香港城市大學
City University of Hong Kong

Sonification of Climate Data

Crossmodal correspondences, Perception and Design

PerMagnus Lindborg, PhD
City University of Hong Kong, 9 September 2022



專業 創新 胸懷全球
Professional·Creative
For The World

DACA +

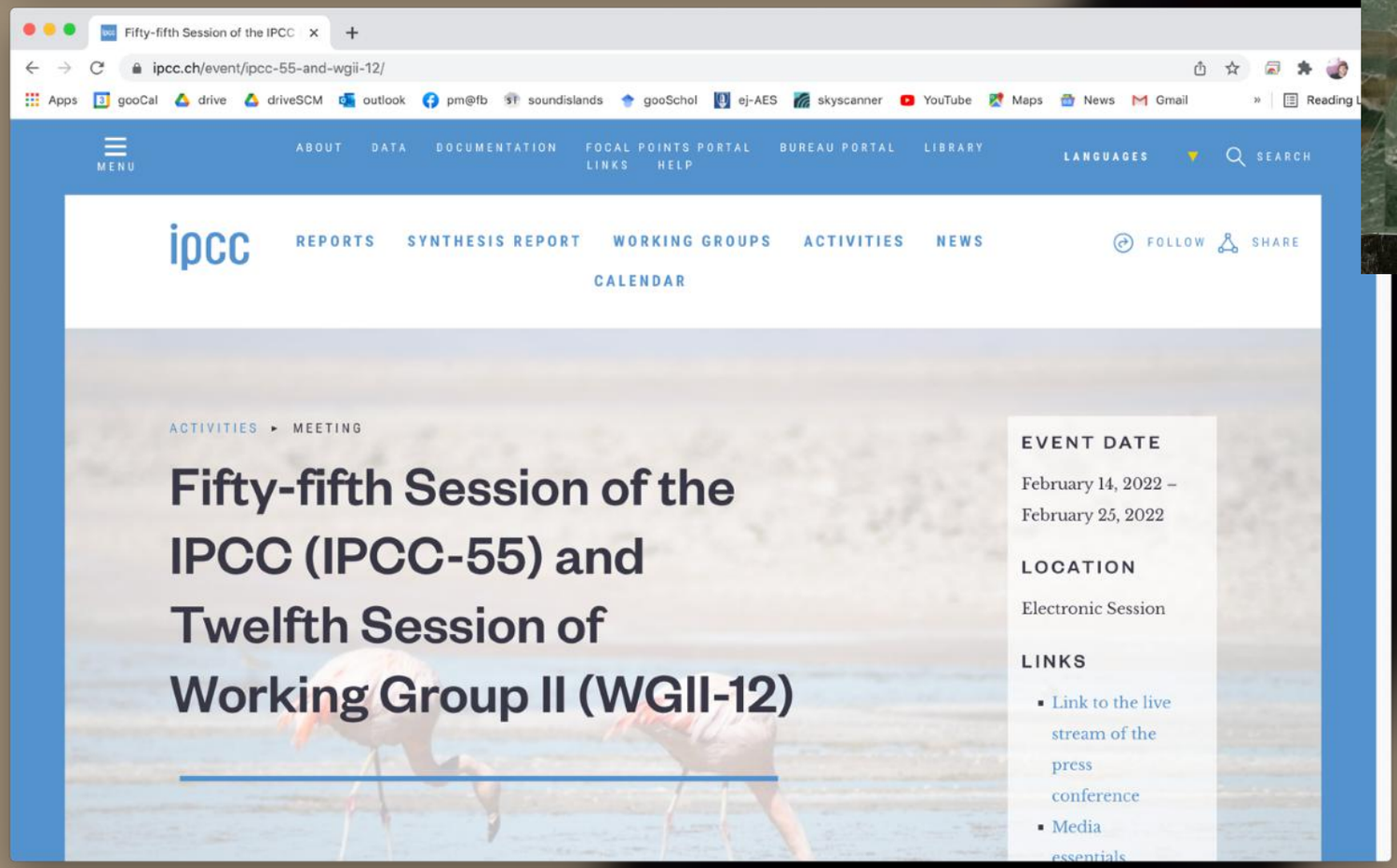
Frontiers RT

"Climate change is an unprecedented and growing threat. The arguments for action are clear"



https://news.un.org/en/story/2022/01/1109372

UN Secretary-General António Guterres



https://www.ipcc.ch/event/ipcc-55-and-wgii-

Data Art for Climate Action – ::

dataclimate.org

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DATA ART FOR CLIMATE ACTION

:: Hong Kong + Graz + Internet :: 12-15 January 2022 ::

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Data Perceptualization for Clim

frontiersin.org/research-topics/20827/data-perceptualization-for-climate-science-communication

Apps | gooCal | drive | driveSCM | outlook | pm@fb | soundislands | gooSchol | ej-AES | skyscanner

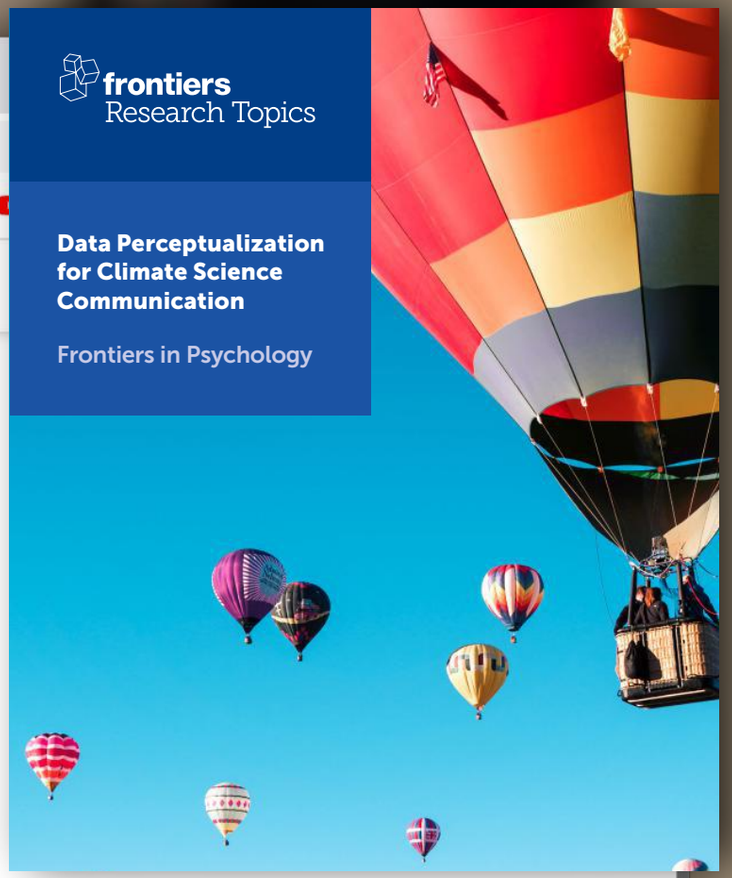
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Research Topic

Data Perceptualization for Climate Science Communication

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About this Research Topic

In 2017, the Secretary-General of the United Nations António Guterres stated unequivocally that climate change is an unprecedented and growing threat, and that the arguments for action are clear. Notwithstanding, it has proven a hard challenge to present complex science so that laymen and non-specialists are convinced. Without developing a deeper affinity towards and trust of science, climate denialism will remain prevalent. To date, climate science is most commonly communicated using texts and still images. Might we gain a deeper understanding and richer appreciation of the data that scientists use to describe large-scale climate change through other means?

Sonification and visualization are processes of data perceptualization that may have either an aesthetic or a utilitarian purpose, or both. Data art is the study, interpretation, and representation of scientific measurements in ways that excite and surprise. As in all human-computer interaction design, it is essential to involve evaluation of output in an iterative process. Multimodal perceptualization hinges on understanding sensory processing, cognitive load, and cross-modal correspondences. While science speaks through words, numbers, and diagrams, art communicates through movement, images, sound, and sculpture. While there is a lot of potential merging the two

Topic Editors



PerMagnus Lindborg
School of Creative Media, City University of Hong Kong
Kowloon, Hong Kong, SAR China

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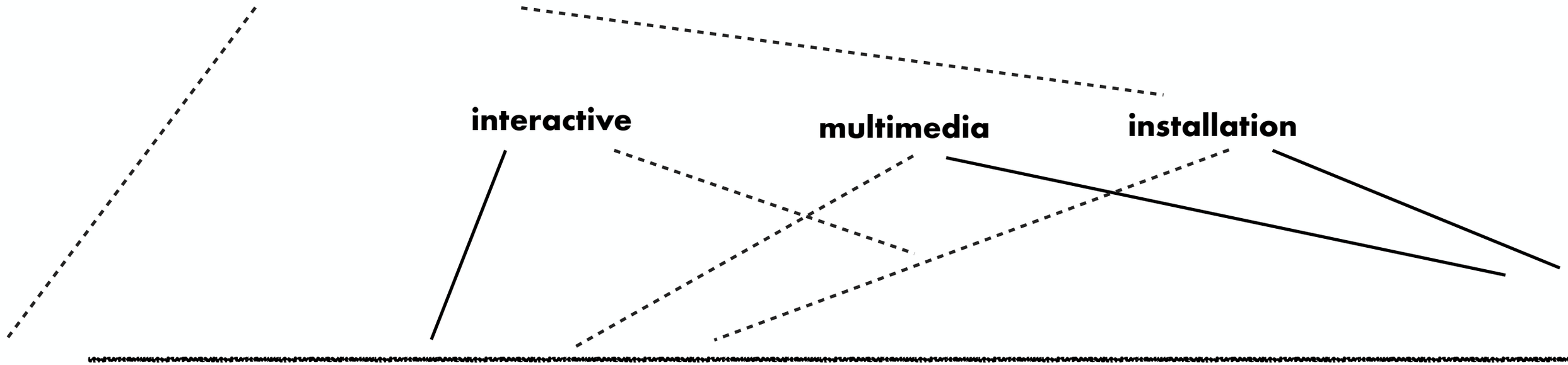


Shauhrat S Chopra
School of Energy and Environment, City University of Hong Kong
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PerMagnus Lindborg, PhD



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After a ‘first career’ as music composer with a penchant for computers and interactive pieces, I migrated towards academic work quite slowly. Over the past 5-6 years I’ve sought to combine art and research - or, in other words, design and perception - more closely together. This is reflected both in my ‘pure’ artwork, empirical research, and also in a few (and so far unfulfilled) attempts at striking a balance between the two extremes.

In this presentation, I will try to bridge the gap by tracing my journey in sonification, highlighting three spatial sound installations based on seismological and meteorological geodata: LW24 (2015), Loki’s Pain (2017), and Stairway to Helheim (2021). The presentation will discuss technical challenges I’ve met when designing spatial sound, and how they might be overcome by focussing on crossmodal correspondences in perception and cognition of sound.

PerMagnus Lindborg (Sweden/Hong Kong), PhD, is a composer, sound artist, and researcher in sound perception. He is Associate Professor (Sound Art) at the School of Creative Media, City University of Hong Kong; creating media installations, films about music, and concert pieces through SOUNDISLANDS; and regularly publishing in journals and conferences. PerMagnus initiated the Soundislands Festivals (2013, 2015, 2017) and currently serves as Asia-Oceania Regional Director and Music Coordinator of ICMA, as well as Review Editor for Frontiers. Forthcoming projects include a 3D sound composition for Asian Composers League 2022, organising the Data Art for Climate Action conference (DACA 2022), and participating in an expeditionary residency with The Arctic Circle 2023 to study underwater acoustic environments.

SoundLab – High Spatial Resolu

soundlab.scm.cityu.edu.hk

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SOUNDLAB

High Spatial Resolution Audio :: Sound Art, Design and Perception Research



2020 ·

Sound Art, Design, and Perception Research with Spatial Audio

20/01/2021 · BY PERMAGNUS

Spatial sound is fundamental to creative audio and music. SoundLab, funded with an ACIM Fellowship and hosted at SCM (CMC, City University of Hong Kong) since



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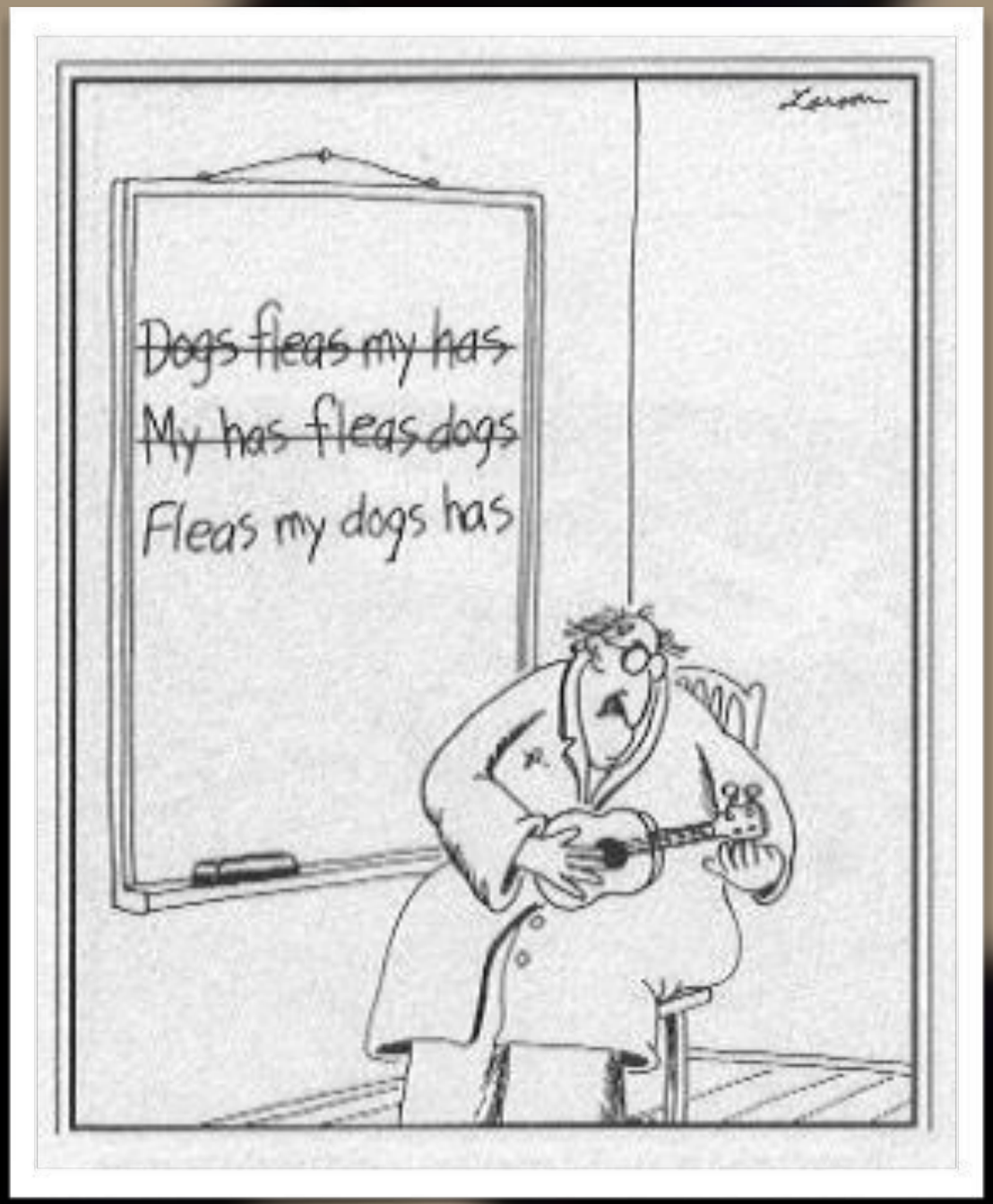
Job opportunity :: Research Assistant

01/12/2021 · BY PERMAGNUS

TAGS

ACIM / Ambisonics / audiovisual / climate change / climate science / collaboration / concert / conference / creative media / design / electronic music / Elem Klimov / EMSAN / festival / field recording / film / film music / guest lecture / HDLA / HKPFS / ICMA / init.synth~ / installation / keynote / listening / loudspeakers / Max / movie / opportunities / PhD / RA / sonification / soundscape / space / spatial audio / streaming / students / symposium / test / UniCamp / Virtual Reality / visualization /

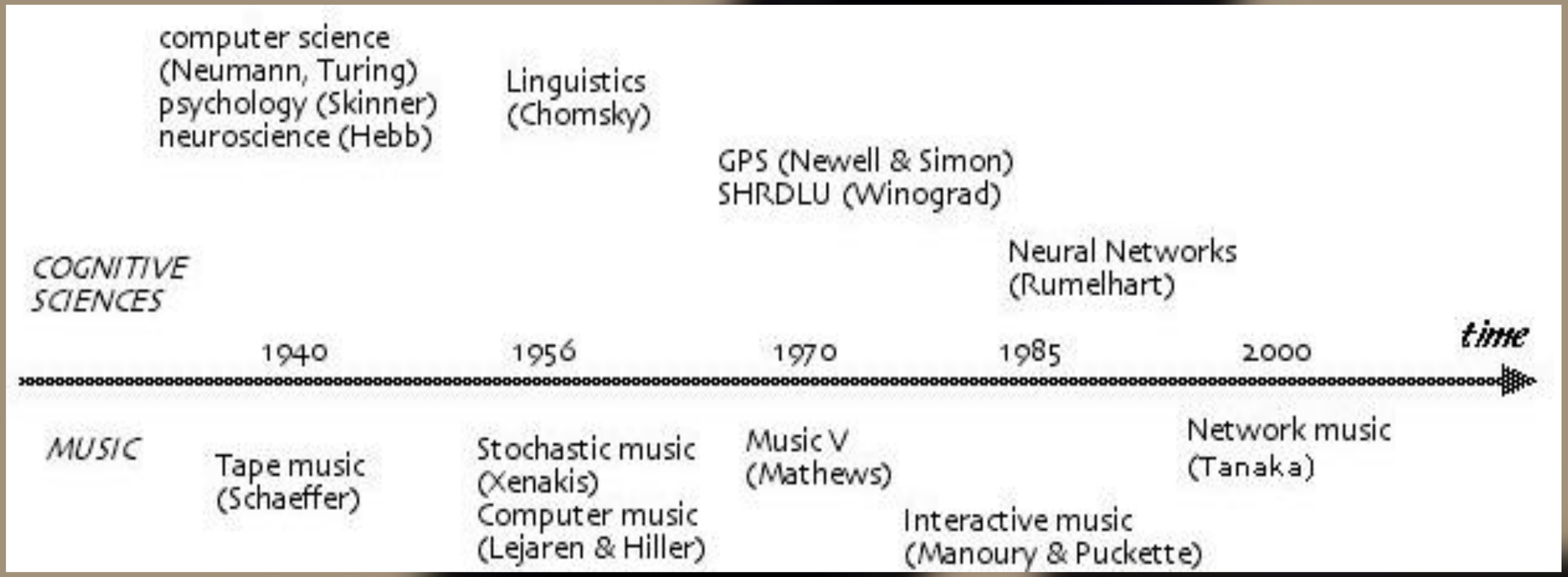
"What might we discover if we were to study musical thinking?" (Minsky 1981)



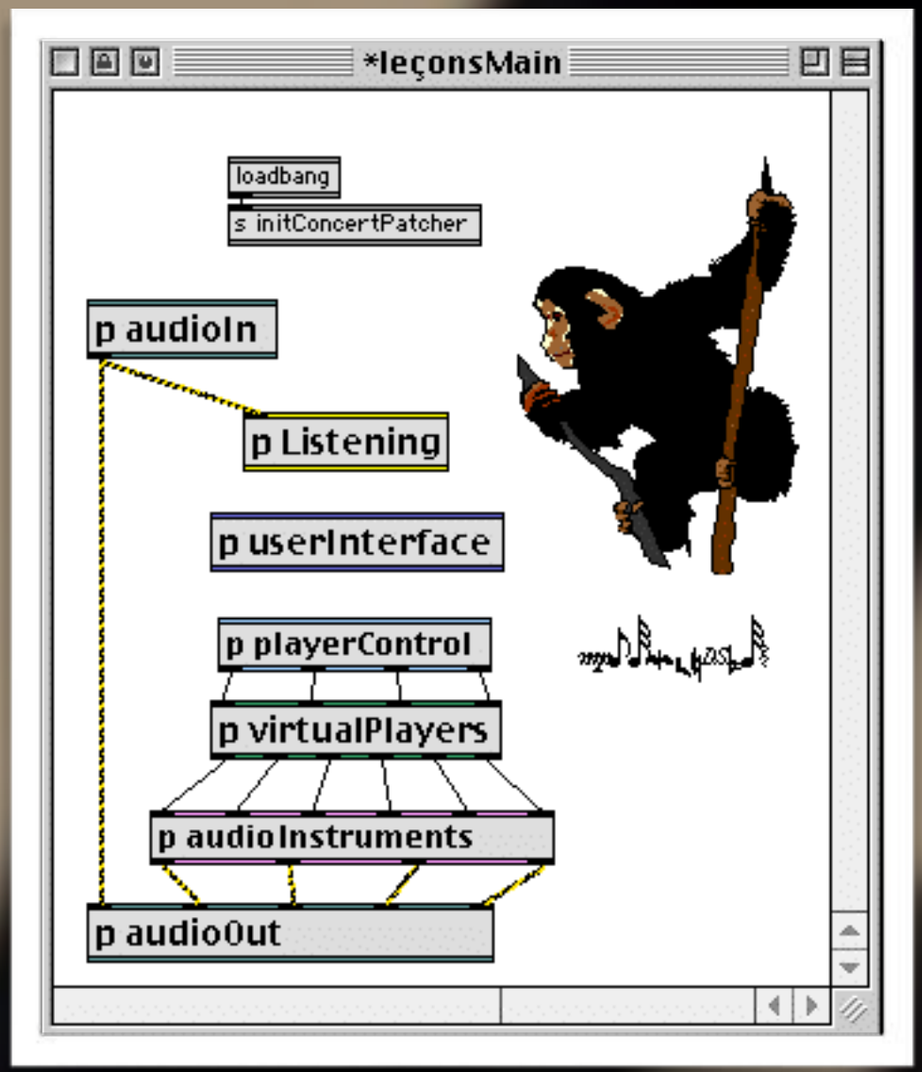
Gary Larson

music + mathematics = TRUE

- Pythagoras (~550 BC, geometrical ratios)
- Josquin (~1450, combinatorics)
- Mozart (~1770, probability)
- Schillinger (~1920, "scientification of music")
- Hiller (~1950, heuristic rules, AI)
- Xenakis (~1960, stochastics)



"Only a machine can appreciate a sonnet composed by another machine" (Turing, quoted by Queneau 1961)



lecons
pour un apprenti sourd-muet

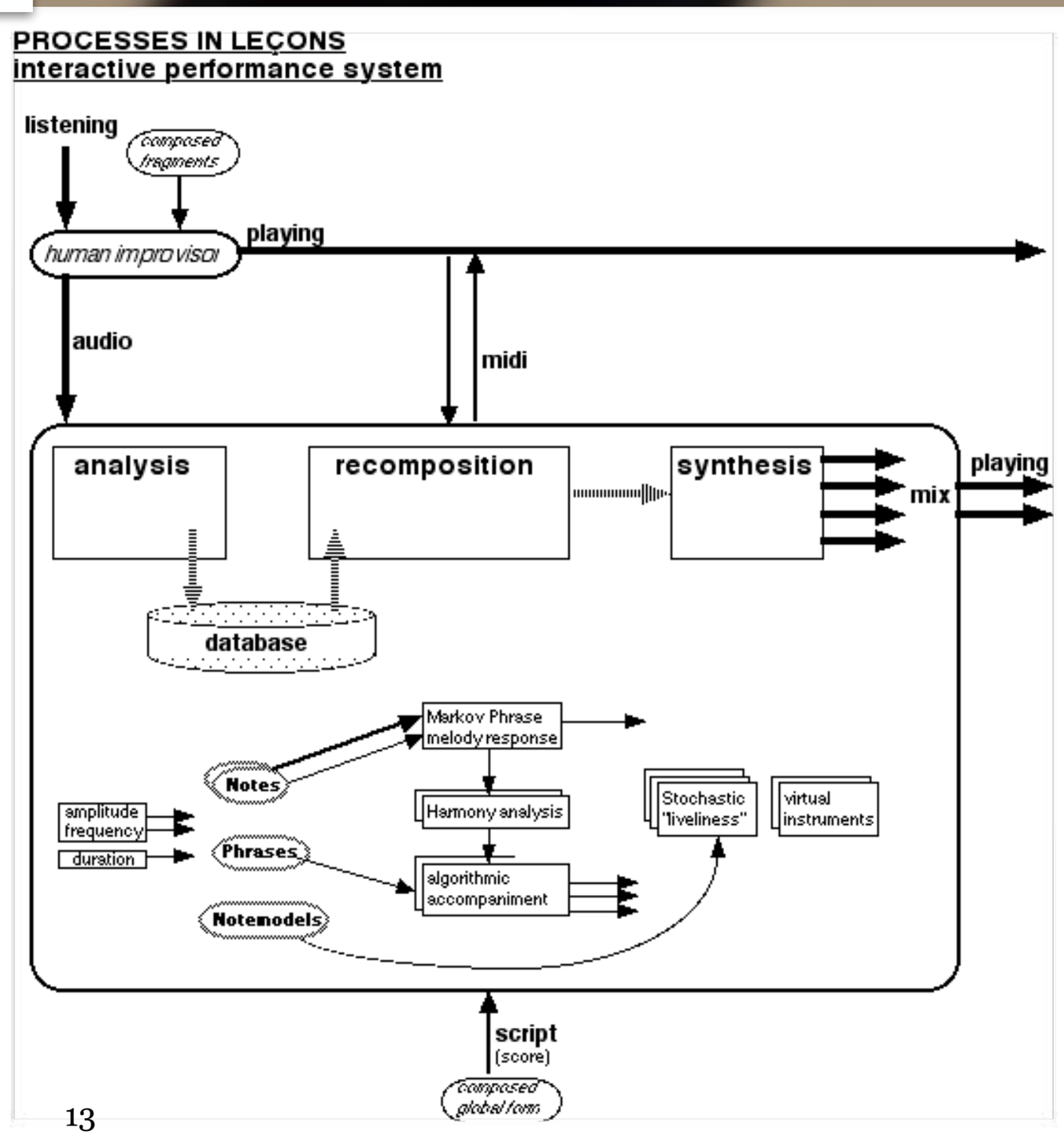
automatic analysis of sax
computer improvisation
real-time synthesis

for two improvisors: saxophonist and computer

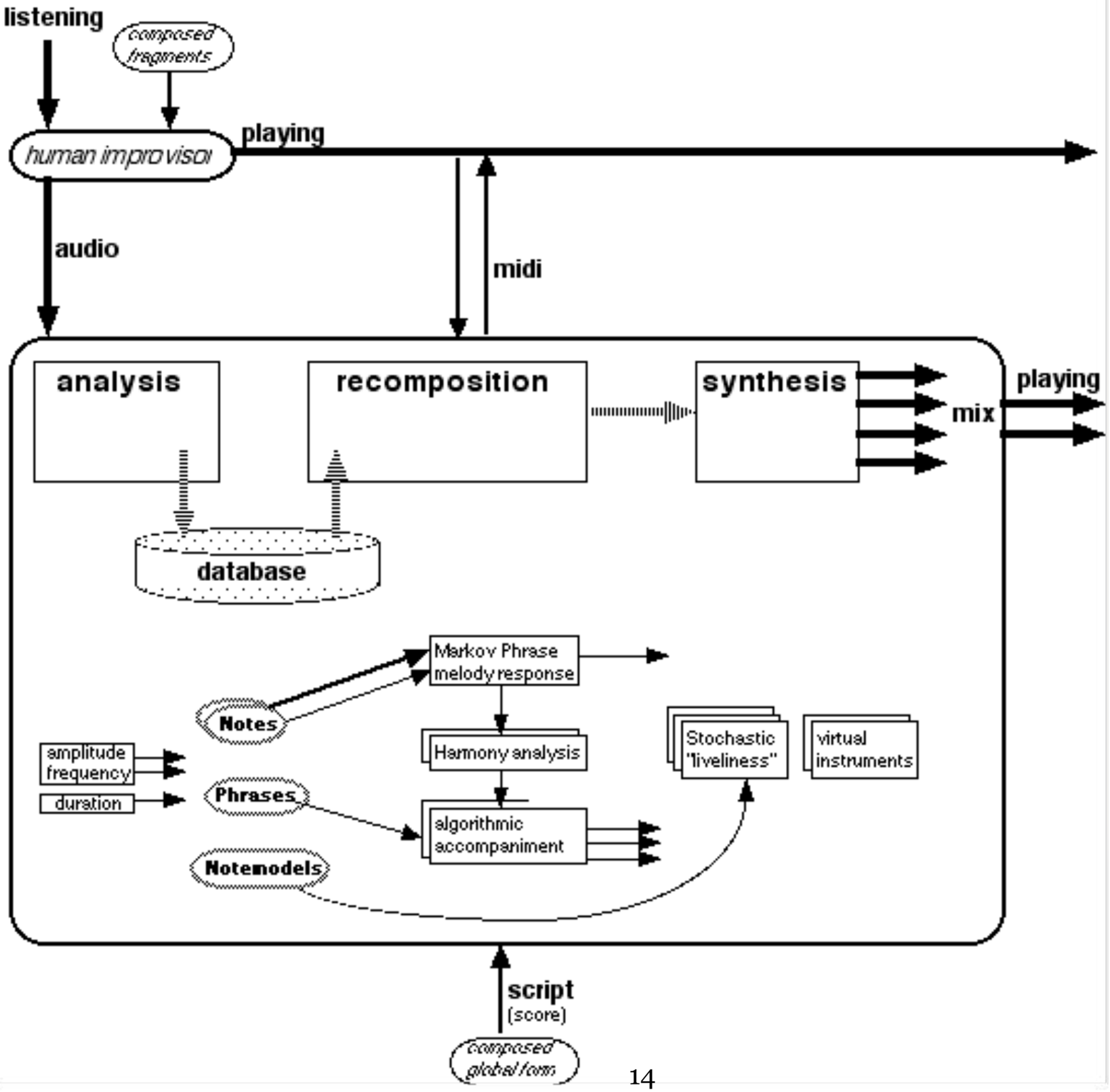
IRCAM, Paris, 1999 (V Davide)
Blå, Oslo, 2001
Inside.Out Festival, Singapore, 2008



