic formats

In May 2021 *Frogland* was performed at Klingt Gut! 5th International Symposium on Sonic Art and Spatial Audio in Hamburg Germany. For this performance I increased the track channels from 16 to 64 to create a 7^{th} Order Ambisonics mix which created a very large rendered sound file, about 8GB in size. For this online event *Frogland* was played in the 33.2 dome, decoded by the Klingt Gut! team using the ALLRAD decoder and streamed live using the Neumann KU100 which facilitated binaural listening. As organiser Thomas Görne said streaming created "more of the 'being there' effect rather than direct binaural rendering of the HOA files".[18] As I listened to the live streamed concerts, I could hear the paper shuffling as the person was introducing the different pieces. Despite not being there in person I was amazed by the size of the performance space which was occupying my headphones. There were times when I kept looking towards the door of my room as I was hearing sounds almost two metres away.

As a result of this experience, I feel that working with ambisonics makes it easier for composers to adapt their work for different loudspeaker configurations as we take our compositions to different studio and performances spaces. Klingt Gut! proved that despite not experiencing the compositions inside the dome, we could still appreciate the composed space within the works in a binaural format.

5. IKO – icosahedral loudspeaker – inside out

There is a significant amount of work that goes into setting up a high-density loudspeaker array/loudspeaker orchestra/sound diffusion system. So, imagine having one speaker which can project a 3^{rd} order ambisonic sound field. This was my first thought when I was introduced to the IKO[19] icosahedral loudspeaker at the University of Greenwich in 2021. Finally, the idea of setting up a spatial audio concert was a little easier – 1 speaker, 1 speaker stand, 1 amp, 5 reflector panels. The reflector panels are used both in the studio/composition space and the performance space.

> For concerts, the artistic practice evolved to set the IKO up together with reflector baffles. A recent study investigated their effect on the perception of moving transient and stationary sounds. The baffles obviously reduce the signal-dependency by contributing more additional reflection paths, contrasting the direct sound. (Zotter and Frank, 2019, p. 166).

The portability of this speaker means it can be easily set up in a variety of locations such as churches, markets galleries or installation spaces. It is also an example where

[18] Email exchange with Thomas Görne, 21st January 2023.

[19] For more information about the design and research of the IKO visit the OCIL (Orchestrating Space by Icosahedral Loudspeaker) webpage. https://www.researchcatalogue.net/view/385081/958807

the loudspeaker setup remains the same for composing as it does for performance. Of course, the difference lies in the acoustics of the performance space.

> The icosahedral loudspeaker (ICO) is a compact playback device that uses acoustic algorithms to project sound beams into freely adjustable directions, also wall reflections leading to the listener. 'Orchestrating Space by Icosahedral Loudspeaker'(OSIL) aims at increasing the practical and theoretical understanding of electroacoustic sound phenomena in computer music that are defined by their sculptural-choreographic nature, i.e., exhibiting localization, motion, and extent (Sharma et al., 2015, p. 2).

> THE IEM ICOSAHEDRAL LOUDSPEAKER (IKO) consists of an icosahedral housing carrying 20 individually driven loudspeakers and has been built in 2006, originally with the idea to holographically mimic musical instruments (Sharma and Zotter, 2014-2019).

> While surrounding Ambisonic loudspeaker arrays play sound from outside the listening area into the audience, compact spherical loudspeaker arrays play sound into the room from a single position (Zotter and Frank, 2019, p. 153).

5.1 Listening to the IKO

As a Research Fellow at the Sound|Image Research Group, University of Greenwich I had the opportunity to take part in some workshops where we were introduced to the IKO (June 2021). Listening exercises and ear training led by Dr. Angela McArthur played an important role in developing an understanding of how sounds behaved within the space. The IKO possesses a dominant presence within the room often located in the centre. Therefore, it is very clear that the sounds are coming from it. It is important to spend time exploring the space and listening from different positions in order to detach ourselves from the commanding visual presence of this loudspeaker and focus on the movements of sound objects. Closing our eyes really helped while listening to sounds and compositions focusing our attention on the behaviour of the sounds within the space.

Studies carried out by those who designed the IKO have shown how both static and moving auditory objects are perceived by the listener:

> Static Auditory Objects: "The experiments used stationary pink noise and could create auditory objects nearly 2m behind the IKO, which corresponds to the distance between the IKO and the front wall of the playback room. The maximum distance of auditory objects created by the IKO is strongly signal-dependent. Experiment showed that the auditory distance of pink noise bursts decreased for shorter fade-in times, while the fade-out time had no influence. A transient click sound was perceived even closer to the IKO. This can be explained by the precedence effect, that favors the earlier direct sound over the reflected sound from the walls. While this effect is strong for transient sounds, it is inhibited for stationary sounds with long fade-in times" (Zotter and Frank, 2019, p. 164).

> Moving Auditory Objects: "The studies extended the previous listening experiments towards simple time-varying beam directions, such as from the left to the right, front/back or circles. To report the perceived locations of the moving auditory objects, listeners used a touch screen that showed a floor plan of the room, including the listening position and the position of the IKO. They had to indicate the location of the auditory object's trajectory every 500 ms. The perceived trajectories depend on the listening position, but they can always be recognized" (Zotter and Frank, 2019, p. 165).

5.2 Composing for the IKO

As a result of Arts Council England 'Developing your Creative Practice' funding, I had the opportunity to compose a new piece for the IKO in 2022. I also reworked an existing ambisonic piece which allowed me to explore ambisonic workflows while listening and contrasting binaural and IKO (3rd order ambisonic) mixes.

When working with the IKO I really felt like I was composing the space within my work. It takes a lot more time to spatialise the sounds within the space – to create an immersive experience. A lot of my sounds just seemed to sit on the loudspeaker. In contrast, when working in 8.0, if I wanted a sound to come from a particular location, I would pan the sound to that speaker while using eq and sometimes reverb to create a sense of distance and perspective.

