PRECIPITATE:

Distributed Machine Listening for Participatory Weather Resonification

By

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Introduction

Precipitate is a globally distributed audience participatory sound art performance piece and web installation that re-sonifies sounds made by the weather. Audience members anywhere in the world with internet access (hereafter referred to as 'remote audience members') can visit the *Precipitate* website on their smartphone where they will see a map with markers placed on the approximate locations of other connected audience members. Remote audience members are asked by the website to go somewhere that the sounds of the weather (rain, hail, snow — perhaps a lack of sound, thunder, etcetera) are audible. After giving their consent, their devices will listen to their immediate sound environment and continuously calculate six machine-listening features that indicate high-level qualities of the sound. The user may then listen to a live re-sonification of those six sound features through headphones, or choose another participating audience member from the map interface (see figure 1a) and listen to a sonification of the weather that surrounds that user. The piece can also be deployed in a live performance setting. During a performance of *Precipitate*, the performer accesses a similar map-like interface (see figure 1b), and re-sonifies the data of globally distributed participating audience members over a large speaker array for an audience in the space (hereafter referred to as the 'co-located audience').

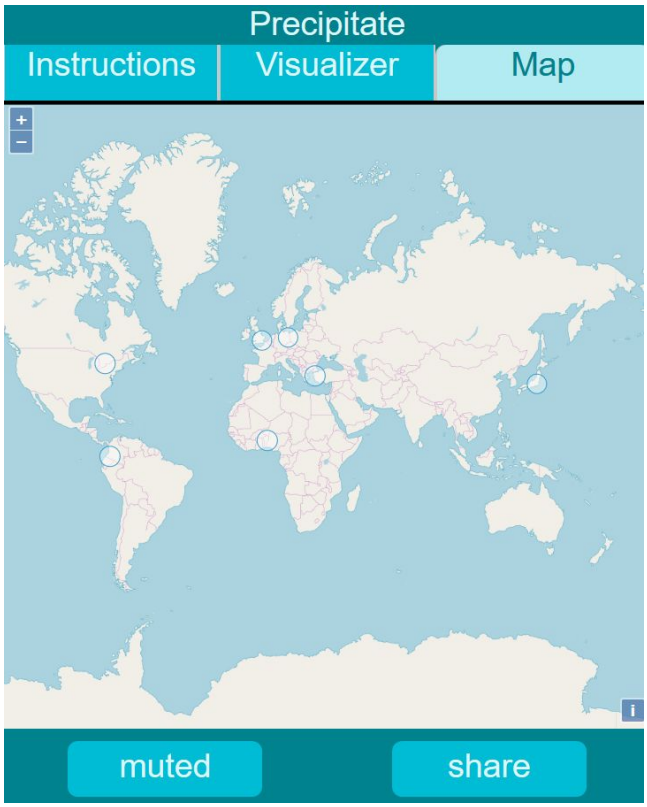

Figure 1a - Web Application Map Interface

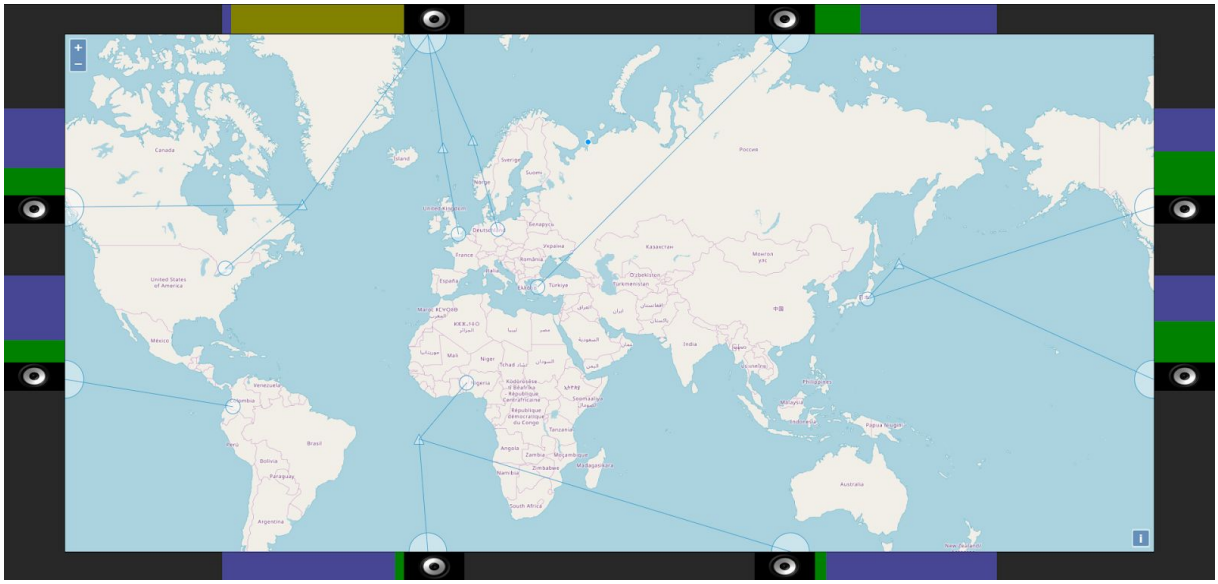

Figure 1b - Performance Interface

Conceptual Framing

Acoustic Ecology

In *The Tuning of the World* (1997), R. Murray Schafer formalized terms and concepts which have served as a lexicon for framing inquiry into "the relationship between man and the sounds of his environment and what happens when those sounds change" (Schafer, 1997, p. 4). Schafer's notion of a *soundscape* as the complete set of sounds in a particular environment has had enduring significance in sound research, including the field of Acoustic Ecology. Soundscape composition, an artistic practice that re-contextualizes soundscapes and environmental ambiance (sonic material more commonly perceived as 'background noise') as music, emerged out of the pioneering work of Schafer and his contemporaries. *Precipitate* has been informed by the practices and theory that have emerged from Acoustic Ecology in its ambitions to realize global weather as an enormous soundscape.