By Megawattbulbman - http://en.wikipedia.org/wiki/File:Ircam.jpg, Public Domain, https://commons.wikimedia.org/w/index.php?curid=9755343



PROCESSES IN LEÇONS
interactive performance system



(sound excerpt, 2 m)

Lindborg PM (2003). In (Wiil, ed.) Computer Music Modeling and Retreival. Lecture Notes in Computer Science , LNCS volume 2771. Springer Verlag,

"Leçons": an Approach to a System for Machine Learning, Improvisation and Musical Performance



Lindborg.2003.LNCS-Lecons.pdf (220.3Kb)

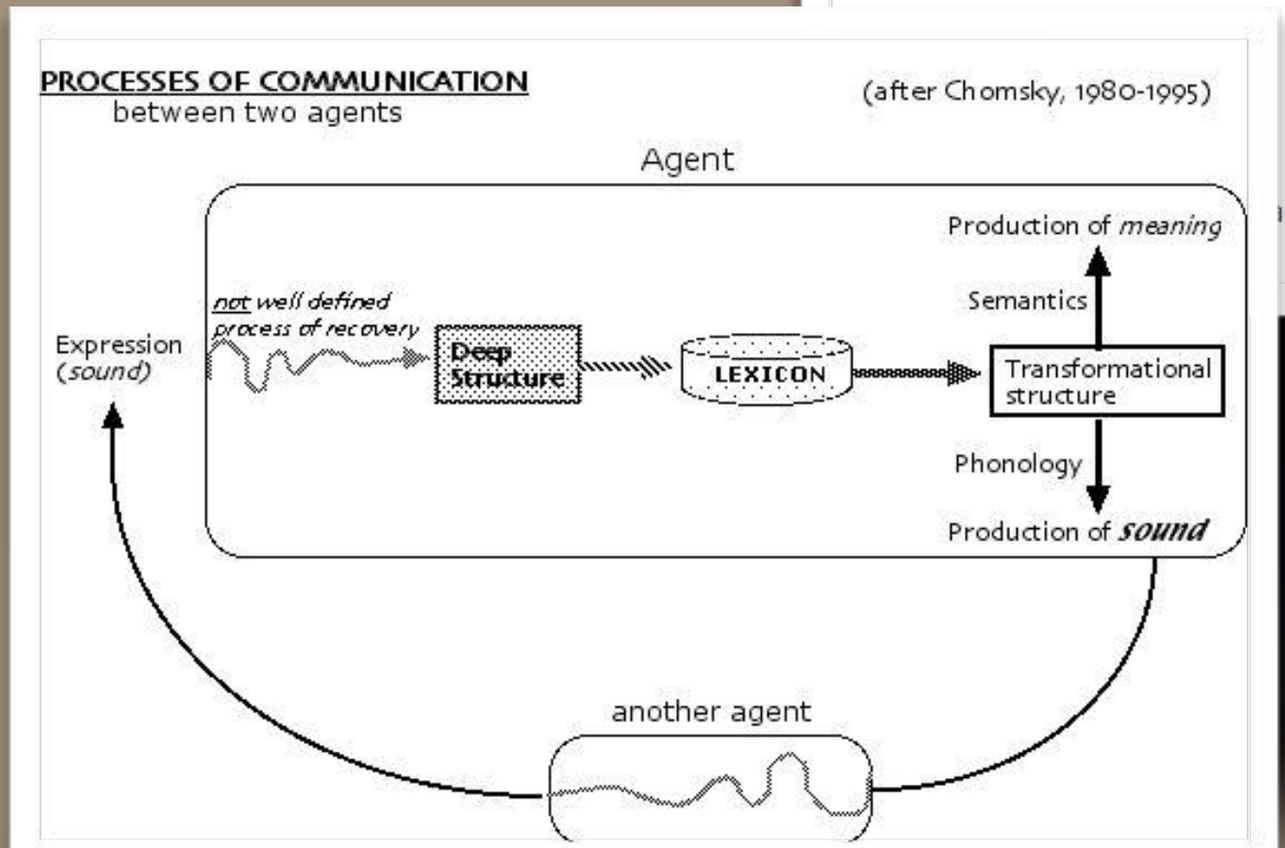
Abstract
This paper aims at describing an approach to the music performance situation as a laboratory for investigating interactivity. I would like to present "Leçons pour un apprenti sourd-muet", where the basic idea is that of two improvisers, a saxophonist and a computer, engaged in a series of musical questions and responses. The situation is inspired from the Japanese shakuhachi tradition, where imitating the master performer is a prime element in the apprentice's learning process. Through listening and imitation, the computer's responses get closer to that of its master for each turn. In this sense, the computer's playing emanates from the saxophonist's phrases and the interactivity in "Leçons" happens on the level of the composition.

Author
Lindborg, PerMagnus

Subject
Artificial intelligence
Musical performance

Type
Journal Article

Series/Journal Title
Lecture Notes in Computer Science



array

ICMA Array, vol 2016, Special Issue:
Proceedings of Si15, Singapore, August 2015, pp 104-107.

Si15

About *When We Collide*: A Generative and Collaborative Sound Installation

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[*]School of Art, Design, and Media, Nanyang Technological University

[†]Nanyang Academy of the Fine Arts, Singapore

permagnus@ntu.edu.sg

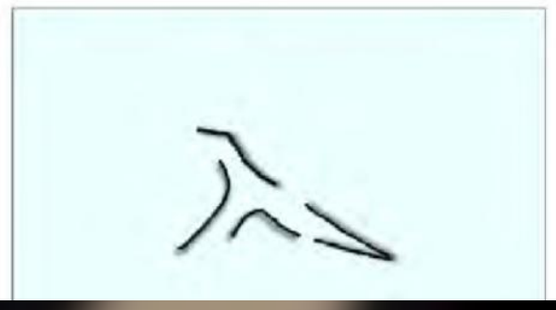
Abstract

The idea for *When We Collide* sprang from Douglas Hofstader's metaphor of creativity as the meeting between records and record players, appearing in his 1979 book "Gödel, Escher, Bach: An Eternal Golden Braid". In our case, the records are soundfiles, whilst the record player is a generative system. The player analyses, selects, mixes, transforms, and spatialises the material created by the composers (monophonic and quadraphonic soundfiles). The system negotiates between algorithms that tend towards monotony (in terms of loudness, spatialisation, and frequency spectrum) and algorithms that tend towards variability (in terms of soundfiles, transformations, and scenes). In a nutshell, the installation is a space where sonic ideas collide and co-exist.

Keywords: generative, installation, composition

1. Introduction

When We Collide is a generative sound installation based on audio material contributed by six composers. It is a development from two previous productions: *On the String*, inspired by String Theory, commissioned by the Singapore Arts Festival 2010; and *The Canopy*, presented at International Computer Music Conference 2011 and World Stage Design Festival 2012



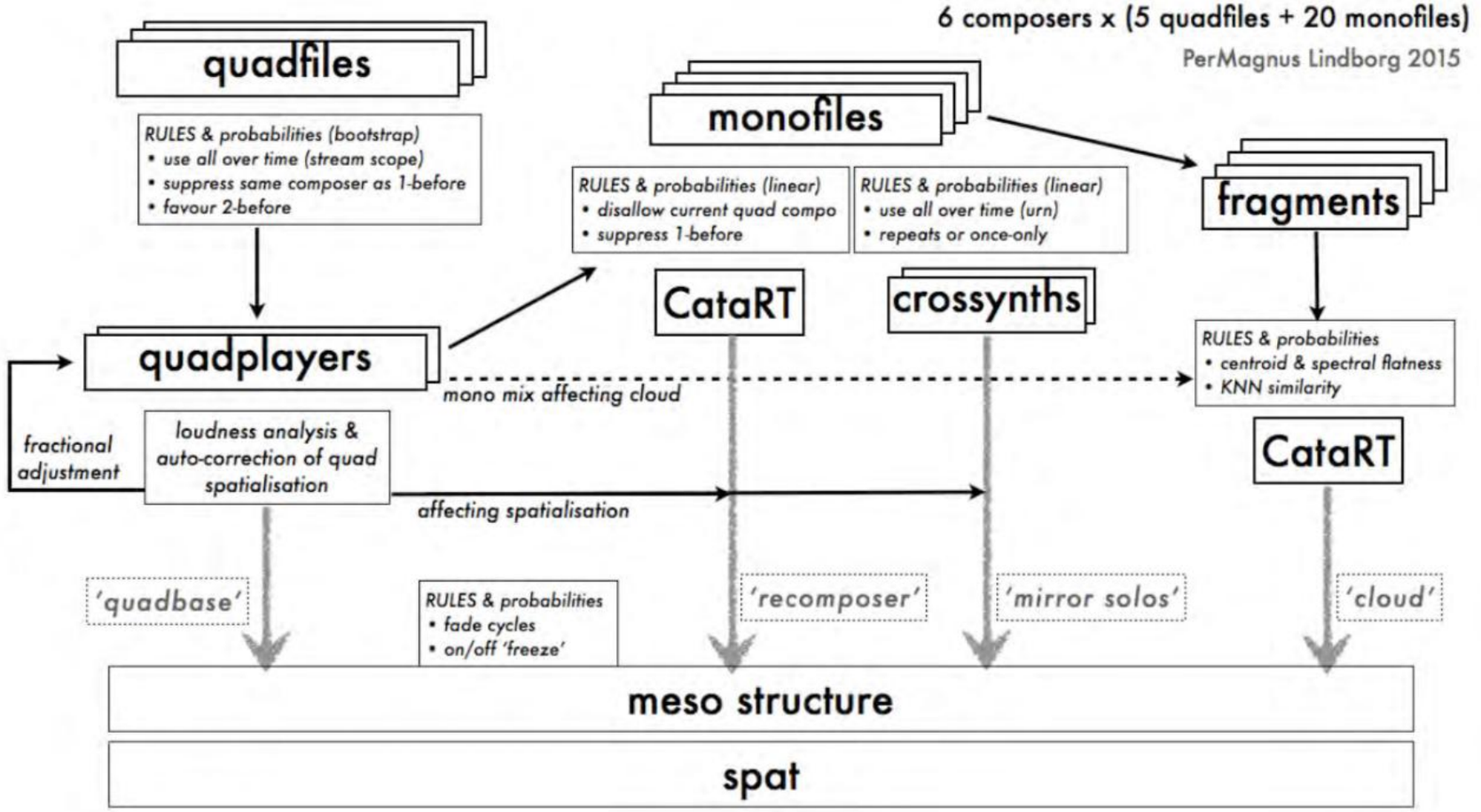


Figure 6. Overview of player design. Top: boxes represent sound files (provided by the artists), and descriptions of selection algorithms. Middle: boxes represent instruments, producing in all 18 channels of audio. The arrows indicate some of the ways that sub-systems influence each other. Bottom: boxes represent meso structure (i.e. control layer) and spatialisation.

perception

VOL. 64, NO. 3 MAY, 1957

THE PSYCHOLOGICAL REVIEW

ON THE PSYCHOPHYSICAL LAW[1]

S. S. STEVENS

Harvard University

After dealing his critics their deserts, Fechner concluded his polemic of 1877 with a defiant five-line *Nachwort* (10).

> The tower of Babel was never finished because the workers could not reach an understanding on how they should build it; my psychophysical edifice will stand because the workers will never agree on how to tear it down.

For nearly a century the critics have pecked at the edifice in the disorganized manner that inspired no fear in Fechner. They have contended that sensation is not measurable, and that it is; that Weber's law is not true, and that it is; that the just noticeable difference is not a proper unit, and that it is; that the logarithmic law is not found in experiment, and that it is. As James put it, Fechner's critics flailed about "smiting

that—to try to show that there is a general psychophysical law relating subjective magnitude to stimulus magnitude, and that this law is simply that equal stimulus ratios produce equal subjective ratios. On numerous perceptual continua, direct assessments of subjective magnitude seem to bear an orderly relation to the magnitude of the stimulus. To a fair first-order approximation, the ratio scales constructed by "direct" methods (as opposed to the indirect procedures of Fechner) are related to the stimulus by a power function of one degree or another. Evidence for this fact is piling up under the impact of ratio-scaling procedures whose development over the past three decades has given a "new look" to psychophysics. The fruits



https://braintour.harvard.edu/archives/portfolio-items/s-s-stevens-and-psychoacoustics

Structural correspondences

increased stimulus intensity (sound, light, weight)

[brain representation] increased neural firing

ACADEMIC PRESS

Multisensory Perception

From Laboratory to Clinic

2020, Pages 239-258



Chapter 11 - Audiovisual crossmodal correspondences: Behavioral consequences and neural underpinnings

Charles Spence [1], K. Sathian [2, 3]

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https://doi.org/10.1016/B978-0-12-812492-5.00011-5

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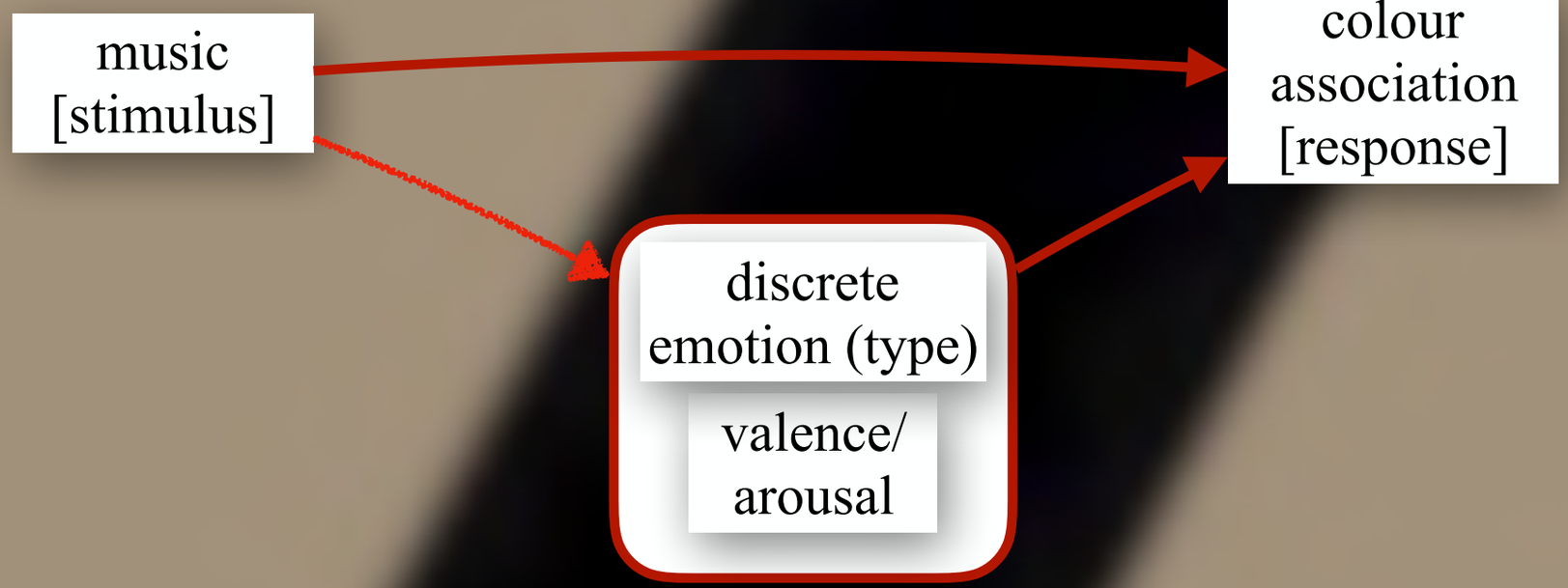
https://www.luxeat.com/blog/charles-spence-the-science-of-food-and-memories/

cross-modal association

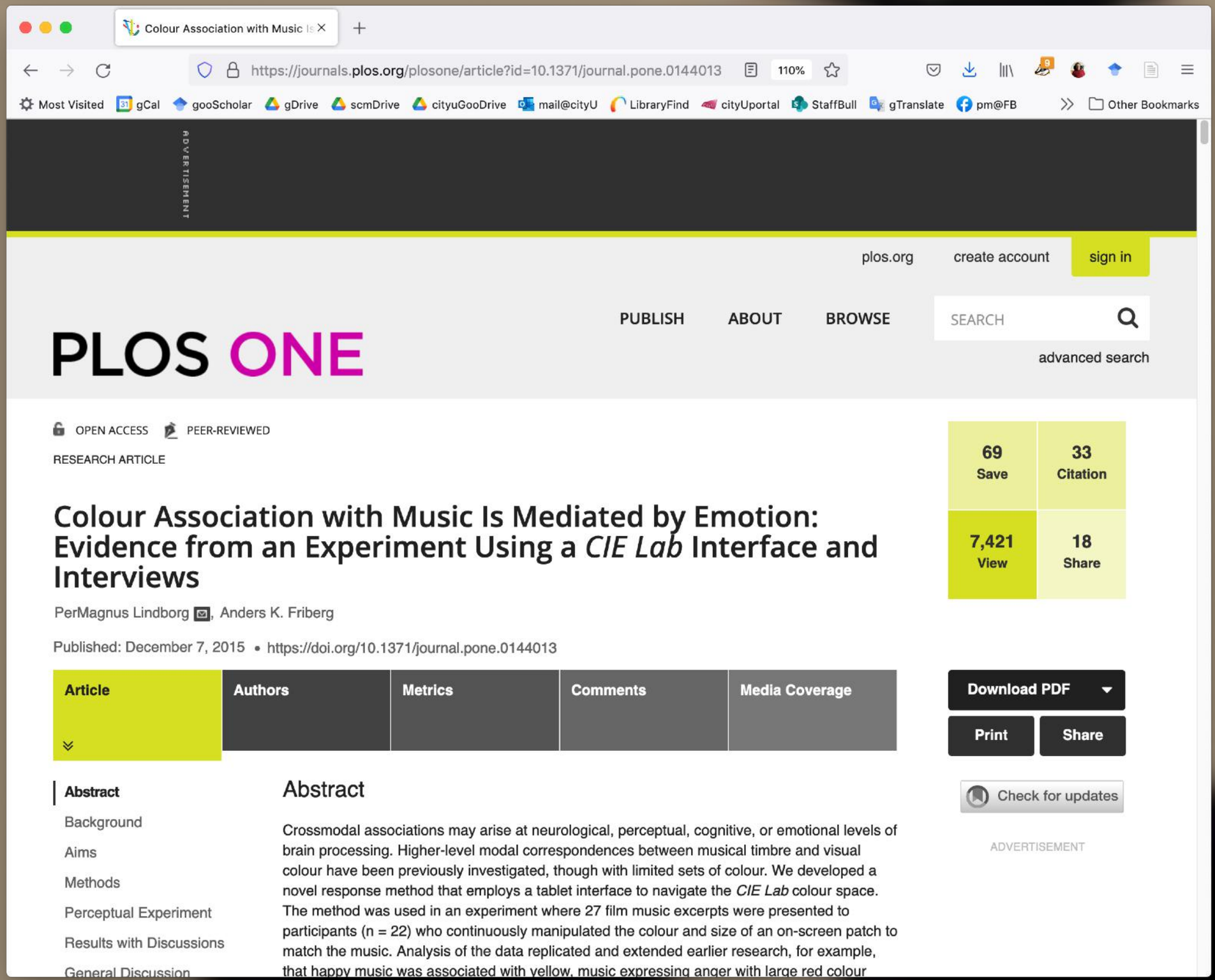
Crossmodal associations can arise at different levels of brain processing:

emotional	learning (cultural)
cognitive	learning (semantically mediated)
perceptual	statistical co-occurrence (ecological perception)
neurological	structural correspondences (encoding, locality in brain)