This new composition *Aisling* (2021) was part of an AV piece. The visuals created in Unity Game Engine, depicted a virtual soundwalk by the sea and a wooded area with a small river and campsite. The composition was a direct response to the visuals. Sound materials included field recordings of the sea, water lapping, a campfire and forest sounds. Usually, I would restrict myself to a sound library of field recordings which were recorded from a specific place. However, some of the field recordings which included broad band sounds like the sea for example were quite difficult to work with on the IKO. After experimenting with eq and panning, I discovered that slow movement of sea sounds in a circle on the azimuth created the illusion of water lapping and moving across the space. To create a sense of distance away from the speaker, I added some synthesised sound materials which occupied a narrower band within the spectral space. These more detailed sounds such as granulated twinkling water sounds (01'00) (Sound Example 4),[20] birdsong (4'22) (Sound Example 5)[21], musical bamboo-like sounds (03'50) (Sound Example 6)[22] and rain drops (05'53) (Sound Example 7)[23]

[20] Audio materials related to this article are available at the following DOI: https://doi.org/10.5281/zenodo.10252743

[21] Audio materials related to this article are available at the following DOI: https://doi.org/10.5281/zenodo.10252743

[22] Audio materials related to this article are available at the following DOI: https://doi.org/10.5281/zenodo.10252743

[23] Audio materials related to this article are available at the following DOI: https://doi.org/10.5281/zenodo.10252743

Figure 4. The IKO with reflector panels at St. Alfege's Church, Greenwich, London.

recorded from Haken Audio's Continuum fingerboard.[24] The addition of these nature-like synthesised sounds really helped to expand the space around the IKO adding detail to the soundscape.

As a result, the piece *Aisling* uses a combination of synthesised sounds and field recordings. With the IKO, I have found it easier to work with synthesised sounds. The combination of both field recordings and synthesised sounds worked very well and removed my purist idea that 'I must only work with field recordings to create this soundscape'.

Of course the spatialisation journey does not stop here. When you take the IKO out of the studio and take it to a church such as St. Alfege's Church in Greenwich, London for example – a reverberant space with lots of reflections. The transition from composition space (studio) to the performance space results in a new listening experience due to the changes in acoustics and our proximity to the loudspeakers. The performance of my piece on the IKO in the church resulted in an overall enhancement and embellishment of the composed space within the work. I heard sounds that I had not heard in the studio. The piece became more immersive as sounds travelled further away as they moved through the big reverberant space of the church. Sounds could be heard about 3 metres in every direction away from the IKO. The composed space

[24] https://www.hakenaudio.com/slim-continuums

Figure 5. IKO with Video project – Performance of AV piece Aisling.

within *Aisling* which had been slowly and carefully sculpted in the studio became bold, brave and more intense within the church as sounds reflected off concrete walls, wooden benches, tiled floors, the glass windows of the church and the reflector panels. It was during this concert that I really heard the potential of this loudspeaker.

6. Composing with layers of different spatial formats

On the 14th of September, 2019 I heard PA Tremblay's acousmatic work, *Bucolic and Broken*[25] at Convergence, International Conference/Festival of Music, Technology and Ideas at De Montfort University, Leicester. The concerts for this conference/festival were held in the PACE Studio 1, a space especially designed for multi-channel diffusion concerts. Within *Bucolic and Broken,* there were many different layers of sounds such as ambient field recordings, piano, tonal materials, delicate rhythmic mechanical textural sounds and synthesised sounds. Some sounds seemed to occupy the whole room, enveloping the listener while others retained their own space within the piece. This was a similar experience to some of Barrett's performances of her work e.g. enveloping soundscapes but with detailed focused points within the piece (*Innermost* ICMC, University of Limerick 2022 *and Speaking Spaces no.1: Heterotopia*, Sonic Cartography Conference, 2022) and I wondered if Tremblay had used ambisonics to spatialise his sounds. I emailed Tremblay to find out more. In our interview style correspondence[26] Tremblay provided detailed answers to my questions, and I discovered that his piece was a hybrid of different types of spatial formats.

> On a different plane, at which technology and aesthetic inform each other, the piece offers a novel way to utilise three competing multi-channel paradigms (third-order ambisonics, cinema 7.1 and classic acousmatic loudspeaker orchestra), where the aesthetic and technical strengths of each implementation are exploited, in the context of allowing the portability of music written for large loudspeakers arrays. Since these are more frequently seen [these days], and that various cultures (cinema, videogame, etc) have started embracing high-count multichannel, this piece offers one proposed avenue to reinvigorate and critique traditional multichannel fixed media, both in the commercial world and in the experimental one (Martin and Tremblay, 2020).

> Whereas the precision of point-sources of the classic cinema setup is used to allow full-range, articulated protagonists to dialogue, the more mobile and diffuse sound of the TOA is used to give breadth to these elements, as well as auditory context and fluidity. The use of a quadraphonic real distant loudspeakers, directly from the GRM tradition, allows to give further distance than the other two paradigm which are anchored on a hemisphere, to allow the composition of a depth of field difficultly affordable otherwise. The final work has therefore only 28 channels and has been successfully decoded on systems varying in loudspeaker count, from 12 to more than 100 (Martin and Tremblay, 2020).

Tremblay spent a lot of time composing this piece and testing it in different studios such as "in the SPIRAL (Spatialisation and Interactive Research Lab) of the University of Huddersfield (UK) and in the hemisphere studio of Notam (Olso, Norway), with road tests and mixing in the spherical studio of the University of Hull (UK)".

[25] https://electrotheque.com/oeuvre/41658

[26] https://www.bronamartin.org/spatialaudiointerview1_pat.html

(Tremblay, 2016-17). Tremblay's extensive experiments and research paid off since this is a piece of music that stands out in my mind where I really remember the performance. I have yet to create a piece which uses a hybrid of spatial audio formats. Even working with one format such as ambisonics requires patience and time to develop an understanding of how our pieces might sound when they are taken out of the studio and into different performance spaces with different loudspeaker arrays and configurations. However, it seems this hybrid of formats works in order to achieve a variety of spatial attributes i.e. point source, diffused sound, depth of field.

7. Sound Diffusion and Performance: sonic transformations beyond the studio

Transferring the work from the studio to a performance space offers even more possibilities for the replication and simulation of the original soundscape environment.