In the late 1960s and early 1970s, Schafer and his students lead an initiative called the World Soundscape Project to document natural and urban soundscapes across the globe. The project produced archives of field recordings and soundscape compositions sourced from across Canada and Europe, 'isobel maps' that depict sound-pressure level distributions over geographic regions, archives of Canadian noise pollution bylaws, and publications pertaining to urban noise. The World Soundscape Project drew attention towards noise pollution in urban soundscapes and soundscape conservationism. Due to

the preference of natural soundscapes over artificial and man-made sounds, the ambitions of the World Soundscapes Project have crossed over into broader environmental conservation efforts. Researchers and artists have employed the practices and techniques of soundscape composition in the contexts of environmental activism (Burtner, 2017), music composition (Westerkamp, 1992; Schafer, 1997), pedagogy (Burtner, 2017), and scientific inquiry (Ozga, 2017).

Contemporary practices in the field of acoustic ecology have leveraged locative and networked media to create interactive and immersive soundscapes. Building upon Hildegard Westerkamp's 'sound walk' practice, in which meditative attention is given to one's acoustic environment, Barclay's *Rainforest Listening* (2015) mobile application allows users to interactively navigate rainforest soundscapes while walking through dense urban environments. *The Montréal Sound Map* (Stein and Stein, 2008) crowd-sources sound recordings taken in Montréal and positions them on a web-based satellite map interface where anyone can listen to uploaded recordings and search for sound snippets catalogued by criteria outlined by Schafer (1997). *Sonic Maps* (Recursive Arts, 2012) and *Recho* (Sollihøgda et al., 2014) are mobile applications where users can pin sound recordings to positions on a geographical map interface that similarly rely on user-generated content. Powell (2015) argues that such applications and artistic installations which implicate location or space with sound foster an interactive and embodied experience as the listener is invited to explore how sound and spatial arrangement are entangled through the positioning and re-positioning of their body.

Acoustic ecology's historical interest in noise pollution and the preservation of 'natural' soundscapes have latent (if not explicit) connections to environmentalism. In *The Tuning of the World*, Schafer suggests not only that soundscapes are musical compositions of nature, but also that we may occupy a role as composers and performers of these compositions. In other words, Schafer envisioned our relationship with natural soundscapes as a form of stewardship over sounds and the things that produce them. The efforts of soundscape composers such as Schafer, Barry Truax, Pauline Oliveros, Hildegard Westerkamp, and others that aimed to foster an appreciation for otherwise unnoticed sounds also have environmentalist undertones in the importance they bestow to 'natural' versus 'man-made' environments.

The form of conservation advocated for (implicitly or explicitly) in Schafer's writings are reflective of the environmentalism of the 1960s and 1970s. Cultural artefacts such as Rachel Carson's book *Silent Spring,* and *The Blue Marble* image of Earth from outer space, and nuclear experiments forced public recognition of the Anthropocene which in turn motivated an environmentalism concerned with conservation and the preservation of 'nature' from 'unnatural' human interference. Schafer's writings echo this environmentalism through a preference for natural soundscapes over urban ones, and hi-fi (low noise) sonic environments over the lo-fi hum of traffic, construction, and other human activity (Minevich, 2013). Schafer (1997) laments how "local culture is pulverized into the background" (p. 71) by airports and factories which exert their power through sound. Goodman (2010) articulates how militaries have instrumentalized the

relation between sound and power through acts of *sonic warfare* that assert dominance through fear and physiological harm. If sound represents or constitutes power, then Acoustic Ecology's historical intentions to reduce the anthropogenic destruction of natural soundscapes may read as a movement also to curb or limit human power over the environment.

Implicit in the conservation efforts of the Acoustic Ecology movement is an anthropocentrism that artificially demarcates the human from Nature. Nature is conceived of as a pristine ideal that flourishes void of any human ('unnatural') intervention. This humanist framing of Nature served its role in both environmentalism and noise pollution activism in the 1960s and 1970s as the particular issues of these movements could be experienced on local and individual (or more broadly 'humanist') scales. The title of the book '*Silent Springs*' is evocative and visceral; one can readily imagine the dystopian scenario Carson imagines with the continued overuse of pesticides. Similarly, Schafer's warnings of the decay of natural soundscapes, or the increase of sound-pressure levels in urban areas are readily tangible. One of the goals of *Precipitate* is to re-contextualize Acoustic Ecology's practices and environmental connotations in light of the looming contemporary ecological catastrophe which often evades immediate perception.

Post-Humanism and Ecology

Contemporary environmental issues such as global warming, ocean acidification, ozone depletion, and algal blooms (generally catastrophes that fall under the broader

umbrella of climate change) are problems of such enormous scale that they often paradoxically evade human perception. The experienced effects of dispelling an aerosol can into the atmosphere or commuting a gas-guzzling SUV lack the same immediacy and perceived locality as the conservation efforts of the late 20th century that were aimed at spatially localized (as opposed to ethereal and omnipresent) and temporally defined issues. Modern weather models and predictors leverage terabytes of RAM and supercomputers to make reasonable weather reports. Multiply the task of weather prediction over the temporal scale of decades, centuries, or millennia, and the spatial scale of the entire earth and beyond (as in solar winds, solar flares, cosmic radiation) — the scale of climate — and the limitations of humanist perspectives in understanding the trajectory of climate change become apparent. The scoping challenges posed by today's environmental emergencies warrant a shift from anthropocentric perspectives on the environment. A post-humanist framing can offer insight into how to approach such daunting and elusive phenomena.

Object-oriented ontology (OOO) is one such framing that has been mobilized as a tool for reasoning and communicating about climate change. OOO posits an anti-correlationist and speculative-realist metaphysics that asserts the existence of objects regardless of conscious human interpretation. Object-oriented ontologists accept epistemological finitude, arguing that knowledge acquisition is severely limited since "no object is going to perfectly translate another into its own terms" (Harman, 2010). OOO's combined adoption of realism and finitude establish metaphysical grounds for

post-humanist and de-anthropocentrized inquiry into objects that correlationists and idealists might argue do not exist. Global warming is one such object that is not necessarily perceived on human scales since its realm of influence is of a much larger spatial and temporal magnitude than what is accessible to human experience. Realism axiomatically asserts that global warming exists as an object whether we perceive it (and our contributions to it) in the current moment or not, while finitude accepts that what we can know about climate change is limited to providing perspectives that fail to sum to holistic knowledge. OOO pragmatically offers a novel approach to reasoning about global warming that can transcend localized human-scale concerns (such as earlier environmentalism and conservationism). The approximately 0.76 degrees Celsius increase in average global air temperature over about the past century (Barker et al., 2007) confirms that global warming exists, but the perceived feeling of such a small change in temperature over supra-human timescales does not inspire action. OOO's recognition of enormous and non-human phenomena as ontologically intact 'objects' bring them somewhat closer to our cognition such that we can interact with them, while its subscription to finitude humbles over-confident and anthropocentric claims that overstep their humanistic epistemological bounds.