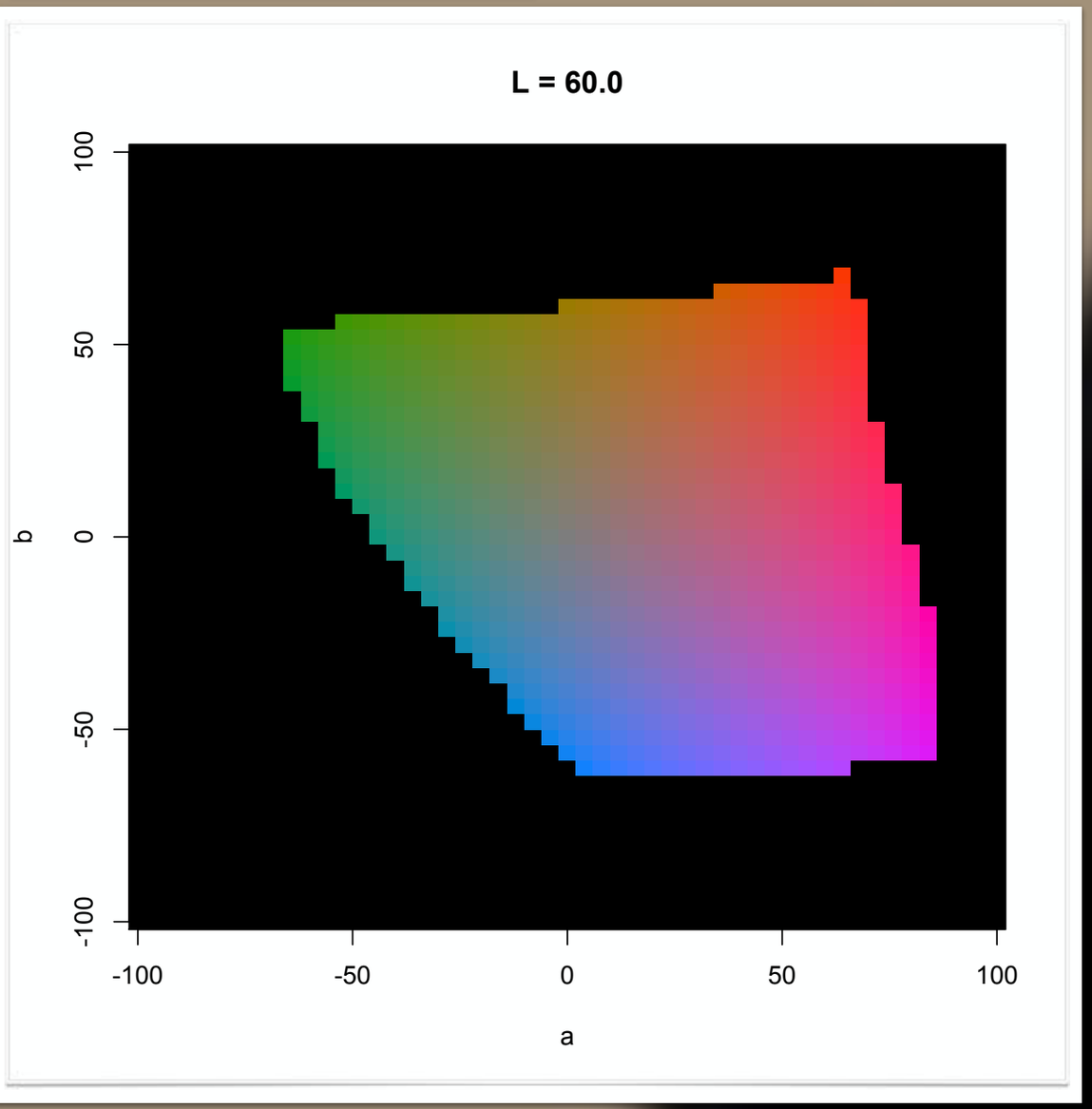
Emotionally mediated correspondences



Multimodal perception and design



CIE L*a*b* – colour space

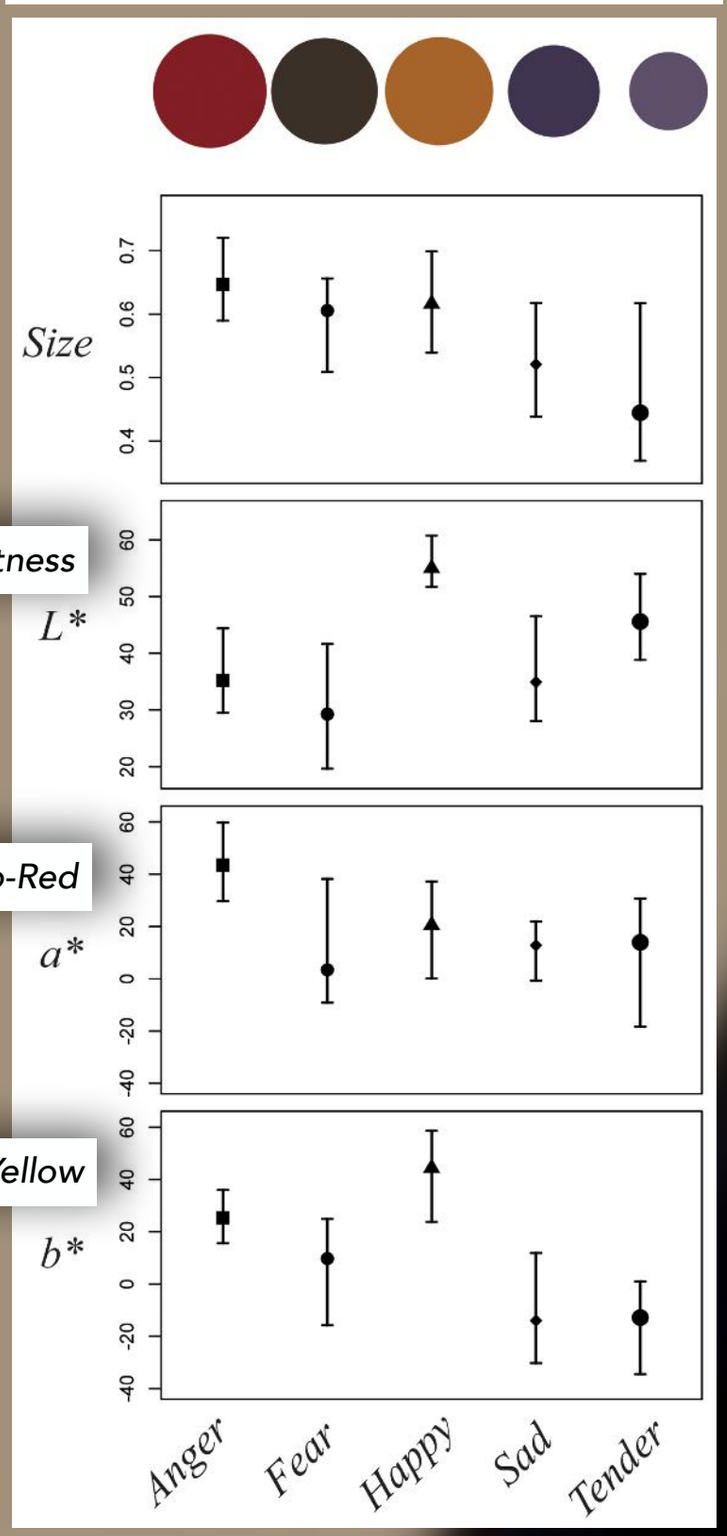




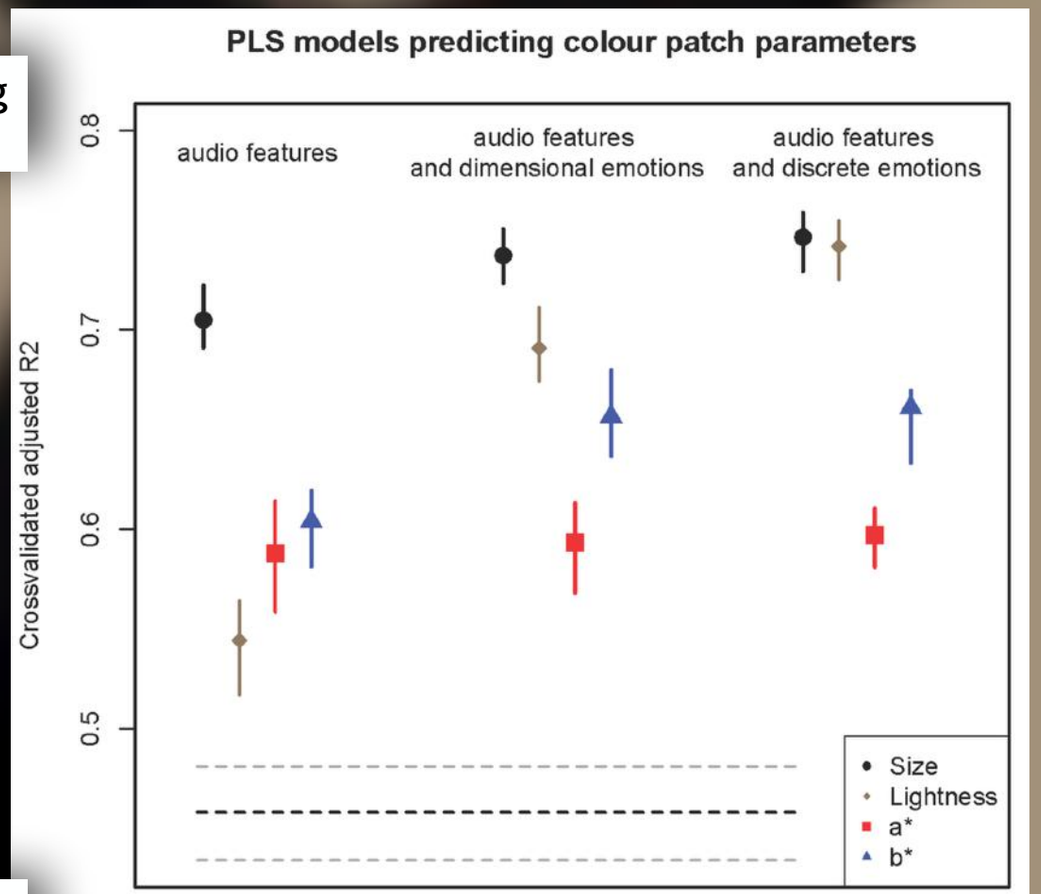
		Colour Patch Parameters			
Type	***Variable***	***Size***	***Lightness***	***a****	***b****
Psychoacoustic	***Loudness***				
	Sharpness	0.63***		(0.48*)	(0.56**)
	Roughness				
	Fluctuation strength	(0.44*)			
Rhythmic & Dynamic	***Tempo***				
	Attack_time	(0.5**)	(0.44*)		(0.4*)
	Lowenergy		(0.39*)		
Timbral	***Spectral centroid***	(0.53**)		(0.44*)	(0.51**)
	Brightness	0.63***		(0.44*)	(0.59**)
	Spectral spread			(-0.42*)	
	Rolloff (85%)	(0.6**)		(0.51**)	(0.51**)
	Spectentropy	0.69***		(0.61***)	(0.57**)
	Spectral flatness	(-0.45*)		(-0.52**)	
	Irregularity		(0.41*)	(-0.43*)	
	Zerocross rate	(0.53**)			(0.57**)
	Spectralflux	0.73***		(0.42*)	(0.61***)
Tonal	***Chromagram (PeakPos)***			(0.43*)	
	Chromagram (Centroid)				
	Keyclarity		(0.56**)		
	Mode		(0.41*)		

Correlation (quantitative analysis)

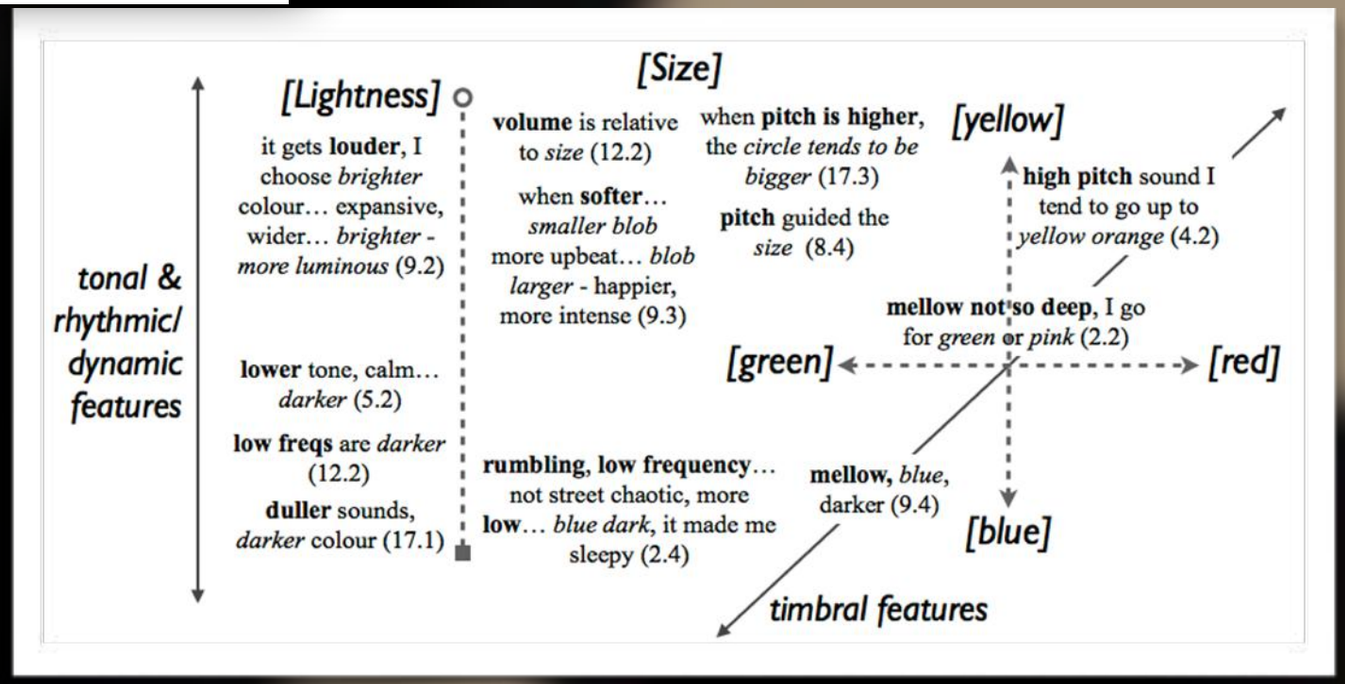
Colour patch responses to music excerpts



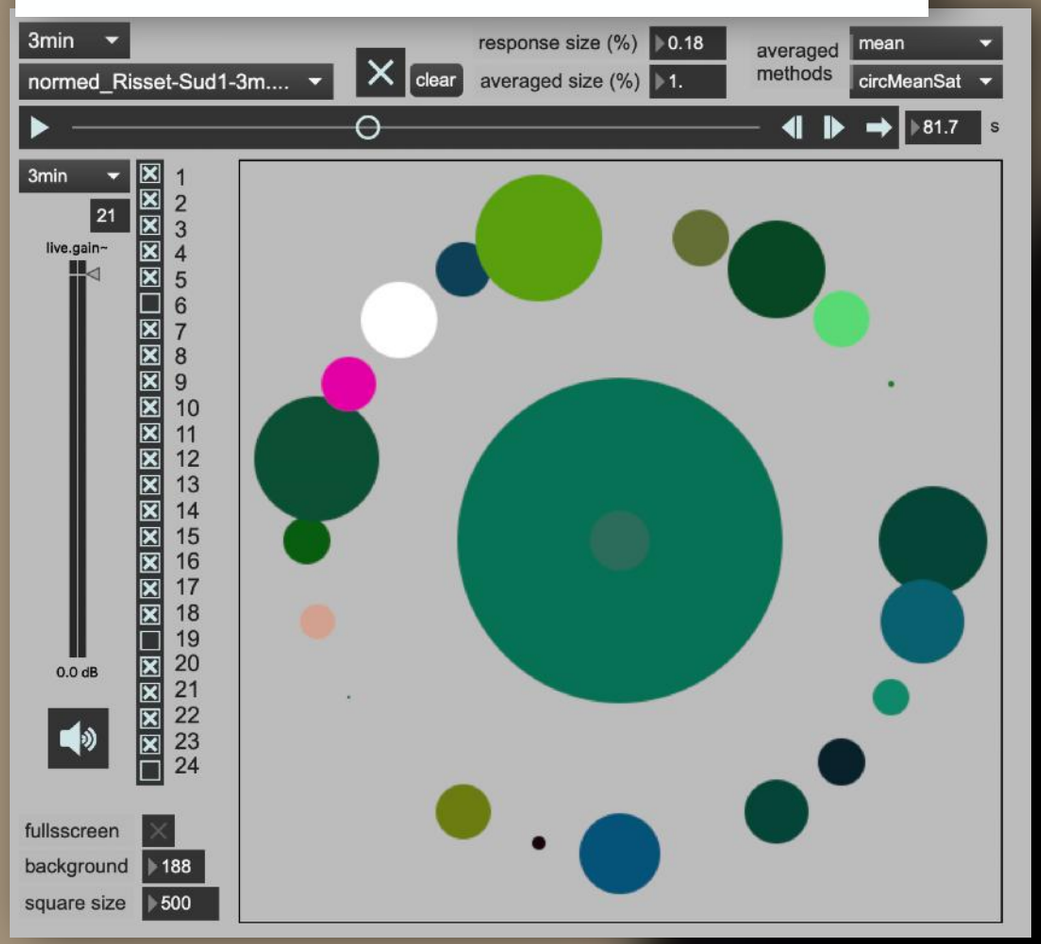
Predictive modelling (regression analysis)

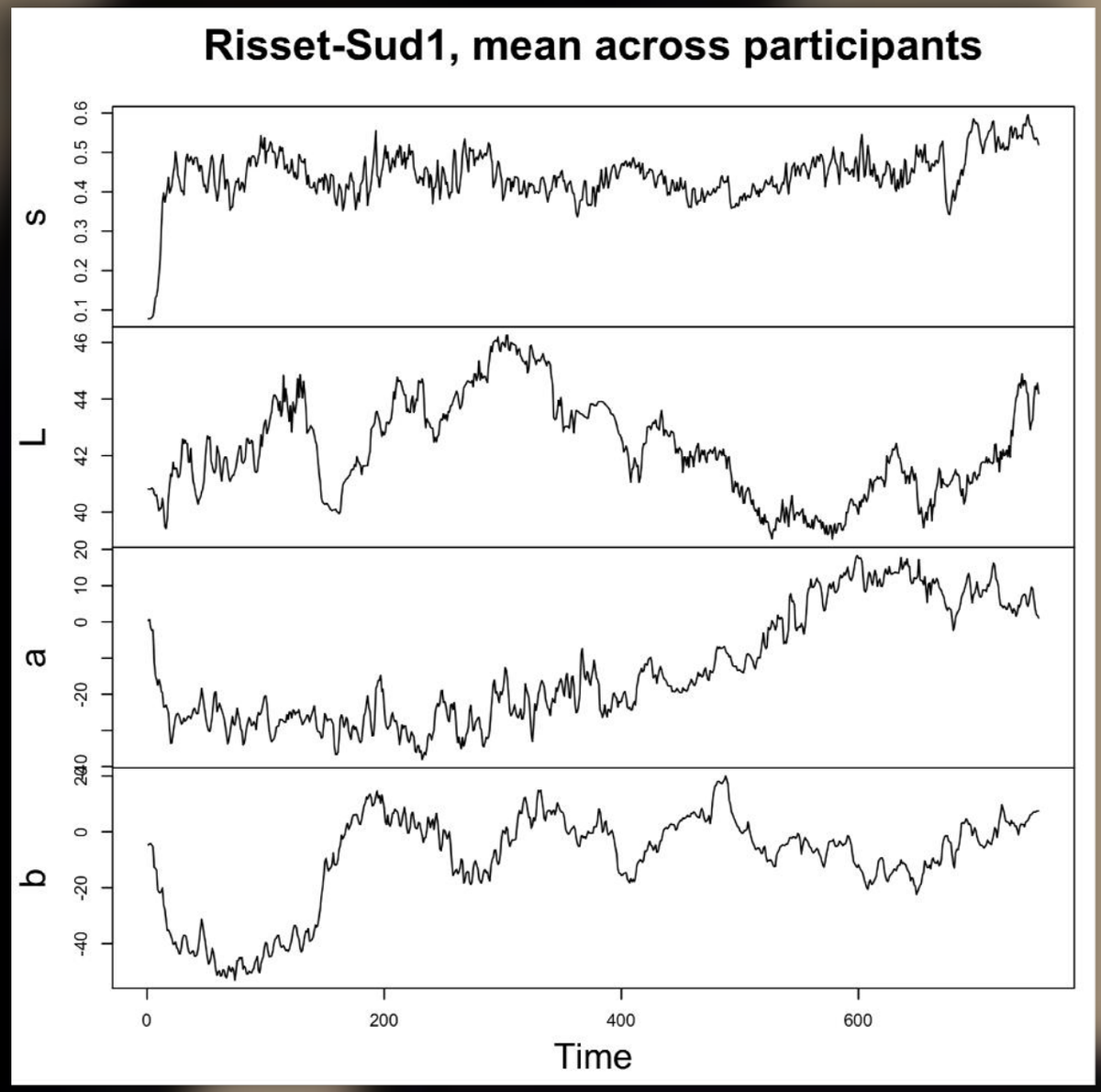


Subjective strategies (qualitative analysis)



Lindborg PM (2019, June) "What Is the Color of That Electroacoustic Music?" *ICMC-NYCEM*

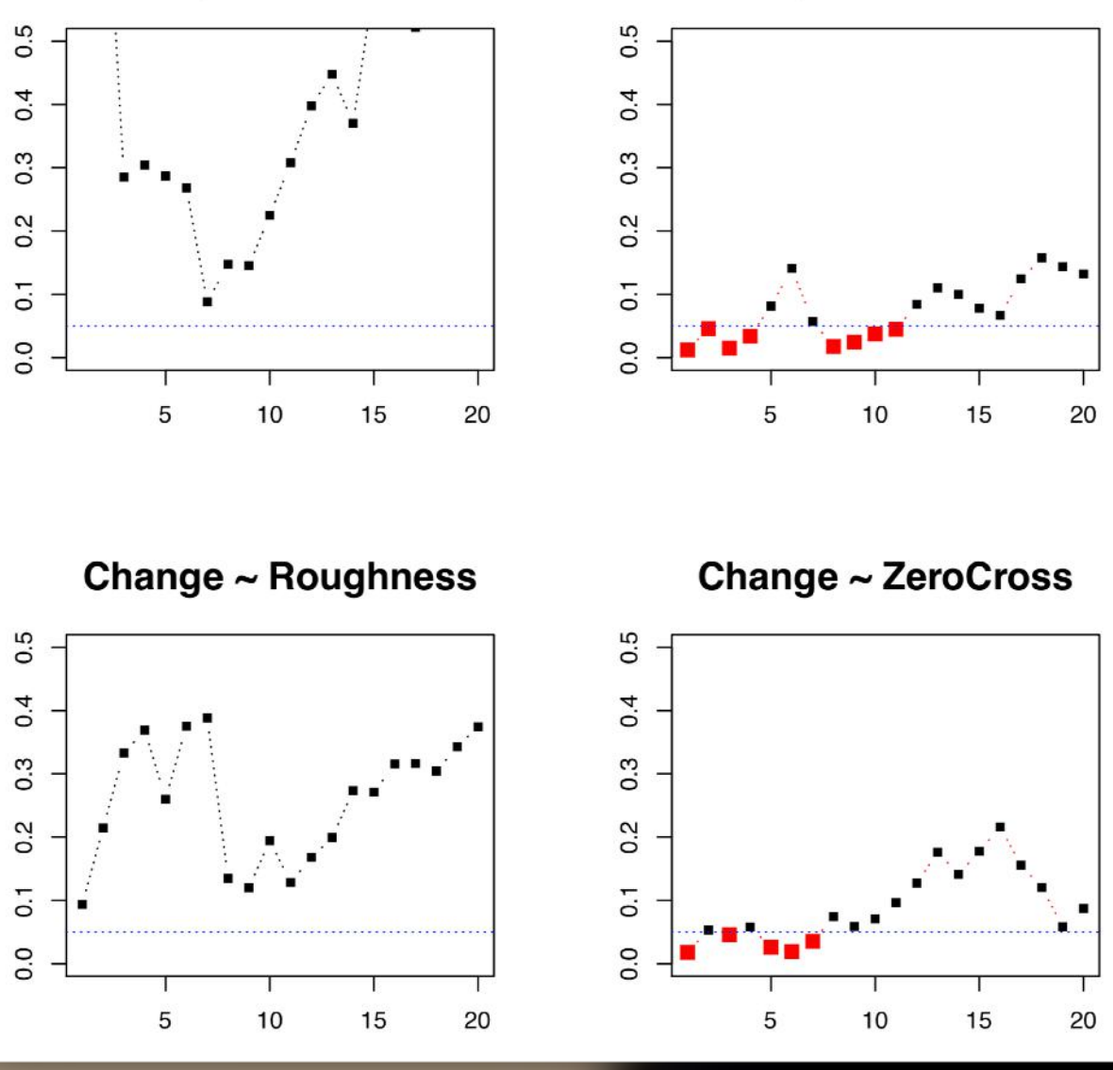




Time Series Analysis

Risset-Sud1

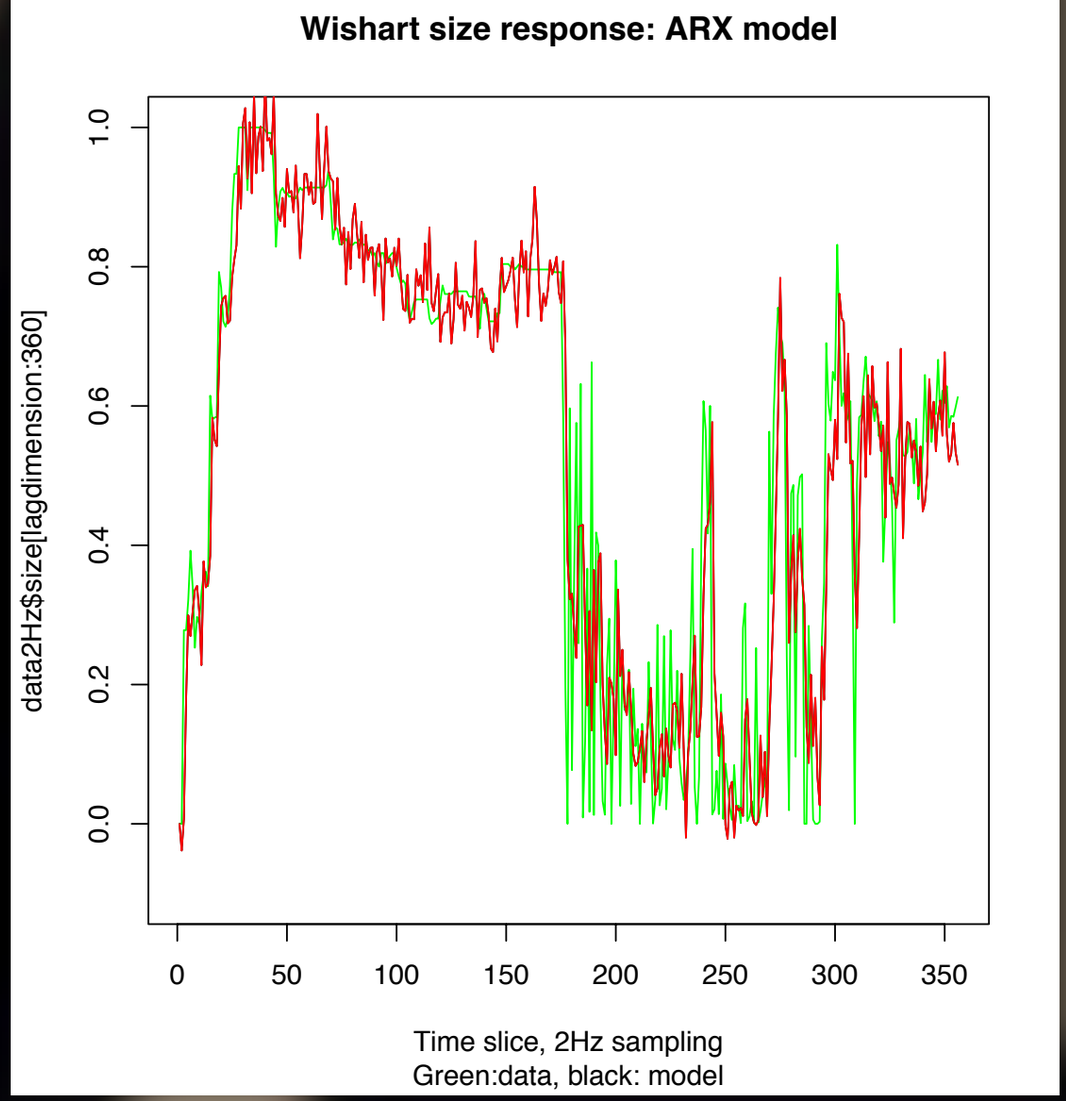
univariate Granger-causality



(Change = PCA1 of Lab+Size)