> Sound diffusion facilitates the transition of the work between *composed space* and *listening space*. This new listening space, the *diffusion space*, further enhances the illusion of the original soundscape experienced by the composer (Smalley, 1991, p. 123).

> By combining speakers placed at different distances and angles from the audience, loudspeaker orchestras furnish performers with complex possibilities to project and enhance spatial contrast, movement and musical articulations. The performer draws on spectral and spatial changes in the music, loudspeakers of diverse frequency response and power, room acoustics, and how changes in the precedent effect and directional volume influence our perception of the spatial scene (Barrett, 2016, p. 55).

Many of my works have been performed within concert halls on sound diffusion systems such as MANTIS[27] (Manchester Theatre in Sound, University of Manchester), BEAST[28] (Birmingham Electroacoustic Sound Theatre, University of Birmingham) and MAAST[29] (Music and Audio Arts Sound Theatre, University of Kent). This is an opportunity for the composer to perform their work where 'the same type of physical gestures that were used to shape material during the process of composition should be used again in performance to enhance further the articulation of the work's sonic fabric.' (Harrison, 1999, P. 118). We can create even more tension and intensity during the performance as textures gradually become louder as layers are added and diffused throughout the space. This can be achieved by gradually increasing the volume of sound being sent to loudspeakers that are outside of the original studio loudspeaker configuration for which the piece was composed as stereo and 8-channel images are replicated across multiple pairs and rings of 8 loudspeakers.

[27] https://www.novars.manchester.ac.uk/connect/mantis-festival/

[28] https://www.birmingham.ac.uk/facilities/ea-studios/about/meet-beast.aspxs

[29] https://blogs.kent.ac.uk/maast/2019/06/04/maast-introduction/

Figure 6. The MAAST System in the Dockyard Church at Chatham Historic Dockyard with loudspeakers located in the balconies. This picture was taken during a diffusion workshop by Dr. Louise Rossiter followed by a concert (https://blogs.kent.ac.uk/maast/2022/05/13/maast-chase-concert/).

7.1 Creating a sense of height within the work

We also have the opportunity to create a sense of height within the work which may not have been possible while composing in the studio on a 2D plane i.e., Stereo, 5.1, 8.0. Depending on the performance space, loudspeakers can be placed in balconies or on very high loudspeaker stands with a high pass filter applied which creates the illusion of sounds rising and moving above us. This can be experienced at a MAAST concert, directed by Dr. Aki Pasoulas, University of Kent. For example, loudspeakers are placed on the balconies within the Dockyard Church at Chatham Historic Dockyard. A high pass filter is also applied to these speakers, adding height and distance to the work as the higher frequencies within certain sounds are enhanced. If there are no balconies within the space, loudspeakers can also be placed on tall speaker stands or ceiling speakers can be used to create a sense of height within the work.

Some sound diffusion systems such as BEAST and BEASTdome[30] at the University of Birmingham have special tweeter tree canopies which create a sense of height within the work. Unlike speakers located in balconies or on higher loudspeaker stands, these tweeter canopies are located directly above the audience. As part of the BEAST

[30] https://beast.cal.bham.ac.uk/offspring/beastdome/

Figure 7. The MAAST System in Slip 3 Mezzanine, Chatham Historic Dockyard for the Sonic Cartography Conference, 2022 (https://research.kent.ac.uk/sonic-palimpsest/sc2022/). Loudspeakers are located on tall loudspeaker stands.

system these speakers are attached to a truss which is then hung above the audience from a lighting grid. Loudspeakers are also placed in balconies when performances are in the Bramhall Concert Hall, University of Birmingham but these do not have a high pass filter applied.

The BEASTdome also includes a ring of tweeter speakers. Some of the speakers are permanently located within the dome itself. This includes an upper ring of 8 loudspeakers (genelec 8040s), Keystone (4 x 8040s) and Tweeter horn speakers in a ring of 8. For concert performances in the Dome, more loudspeakers are added such as, a mains stereo pair (2 x Genelec 1037) and a lower ring of 8 (8 x Genelec 8040).

7.2 Diffusing NightEscape on the BEAST System

At BEAST FEaST 2018, I performed *NightEscape* (2018)[31] in the Bramhall Concert Hall. For me, this performance stands out as one of my most memorable as the soundscape was free to explore and react to the acoustics of this large concert hall. It became

[31] https://beast.cal.bham.ac.uk/beast-feast-2018-featured-artist-brona-martin/

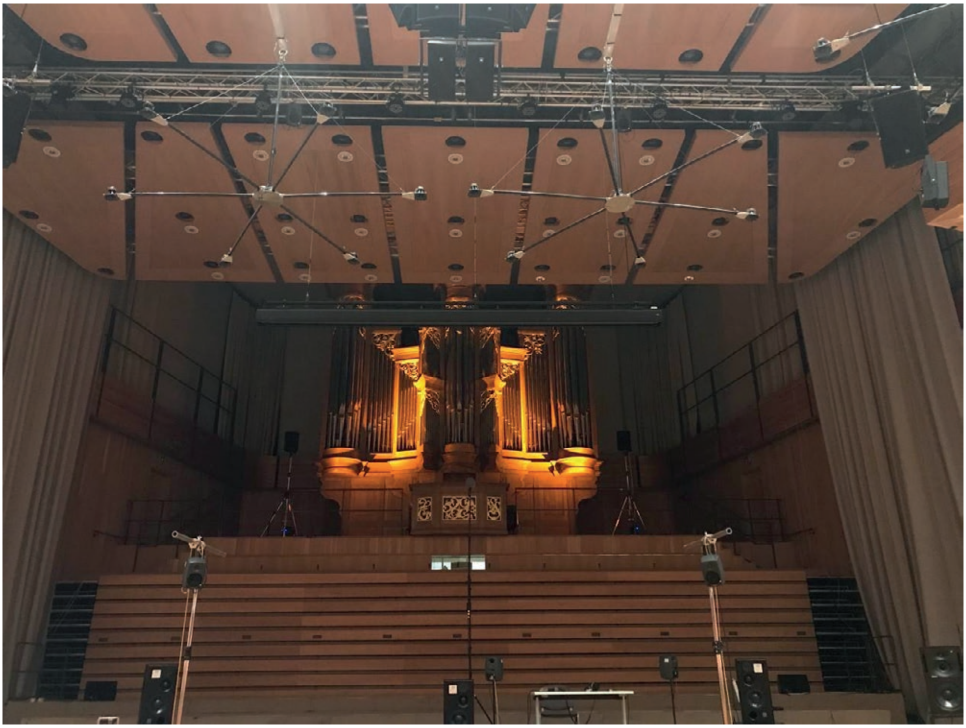

Figure 8. BEAST Tweeter Canopy in the Bramhall Concert Hall, set up for BEAST FEaST 2018 (https://beast.cal.bham.ac.uk/beast-feast-2018/).