Morton (2013) refers to such post-humanist and out-of-reach phenomena as 'hyperobjects'. Hyperobjects are non-local (they are everywhere at once) and exist on enormous finite timescales. Plutonium is one such object that fits Morton's criteria; its shelf-life belongs on geological timescales and its radiative properties ensure that

quantum bits of it exist everywhere. Styrofoam is another example according to Morton; its rate of decomposition is measured in centuries, and our irresponsible overuse of it ensures that it will pollute landfills and ecosystems around the world for a very long time. Global warming is the hyperobject elephant-in-the-room. Regardless of our capacity to respond to the climate crises, the effects of climate change are projected to continue unfolding over centuries into the future. Global warming has it's limbs in nearly every daily human activity and has seeped into the background of consciousness and conversation (how about the weather today?).

To approach the hyperobject of global warming, Morton (2010) argues we must do away with fetishized notions of Nature as a pristine resource that flourishes without human interference. Such attitudes justify a form of laissez-faire environmentalism which erases human agency and responsibility in issues of ecological concern. For instance, as Morton (2010) notes, some global warming deniers have argued for inaction in the current climate crises on the basis that the Earth has warmed and cooled before as part of its 'natural' geological and climactic processes. Other post-humanists have waged similar critiques of how notions of Nature have been constructed in order to be instrumentalized. Halberstam (2011) demonstrates how nature documentaries such as *March of the Penguins* artificially portray Nature to fit particular heteronormative familial ideals. In other words, Nature is constructed in these documentaries in a way that sits more comfortably with particular cultural contexts. We might then probe how a notion of

'Nature' is similarly constructed by so-called 'natural' and 'urban' soundscape composition.

Notions of "the mesh" appear frequently in post-humanist literature; Barad's (2003) agential realist ontology advocates for an understanding of how beings are *entangled* with each other in processes of mutual becoming, Donna Harraway's (1990) Cyborg Manifesto advocates for the demolition of conceptual boundaries between the human, the animal, and the technological, Guattari's (2000) ecosophy on the relations between environment, social relations, and human subjectivity, and various notions of the *assemblage* are some related examples. Morton (2010) describes "the mesh" as "the interconnectedness between all living and non-living things" (p. 30). Part of the imperative for realizing existence as an enmeshed experience is to call to attention the problematic way in which it is comforting for humans to imagine that things exist independently of other objects (such as how Nature has been conceived of as non-human). Concretely, "the mesh" indicates to us that we are more than just contributors to global warming, rather we are fundamental components of the hyperobject of climate change.

If we accept a post-humanist perspective (and one largely inspired by Morton), then the thing we call Nature consists of a highly interconnected web of objects that is far more complicated than idealized images of forestry, landscapes, and rivers. By accepting this complexity, the convenience of conceiving of Nature as neatly partitioned ecosystems vanishes along with our reference point for reasoning about all issues Nature,

"which has resulted in a creepy sensation that there is literally no world anymore" (Morton, 2010, p. 30). By implication, environmental art becomes "an aura without an object" (Morton, 2010, p. 105). What does Nature look or sound like when it is de-natured?

Morton (2010) suggests that ecological art may take three forms; art that emphasizes generative processes, art that illuminates consciousness of "the mesh", and simulations that demystify so-called 'Nature' by showing how it can be convincingly modelled by science. The goal of post-humanist object-oriented art would not be to claim totalizing truths about an object since such an ambitious goal violates the axiomatic assumptions of finitude to OOO. Instead, art can play a role in offering perspectives or "parallax" on an object, while recognizing the limitations of such perspectives (Morton, 2010).

The artistic practice of data sonification can be viewed as an epistemological method that embraces its limited capacity in providing perspectives on objects where totalized knowledge is unattainable. Turning objects into data, and then into sound clearly involves several stages of mediated translation whereby properties of the original phenomenon are removed or appended to in order to make the resulting abstraction useful to some purpose. Gitelman (2013) argues that data is never 'raw' and always cooked (subjective decisions are made during datafication), and the same could be said about mappings made to produce sound from data. When listening to Marty Quinn's *Climate Symphony* (2001), a sonification of ice cores from Greenland that indicate global climate

patterns over the past 110,000 years, the listener is astutely aware that a carefully contrived mapping from data to sound has occurred. The piece maps data onto musical abstractions (a 4/4 metre, twelve-tone scale, familiar orchestral instruments, etcetera) to make it accessible. Clearly the audience of *Climate Symphony* is not listening to the essence of 'ice cores' or data about them (do ice cores or data produce sound?), but rather a useful abstraction of their properties. OOO generalizes this sentiment by arguing that knowledge acquisition is a similar act of translation from an object that harbours its own truth and existence to the human who can perceive it in some limited way. Data sonification as an artistic form is well suited to the task of illuminating OOO's epistemological profundities, and the compulsions for doing so are both pragmatic and philosophical.

Having lost our reference point to an absolute 'Nature' or 'environment', data sonification suggests another possibility for environmental art: to provide multiple and diverse perspectives of these slippery phenomena while appreciating how such perspectives are arrived at through anthropocentric acts of translation. Environmental art with an object-oriented framing can illuminate how phenomena such as Nature, the environment, and global warming exist independent of our perception of them, while also recognizing the limitations of the human condition to perceive such objects. The realizations offered by environmental art may be vital for mobilizing action around objects that easily evade human perception. A core goal of this work is to further explore what environmental art looks like in light of the disappearance of the environment and

Nature as tangible entities. *Precipitate* engages in this exploration by providing new perspectives on the hyperobject of global weather through distributed real-time data sonification.

Artistic Design

The Hyperobject of Weather

Precipitate is an ironic sound art piece about weather and hyperobjects. The Weather was chosen as the focal sound object due to its awesome hyper-ness, and its entangled connotations with Nature. Goodman (2010) and Powell (2015) recognize sound as an articulation of power, and in any outdoor environment, the weather plays a dominating or 'keystone' (to use Schafer's (1997) terminology) role in the soundscape. Rain can wash out any hi-fidelity sounds in a sea of noise, thunder commands immediate attention, wind is the nightmare of all field recordists, and snowfall can bring urban hum to near silence by impeding traffic and the propagation of sound through the air. The influence of weather over soundscapes humbles weapons of war and even supersonic jets as keystone sound elements.