Wishart-Encounters1

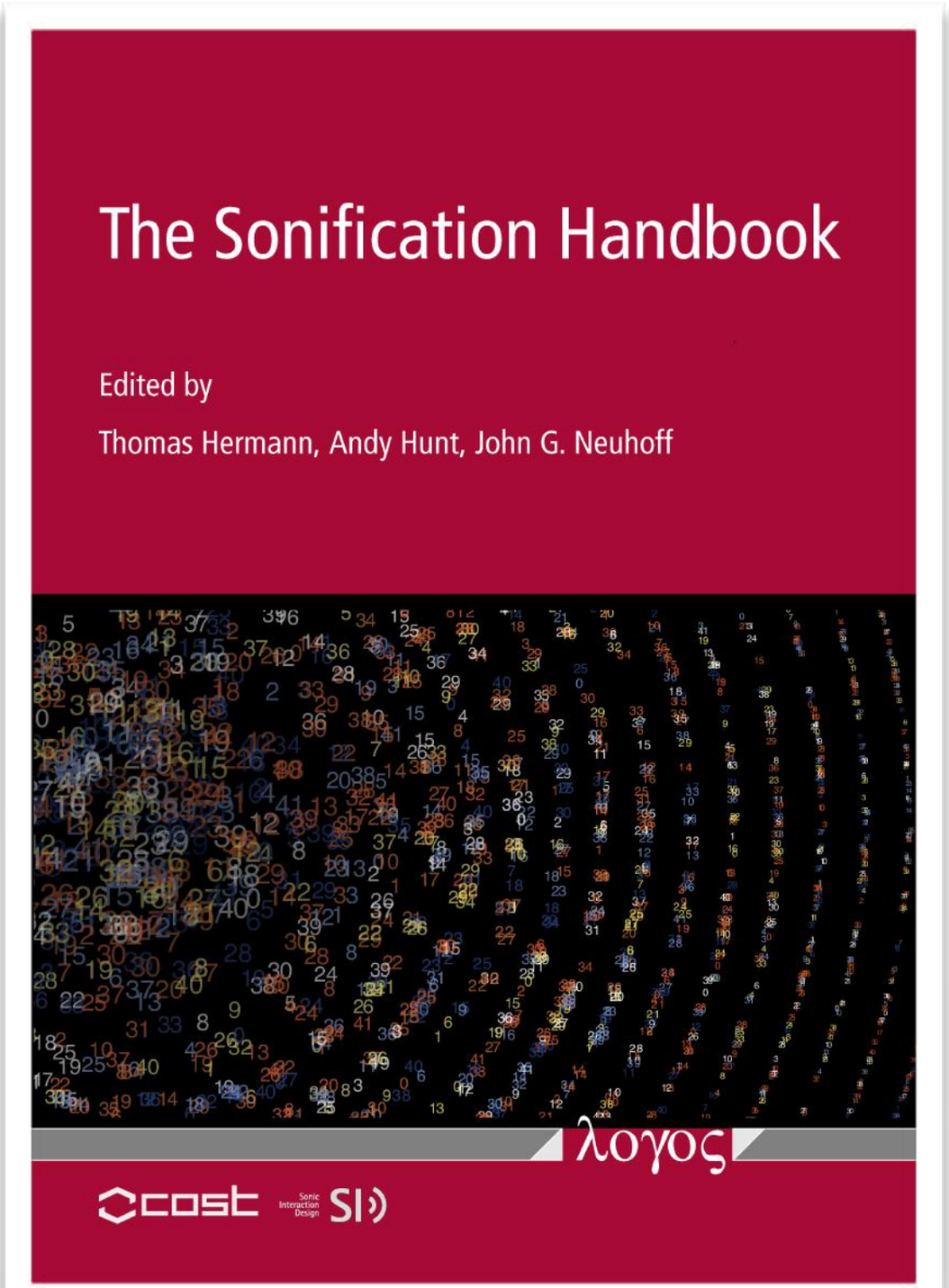
multivariate modelling

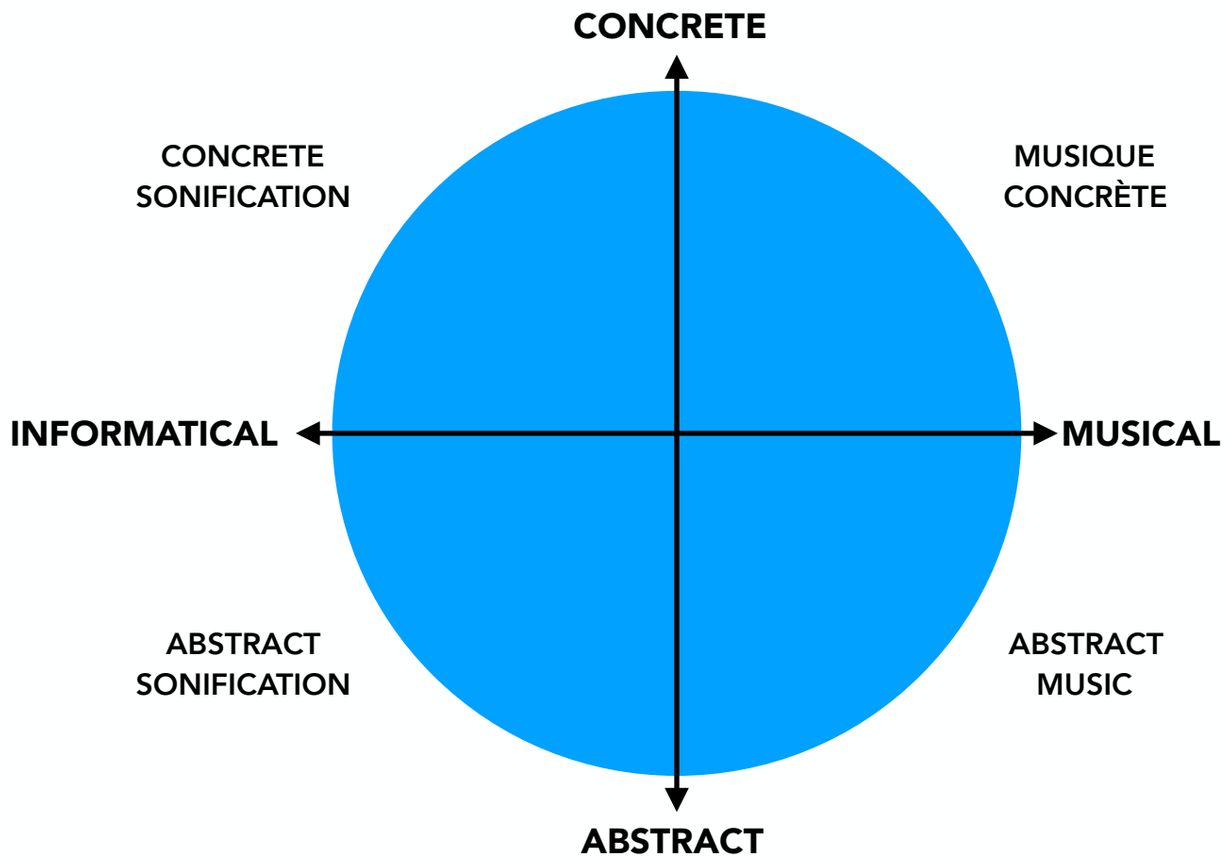


(model = Size ~ audio descriptors)

sonification

Sonification makes data *audible*



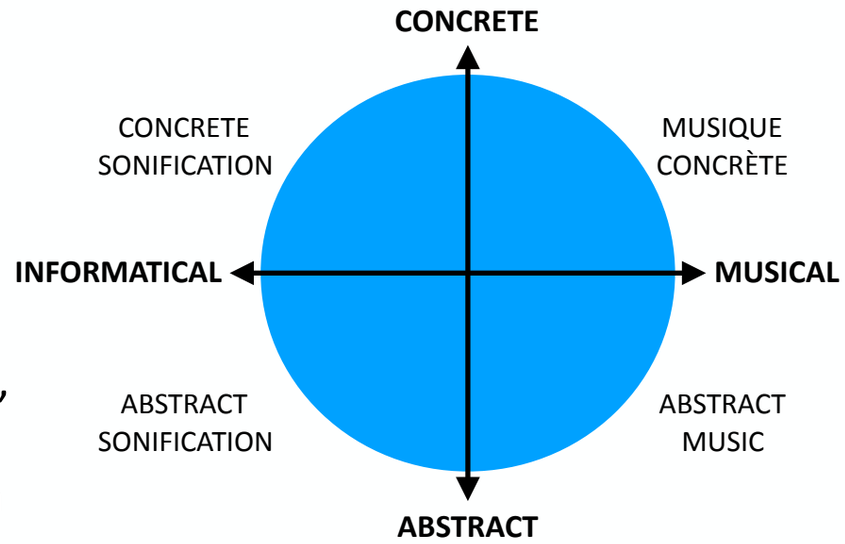


Aesthetic Perspective Space
(Vickers & Hogg 2006)

Sonification makes data *audible*

– a set of techniques and an aesthetic, navigating ars musica and ars informatica

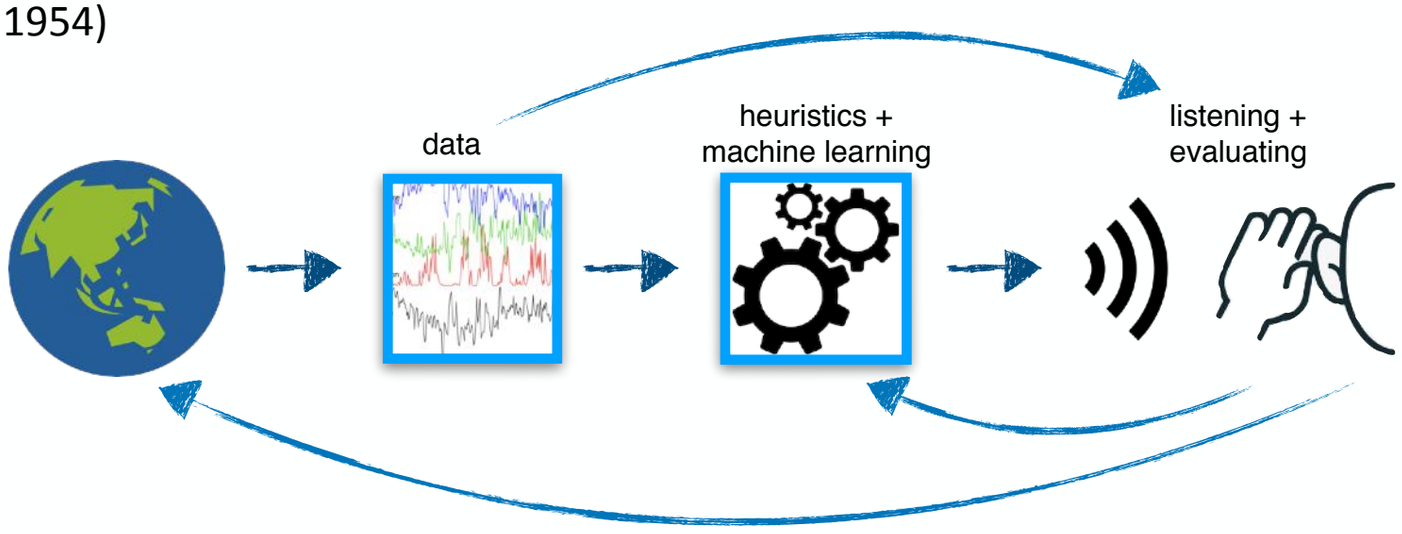
- scientific sonification is an exploratory method for pattern detection, trend identification, and systems monitoring (Hermann 2008)
- strong ecological principles for aesthetic sonification can be found in experiences of natural [non-designed] environments (Lindborg 2015)
- meanings of semantic listening are affordances of cultural behaviour (Tuuri & Eerola 2012)



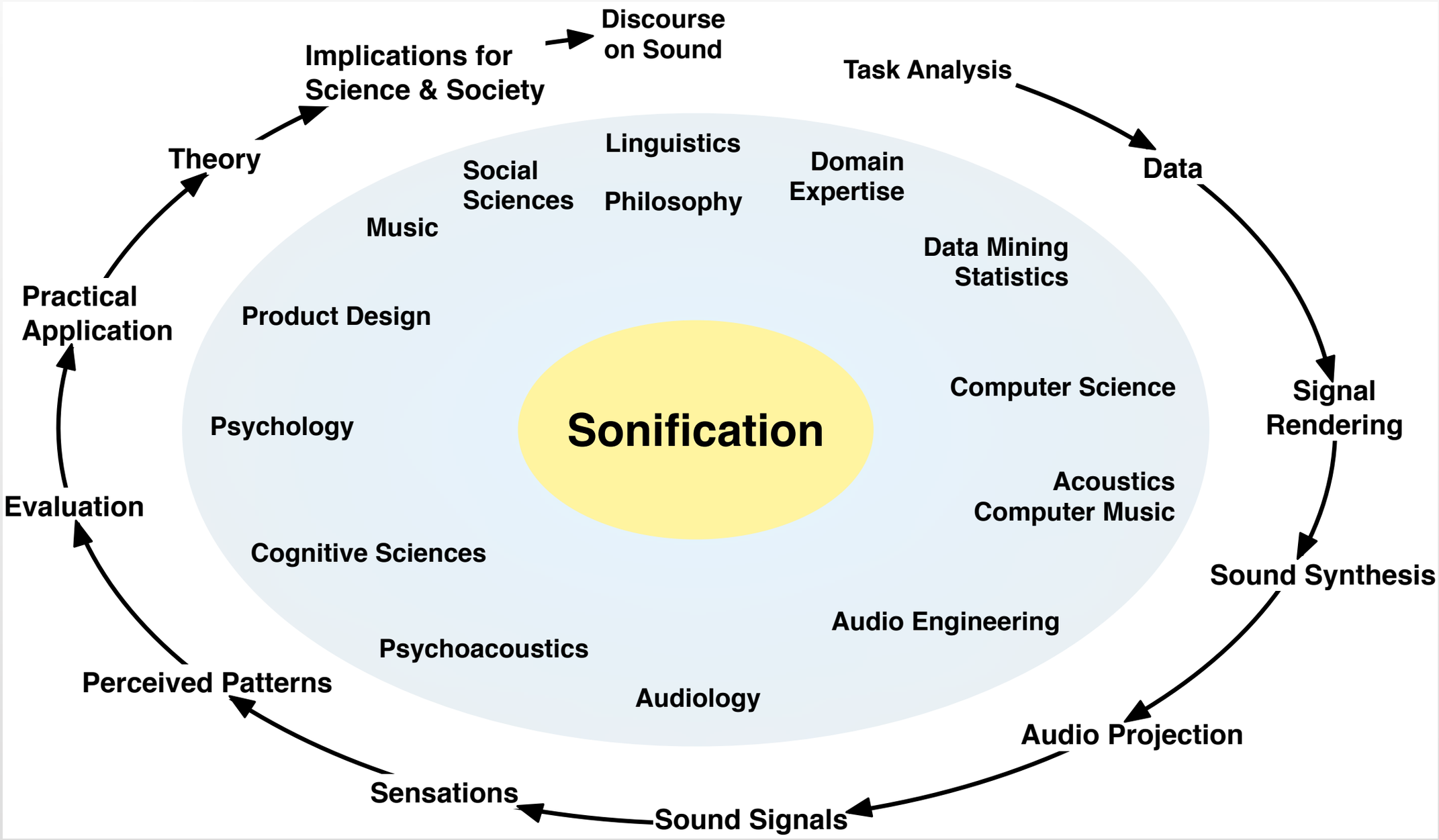
Aesthetic Perspective Space *(Vickers & Hogg 2006)*

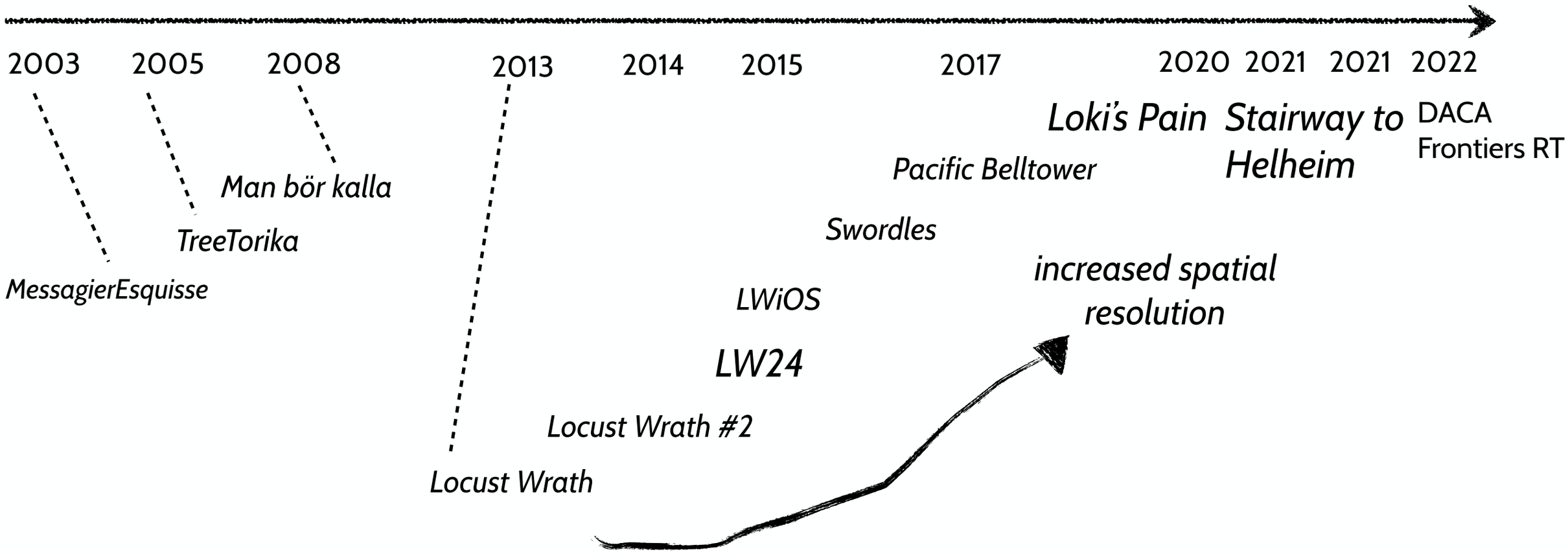
Sonification is a *design process*

"any technique that translates data into sound with a systematic, describable, and reproducible method, in order to reveal or facilitate communication, interpretation, or discovery of meaning that is latent in the data, having a practical, artistic, or scientific purpose." (Liew & Lindborg 2020; cf. Kramer 1994; Grinstein & Smith 1990; Pollack & Ficks 1954)



Sonification makes data *audible*




2003
2005
2008
2013
2014
2015
2017
2020
2021
2021
2022
MessagierEsquisse
TreeTorika
Man bör kalla
Locust Wrath
Locust Wrath #2
LW24
LWiOS
Swordles
Pacific Belltower
Loki's Pain
Stairway to Helheim
DACA
Frontiers RT
increased spatial resolution

LW24


factorie

Locust Wrath - LW, LW#2, LWiOS, LW24

Series of four designs (2013–15)
– interactive sonifications of climate data
–sonic map of large areas (SE Asia, Mediterranean)
and time periods (historic records & predictions).

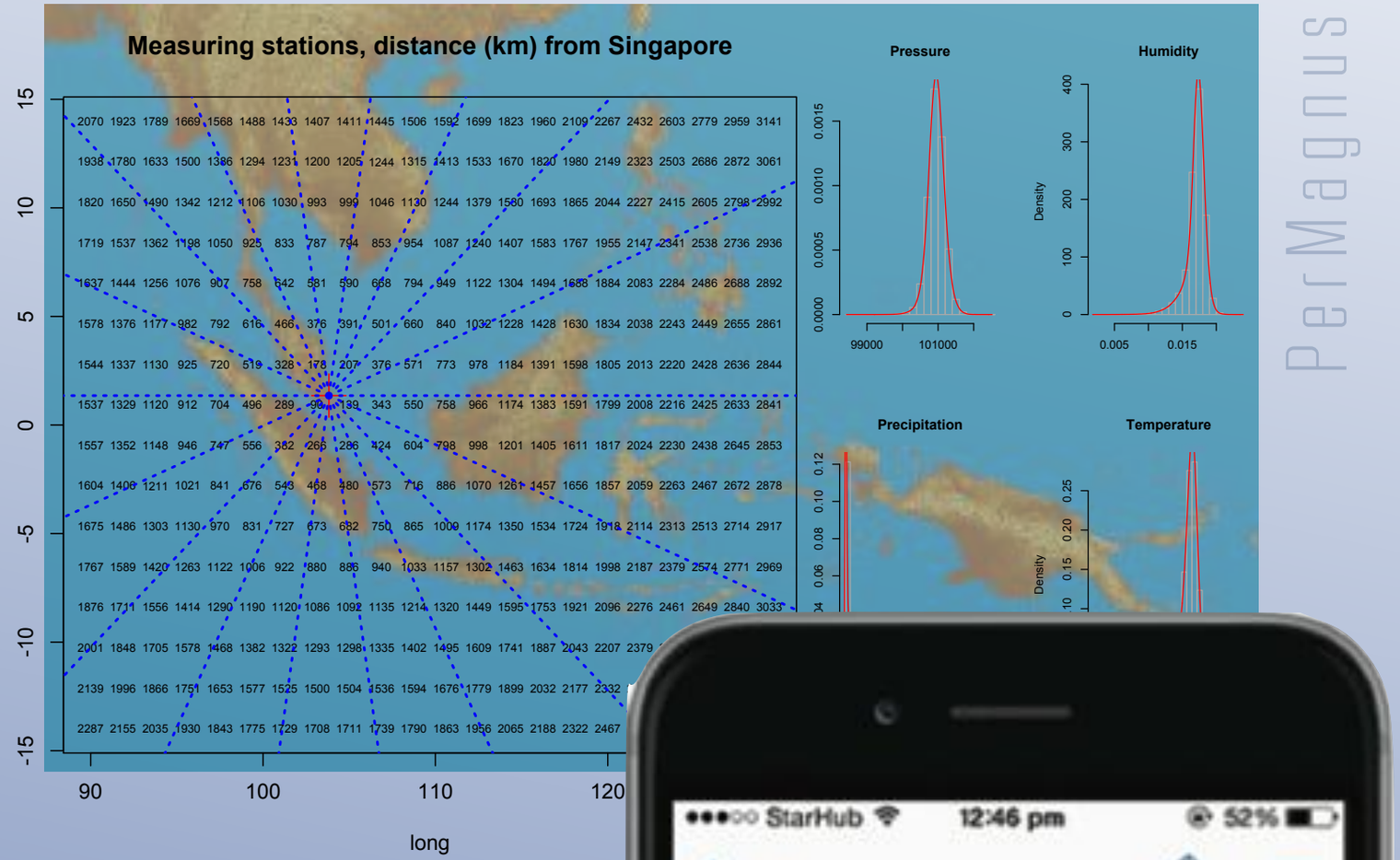
> *"The climate is rendered as a music, whose form - gesture, timbre, intensity, harmony, spatiality - is determined by the data."*

– plucked-string synthesis (300+ geo-locations)
– spatialised harp-like virtual instruments
– 38 million values rendered in 60 min., 21 ch.
– tool for scientific & pedagogic discovery of patterns

In collaboration with Tropical Marine Sciences Institute and Arts Fission Dance Company.



National Gallery Inaugural Exhibition, Singapore, Dec. 2015
National Design Centre, Singapore, Feb. 2015
Onassis Centre, ICMC, Athens, Oct. 2014
HeluTrans Gallery, Singapore, Sep. 2013



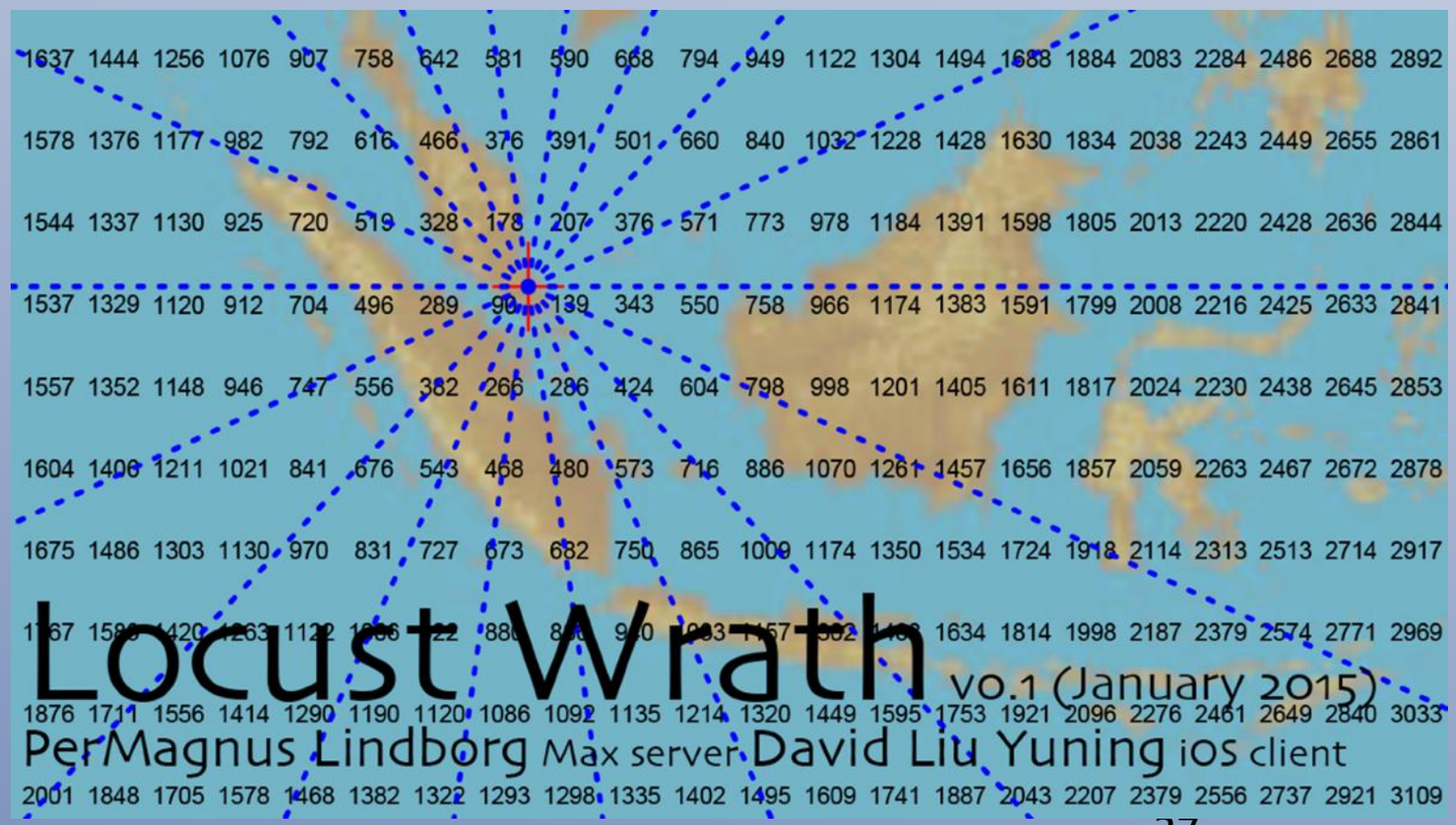
http://permagnus.org/zold/pm/artwork/sonifications/LocustWrath/