even more enveloping as layers of sound were diffused around the audience, some from very distant speakers and some in close proximity to the listeners. Composed for a ring of 8 loudspeakers on a 2D plane, the addition of height and depth enhanced the overall immersion of the piece as sounds could be localised further in the distance such as planes flying overhead creating the illusion of being within a much bigger soundscape.

Within this piece a gradual climax begins (04'24) (Sound Example 8)[32] as a result of tonal material derived from the sound of the plane being pitch shifted upwards creating a sense of expectation. This sense of moving upward was enhanced by placing the sounds in the tweeter canopy above the audience and the speakers in the balconies creating a sense of being elevated within the sound.

7.3 Sound Diffusion and Spoken Word

A bit closer to home (2014) has been performed on the 48-channel MANTIS (Manchester Theatre in Sound) diffusion system, at NOVARS Research Centre,

[32] Audio materials related to this article are available at the following DOI: https://doi.org/10.5281/zenodo.10252743

Figure 9. BEASTdome concert setup.

University of Manchester and also at the Sonic Lab[33] (Sonic Arts Research centre, Queen's University, Belfast). During the first diffusion of this work on the MANTIS system, I quickly discovered that since channels 1 & 2 were mapped to other loudspeakers including those on the ceiling, I would lose control over the location of the spoken word. This would disrupt the illusion of the narrator sitting in front of the audience, telling their story. In the last few years, I have composed many works which include spoken word such as interview and archival materials. As a result of my diffusion experience, I always create two versions of a composition, one for sound diffusion for performance and one normal playback. The diffusion mix includes a separate render of the spoken word, which will be mapped to a stereo pair at the front (fig 2) resulting in a 4-channel mix, if the piece is stereo and a 10-channel mix if the piece is 8-channel. This ensures that the narrative component does not get lost within the diffusion, ending up on the roof speakers for example.

[33] https://www.qub.ac.uk/schools/ael/Discover/facilities/soniclab/SonicLabSpecs/

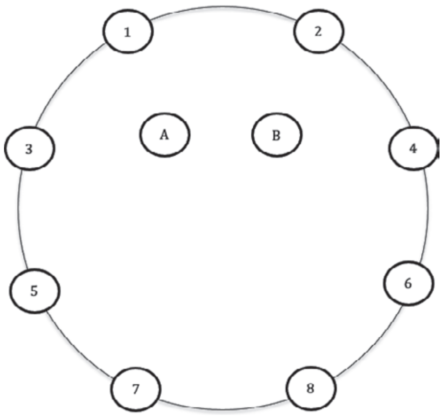

Figure 10. Speaker layout for 8-channel works with spoken word fixed on loudspeakers A&B, while the ring of 8 is diffused over an array of loudspeakers.

7.4 Sound Diffusion – Moving sounds below us

For some diffusion systems such as the MANTIS system the lowest point for a loudspeaker is on the floor, the same level as where the audience are seated. Often smaller loudspeakers such as Genelec 8030As are placed under the seats of the audience so listeners can experience sounds within their 'proximate space'.[34]

The Sonic Lab, at SARC (Sonic Arts Research Centre)[35] University of Belfast is an example of a 'permanent high-density loudspeaker array'.

> Although loudspeaker orchestras, stereo diffusion, and more recently hybrid performance techniques remain alive especially in Europe, there is a trend towards fixed installation, high-density loudspeaker arrays, which I will call permanent-or P-HDLAs to differentiate from loudspeaker orchestra HDLAs (Barrett, 2016, p. 35).

In the Sonic Lab, the audience are placed 4 metres above a ring of 8 loudspeakers and 2 subwoofers. The current system at the Sonic Lab is unique in that "audiences and researchers enter the lab at ground floor level and walk out onto an acoustically transparent, modular grid floor suspended 4m above the structural floor of the lab located at lower ground floor level."[36] There are four layers of Meyer and Genelec loudspeakers – High, Mid Height, Ground and Basement with the audience seated on the ground level.

In 2015 *A Bit Closer to Home* was performed in the Sonic Lab as part of the Sonorities Festival. For this performance the spoken word remained on a main stereo

[34] Proximate space: Space closest to the listener (Smalley, 2007, p. 36).

[35] https://www.qub.ac.uk/sarc/

[36] Sonic Lab Specs, https://www.qub.ac.uk/schools/ael/Discover/facilities/soniclab/SonicLabSpecs/, accessed 5/12/22.

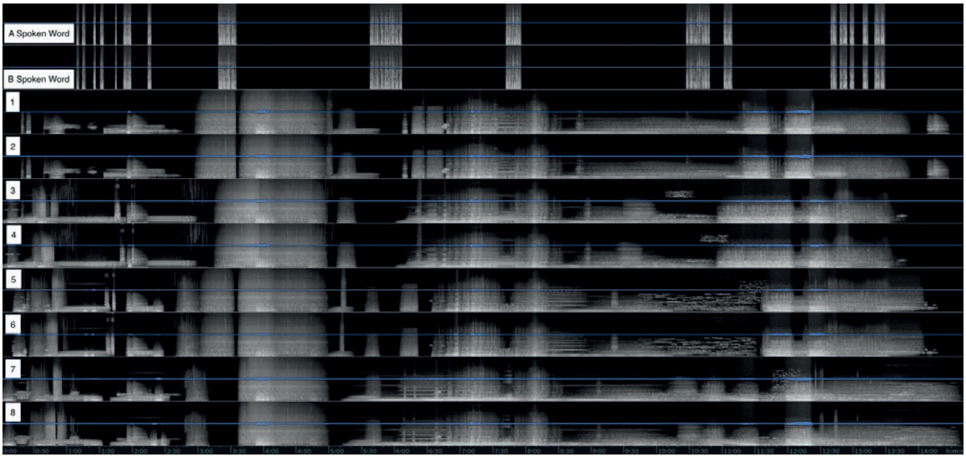

Figure 12.