In 2018, weather straddles a border between the so-called 'natural' and 'man-made'. On a pleasantly cool sunny day, the weather is appreciated as a beautiful component of Nature. During catastrophic weather events, we feel helpless unto the forces of Nature, while a nagging subconscious voice wonders to what extent the heat wave or hurricane can be traced back to anthropogenic global warming. Radical efforts of

geoengineering such as stratospheric sulfate injections suggest that weather can be intentionally 'engineered' by humans. The grey zone occupied by weather between the natural and man-made alerts us to the artificiality of Nature.

Morton (2013) indicates how mundane elevator small-talk about the weather has transformed into an anxiety-inducing confrontation with global warming. *Precipitate* is unavoidably implicated with global warming due to its focus on weather sounds. The hyperobject of global warming is like a black hole in our consciousness that exerts an immense gravitational force on all tangentially related concerns. Global warming and weather form a Venn diagram where the edges of the circles constitute two event horizons; one cannot be avoided when reasoning about the other. This is a fascinating property of hyperobjects that *Precipitate* seeks to appreciate and aestheticize.

Performance Scenario

Conceiving of weather as a hyperobject, *Precipitate'*s imperative to re-sonify weather is set up to fail. How could something as enormous as The Weather be re-sonified, or even experienced in its entirety? In this way, *Precipitate* is ironic. Remote audience members are instructed to listen to the weather in their area, without much further instruction of what 'counts' as weather. Recognizing their vital contributions to the piece, remote audience members might ask themselves "is this weathery enough?" At no point will audience members hear The Weather as some complete experience, but some sounds seem more weathery than others. Such a question prompts a closer

examination of what the weather is (and perhaps if we have ever actually experienced The Weather?) until we get frustrated and accept the limitations that our perception and tools impose. Contributing to this insecure feeling that we have never really experienced The Weather, the map interface on the remote audience member's phone alerts them to the fact that other individuals around the world (appearing as markers on the map) are simultaneously listening to their local weather. When we realize that other weathers are concurrently unfolding, concretized notions of what The Weather is evaporate and we are forced to acknowledge The Weather as an enmeshed hyperobject. A raindrop felt in North America is not The Weather and a storm is not 'over' once it has passed a city.

Precipitate seeks to further explore these strange feelings of networked presence as a networked music piece. Barbosa (2003) offers classifications for networked music systems with reference to time and space. Networked music pieces may be co-located for instance when a local area network supports collaboration, or remote when performers are geographically dispersed. They may be synchronous, introducing technical complexity around latency and jitter, or asynchronous. The systems that facilitate networked music expand earlier notions of a 'soundscape' by hosting "displaced soundscapes" (Barbosa, 2003) that persist through electricity and electromagnetic networks. Participating in such a 'displaced' music scenario (especially in remote as opposed to co-located situations) is a strange feeling. Networked music practitioners can attest to the odd feeling of looking up from their computer in an internet cafe after a networked performance, surrounded by patrons who seem more confused by the last

twenty minutes of head-banging than appreciative of the art that accompanied it. Morton (2010) articulates a similar odd feeling that results from one's realization of how everything is deeply enmeshed: "The ecological thought realizes that all beings are interconnected... the boundaries between, and the identities of, beings are affected by this interconnection... the ecological thought finds itself next to other beings, neither me nor not-me" (Morton, 2010, p. 94). When musicians gather remotely via networked technologies to produce art these strange feelings of interconnectedness are quite visceral. *Precipitate* invites remote audience members to participate and experience the odd feeling of collaborating with geographically dispersed strangers.

Precipitate also communicates to participating audience members that something about what they are doing right now is having an impact on other beings around the world and that their significance in "the mesh*"* is greater than their immediate surroundings. The game *Journey* (thatgamecompany, 2012) beautifully leverages this strange feeling of anonymous networked collaboration; players begin a cooperative quest encountering other anonymous players. Communication between players is limited to a few gameplay sounds and the identity of other players is kept anonymous until the game is complete. Oliveros et al. (2009) suggest that telematic music performance scenarios may someday be "better than being there". *Precipitate* attempts to aestheticize the strange feeling of remote musical collaboration.

Research in the fields of Human-Computer Interaction and Computer-Supported Collaborative Work have studied how collaborative systems can be designed to manage

the growing privacy concerns of users (Iachello and Hong, 2007; Ackerman and Mainwaring, 2008). The smartphones through which *Precipitate* asks audience members to participate have gained notoriety as devices capable of being used for surveillance, and so the system has been designed to manage ethical and user-experience concerns. The longitude-latitude positions of remote audience members are rounded to the nearest tenth of a degree and the map interface can only be zoomed to a resolution of about 200 square kilometres. The only data shared by remote audience members (should they consent to share such information) are their approximate location, and a stream of values for each of the sound features extracted by their phone (ie. values for clarity, strength, pitchedness, turbidity, spectral centroid, and perceptual loudness). Furthermore, the sound features are calculated in such a way that they cannot be used to produce identical or even near-identical reconstructions of the original sound. One design challenge has been to communicate the specifics of audience participation in a way that adheres to ethical and transparent data practices while preserving the context of a sound art performance and installation. Warnings about the use of data are foreign to most musical performance contexts so a “Terms of Use” or “Data Policy” would likely evoke more unnecessary anxiety than assurance. Instead of providing a legal manuscript, the instructions page for remote audience members on the *Precipitate* website includes all details about data sharing (see figure 2). As an additional measure of transparency about data practices, the web-based interface provides real-time visualizations of the machine listening features as they are calculated by the audience member’s device (see figure 3), which can be viewed

before any data is shared. The real-time visualization of data is a philosophy informed by the field of Live Coding which appreciates the transparent display and theatrics of algorithmic processes (Rohruber et al., 2007; TOPLAP collective, 2005). One way data-intensive art can assure (or mislead if done improperly) data-subjects of their privacy is through such real-time projections.