soundislands.com/locust-wrath/



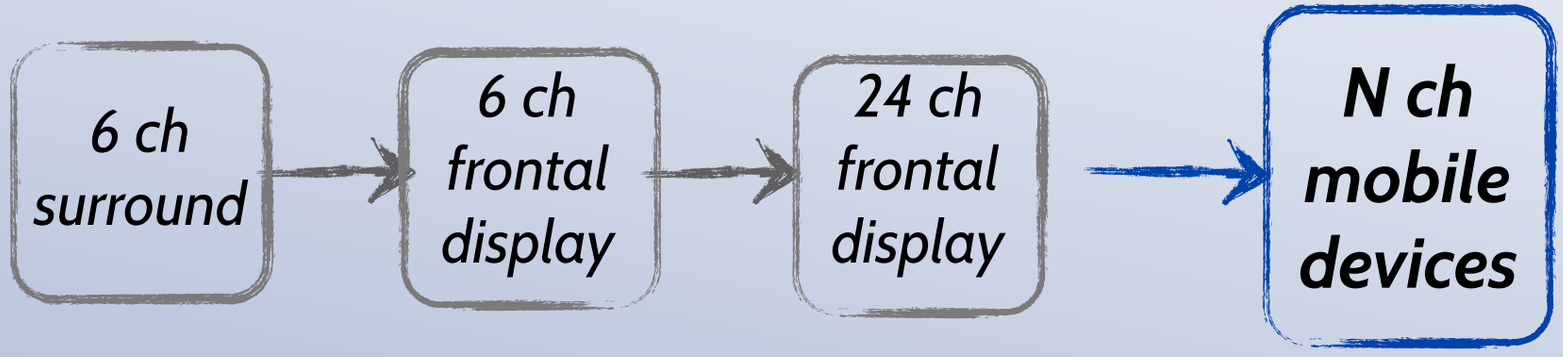
PerMagnus Lindborg
portfolio of works

Spatial resolution + *Mapping strategies*

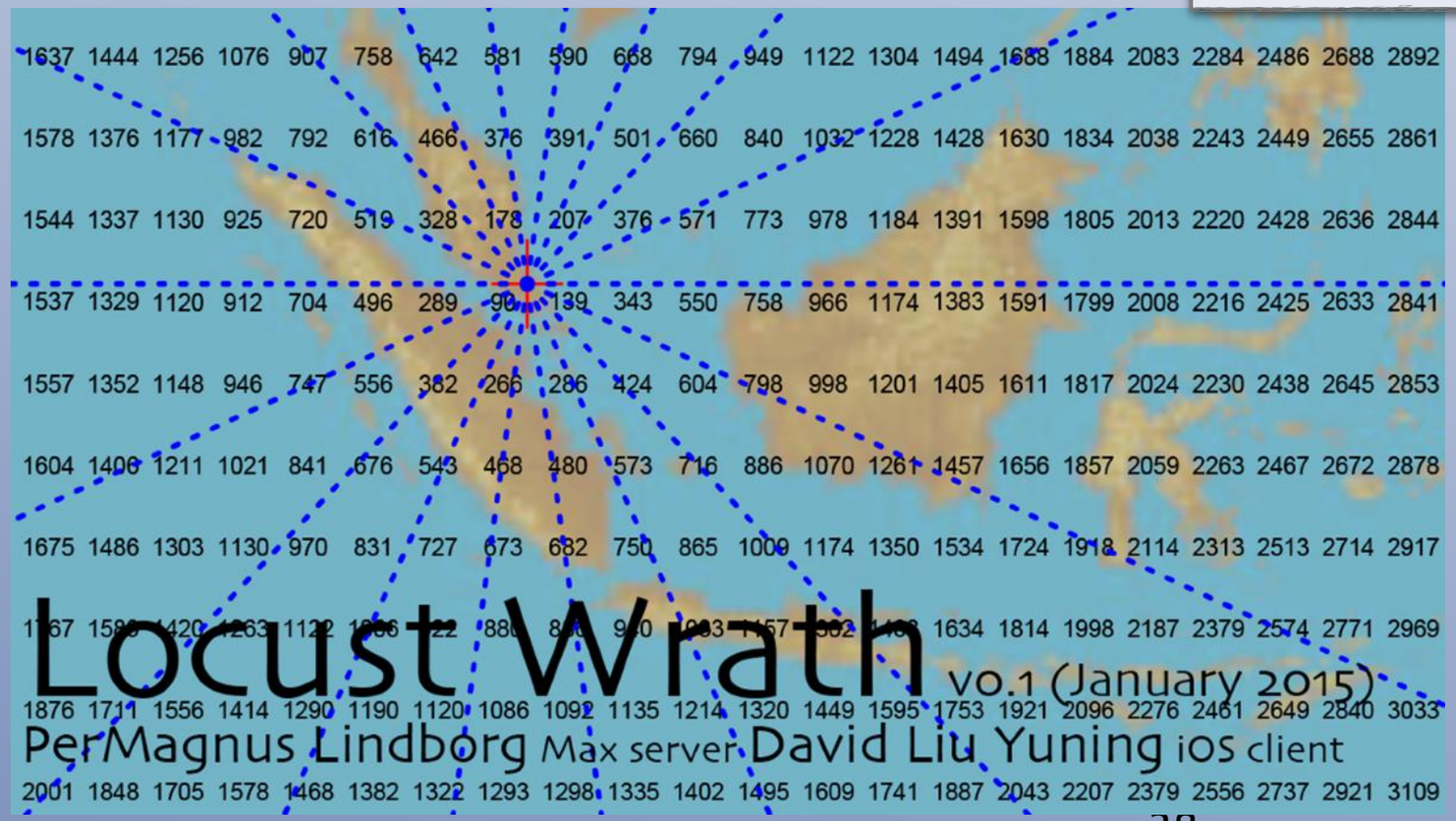




Spatial resolution



How can we make the sonification soundscape truly *immersive*?

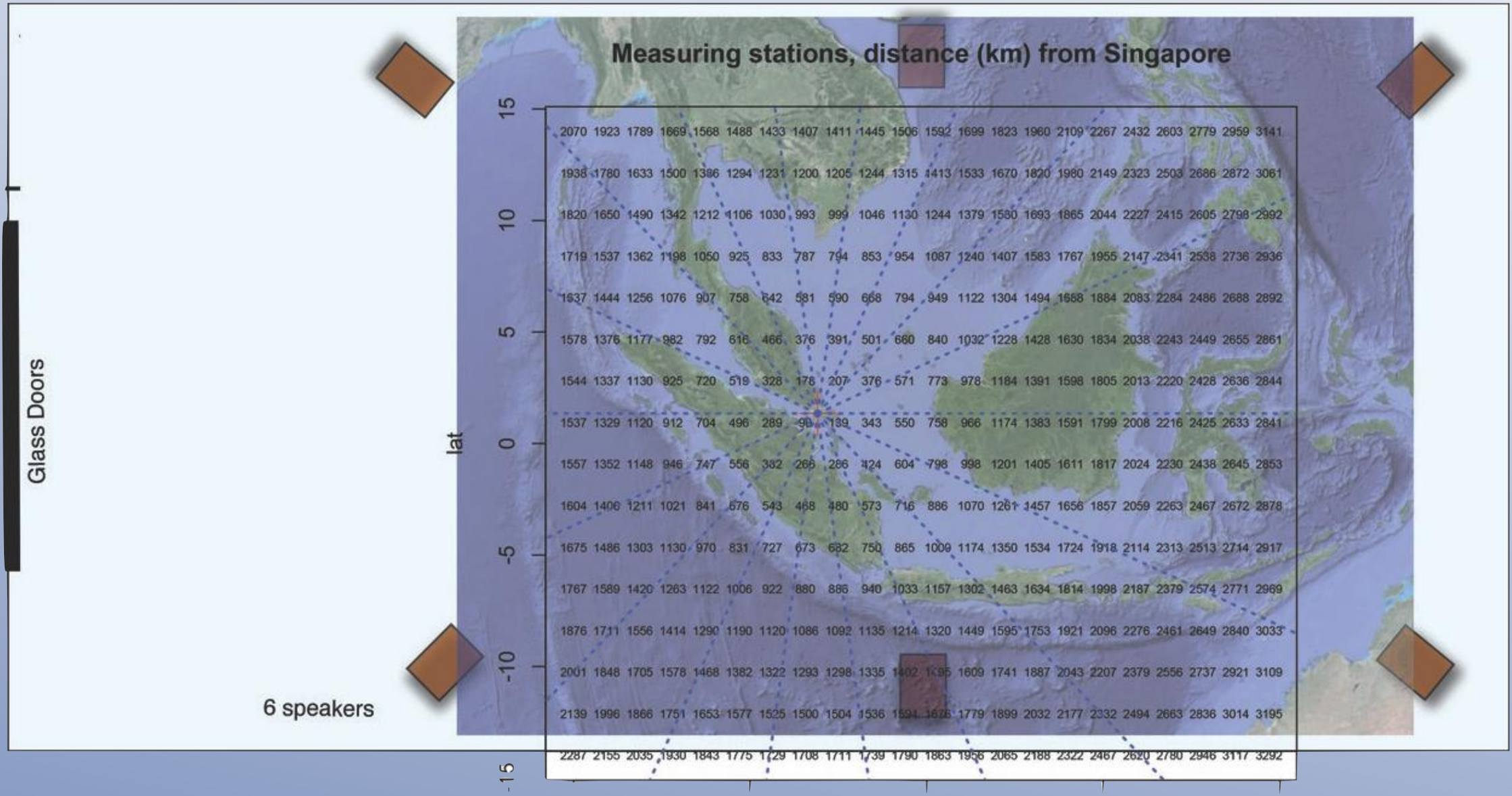




Locust Wrath *(2013, first in the series)*

superposition of: geography, virtual instrument spatialization, and physical performance space

6 ch surround sound

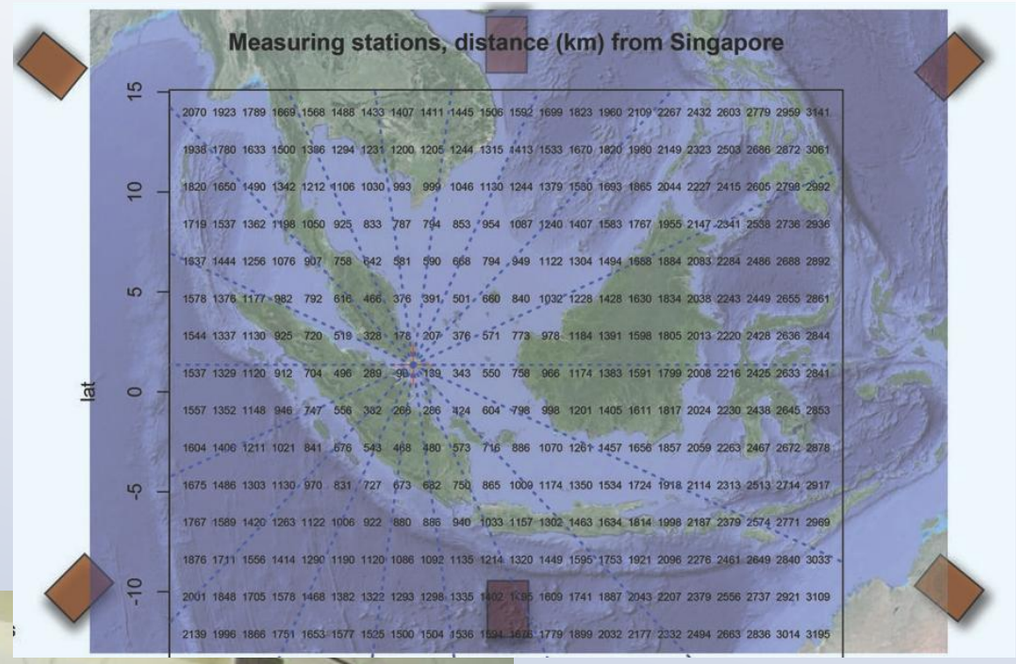


Locust Wrath *(2013, first in the series)*

with **ArtsFission** dance company

HeluTrans Gallery, Singapore 2013

Liong A, Koh JBT, Lindborg PM, ArtsFission (2013). The Locust Wrath, multimedia dance performance.

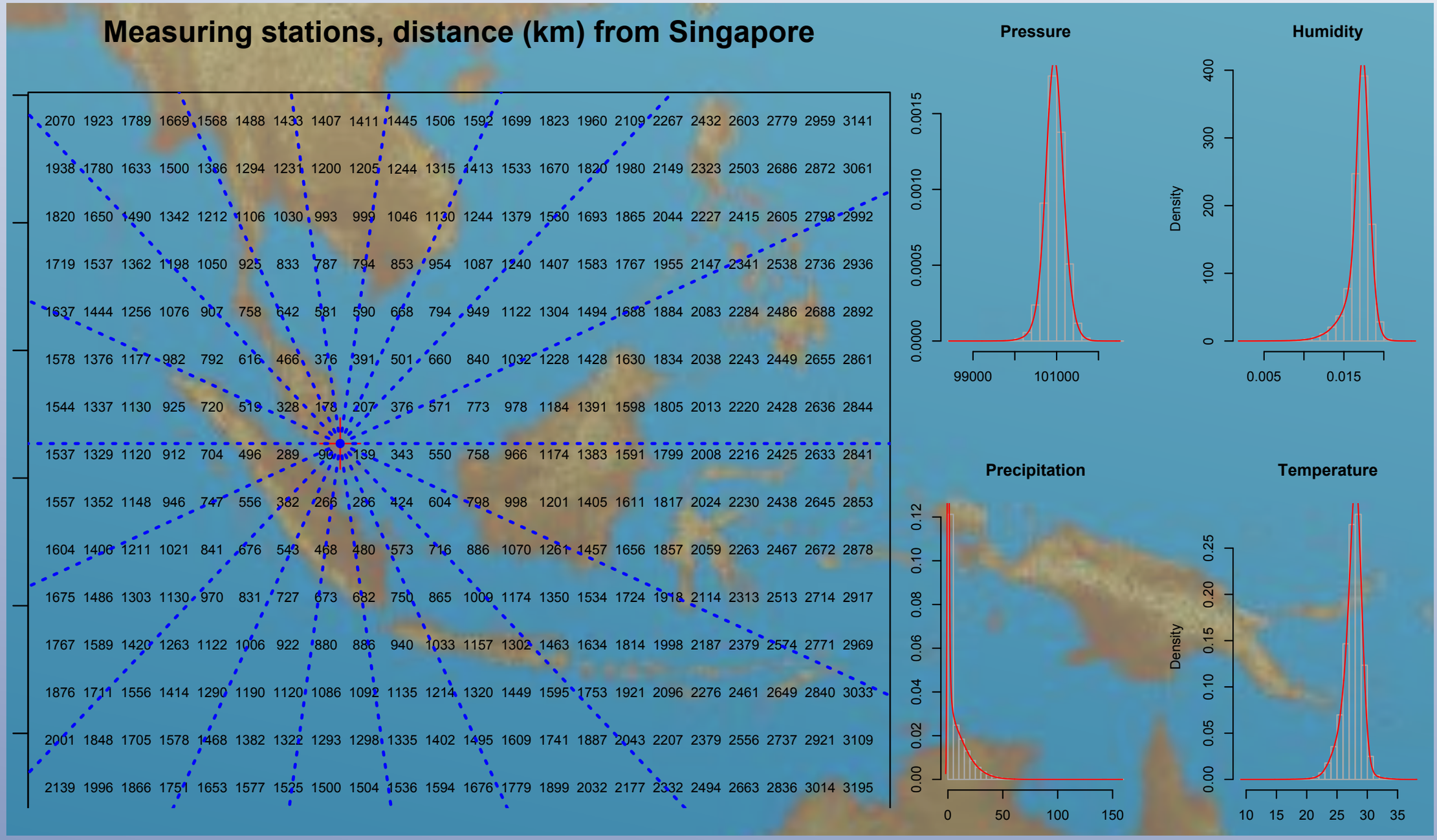




LW24 *(2015, third in the series)*

sonification installation for weather predictions 2015–55 in South-East Asia

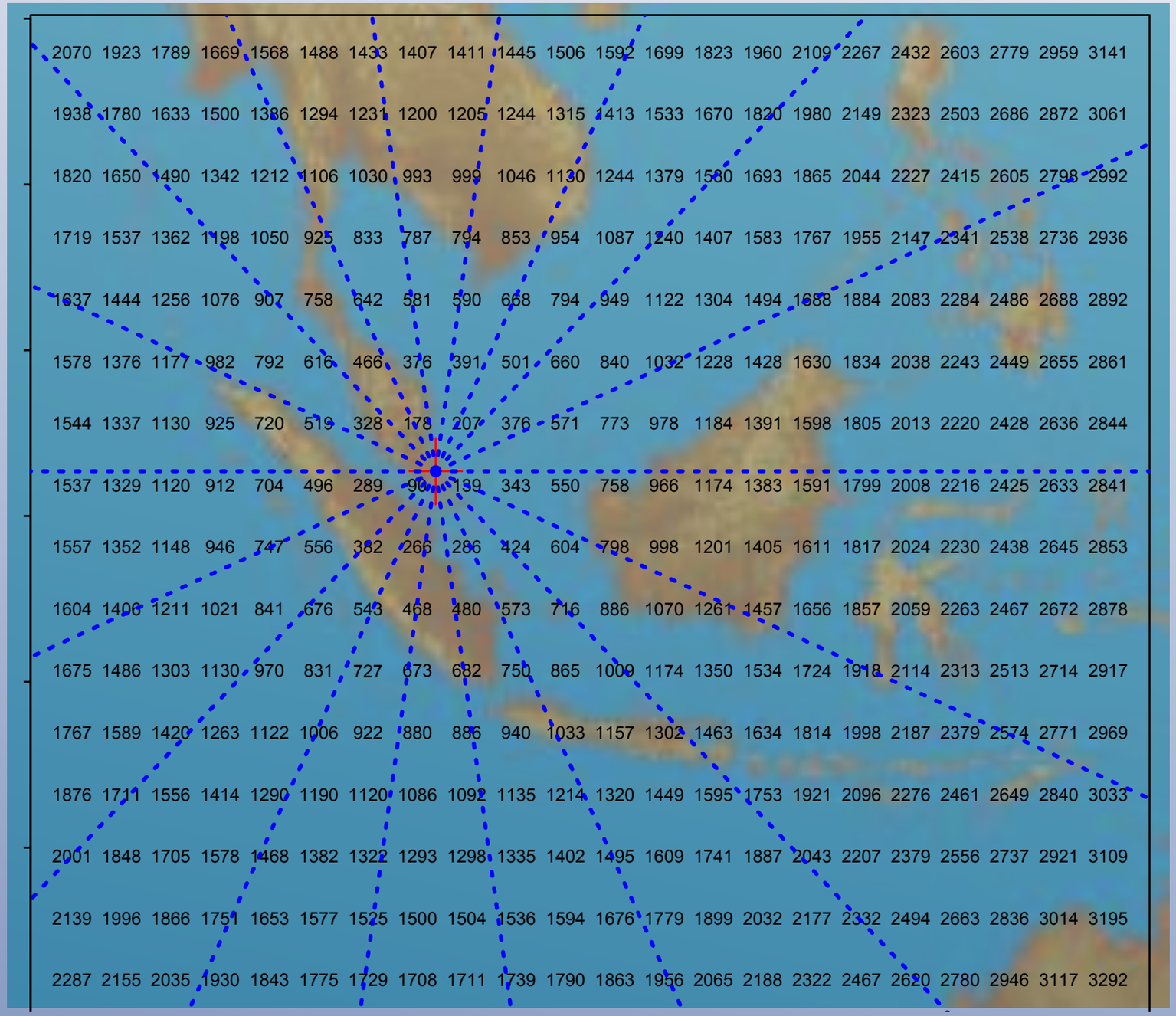
National Gallery of Singapore
Opening Festival, *2015*



LW24

sonification installation for weather predictions 2015–55 in South-East Asia

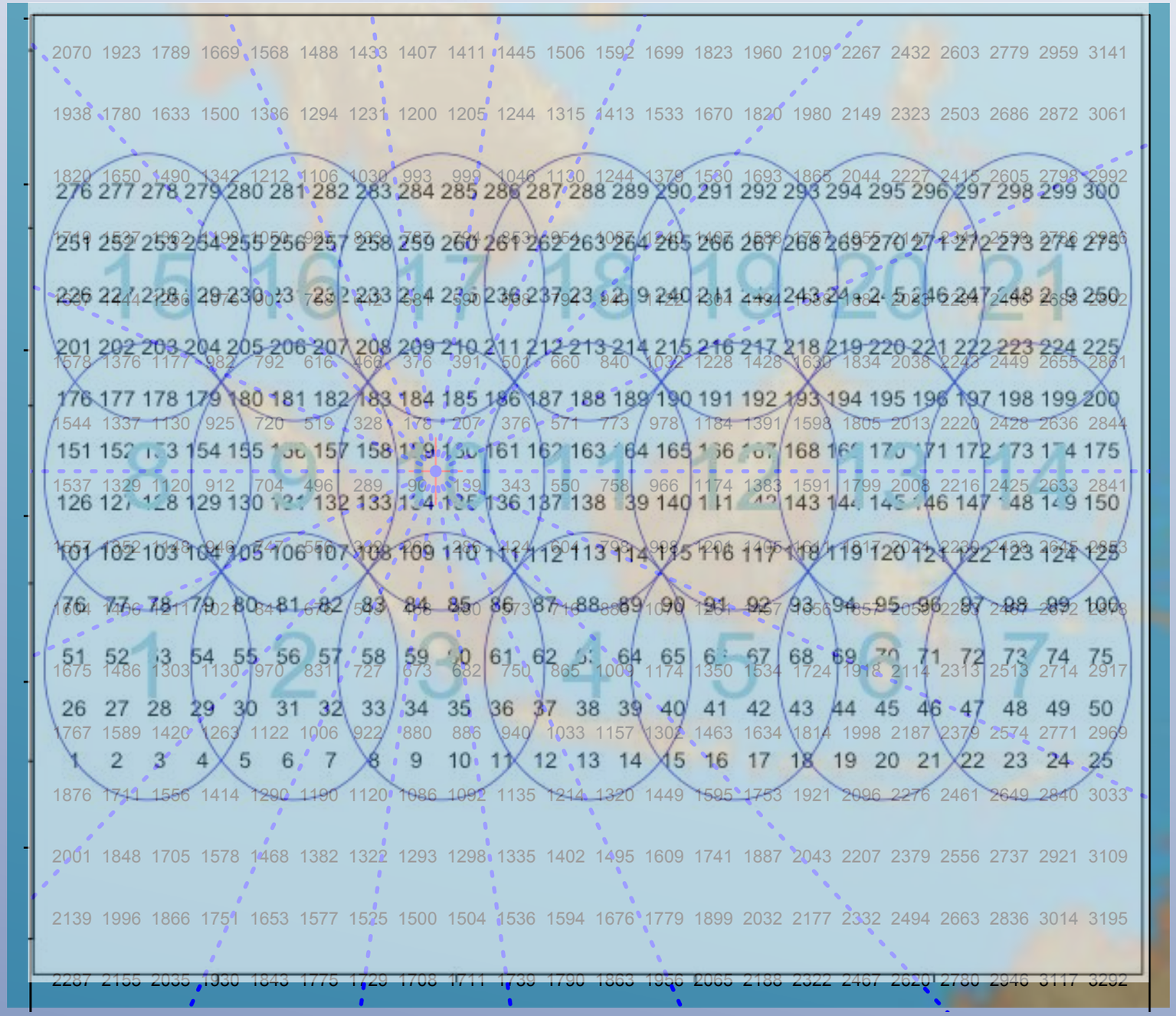
National Gallery of Singapore
Opening Festival, *2015*



LW24

sonification installation for weather predictions 2015–55 in South-East Asia

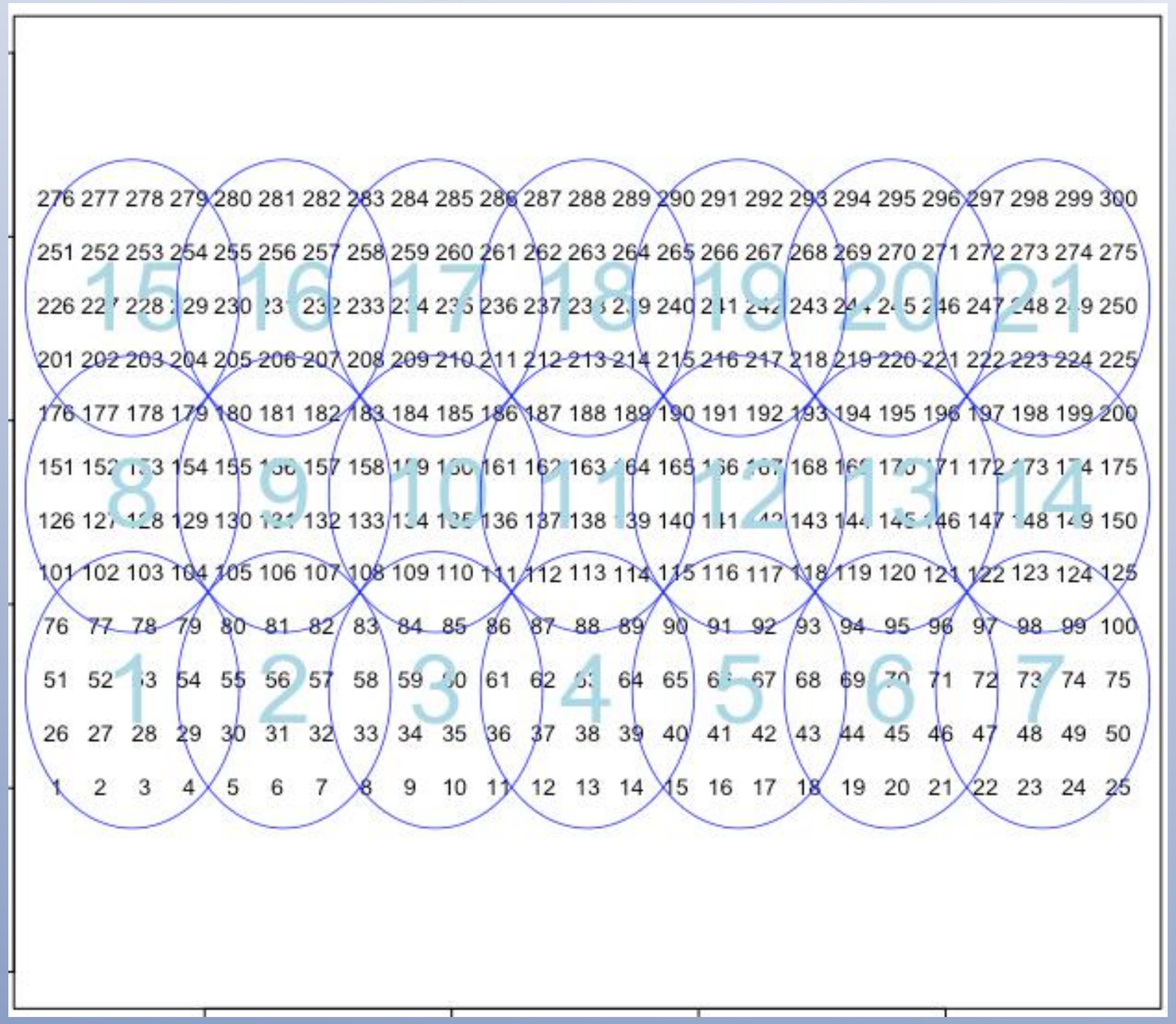
National Gallery of Singapore
Opening Festival, *2015*