pair. The rest of the material was diffused throughout the space. This was the first time I had the opportunity to diffuse sounds below me and really explore distance where usually I have focused on diffusing sounds above the listener to create a sense of height. For example, during the 'thunder scene' mentioned above in section 2, sounds were placed in the upper ring of eight loudspeakers. In order to change the perspective from 'distant' to 'close' the amplitude was slowly increased on the mid-high loudspeakers and then on the floor level loudspeakers bringing the sounds closer to the listener gradually enveloping the audience. Sounds of rain were placed in the high ring of loudspeakers while sounds of lapping water were placed in the floor level speakers surrounding the audience. The diffusion of this piece at The Sonic Lab[37] emphasised the spatial characteristics within the piece while enhancing and embellishing the sonic material creating an extended and more realistic soundscape.

7.5 Sound Diffusion Aesthetic

Before a MAAST concert[38] in the Dockyard Church in Chatham Historic Dockyard on May 13th 2022, I had the wonderful opportunity to participate in a Sound Diffusion Workshop facilitated by award winning composer and former winner of the L'espace du son international spatialisation competition (2012), Dr. Louise Rossiter[39]. Rossiter discusses her approach to Sound Diffusion:

> The idea of scenes comes from both my listening and my compositional practice and in particular diffusion practice. So, if I'm listening to a piece of music for diffusion, not

[37] Since my performance at the Sonic Lab, there have been some changes to their speaker layout to accommodate a Dolby Atmos Configuration.

[38] https://blogs.kent.ac.uk/maast/2022/05/13/maast-chase-concert/

[39] https://louiserossiter.com/

> just my own music but also other people's, quite often I spend a long time listening to that music and drawing a diffusion score. The main purpose of that process is to learn a piece but also to pick out the main scenes which I feel are the most important. For example, if you've got a plane in a piece, you would expect that to fly overhead. My job is to make that sound as realistic as possible. Then I have to think about the sounds that go on around the plane. It's about looking at the source of that sound, how that sound has materialised and developed to being there and then fitting those sounds around the main object in that scene to make it make sense. The diffusion score quite often won't have a drawing of a plane in it, but it will have something like 'plane overhead' and that will be higher up vertically on the score. Then you might have some gestural material happening underneath.
>
> When I am rehearsing for diffusion that's when I start to write my directions, what direction things are going to be coming from. The loudspeaker orchestra or collection of loudspeakers are there to facilitate the composers sounds and it's my job as the diffuser to make that work in the best way possible.
>
> In terms of compositional practice, I also do pre composition scores because I'm using image quite a lot as inspiration. The way my mind works, I need to write those ideas down in abstract image form. If you compare the pre composition score to the diffusion score it's built up in scenes so the main gestures and sound sources will be in there. The idea of scenes is almost like a map for diffusion or a map for composition because it not only makes it easier for me to understand but also for the audience. (Martin and Rossiter, 2022)

Rossiter's use of a diffusion score provides a visual breakdown of the piece into various scenes. The scenes will remain the same, but the diffusion will always be dependent on the loudspeaker array and will therefore be different for every performance. I have never used a diffusion score for performance as I feel I have enough to do in listening and managing the faders. However, I feel it is an extremely useful tool in ensuring specific scenes are diffused in certain way which have been planned out in the rehearsal. This is especially useful when we have the option of using over 50+ loudspeakers within the diffusion performance which can sometimes be overwhelming especially if rehearsal times are short.

8. Conclusion

This paper explores the author's experience of composing with a range of spatial audio formats. It also examines the impact of working with new technologies and their influence on the creative process and compositional explorations through space. The application of different tools results in the composer exploring different compositional workflows while examining how these tools both compositional and performance, enhance the composition of space within the work.

From my experience of working with these systems I have found that creating immersive works using ambisonics is an adaptable format for performance since the piece can be decoded for different loudspeaker arrays while retaining the composed

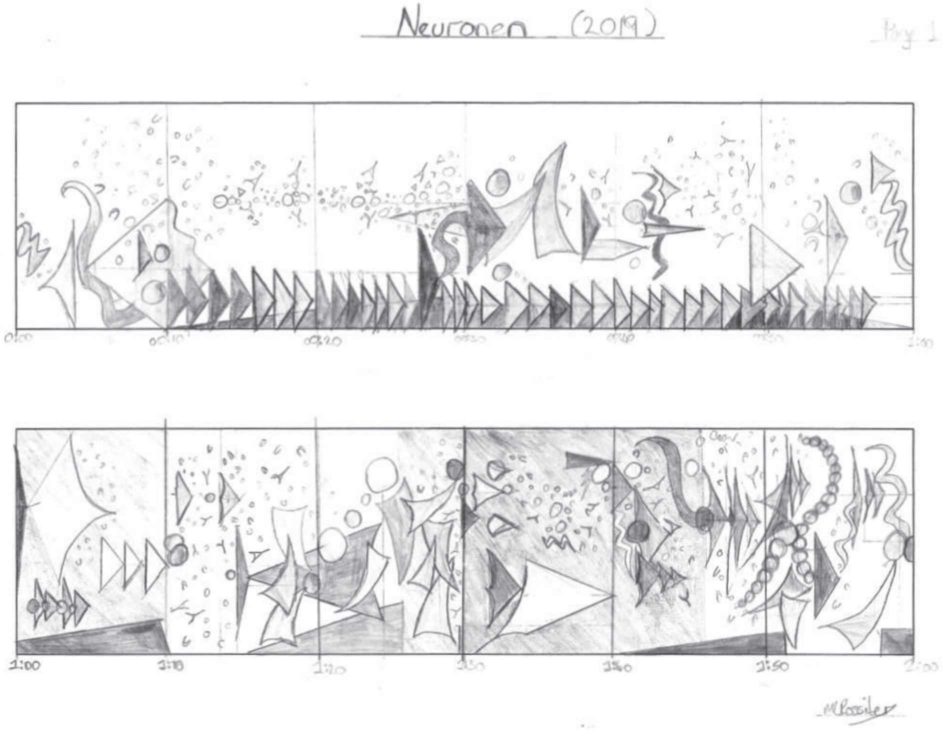

Figure 12. Rossiter's Diffusion Score for Neuronen (2019).