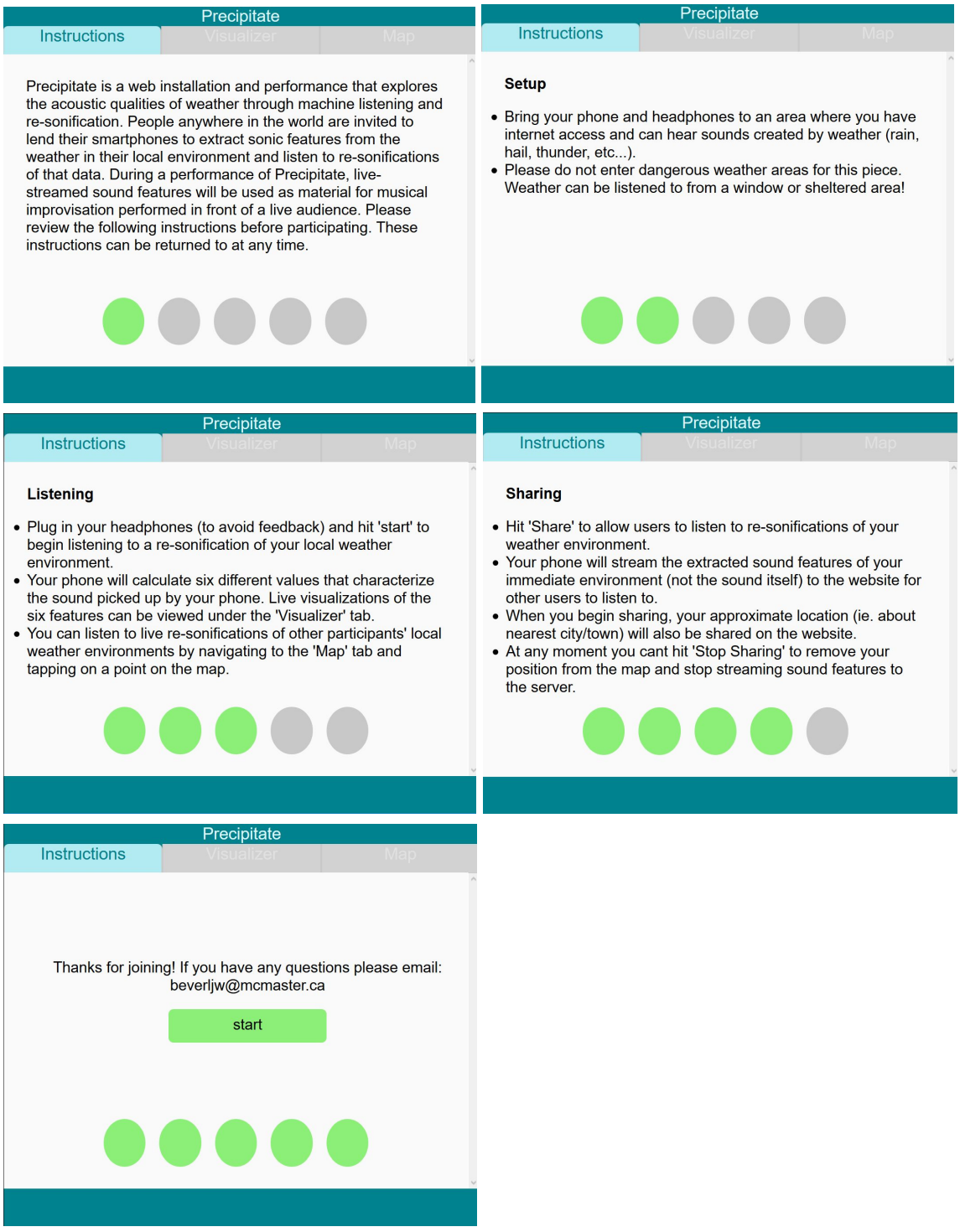

Figure 2 - remote audience instructions and terms of data use

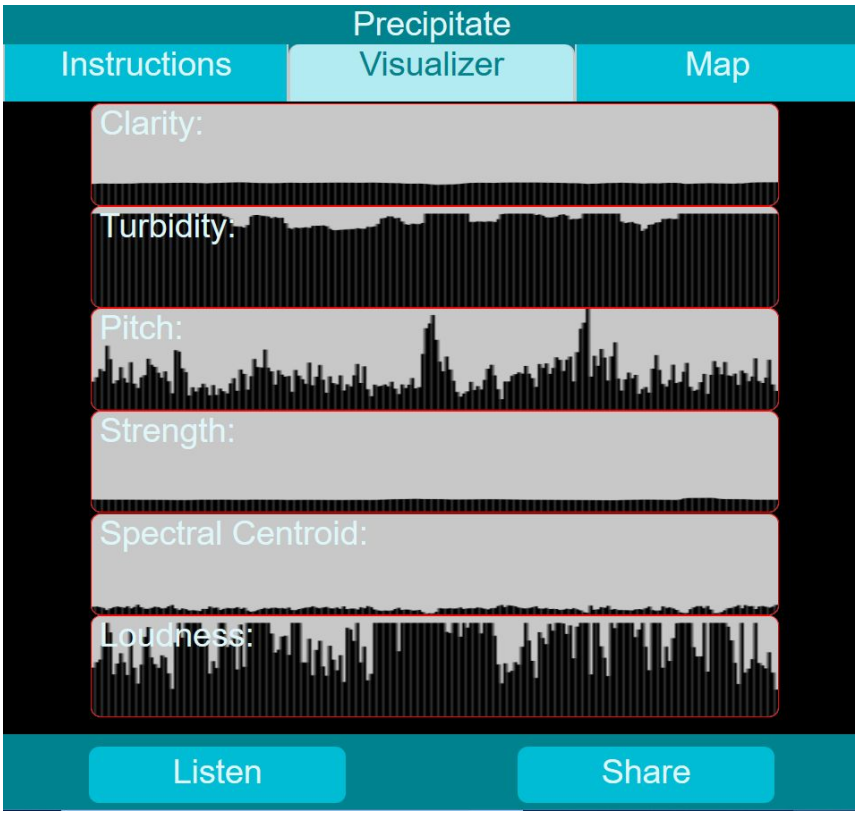

Figure 3 - Web Application live data visualization

Sound Aesthetic and Listening

Soundscape composition has historically been invested in preserving the original quality of field recordings to the extent that the source of the sound is recognizable in the composition. Indeed, Truax (1996) suggests that "listener recognizability of the original source material" (63) is a core principle of soundscape composition. While *Precipitate* does not claim to be a soundscape composition, enlisting an audience to engage in field recording implicates it with Acoustic Ecology. The claim has been made that the soundscape(s) being re-sonified in *Precipitate* cannot really be experienced or captured;

The Weather is not "recognizable" even when perceived first-hand. This complicates Truax's suggestion, and we might ask how soundscape composition should portray soundscapes that are unrepresentable; how can hyper-soundscapes translate into art? One answer would be to loosen adherence to Truax's principle and provide a perspective on the soundscape while recognizing its limitations. Irony is one method of providing a perspective while simultaneously embracing its shortfalls.