LW24

sonification installation for weather predictions 2015–55 in South-East Asia

National Gallery of Singapore
Opening Festival, *2015*



LW24

sonification installation for weather predictions 2015–55 in South-East Asia

National Gallery of Singapore
Opening Festival, *2015*





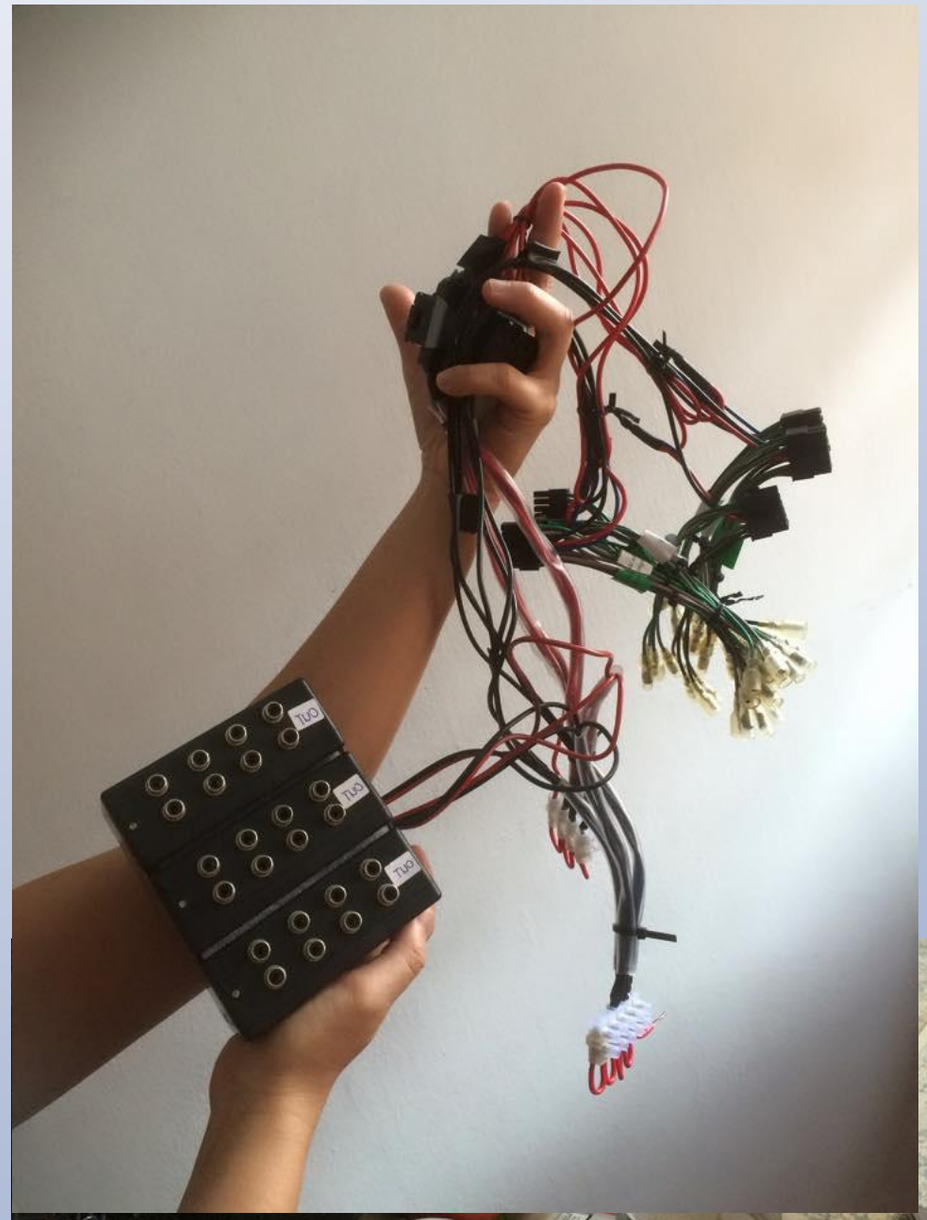


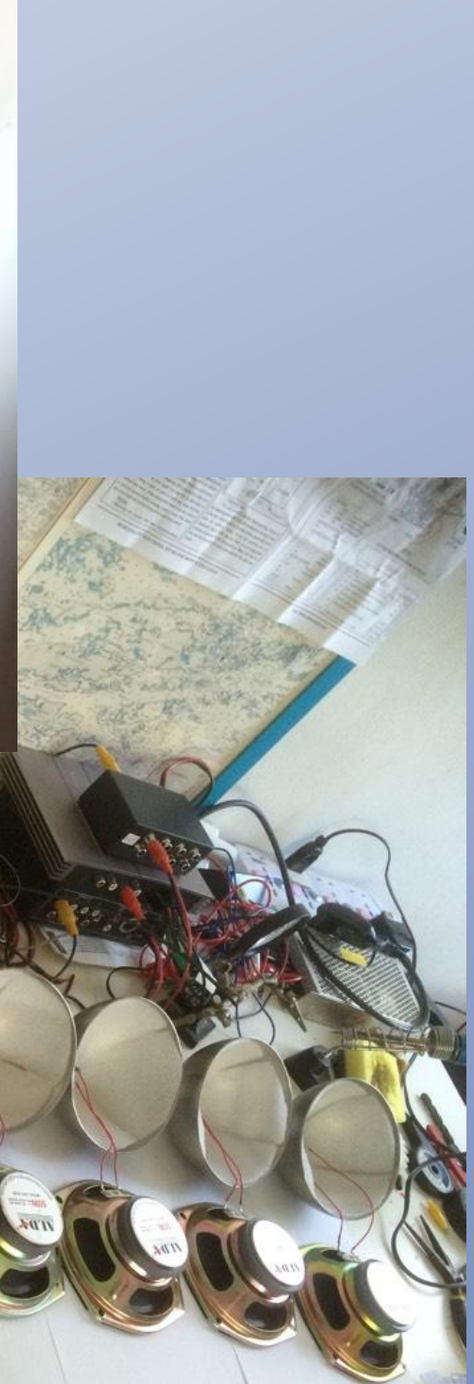
LW24

sonification installation for weather predictions 2015–55 in South-East Asia

National Gallery of Singapore
Opening Festival, *2015*









LW24

sonification installation for weather predictions 2015–55 in South-East Asia

National Gallery of Singapore
Opening Festival, *2015*

Lindborg PM (2014-15). Sculptural frontal auditory display. System consisting of 24 channels synchronised fixed-media playback devices, pre-amplification, amplification, audio cables, suspension strings, custom-built loudspeakers, and large portable grid structure. Mixed materials.

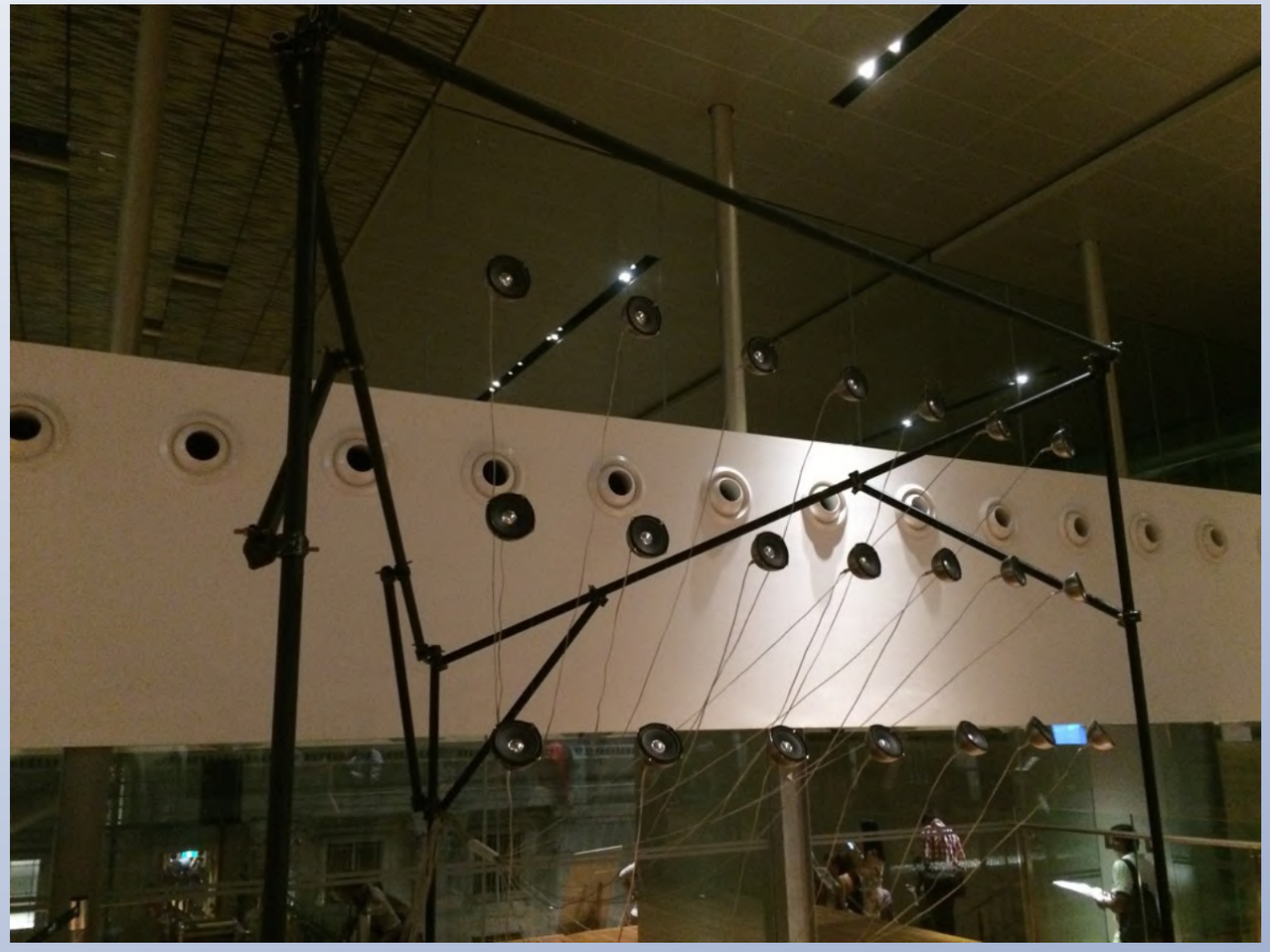


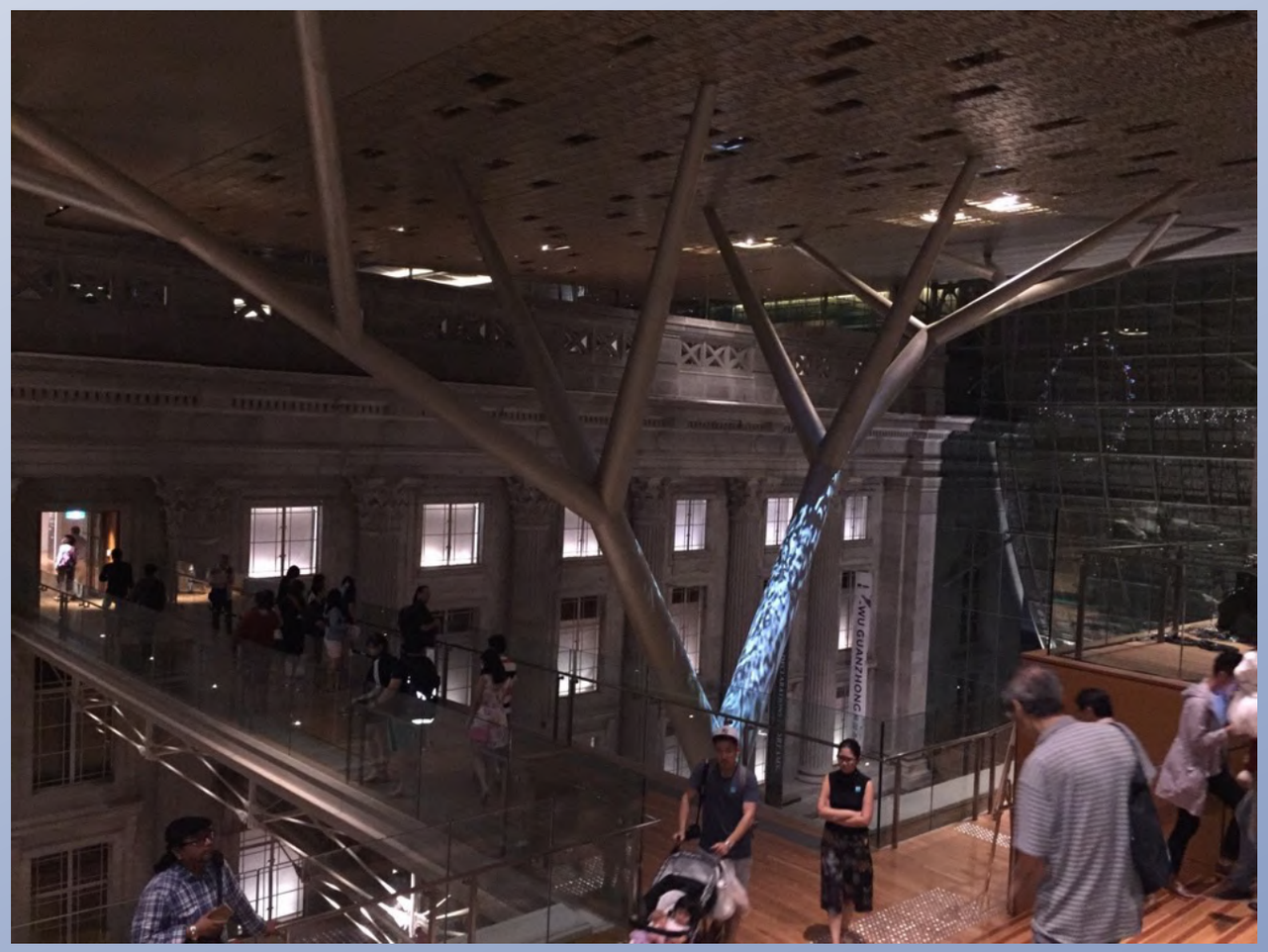


LW24

sonification installation for weather predictions 2015–55 in South-East Asia

National Gallery of Singapore
Opening Festival, *2015*





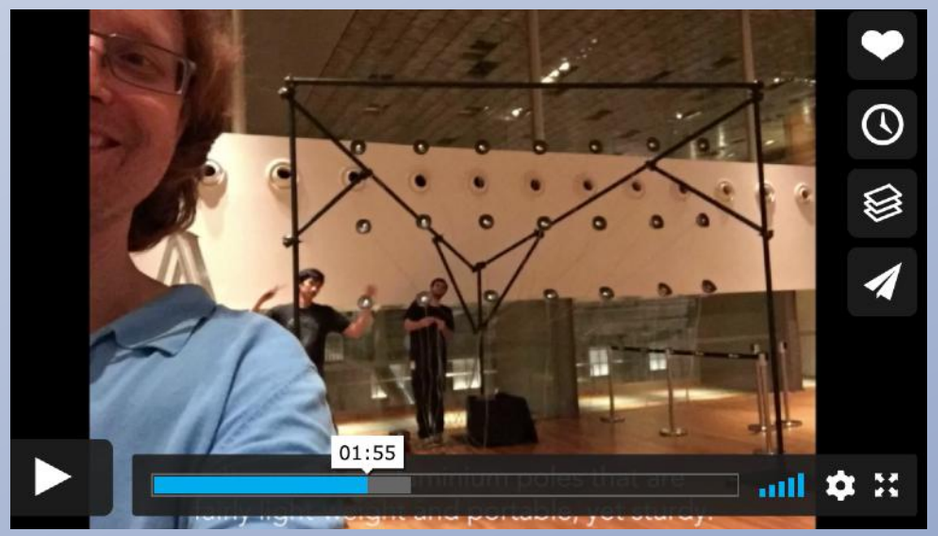
LW24

sonification installation for weather predictions 2015–55 in South-East Asia

National Gallery of Singapore
Opening Festival, *2015*

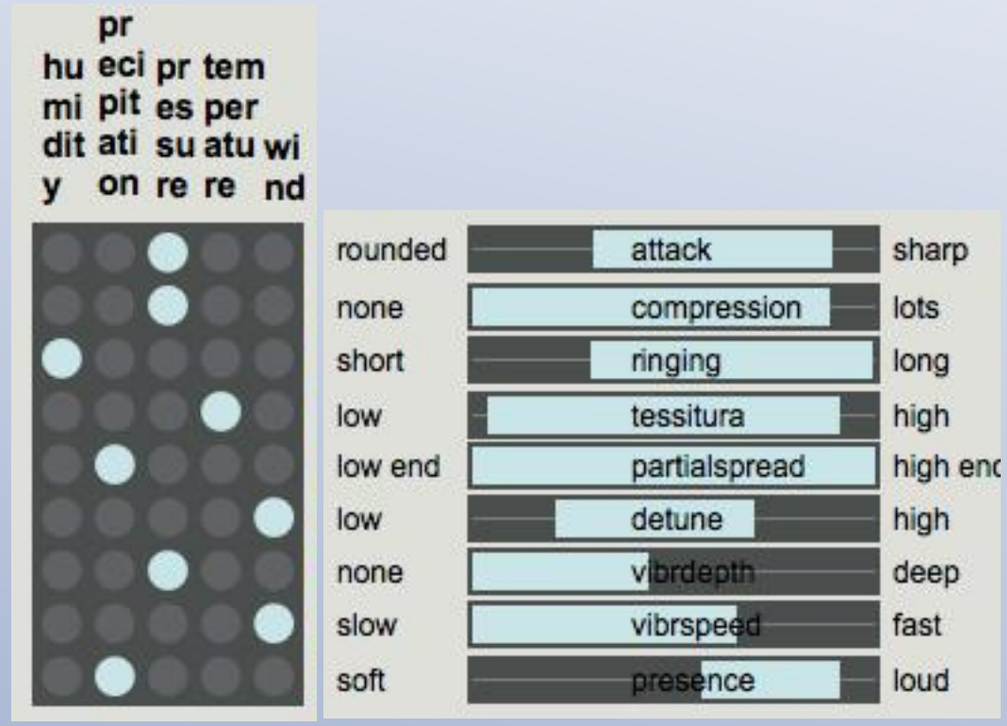


https://vimeo.com/272069085



Mapping strategies





sonification should embrace **soundscape** research (Gresham-Lancaster & Sinclair 2005)

listeners "might be able to recognise structural elements in music that represent the conventions or rules of the cultural field… [the] meanings of semantic listening [are] affordances of cultural behaviour" (Tuuri & Eerola 2012).

border between aesthetic sonification and electroacoustic music is blurred: "the difference… is largely one of perspective." (Vickers & Hogg 2006)

strong principles for aesthetic sonification can be found in experiences of natural, *non-designed* environments (Lindborg 2015, 2016/18, 2019)



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Interactive Sonification of Weather Data for *The Locust Wrath*, a Multimedia Dance Performance

PerMagnus Lindborg
(composer, sound artist, researcher), School of Art Design Media, Nanyang Technological University, Singapore. Email: permagnus@ntu.edu.sg.

PerMagnus Lindborg is an assistant professor at the School of Art, Design, and Media at Nanyang Technological University, Singapore. His sonic investigations include making interactive installations, researching sound perception and diving coral reefs.

Abstract

To work flexibly with the sound design for *The Locust Wrath*, a multimedia dance performance on the topic of climate change software was developed for interactive sonification of climate data. An open-ended approach to parameter mapping allowed tweaking and improvisation during rehearsals, resulting in a large range of musical expression. The sonifications represented weather systems

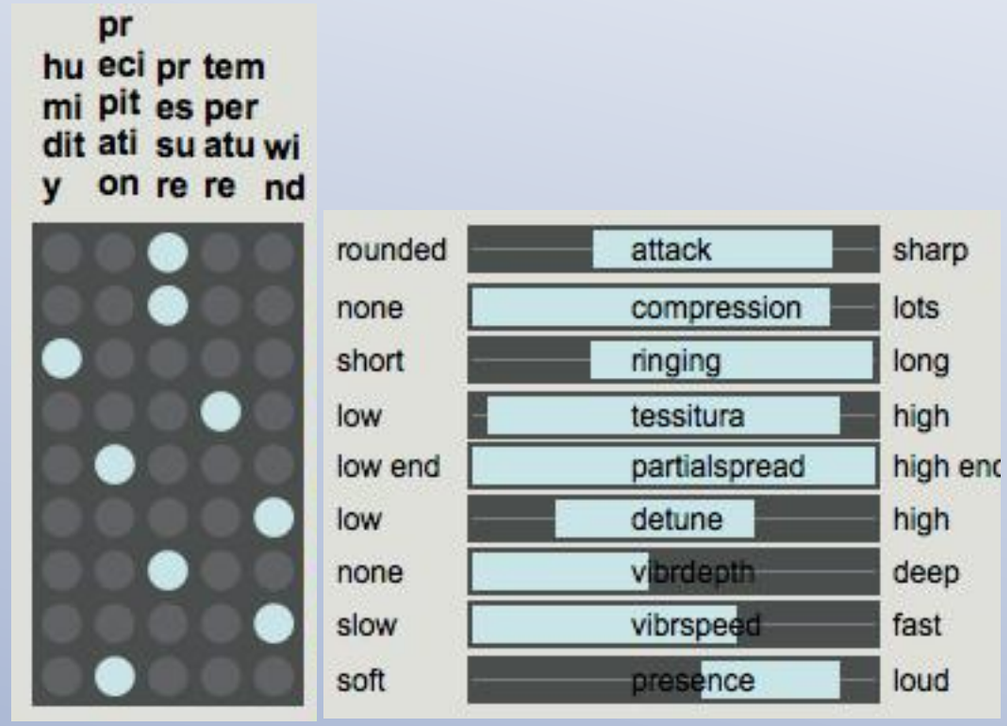
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Mapping strategies





Journal of New Music Research
2012, Vol. 41, No. 2, pp. 137–152

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Formulating a Revised Taxonomy for Modes of Listening

Kai Tuuri and Tuomas Eerola

University of Jyväskylä, Finland

Abstract

Listening to sounds or music is not a homogeneous act of grasping meanings by hearing. Yet it is often portrayed as such, especially when the intentional stance of a listener is overlooked. This paper distinguishes listening as the action-oriented intentional activity of making sense of the world. It is proposed that the multifaceted and heterogeneous nature of 'understanding by listening' can be outlined in terms of distinct modes of listening. Building upon previous accounts, a revised taxonomy of nine listening modes (reflexive, kinaesthetic, connotative, causal, empathetic, functional, semantic, reduced and critical listening) is proposed and illustrated by examples. Modes refer to different constituents of meaning-creation in the process of listening. In the taxonomy, they are schematically arranged into three levels (experiential, denotative and reflective). The theoretical framework of this revised taxonomy utilizes an embodied cognition paradigm. The experiential basis of meaning in listening is theoretically conceived of as emerging resonances between experiential patterns of sensations, structured

passive receiving'[1] of a sound and the latter as an intentional and attentional creation of meanings on the basis of the sonic experience. Intui
acknowledge that this meaningful expe
dent on the way the sound is involved
and how we see its relevance to the conte
In most cases we do not experience sou
qualities or musical features; rather, we
sources and events taking place in a pa
ment. This already exemplifies two sep
listening, each referring to different ways
of potentially the same sound. The cen
article is to deepen understanding about
nature of knowing through sounds, and
coherent typology of different listening
basis of multidisciplinary literature, we
each mode of listening is related to its
between the sound as an acoustic
perceiver's intentionality. In the cours
the different ways of meaning-creation h
been shaped to serve different aspects of
world.

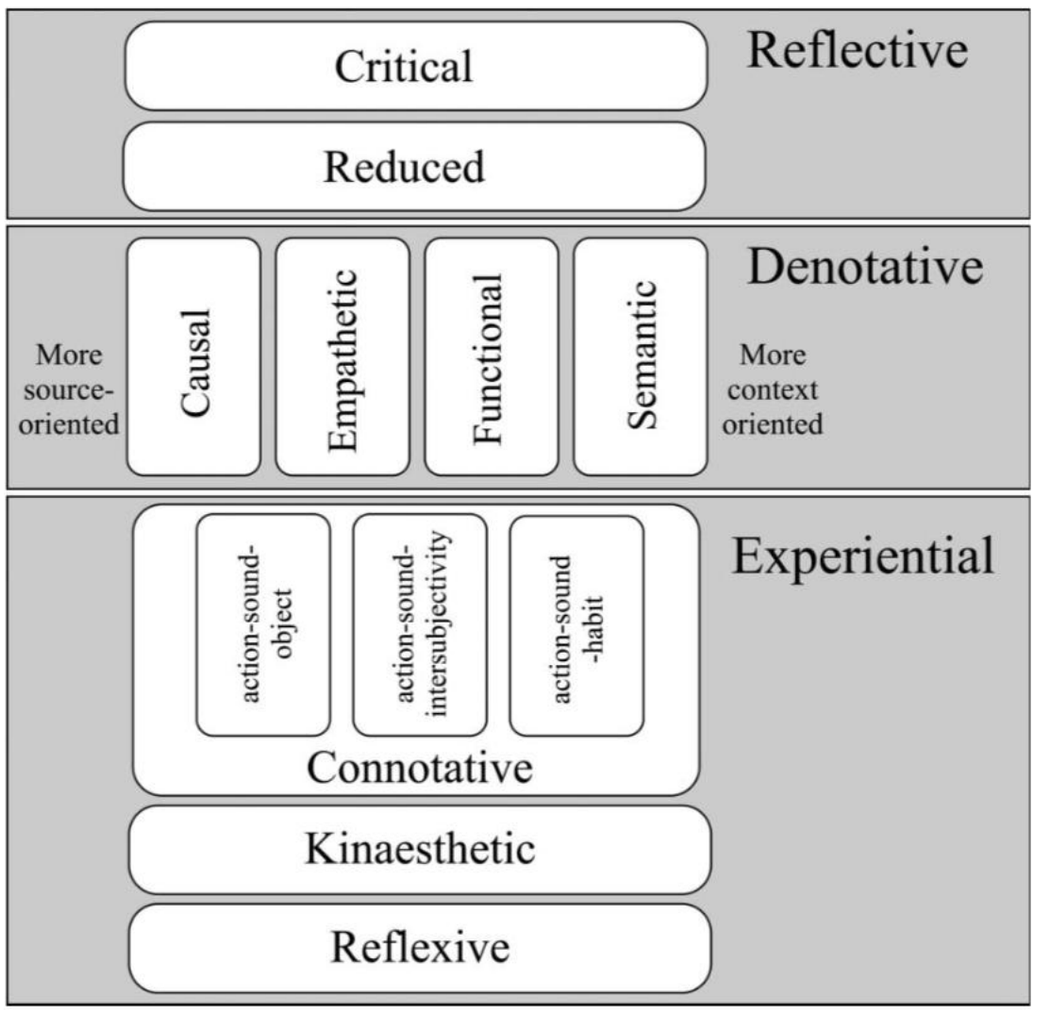


Fig. 3. Overview of the revised scheme for modes of listening.

How do we listen?

PerMagnus Lindborg
Department of Composition, College of Music, Seoul National University
Permagnus [at] snu.ac.kr
http://permagnus.org

Situations of listening

> As I close my door and walk down the stairs, the motor-driven lock mechanism heralds a sequence of percussive metallic clicks, in counterpoint with my creaking shoes and, through their door, laughter from the neighbor's child. I'm in a space with stone floor and concrete walls. I stop, hold my breath, and wait for the reverberation tails of all three sounds to fade out. Silence is relative, and my attention is seamlessly drawn sounds from the outside: cars, birds, rustling leaves. I'm late.

In what ways do we listen to the soundscape? How do our concurrent activities, moods, and abilities determine the listening mode? What is it that allows us to experience arbitrary sounds in an everyday environment as elements in a musical composition?

> I am running through the rainforest along one of my favorite tracks that circles the hill: one hour outdoors activating muscles, bones, and ligaments. A heightened awareness of my heart: when running, I pay it due attention and gratitude. Suddenly I realize that for some time there has been music in my mind's ear – a motive, an ostinato, a chord sequence – and that I have had no awareness whatsoever of the forest sounds, or my footsteps, or breathing. Yet in the instant this observation emerges, the music evaporates, and all that I hear is exactly forest, footsteps, and breathing. The music remains as a trace in memory: a mental notation.