spatial image. Issues such as blurring may arise if the piece is encoded to higher order and then decoded to a lower order of loudspeaker 'due to the reduction of spatial resolution.' (Carpentier et al., 2016, p. 17). However I worked mainly in 3rd order ambisonics so this was not an issue.

The various interfaces used for spatialisation also had an impact on how I positioned my sounds within the space and created the spatial image, placing sounds within a hemisphere rather than along a 2D plane. As a result, I spent much more time composing space compared to creating works for an 8-channel setup. The creation of space developed along with the composition. For example, while composing with the IKO I spent a lot more time spatialising materials to create movement and spatial trajectories while using EQ automation to create a sense of distance. A lot of time was spent positioning sound sources in precise locations. I also began to explore different types of sonic materials other than field recordings which I was not intending to use. Synthesized sounds were easier to work with and spatialise resulting in the addition of detailed sonic gestures which weaved in and out amongst soundscape materials.

Sound Diffusion also allows us to adapt our pieces for different spaces and where the composer has the opportunity to enhance physical gestures and spatial motion within the piece in real-time. However, despite the piece being fixed, this type of performance allows the composer to continue to interact with the sound material outside of the studio. Musical events can be further shaped and embellished while dynamics within the piece can be enhanced facilitating the adaption of the work for a larger reverberant performance space. Sound diffusion allows me to play with my piece within the space where the sounds are no longer restricted to the confines of the studio.

Regardless of how we perform and spatialise our work, we will continue to learn from each performance. Despite all of this wonderful technology, listening is fundamental in developing our understanding of how sounds behave in space. Alongside listening it is also important that we continue to create opportunities where we can discuss music and compositional aesthetic e.g. in a workshop scenario so that we can learn from each other while engaging with a language that helps us to discuss and listen to works composed for different spatial audio loudspeaker configurations.
Since all performance spaces are different in terms of size, acoustics and loudspeaker setup no performance is the same. With every performance we learn something new about our compositions in relation to the composed space within the work and the spectral content of our sounds.

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

Luc Döbereiner and David Pirrò

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

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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

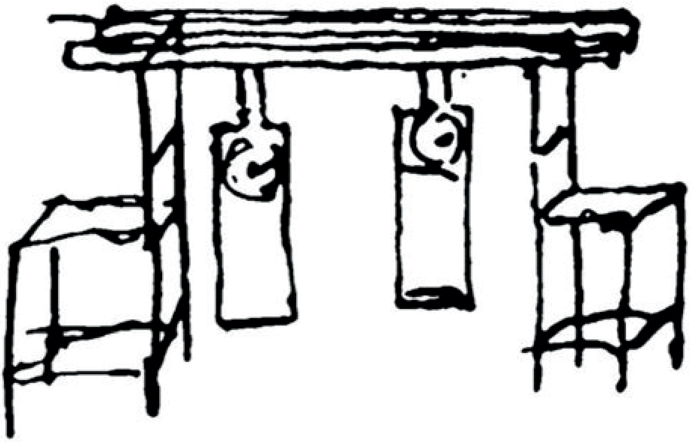


Figure 1. Drawing by Huygens of his 1665 experiment.

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.

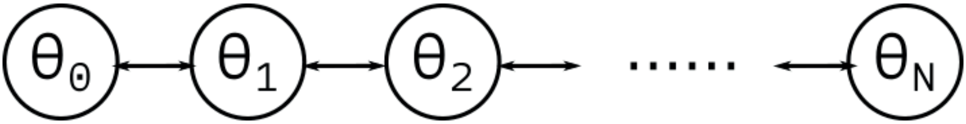


Figure 2. Coupling oscillators with nearest neighbors.

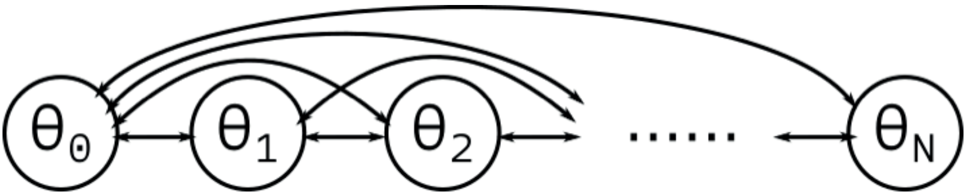
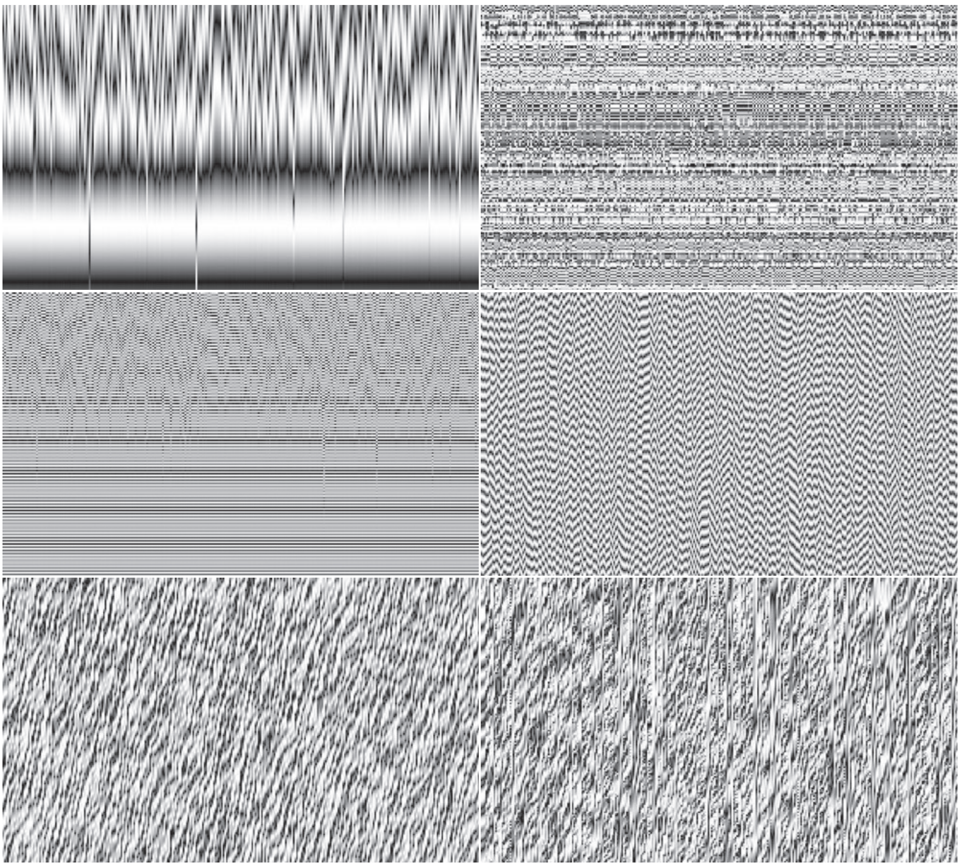