Precipitate re-sonifies weather but the result sounds nothing like what one might intuitively associate with The Weather. A microsound synthesis technique in which very short (~100ms) sound 'grains' from a corpus of recordings are spliced and rearranged for playback is employed, yielding a very abstract, 'unnatural', and often quite noisy sound result (see section "System Implementation – Synthesis Engine" for a more detailed explanation of the synthesis implementation). If the audience, expecting to hear wind, rain, or hail (familiar localized samples of The Weather), is surprised by the highly artificial aesthetic, perhaps they will reflect upon their expectations when they agreed to listen to the weather from around the world. Ironically, a highly abstract, gritty, immersive, and unsettling sonic result is no less 'accurate' at describing the hyperobject of The Weather than the highly selective weather sounds we intuitively call to mind when asked to imagine what weather sounds like.

Precipitate's sound aesthetic was also developed in consideration of Pierre Schaeffer's (2012) notions of 'referential' and 'reduced' listening. Referential/causal listening emphasizes the object that made the sound; when asked what they hear,

someone listening referentially may name instruments. Truax's suggestion that soundscape compositions should make the original source material recognizable is a statement that suggests that referential listening is an important part of soundscape composition. Reduced modes of listening direct the listener's attention towards the inherent qualities of the sound as it is perceived by the listener. Someone engaging in reduced listening describes sound with words such as *bright* and *dark*, *low* and *high*, *wet* and *dry*. Schaeffer's notion of reduced listening emerged with the advent of *musique concrète* in the mid-1900s when technologies such as the gramophone and magnetic recording tape permitted sounds to be enjoyed in separation from the physical instruments heard on the recording. Referential and reduced listening are not mutually exclusive; while Truax has indicated that referential listening is important to soundscape composition, the focus of Acoustic Ecology on hi-fidelity sounds (ie. low levels of noise - "noisiness" being a reduced sound quality) is indicative also of the importance of reduced listening.

In *Precipitate*, both the audience and audience smartphones are asked to listen. When dealing with hyperobjects as sound objects, referential listening is tricky since the referent is an elusive phenomenon. The task of determining the source of a sound is set up to fail. For this reason, *Precipitate's* mobile phone interface has been designed to listen for reduced sound qualities in preference to conducting acoustic scene classification. Remote audience members' smartphones listen for human-recognizable qualities (namely 'clarity,' 'strength,' 'turbidity,' and 'pitchedness') rather than listening

to indicate that it currently sounds like rain/thunder/wind/snow. *Precipitate's* sound aesthetic is similarly inspired by reduced modes of listening. Tiny grains of sound are selected for playback based on how well their reduced sound qualities match with what remote audience members' phones are hearing, rather than their likeness to a particular referent weather event. Musique concrète caused a referential crisis and addressed it by proposing a new way to perceive sound. *Precipitate* engages in the ecological referential crises articulated by Morton, offering its perspective through reduced sound qualities. In *Precipitate*, the hyperobjective nature of The Weather prevents all loss of referentiality, however. The Weather is not heard in its entirety in the sound, but due to the framing of the piece and how the sonic output is ultimately driven by weather sounds, The Weather is unavoidably a central referent to the resultant sound.

Given the post-humanist framing of this work, one might ask how the privileging of 'reduced' sound qualities is in any way de-anthropocentrized since these qualities are highly dependent on the human perception of sound. "Human recognizable qualities" such as clarity, strength, turbidity, and pitchedness similarly cater to the human. While these allegations are fair, OOO and post-humanism do not seek to erase the human; in the end, any phenomenon that is perceived is no longer 'post-human' in its own entirety. Post-human objects (like hyperobjects) cannot be perceived so at some level translation is required if we intend to speak about them. The best we can do then is recognize such translations and their limitations, and be transparent about the process of translation.

Precipitate's machine listening algorithm relies on one human's vague ideas about what clarity, strength, pitchedness, and turbidity sound like in weather sounds.

System Implementation

The *Precipitate* system is composed of four interconnected modules; the Synthesis Engine, the Web Application, the Performance Interface, and the Server (see figure 4 for a top-level view of the system architecture). The performer uses the Performance Interface to control the way in which the Synthesis Engine re-sonifies the audio extracted by the smartphones of remote audience members who are connected to the Web Application during a performance of *Precipitate*, while the Web Application is available to be viewed at any time.