Why do ways of listening sometimes feel categorically different? Are there multiple parallel processing streams in our mind that compete for attention, as it were, knocking on the door to our executive control room? Or is what we call 'conscience' an emergent property, a mental scheme in temporary equilibrium: froth bouncing on streams of multiple parallel processes?

> The concert hall ushers didn't let me enter carrying a small backpack and sent me back to the ticket desk. I managed to

The reader might recognize or recall similar situations of listening. There is an infinite range of such stories, yet it might be possible to describe the range of listening modes with a fairly small number of concepts. Occasionally consciously and most often not, we sense, perceive, and inquire the relations between three entities: the soundscape – the perceived acoustic environment; its constituent elements – the observed, implied, or imagined sources that produce the sounds we perceive; and ourselves. We have an innate capacity to evaluate sounds in terms of usefulness and danger. Listening is what mediates between the perceiving organism and its environment.

The first situatio
learn about our
and identifying th
other beings mig
Just as smelling
toxic plants, list
Sounds from sou
attention. As bio
faint sounds with
complexity, such
By contrast, shar
mechanism, signal danger even if the sounds are faint. The second vignette was about the internal process of sonic imagination. The principle of homeostasis explains an innate tendency to adapt our attitude towards the surroundings so as to maximize our chances of utilizing objects and beings to our benefit. Some soundscapes are dense in signals about danger, pleasure, friends and foes. Most often these are essential, but occasionally our survival instinct is suspended and the soundscape is largely

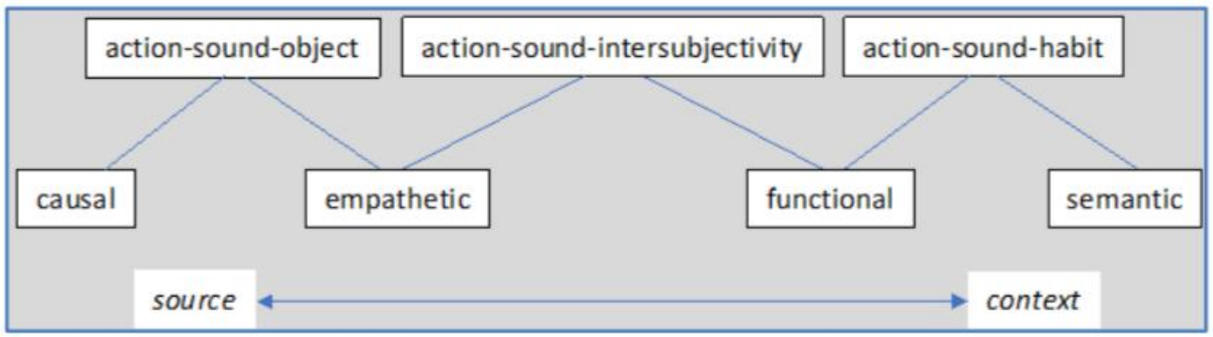


Figure 2. Associations between connotative (upper) and denotative (lower) listening modes. After Tuuri/ Eerola (2012).

How do we listen?

PerMagnus Lindborg
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http://permagnus.org

Situations of listening

As I close my door and walk down the stairs, the motor-

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nor second. Inexorably they bring on a crescendo to forte… Tartini on rampage… wild beating on everyone's eardrums. The audience writhes in awe.

The reader might recognize or recall similar situations of listening. There is an infinite range of such stories, yet it might be possible to describe the range of listening modes

ers/ Hogg 2006; further discussed in Vickers 2013, Vickers 2017), and Kai Tuuri's taxonomy for modes of listening

Schaeffer (1966)	Chion (2012)	Truax (2002)	Huron (2002)	Tuuri et al. (2007)	Tuuri/ Eerola (2012)	Juslin/ Väs tfjäll (2008)
ouïr	—	background listening	reflexive	pre-attentive	reflexive	brain stem reflex
					kinaesthetic	rhythmic entrainment
écouter	causal		connotative		connotative (three action-sound couplings)	evaluative conditioning
comprendre	semantic	listening-in-readiness	denotative	source-oriented	denotative (causal, empathetic, functional, semantic)	
			empathetic			emotional contagion
			associative	context-oriented		visual imagery
						episodic memory
entendre	reduced	listening-in-search		quality-oriented	reduced	musical expectancy
—	—		critical	(context-oriented)	critical	aesthetic judgement

Table 1. Overview of listening modes in different theories and frameworks.

Mapping strategies

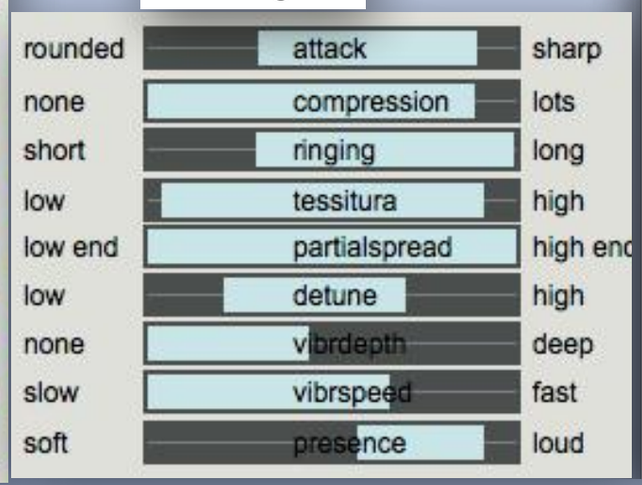
Auditory system: ecological approach

perceptual principles ~ cross-modal association (Lindborg & Friberg 2015, Lindborg 2016)

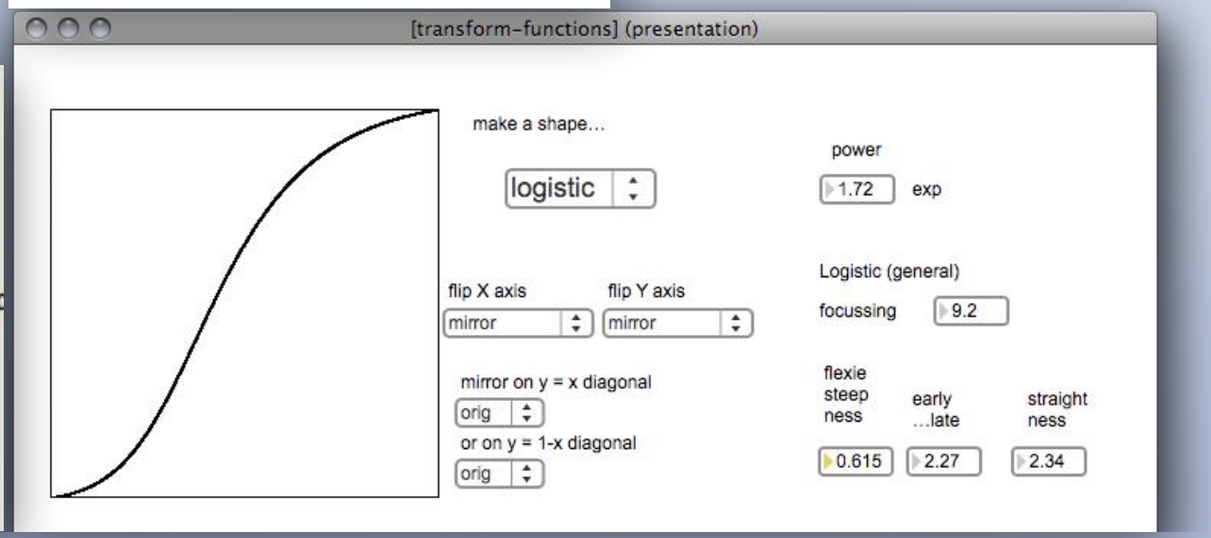
interactive parameter mapping



linkages



transfer functions



Mapping strategies

Auditory system: ecological approach

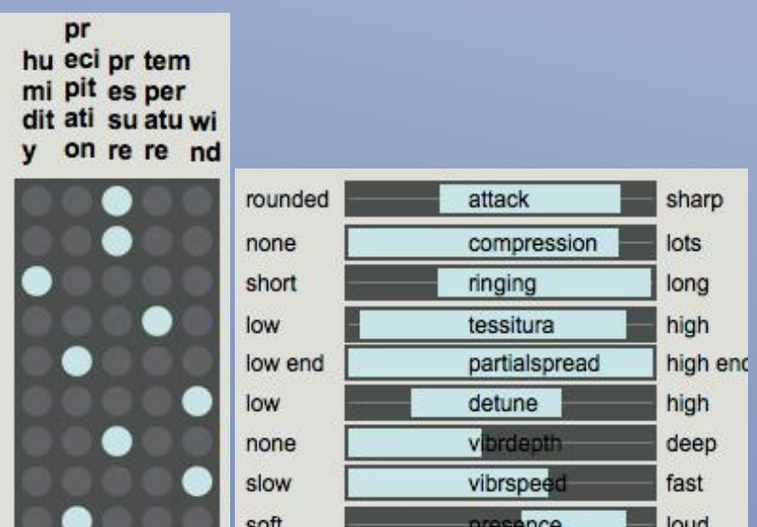
(Spence, "Crossmodal…tutorial" 2011)

(Tuuri & Eerola, "Taxonomy… Listening Modes" 2012)

(Huron, "Sweet anticipation" 2010)

(**reflexive**) "Is there an immediate danger!?"
- innate responses
- structural crossmodal associations

urgency ⟵ switch "on"





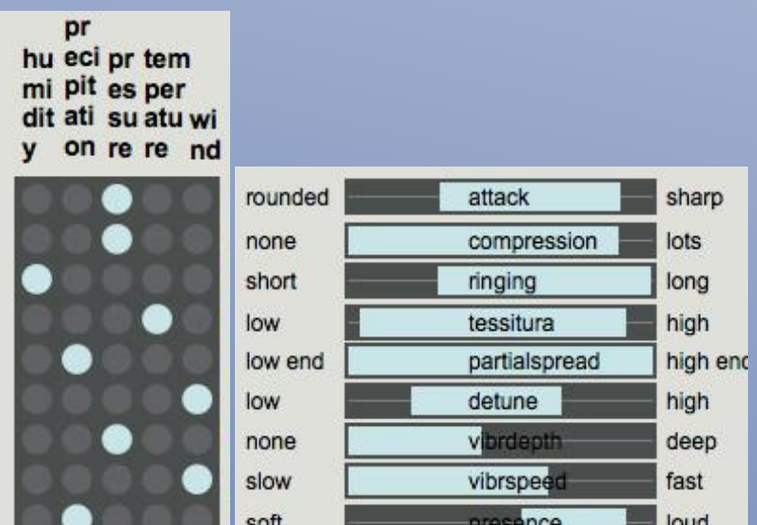
Mapping strategies

Auditory system: ***ecological approach***

(**kinaestethic**) affordances of perceptual experiences:
- "How does the sound physically manifest itself?"
- enactive perception (*doing*, cf. Noë 2004)

...harp-like structures scattered on a hill, lying on their back in the rain, with each drop causing a string to sound...

the pluck of a string is like a drop of rain ← Karplus-Strong synthesis string model



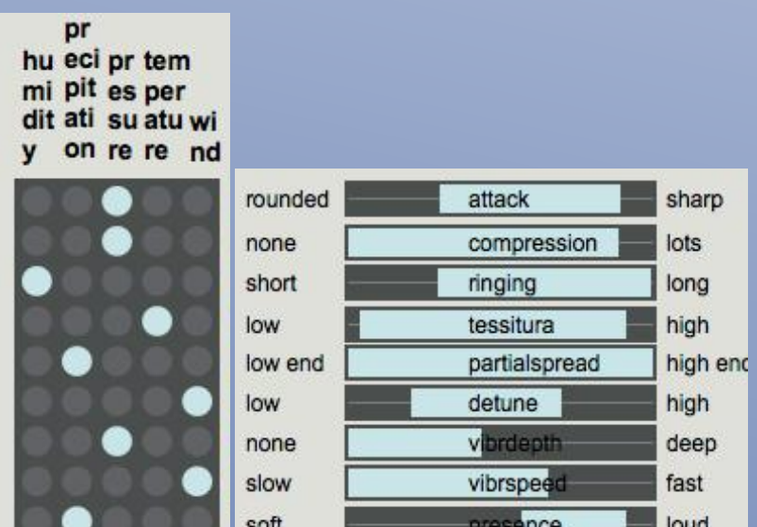


Mapping strategies

Auditory system:
ecological approach

(**kinaestethic**) "Where does the sound come from?
Is it approaching or receding?"
•processing of spatial cues is largely pre-attentive
•gestural signatures (friend or foe)
•kinaesthetic action-sound couplings (mostly acquired)

geography ← *illusion of movement* ← spatialisation





Mapping strategies

Auditory system:
ecological approach

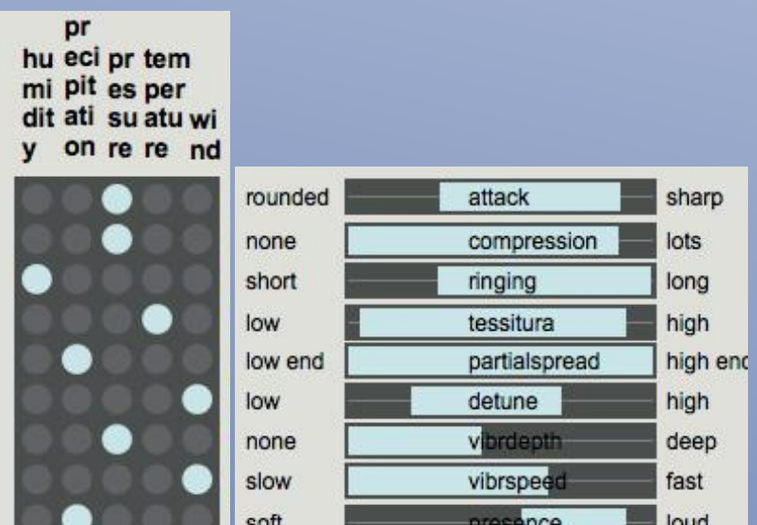
(**connotative**) *Kinaesthetic affordances* of perceptual experiences
- "What does the sound *evoke* in me? Is it aggressive or inviting?"
- contextual orientations and anticipations
- listening mode depends on *emotional* crossmodal associations

cognitive appraisal of response alternatives (cf. "decisional consequences")

wind ← *illusion of 'bending'* ← harmonicity of chords [detuning]

pressure ← *emphasis* ← vibrato

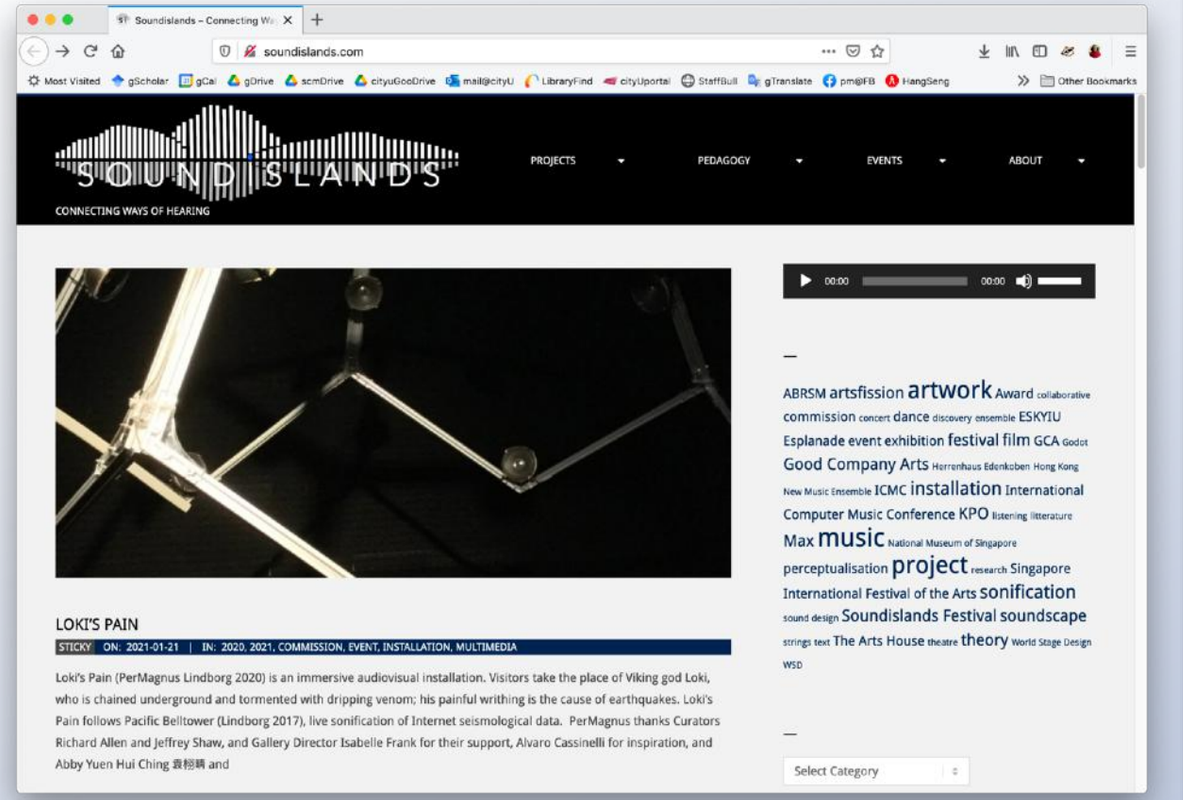
humidity ← *resonance* ← feedback

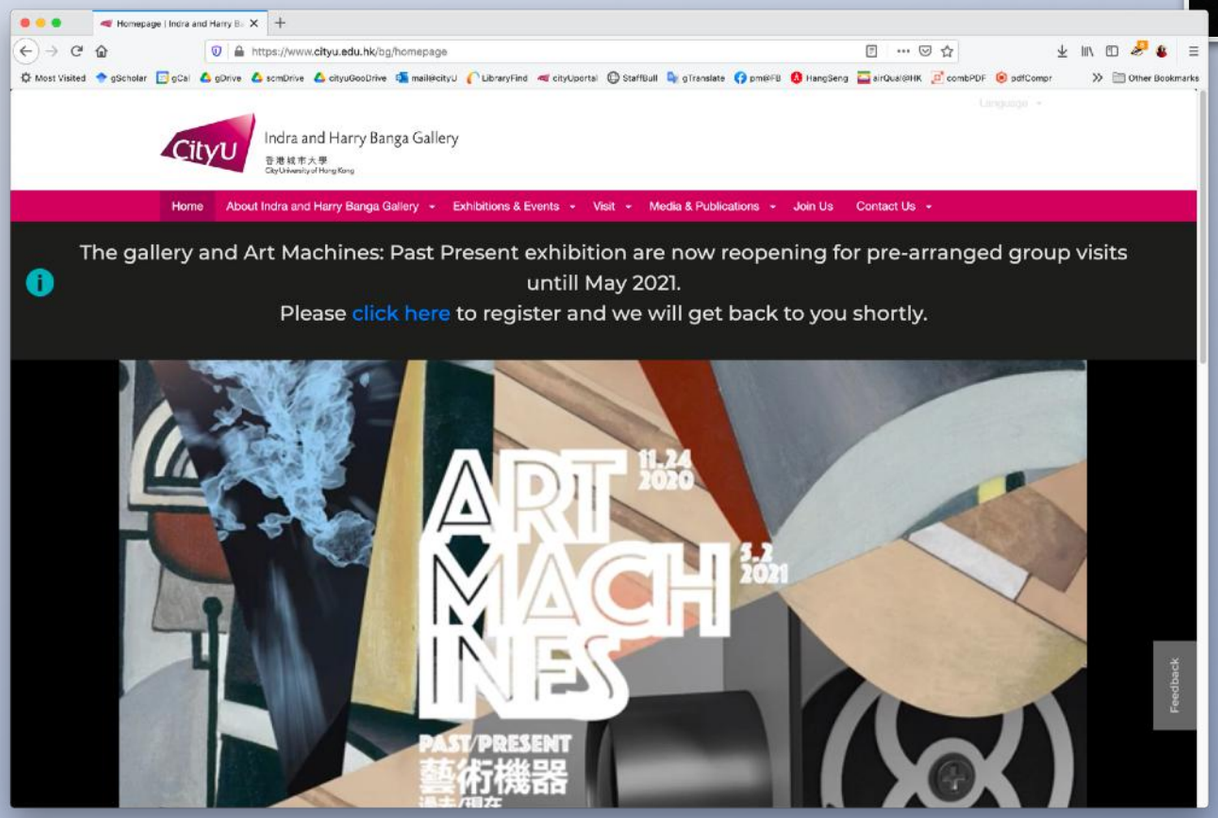




Loki's Pain









Loki's Pain (Lindborg 2020) is an immersive installation: a 16-channel 3D audio sonification of planetary seismological activity. Visitors take the place of Loki, who according to a Norse legend was "punished by the gods by being chained to three rocks in a cave using the entrails of his dead son, with a venomous serpent poised above his head. When the serpent's poison fell on Loki's head it caused him to shake uncontrollably, thereby unleashing an earthquake" (Allen 2020, p. 148-9). The installation is a physical structure, designed and built by the Author, in the shape of a hemi-dodecahedron. As show in Figure 1, the LOKI structure envelops the listener, and the immersive space may be shared by two visitors. They hear the striking of virtual cymbals, created by physical modelling, spatialised according to the geographical location of seismological events, as if they found themselves at the centre of planet Earth.

Playing *Loki's Pain,* the LOKI installation structure holds 15 custom-built loudspeakers mounted so as to produce a 3D immersive sonic environment. The structure is suspended from the ceiling rig, not touching the floor. Visitors band a little and step inside the installation space, and sit down on a subwoofer, which is lightly vibrating. They listen to a 10-minute sonification of the most recently retrieved earthquake data from the Internet. Seismological magnitude and epicentre depth are mapped onto the parameters of real-time physical modelling synthesis with Modalys (IRCAM). Data from IRIS is retrieved from the Internet and pre-processed in R (R Core Team), and then sonified in Max (Cycling'74) using virtual cymbals that are spatialised with Spat (IRCAM).

Loki's Pain grows out of the author's previous work with sonification of geodata (Lindborg 2017, 2018). The artwork aims to remind visitors of the fragility of the Earth's crust, and the reality faced by people exposed to the terrifying power of earthquakes and volcanic activity.

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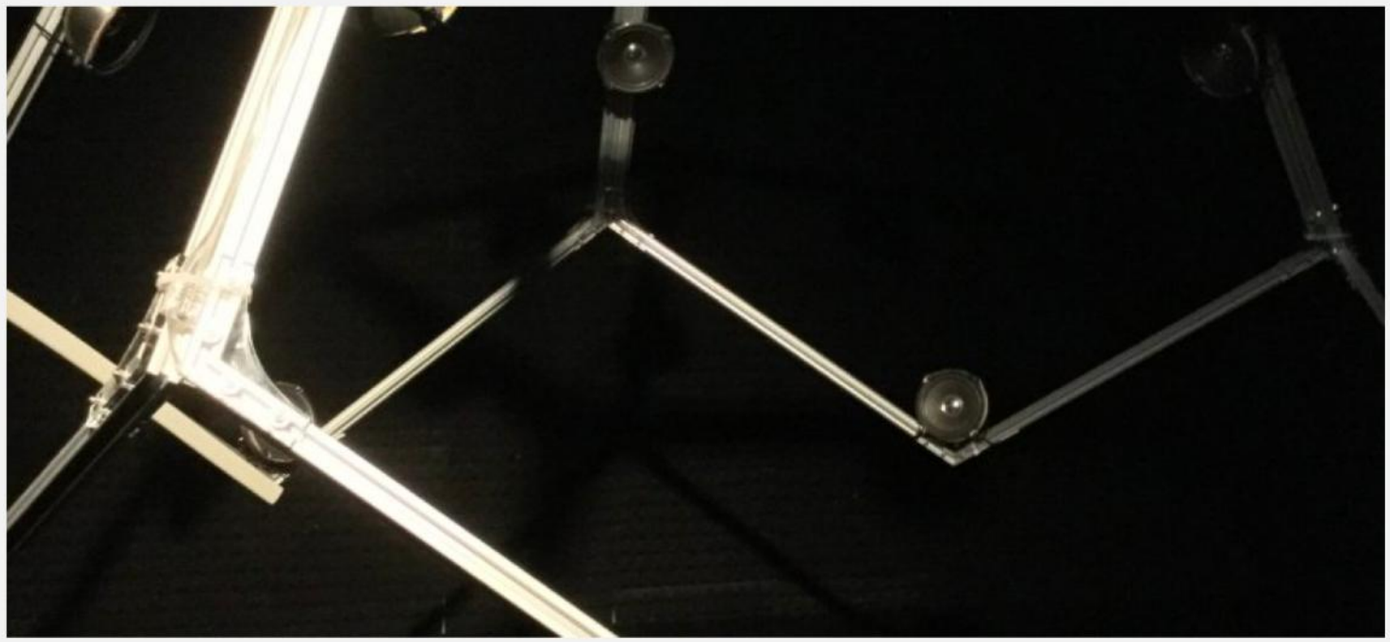
soundislands.com

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PROJECTS | PEDAGOGY | EVENTS | ABOUT



00:00 00:00

LOKI'S PAIN

STICKY ON: 2021-01-21 | IN: 2020, 2021, COMMISSION, EVENT, INSTALLATION, MULTIMEDIA

Loki's Pain (PerMagnus Lindborg 2020) is an immersive audiovisual installation. Visitors take the place of Viking god Loki, who is chained underground and tormented with dripping venom; his painful writhing is the cause of earthquakes. Loki's Pain follows Pacific Belltower (Lindborg 2017), live sonification of Internet seismological data. PerMagnus thanks Curators Richard Allen and Jeffrey Shaw, and Gallery Director Isabelle Frank for their support, Alvaro Cassinelli for inspiration, and Abby Yuen Hui Ching 袁栩晴 and

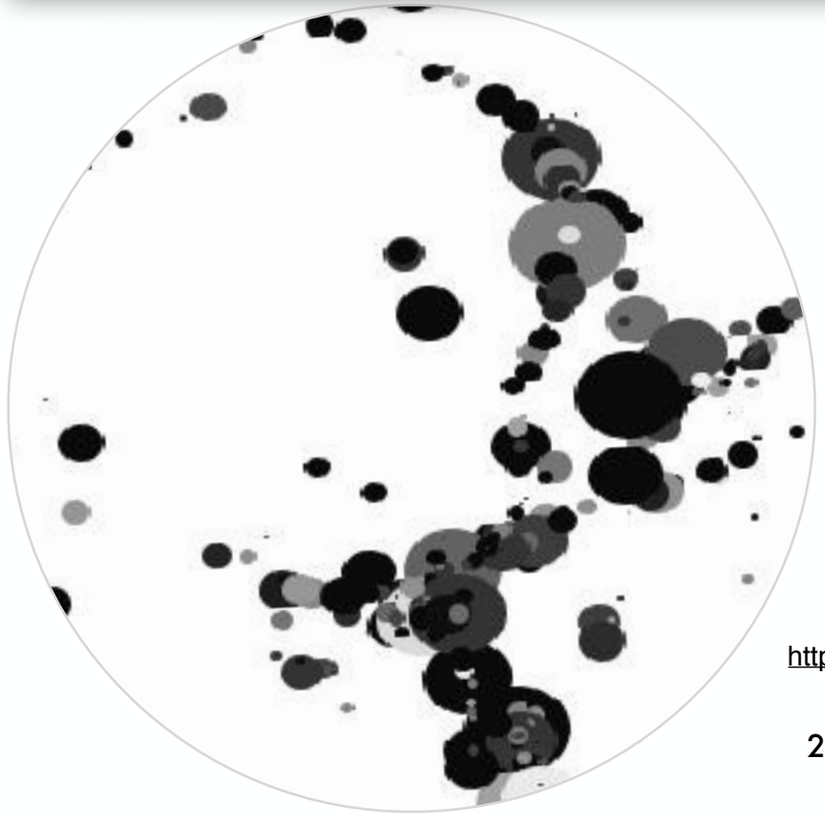
ABRSM artsfission artwork Award collaborative commission concert dance discovery ensemble ESKYIU Esplanade event exhibition festival film GCA Godot Good Company Arts Herrenhaus Edenkoben Hong Kong New Music Ensemble ICMC installation International Computer Music Conference KPO listening litterature Max music National Museum of Singapore perceptualisation project research Singapore International Festival of the Arts sonification sound design Soundislands Festival soundscape strings text The Arts House theatre theory World Stage Design WSD

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Pacific Belltower

Interactive installation for live sonification of Internet earthquake data.