Figure 3. Coupling of all oscillators with all other oscillators.

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)

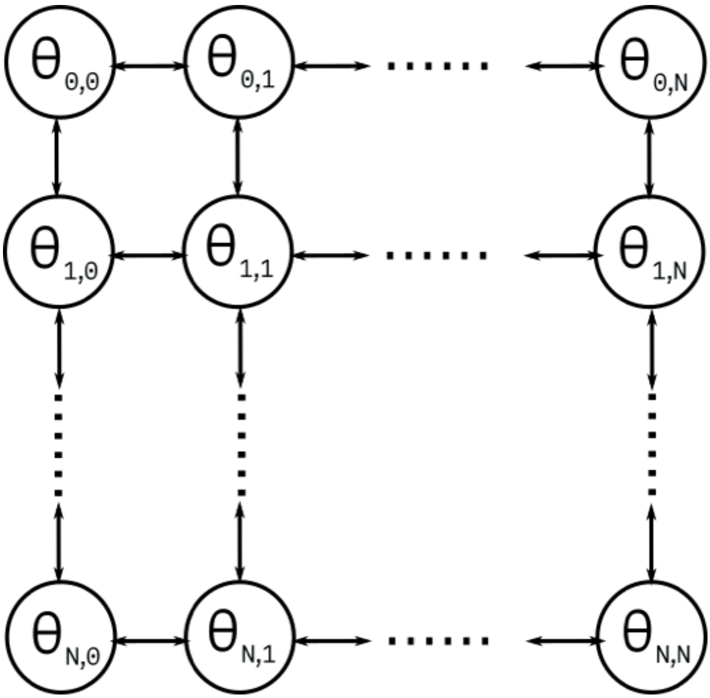


Figure 4. Two-dimensional coupling with a set of nearest neighbors.

(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.