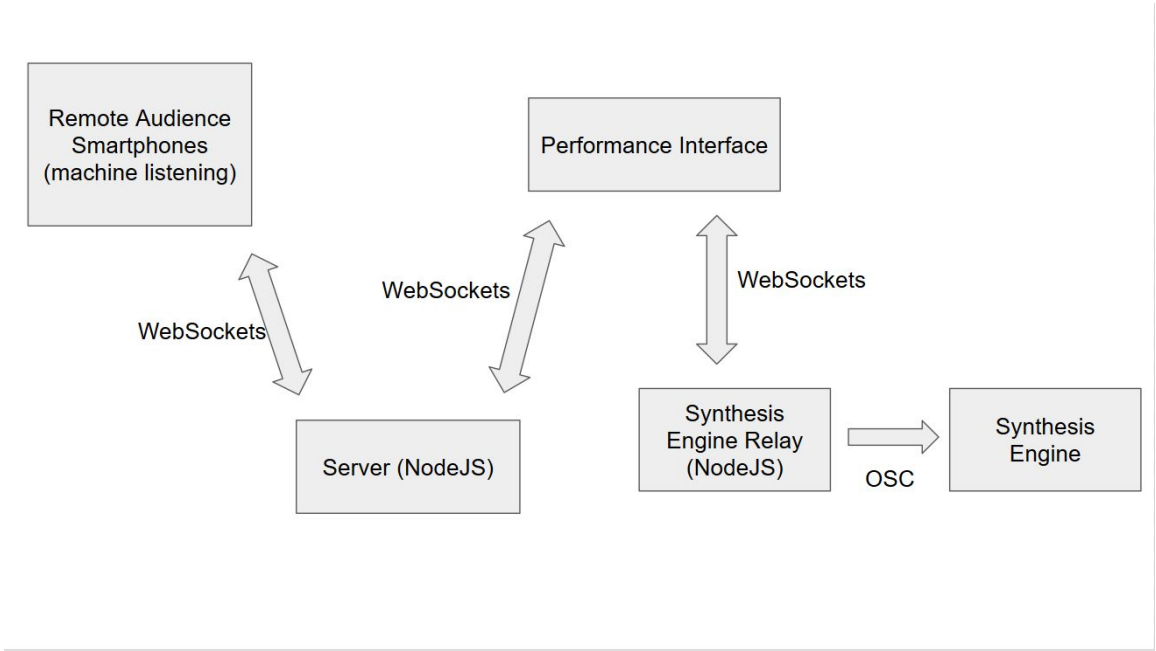

Figure 4 - system architecture

Synthesis Engine

The Synthesis Engine employs concatenative synthesis to render all audio during a concert performance of *Precipitate.* In concatenative synthesis, short 'grains' of sound (usually 100ms or shorter) are selected from a large corpus of recordings and then re-arranged and overlapped to be played back (Schwarz, 2006). The grains are selected by an algorithm that returns the appropriate grain given a 'target' signal that represents the desired output. *Precipitate's* concatenative synthesis algorithm selects a grain to be played by comparing six different descriptors of the sound (quantified as numbers between 0 and 1) to the same six descriptors of the grains (which are calculated prior to performance).

The descriptors (also referred to as 'machine-listening features') are calculated by conducting machine listening; low-level properties of the sound (such as frequency distribution and loudness) are calculated and then combined in mathematical functions to produce more abstract descriptors that approximate subjective and human-relatable sound qualities. *Precipitate*'s machine-listening features include *clarity*, *turbidity*, *pitchedness*, *strength*, *spectral centroid*, and *loudness*. Clarity, turbidity, pitchedness, and strength are subjective higher-level sound features chosen and calibrated according to the aesthetic criteria of the piece, while spectral centroid and loudness have more formalized definitions in sound research. Following Hunt and Wanderley's (2002) parameter mapping strategy for synthesis engines, *Precipitate's* machine listening algorithm

establishes an intermediary semantic layer between low-level listening features and synthesis outputs (the re-sonification). High-level definitions such as clarity, pitchedness, turbidity, and strength are more intuitive to reason about than a larger collection of low-level features.

Prior to a performance of *Precipitate,* sound files from a large corpus are chopped into shorter files ("grains") of about 100ms to 500ms in duration. A machine listening algorithm then generates a database that correlates each grain to their six machine-listening features. The *Precipitate* SuperCollider extension reads the database to load the corpus, and given a value for each of the six machine listening features, will run a search algorithm to select the grain from the corpus that most resembles the six features. The 'target' in *Precipitate's* concatenative synthesis algorithm is represented by one set of the six machine listening values. The search algorithm starts from a random grain in the corpus and calculates the six-dimensional Euclidean distance from that grain to the target grain. If the distance falls within a configurable tolerance range then that grain is selected for playback. A tolerance of zero will select the closest grain in the corpus to the target grain, at maximum computational cost.

A NodeJS program communicates to the web-based performance interface over web-sockets and coordinates state with the SuperCollider Synthesis Engine via Open Sound Control (OSC). Instructions from the Performance Interface are translated into SuperCollider 'PChain' patterns which apply audio effects and play individual grains.

Web Application

The web application is the *Precipitate* website where remote audience members can listen to re-sonifications of weather sounds from other connected users and share features of their sound environment for other users to listen to. Before gaining access to the application, the user must scroll through four instructions pages which also detail how data is being retrieved and shared. After reviewing the instructions, the user can toggle between the map interface, the data visualization, and the instructions.

The map interface (see figure 1a) shows a global map with markers at the approximate locations of other connected users. By clicking or touching a marker, the user can listen to a live resonification of the weather at that location. The map interface employs the Open Layers v4.6.5 (2018) JavaScript API.

At any moment, the user can choose to share (or stop sharing) sound features from their immediate environment by hitting the ‘share’ button. Upon hitting ‘share’ the user’s phone begin’s listening to their environment and calculating the six machine-listening features (see “Synthesis Engine” above) using the Meyda web-audio machine listening library (Rawlinson et al., 2015). Once the user has agreed to share their machine listening features, a marker appears on the map of other connected users at the location of the sharing user, and other audience members can choose to listen to a re-sonification of that user’s sonic environment.

Upon selecting another user from the map, the user's device subscribes to receive a stream of machine-listening features from the selected user. The six values received (one value between zero and one per sound feature) are then consumed by a concatenative sound-synthesis algorithm which produces sound that the user can listen to through headphones. The sonification algorithm is a re-implementation of the concatenative synthesis algorithm described above (under "Synthesis Engine"), written in JavaScript using the Web Audio API and featuring a reduced corpus for efficiency purposes.

The data visualization page (see figure 3) shows six real-time graphs of the values of the machine listening features over time. The y-axis of each graph indicates the value between zero and one of the feature, and the x-axis depicts time. Each graph shows the calculated machine listening values over just the past five seconds.

Performance Interface

The performance interface (see figure 1b) is a web application used in a live performance of *Precipitate*. The application features a map interface similar to the web application used by remote audience members, where users who are sharing sound features from their environment appear as circles on the map at their approximate location. The map has images of speakers and sound level indicators along its perimeter corresponding to the position of speakers in the performance space. When the performer clicks on a point on the map (representing a remote audience member who is connected

to the Web Application), they can draw a line that connects that user to a speaker. When a connection is made between an audience member's marker and a speaker on the interface, the Performance Interface instructs the Synthesis Engine to sonify that audience member's sound features in the corresponding speaker. The connections between audience members and speakers on the map represent data flow; the stream of machine listening features of each audience member can be directed toward any speaker in the space.

The performer can also right-click anywhere on the interface to create a "computation" object which appears as a triangle on the map. Computation objects represent some modification or effect that can be made to the stream of machine listening features from an audience member. Currently supported computations include:

attack - attack duration of the envelope for each sound grain.

release - release duration of the envelope for each sound grain.

reweight - specify how important each machine listening feature is in selecting a grain in the concatenative synthesis algorithm.

repeat - specify how many times a sound grain repeats.

tolerance - specify how similar the selected grain must be to the sound from the audience member's device.

corpus - select which corpus the grains should be chosen from.

dur - specify the duration between each grain being played.

undefined - a placeholder computation that does not affect the sound.

This set of computation objects is likely to expand to include more control over the sound synthesis algorithm. Common granular synthesis parameters outlined by Roads (2004) including grain randomness, duration, overlap, and windowing will be added as computation objects in future iterations of the software. An arbitrary number of computation objects can be connected in series to conduct multiple computations on one audience member's stream of sound features.