Pacific Belltower is a sonification installation about earthquakes. Twice every hour, the installation plays a peal of virtual bells, lasting one minute. Each peal is unique. It is generated in real-time from Internet data that represent the most recent earthquakes. The bell sounds are spatialised according to the geographical location of events; pitch reflects epicentre depth, and harmonicity reflects magnitude. The Pacific Belltower tolls to remind of the fragility of the Earth's crust, and the reality faced by people around the Pacific Ocean (and elsewhere) exposed to the terrifying power of seismic activity.



Xuhui Art Museum *Shanghai, China,*
ICMC *jury selection, 15-20 Oct. 2017.*
Yale-NUS *College, Singapore,*
11–14 Nov. 2016.
Volume #2 *Symposium*, **Aalto University**,
Finland, 22–25 Nov. 2016.
ADM *Exhibition Grant 2016.*

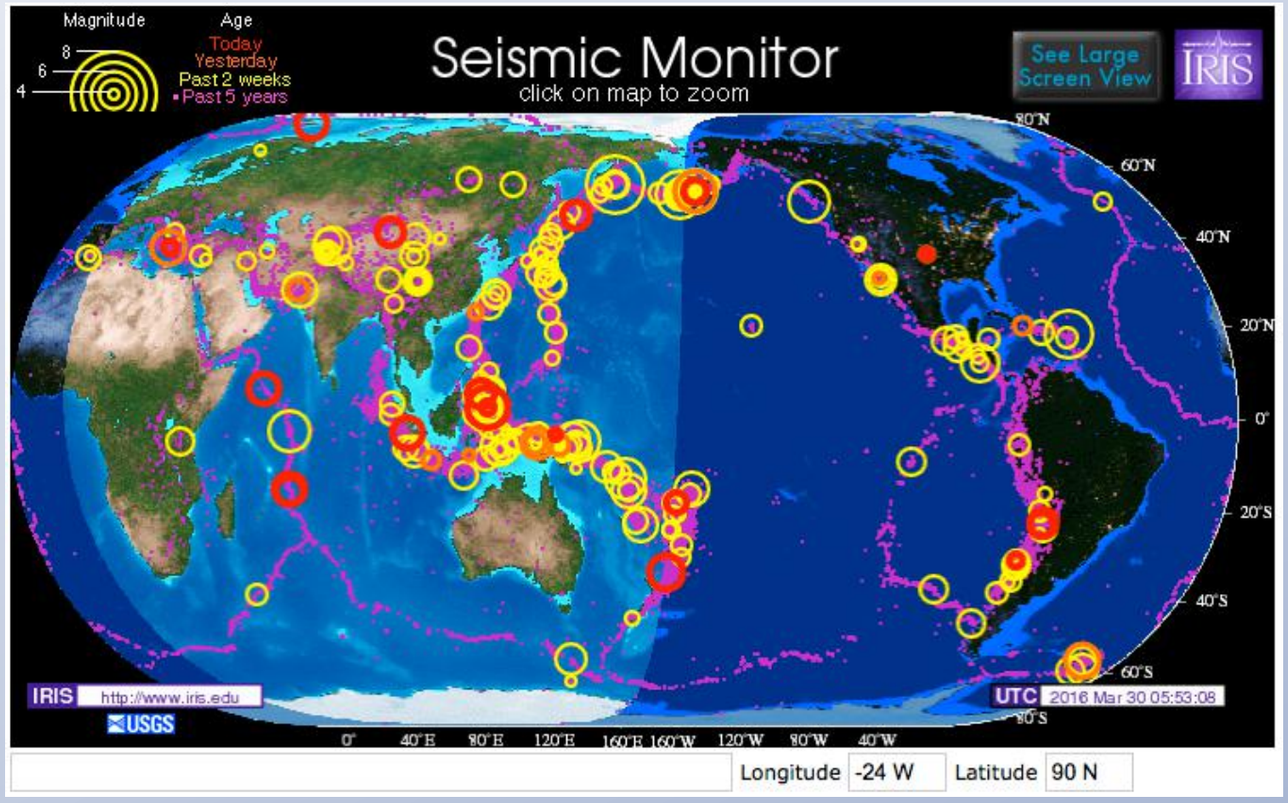


https://vimeo.com/272068981#t=309s

http://soundislands.com/2020/01/16/pacific-belltower/

Loki's Pain (2020)

a sculptural sound installation for
[live] sonification of earthquake data



http://www.iris.washington.edu/seismon/eventlist/index.phtml

Internet

data parsing

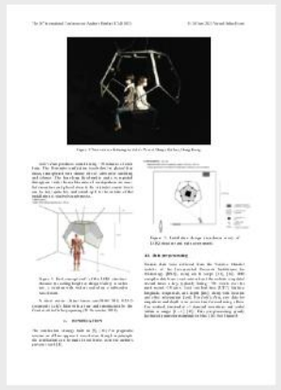
visualisation

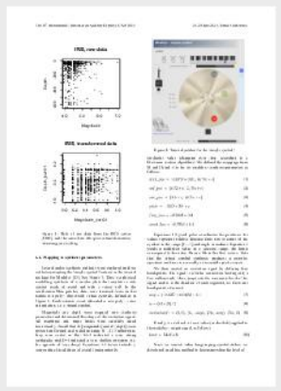
parameter mapping

sonification

spatialisation







The 26th International Conference on Auditory Display (ICAD 2021) 25–28 June 2021, Virtual Conference

FEELING LOKI'S PAIN: DESIGNING AND EVALUATING A DIY 3D AUDITORY DISPLAY FOR GEODATA SONIFICATION

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Hong Kong SAR
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ABSTRACT

Loki's Pain is an immersive 3D audio installation artwork, a sonification of seismic activity. Visitors take the place of Loki, who was punished by the gods and caused earthquakes. We designed an auditory display in the shape of a hemi-dodecahedron and built a prototype with a low-budget, DIY approach. Seismic data were retrieved from the Internet. Location, magnitude, and epicentre depth of hundreds of recent earthquakes were sonified with physical modelling synthesis into a 10-minute piece. The visitor experience was evaluated in a listening experiment (N = 7), comparing the installation with a version for headphones. Differences on eight semantic scales were small. A content analysis of focus group discussions nuanced the investigated topics, and qualitative interpretation strengthened the quantitative findings. Verbal expressions of immersivity were stronger in the installation, which stimulated longer and more detailed responses. Aspects such as audio quality, the structure's physical-visual shape, and multisensorial design evoked both positive and negative emotions, and elicited imagination and memory recall. However, the assumed capacity of the LOKI structure to stimulate a richer social experience than that of headphone listening was not supported by the responses in this study.

1. LOKI'S PAIN

Loki's Pain[a] is an immersive sound installation: a 16-channel 3D audio sonification of seismic activity [1]. Visitors take the place of Loki, who, according to a Norse legend, was "punished by the gods by being chained to three rocks in a cave using the entrails of his dead son, with a venomous serpent poised above his head. When the serpent's poison fell on Loki's head it caused him to shake uncontrollably, thereby according to the geographical location of seismic events, as if they found themselves at the centre of planet Earth. *Loki's Pain* continues the author's work with geodata sonification and the LOKI structure builds on his previous designs of loudspeaker arrays [3], [4], [5], [6].

2. LOKI STRUCTURE

The LOKI structure is a hemi-dodecahedron and it was designed from scratch with inspiration from [7], [8]. The author and his assistant cut 30x aluminium profiles (T-slot Extrusion, 20 mm wide and 750 mm long), fabricated 160x laser-cut acrylic parts of three kinds, and assembled parts with 140x nuts/bolts and 40x cable ties. The final structure is ~220 cm wide, ~75 cm tall, and weighs ~25 kg. It has four ∩-fittings so as to be suspended from the ceiling grid with adjustable-length hooks and four 1.5 mm coated wires. The total cost of materials and a few special tools was ~4,500 HKD (~800 USD) and took an estimated ~80 man-hours to make.

The structure was fitted with 15 custom-made 'bowl speakers' from a previous project [6]. Audio cables were run from the loudspeakers upwards, so as not to interfere with visitor movement, to a small platform concealed in the Gallery ceiling grid. The platform supports the audio playback system, consisting of two 8-channel fixed-media players (WavePlayer8), two 8-channel custom-built pre-amplifiers, two 4-channel power amplifiers (Pioneer GMX84), and a 12V DC power supply. The purchase cost of this equipment was ~1,600 USD. It took ~20 man-hours to assemble, install, and tune the piece on site. A single AC on/off switch was handled by the Gallery personnel every morning. More information and photos from the construction and installation are available on the project website (http://soundislands.com/2021/01/21/lokis-pain/).

Stairway to Helheim


Eight-channel site-specific sound installation
PerMagnus Lindborg

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STICKY ON: 2021-11-10 | IN: 2021, EVENT, INSTALLATION

by PerMagnus Lindborg (2021). Eight-channel site-specific sound installation for Soundislands: Re:Sound at ArtScience Museum, Singapore. Stairway to Helheim is a sonification of meteorological data for Hong Kong covering 138 years, between January 1884 and September 2021, of daily rainfall and temperature, monthly 'hot nights' and 'hot days', as well as yearly sea level averages in Victoria Harbour. The data were calculated from files graciously provided by Hong Kong Observatory. A total of 1654 rows of

ABRSM artsfission artwork Award commission composition concert dance data art debut documentary environment ESKYIU Esplanade event exhibition festival film GCA Godot Good Company Arts HKNME Hong Kong ICMC installation International Computer Music Conference Korea KPO listening Max multimedia music music video perceptualisation project Singapore Singapore International Festival of the Arts sonification sound design Soundislands Festival soundscape strings text The Arts House theory

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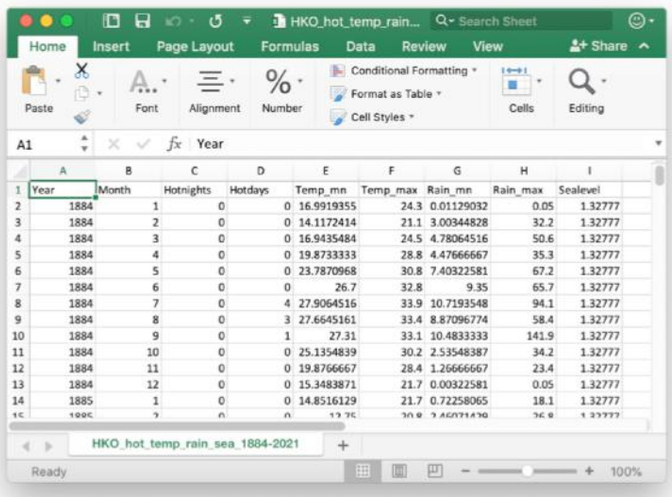
Stairway to Helheim

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Abstract

In Norse mythology, Helheim is the lowest part of the afterworld: the world of the dead. It is ruled by the goddess of death, Hel, a daughter of Loki. As visitors tread the steps of the central staircase of the Run Run Shaw Creative Media Centre, they are met with sonic objects falling onto them; cascading down the steps; obscenely bouncing like yoga balls, a hundred tennis balls, a thousand ping pong balls; splashing incessantly against their head as if they are crawling up a river; heavy objects crashing into invisible walls; objects sliding stealthily in the opposite direction…. The stream of sonic objects seemingly never-ending, the visitors will nevertheless eventually succeed to reach the highest floor. Released from the struggle, they float serenely into the calm of the top level – is Helheim a Parnassum, or is it Purgatory? Or is it another test altogether?

Sonification

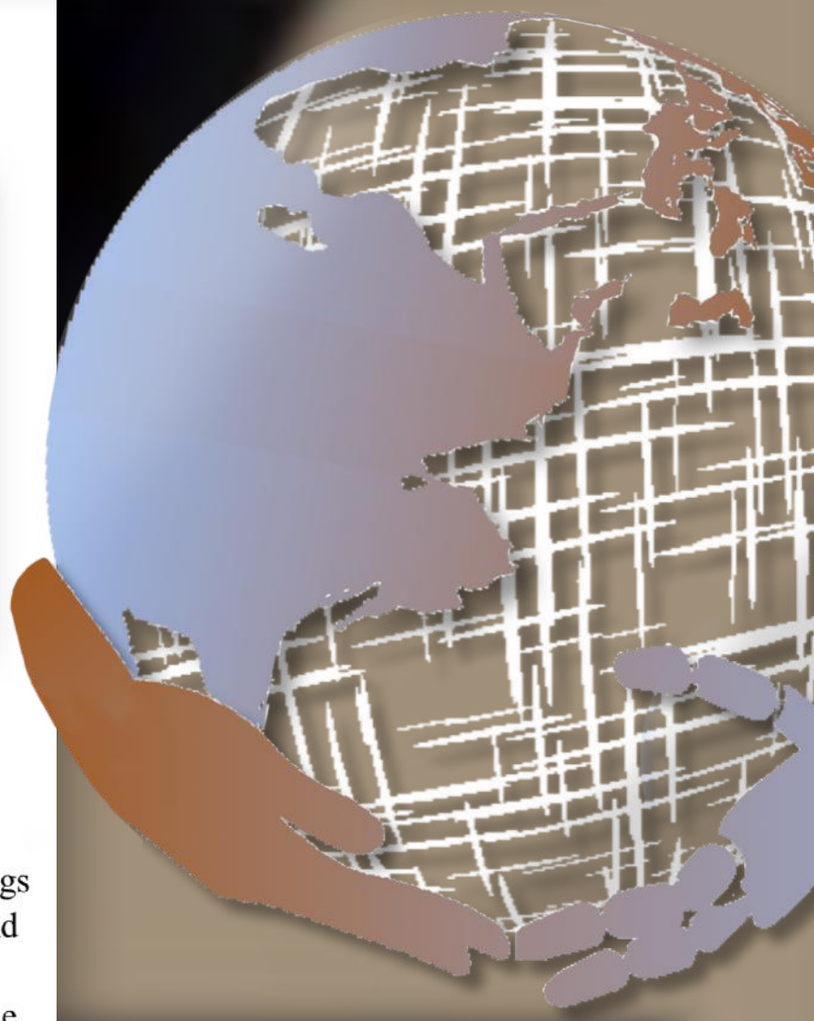


Year	Month	Hotnights	Hotdays	Temp_mn	Temp_max	Rain_mn	Rain_max	Sealevel
1884	1	0	0	16.9919355	24.3	0.01129032	0.05	1.32777
1884	2	0	0	14.1172414	21.1	3.00344828	32.2	1.32777
1884	3	0	0	16.9435484	24.5	4.78064516	50.6	1.32777
1884	4	0	0	19.8733333	28.8	4.47666667	35.3	1.32777
1884	5	0	0	23.7870968	30.8	7.40322581	67.2	1.32777
1884	6	0	0	26.7	32.8	9.35	65.7	1.32777
1884	7	0	4	27.9064516	33.9	10.7193548	94.1	1.32777
1884	8	0	3	27.6645161	33.4	8.87096774	58.4	1.32777
1884	9	0	1	27.31	33.1	10.4833333	141.9	1.32777
1884	10	0	0	25.1354839	30.2	2.53548387	34.2	1.32777
1884	11	0	0	19.8766667	28.4	1.26666667	23.4	1.32777
1884	12	0	0	15.3483871	21.7	0.00322581	0.05	1.32777
1885	1	0	0	14.8516129	21.7	0.72258065	18.1	1.32777

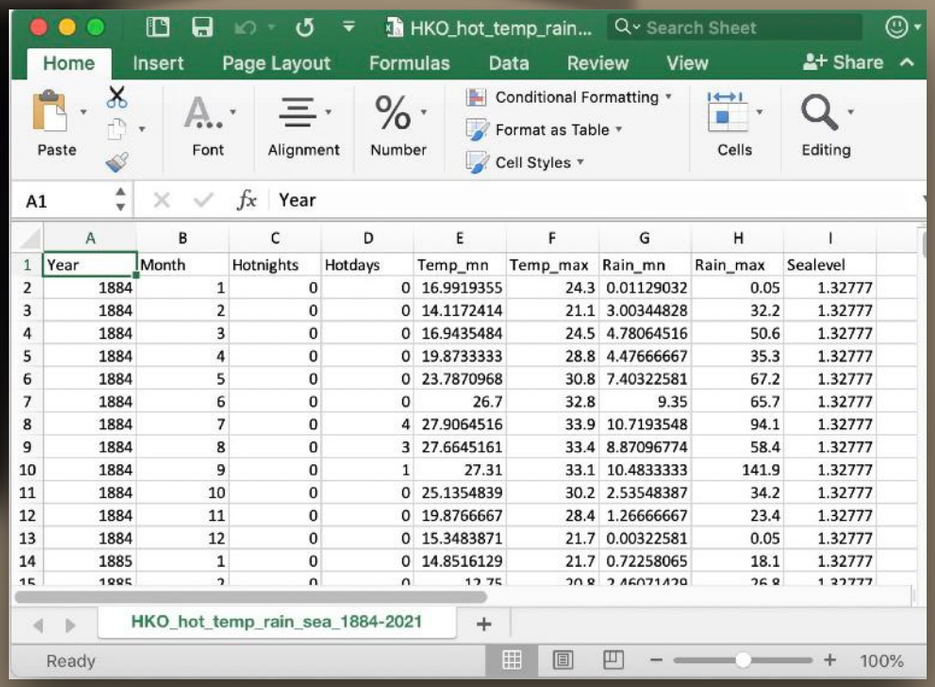
Fig 1. Weather data in CSV format used for the signification.

Sonic material

The sonic material was based on action recordings of sound objects such as chairs, bottles, balls, and compact discs, made in October 2021 at SoundLab, City University of Hong Kong, by the



Stairway to Helheim



	A	B	C	D	E	F	G	H	I
1	Year	Month	Hotnights	Hotdays	Temp_mn	Temp_max	Rain_mn	Rain_max	Sealevel
2	1884	1	0	0	16.9919355	24.3	0.01129032	0.05	1.32777
3	1884	2	0	0	14.1172414	21.1	3.00344828	32.2	1.32777
4	1884	3	0	0	16.9435484	24.5	4.78064516	50.6	1.32777
5	1884	4	0	0	19.8733333	28.8	4.47666667	35.3	1.32777
6	1884	5	0	0	23.7870968	30.8	7.40322581	67.2	1.32777
7	1884	6	0	0	26.7	32.8	9.35	65.7	1.32777
8	1884	7	0	4	27.9064516	33.9	10.7193548	94.1	1.32777
9	1884	8	0	3	27.6645161	33.4	8.87096774	58.4	1.32777
10	1884	9	0	1	27.31	33.1	10.4833333	141.9	1.32777
11	1884	10	0	0	25.1354839	30.2	2.53548387	34.2	1.32777
12	1884	11	0	0	19.8766667	28.4	1.26666667	23.4	1.32777
13	1884	12	0	0	15.3483871	21.7	0.00322581	0.05	1.32777
14	1885	1	0	0	14.8516129	21.7	0.72258065	18.1	1.32777
15	1885	2	0	0	12.75	20.8	2.46071429	26.8	1.32777

HKO_hot_temp_rain_sea_1884-2021

Ready

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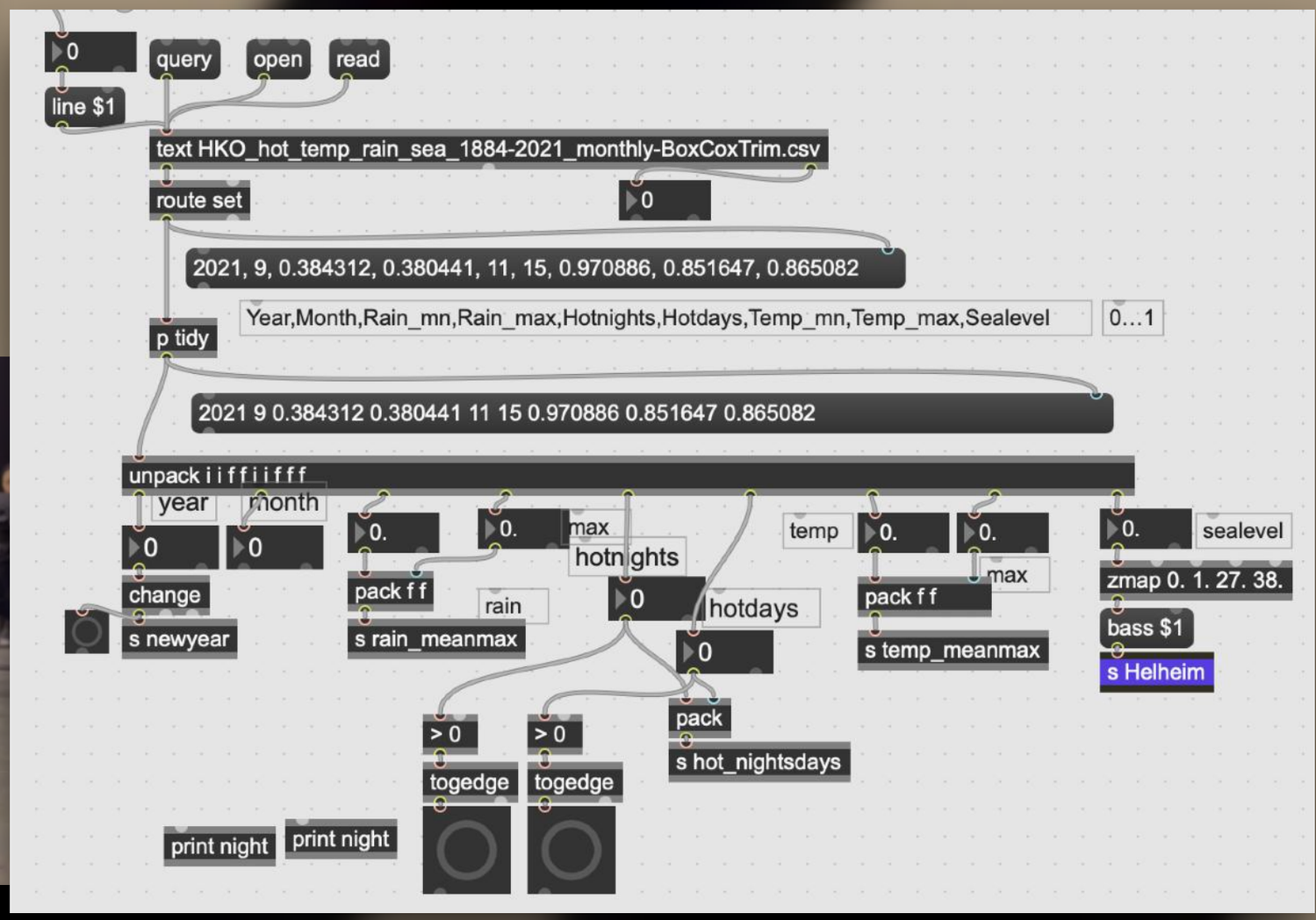
138 years of meteorological data provided by Hong Kong Observatory

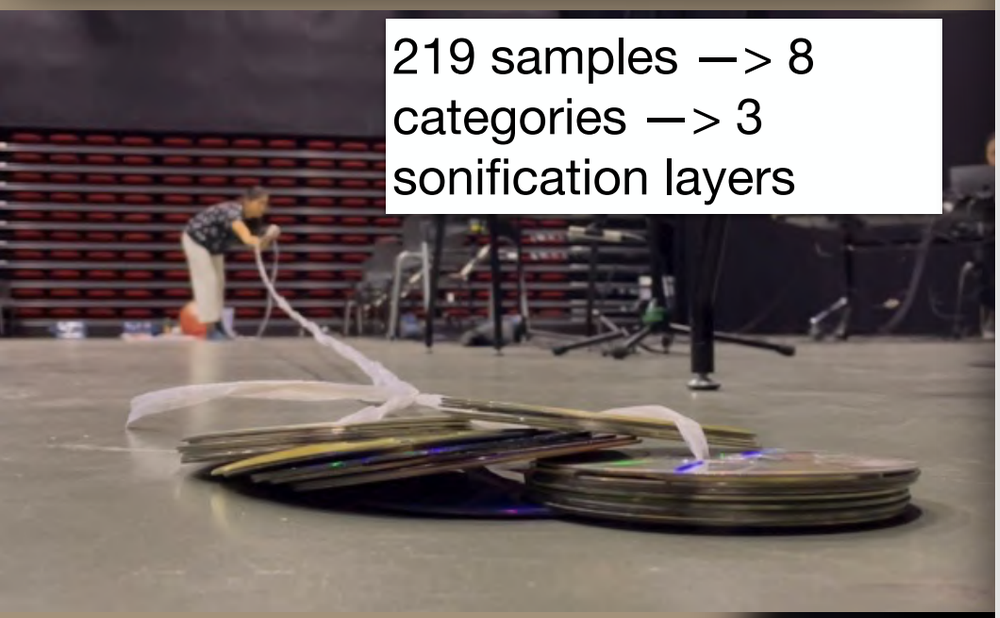
pre-processing (R: Box-Cox transformations, scaling)

sonification (Max)

sea water level —> tonality

temperature —> original–sawtooth cross-synthesis





219 samples —> 8 categories —> 3 sonification layers

Conferences

International Community for Auditory Display. “ICAD is a forum for presenting research on the use of sound to display data, monitor systems, and provide enhanced user interfaces for computers and virtual reality systems.” https://icad.org/

Interactive Sonification. “an emerging subfield of sonification and auditory display research… acknowlegdes the importance of human interaction for understanding and using auditory feedback.” https://interactive-sonification.org/

Sonification.de “Sonification – the auditory equivalent of scientific visualization – is gradually becoming more and more established”. https://sonification.de/

Books

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