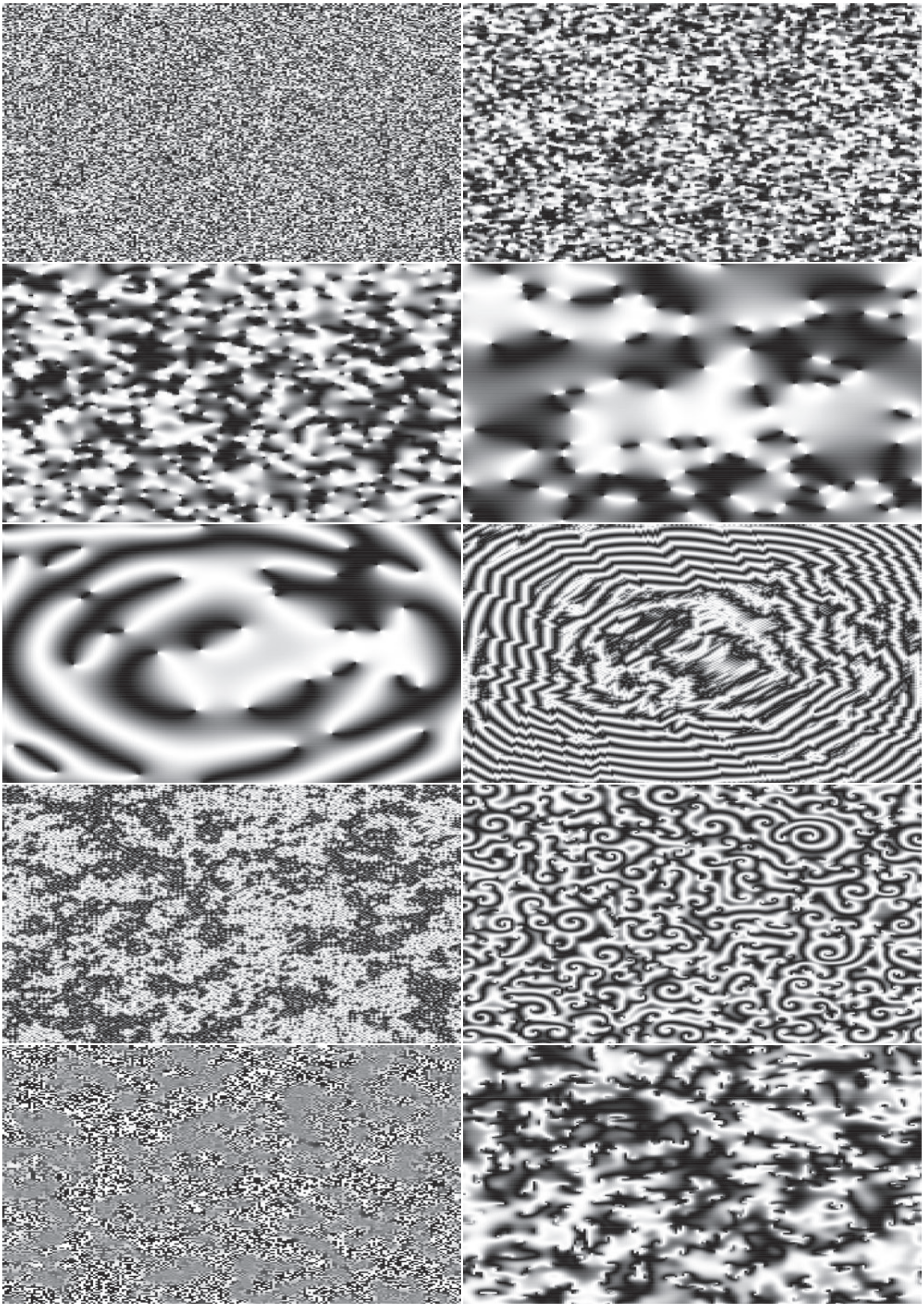
On-Site Installation

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.

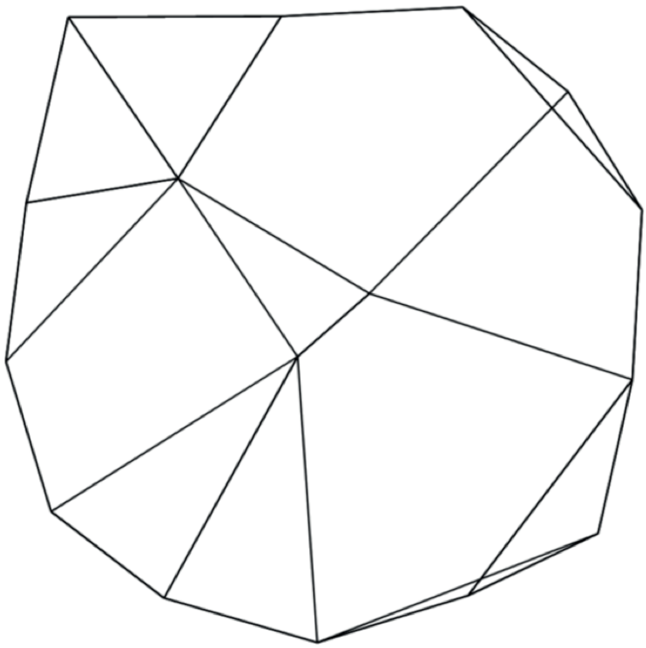


Figure 5. Visualization of the connections between oscillators in Iteration 3.

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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Abstracts

Angela McArthur

Swimming in space: exploring spatial sound through underwater experience

Spatial sound is under-theorised, in terms which combine the aesthetic with the practical. Practical aspects of sound space are universalised through technologies, though these tools have a limited range of affordances, and a tendency to direct our conceptual engagement. Yet much theory is too abstract to be of pragmatic value to practitioners. This article takes the phenomenological experience of being underwater, as a means of exploring the gap between the aesthetic and practical, for spatial sound. Watery orientations can avoid habitual, terrestrial ways of engaging with phenomena, and offer medium-specific correspondences which can be helpful for those making work.

Keywords: Spatial sound, aesthetic, phenomenological experience, underwater.

Ji Youn Kang

Artistic approach to the WFS system

This paper, "Artistic Approach to the Wave Field Synthesis system," explores the diverse characteristics of the WFS system as a musical instrument and examines artistic approaches to spatializing sounds in electroacoustic music composition. It delves into the unique attributes of the system, providing detailed examples of compositions and discussing potential challenges and limitations. The paper raises questions about how such a spatial audio rendering system can impact our listening experience, particularly in relation to fixed media compositions. Additionally, the possibilities of using WFS in live electronic music are also explored.

Keywords: Spatialization, electroacoustic music, Wave Field Synthesis, spatial audio.

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Giulia Vismara

The aesthetic implications of 3D technologies on the spatial conceptualizations, configurations, and articulations of my compositional process

Incorporating 3D spatialization technologies into my artistic practice allowed me to explore a different perspective about the sound capacity to transform and broaden our understanding of space. This article delves into the effects of various methods, techniques, and 3D spatialization tools on the way I approach composition. It offers insight into my creative process, covering conceptualizations, configurations, and articulations, through the presentation of two projects and future trajectories.

Keywords: 3D audio technologies, spatialization, aesthetic, electroacoustic composition, different configurations.

Brona Martin

3D Spatialisation Technologies and aesthetic practice within electroacoustic composition: A journey through Listening, Composition and Performance

This paper discusses the relationship between creative practice and spatial audio technologies. Various compositions are discussed based on the author's experience with spatial audio, reflecting on how different technologies, workflows and performance scenarios inform and influence the compositional approach within the genre of electroacoustic composition. This includes working with different spatial audio software tools including channel-based audio, object-based audio, ambisonic workflows and different types of performance setups. This paper also reflects on how these technologies and spatial audio aesthetic influence various project outcomes.

Keywords: Creative practice, spatial audio technologies, aesthetic, spatialization techniques, electroacoustic composition.

Luc Döbereiner, David Pirrò

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

*Contingency and Synchronizatio*n is an ongoing research project exploring the interplay between openness and predictability in computational art. Utilizing distributed multi-agent networks, the project investigates computational synchronization phenomena across installations and visualizations. Central to the project are the concepts of contingency and synchronization, providing a framework for understanding aesthetic nuances arising from computation, sound, site, and collaborative decision-making. This paper examines the project's conceptual and artistic impact. It explores the relationship between contingency and synchronization and addresses repercussions for

concepts of listening, emergence, computation, space, and performance, and presents speculative theses outlining preliminary findings.

Keywords: Computational art, openness and predictability, synchronization phenomena, contingency, collaborative decision-making.

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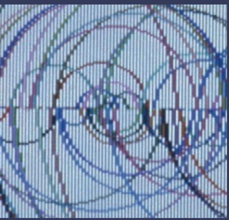

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