When an audience member or computation object is selected (shift + click), a context menu appears on the top right of the interface, containing a list of the selected objects. An item in the list can be clicked on to reveal a set of controls for that object (see figure 5). On the context menu, computation objects can be clicked on to reveal widgets where values for computation parameters can be set. The values for audience members' six machine listening features can be viewed in the context menu when audience members are selected on the map.

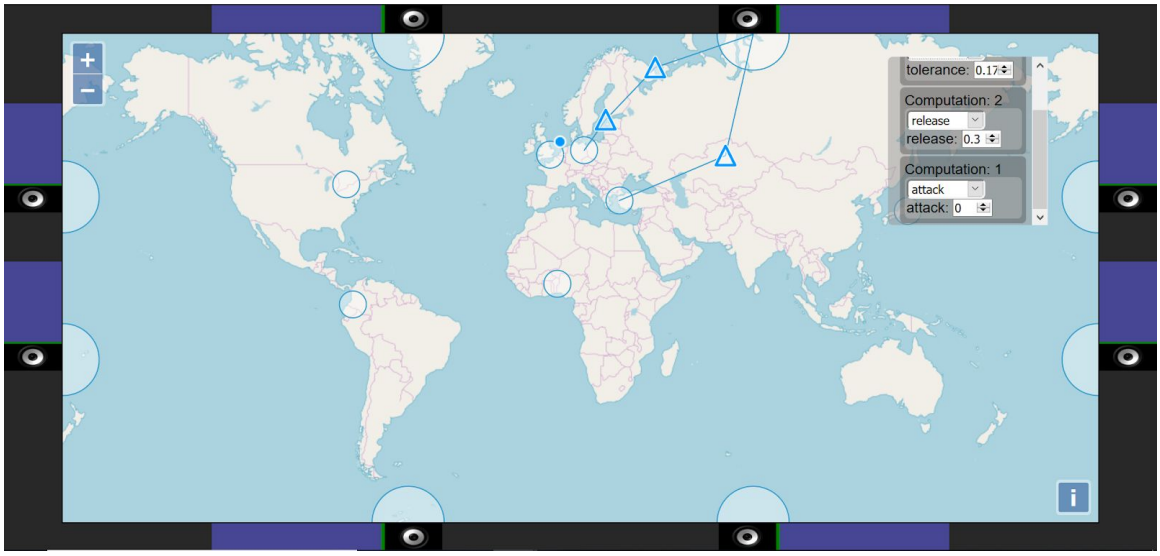

Figure 5 - Performance Interface controls menu

Precipitate's performance application draws inspiration from musical 'patcher' interfaces that articulate data flow by connecting closed shapes with lines, including Max/MSP, PureData, the ReacTable (Kaltenbrunner et al., 2006), and Auraglyph (Salazar, 2017). To some programmers, visual articulations of algorithms are more intuitive than text-based ones, and patcher interfaces can provide representations that appeal to familiar analog data transmission (for instance, connecting and disconnecting cables to modules such as effects pedals). Visual interfaces can also contribute their own aesthetics in contexts where the performer's instrument is in the foreground. A core practice in Live Coding performances is for the performer to share their screen, potentially offering greater insight into the thought process of the artist, and another medium through which the performer can choreograph theatrics. Salazar's (2017b) performance of *Pulse* using *Auraglyph*, a musical patcher language for tablets concluded

in a theatrical ‘zoom-out’ from a high-resolution perspective of chaotic waveforms travelling between 2D shapes to a large-font inscription of the name of the piece. *Pulse* is a demonstration of the value of exploring new visual articulations of performance interfaces and how they can be aestheticized. ReacTable (2006) and Auraglyph (2017) also explore how manipulations of data flow and algorithms can be expressed gesturally; the former through the orientation of tangible blocks on a screen, and the latter through drawing motions with a stylus. *Precipitate* has been designed so that the aesthetics of visual interfaces and the gestures they may suggest can be explored further. In a performance of *Precipitate*, the performance interface is projected for the audience to view, allowing visual theatrics similar to Salazar’s performance of *Pulse* to unfold. For instance, a performance of *Precipitate* could start from a very zoomed-in part of the global map and later zoom out to reveal remote audience members in geographically diverse regions. The map of the Performance Interface can also be substituted live for other projections, such as satellite and demographic maps or any .PNG file. The Performance Interface can also run on a Windows 10 tablet, offering support for gestural interaction when using a stylus.

Server

A NodeJS application serves both the Web Application and the Performance Interface. The Server communicates to all instances of the Web Application and Performance Interface via WebSockets and maintains a dictionary of connected clients to

facilitate streaming of machine listening features from audience members to other audience members, as well as to the Performance Interface.

Future Work

Future iterations of the *Precipitate* performance interface will be more tablet-friendly by removing the dependencies on 'shift' and 'ctrl' keys. The capabilities of the Open Layers API will be leveraged to expand upon supported gestural interactions such as freehand drawing. The concatenative synthesis implementation currently depends on an inefficient algorithm that in the worst case compares the target grain to all grains in the corpus. Future versions of the Synthesis Engine will explore optimizations for real-time concatenative synthesis. One potential efficiency improvement may come by implementing the n-dimensional search algorithm using 'R-trees' (Guttman, 1984). Lastly, the mobile web application will be improved once the Web Audio API is standardized and Web Audio Workers are implemented to replace the Web Audio Script Processor Node. The current system depends on deprecated Web Audio Script Processor Nodes which compete for global resources on the main thread, meaning the user may experience audio drop-outs when interacting heavily with the map interface.

Precipitate seeks to illuminate the weather as a hyperobject through a participatory and globally distributed sound art performance and web application. The 'strange' feeling of collaborating in a networked ensemble is similar to the 'strangeness' of being in "the mesh", and thus networked music has the potential to clarify the

mysterious properties of hyperobjects. Environmental art should explore theses potentials further as the enormous looming threats of global warming increasingly filter down into human-scale catastrophes. A post-humanist framing of hyperobjects emphasizes how some phenomena are too large to be entirely tangible, and suggests that art may play a role in translating supra-human objects back down to human recognizable scale.

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Appendix A - Links

Precipitate Code Repository: www.github.com/JamieBeverley/Precipitate

Precipitate Demonstration Video: https://youtu.be/d6MJ-zE9CFE