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# Radio Explorations: Architectonic Studies of Electromagnetic Milieux

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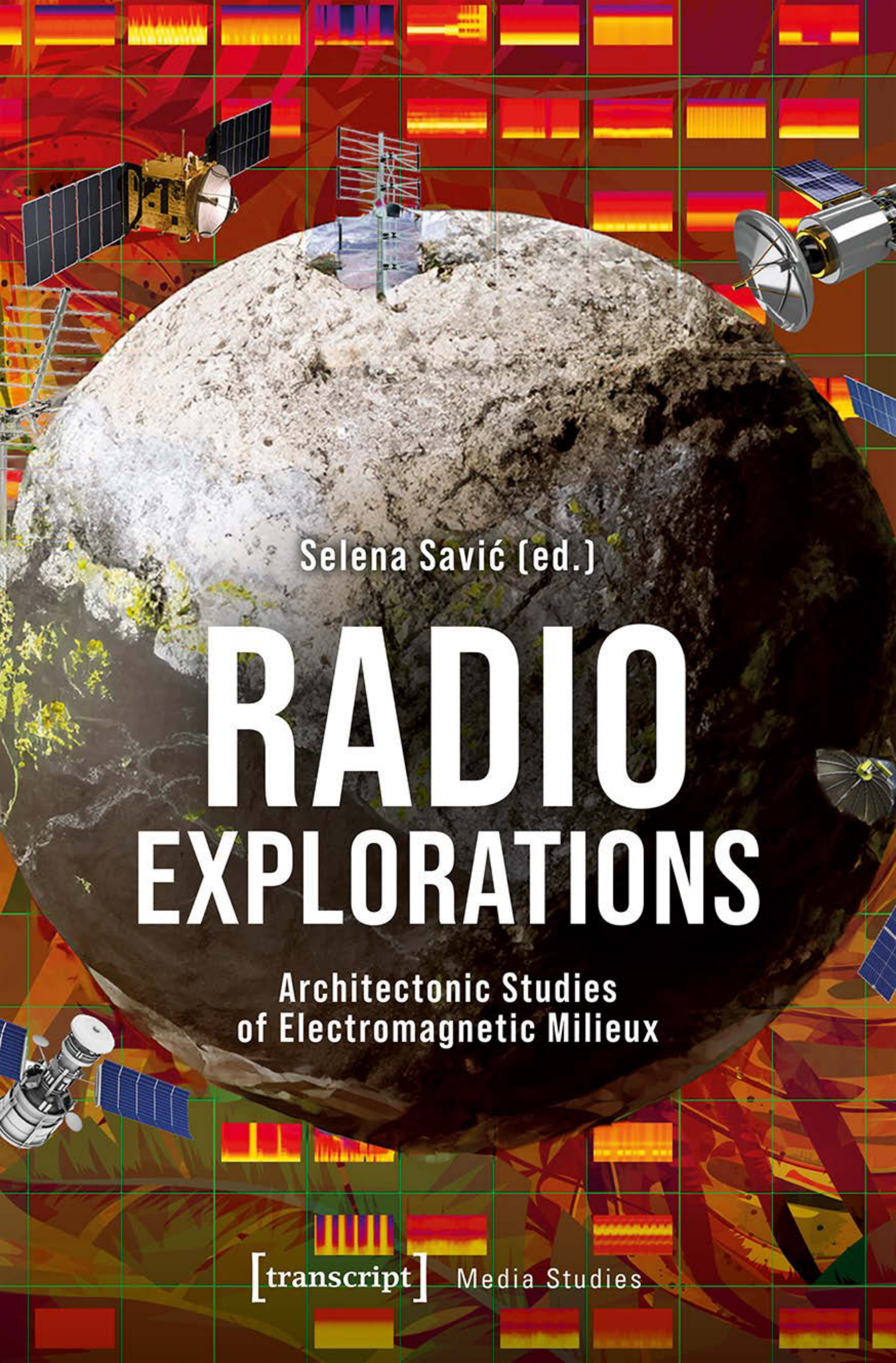
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Selena Savić (ed.)
Radio Explorations

**Media Studies** | Volume 112

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Selena Savić (ed.)

# Radio Explorations

Architectonic Studies of Electromagnetic Milieux

[transcript]

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*To my electromagnetic companions with attitude*

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# Introducing Radio

# Architectonic Explorations of Radio

*Selena Savić*

## Introduction

The book *Radio Explorations* engages with digital data on radio signals to trace the entanglements of nature and culture in this electromagnetic medium. The wider scope of this effort is to challenge the foundational essentialization of opposites in modern conceptions of the world – body-mind, nature–culture, matter-information, one and the other – and to do that by exposing the necessity of an intersectional perspective on technology. Radio signals do not easily fit the categories: they can be 'natural' (i.e., solar storms) and 'cultural' (i.e., telecommunications); they are 'immaterial' and yet able to transport information across space.

This book is the result of a practice-based exploration of digital and computational processes, materiality of radio signals and the promise of data self-organization. Rooted partly in practice of experimental design, and partly in feminist new materialism and intersectionality, this research reimagines what it means to know radio signals, that is, to articulate an architectonic position engaging with their material, informational, mediating, political and social aspects. While this research can claim none of the academic fields it visits as its own, it seeks to frame the problem of the conceptualization of radio signals as an interdisciplinary problem that relates and connects different disciplines, without reducing them to one dominant view. The diversity of contributions in the present volume demonstrates the importance of intersectional perspectives on radio signals, digital archives, and technical artefacts more generally. Radio cannot be known through engineering knowledge alone, nor can it be reduced to a singular disciplinary perspective. In *Data Feminism*, Catherine D'Ignazio and Lauren F. Klein[1] engage with intersectional analysis of the ways in which systems for data collection and classification perpetuate oppression. They recognize an initial impasse: to be put to use, data must be classified in some way, as Geoffrey Bowker and Susan Leigh Star pointed out[2]. Once the system works, it becomes 'naturalized'. To question classification is a feminist concern: how are people divided in categories by age, gender, race, place of birth or postal code?

The collection of texts presented here documents the encounter of invited artists, architects and scholars at two research meetings held as part of the research project *Negentropic Explorations of Radio*[3] (2020–21). This collection is complemented by two interviews which extend the perspective on radio between technical expertise of telecommunication and artistic concerns for the materiality of energy. The starting point for the discussions and reflections in this volume is the experimental design engagement with digital information, which itself starts from a digital archive, the Signal Identification Guide (SIGID).[4] The SIGID wiki documents listening practices of a community of radio amateurs and enthusiasts. Recordings of radio signals 'in the wild' can capture the interest of a telecommunications engineer, a media archaeologist, a data scientist, an ecologist, a historian of science and technology. The outcome of the experimental work with the data are two 'data observatories' which pro-

1 Catherine D'Ignazio and Lauren F. Klein, *Data Feminism* (Cambridge, Massachusetts: MIT Press, 2020).

2 Geoffrey C. Bowker and Susan Leigh Star, *Sorting Things out: Classification and Its Consequences*, 1st paperback edition, Inside Technology (Cambridge, Massachusetts London, England: The MIT Press, 2000).

3 Documentation of the SNSF-funded project Negentropic Explorations of Radio (SNSF 190310) is available at: http://radioexplorations.ch (accessed 11.12.2021).

4 The SIGID guide wiki is a collection of digital recordings of radio signals captured 'in the wild' by the wiki contributors. Information on the signals is gathered mainly for the purpose of identifying signals by this community of radio amateurs. All recordings and descriptions are available here: https://www.sigidwiki.com/ (accessed 11.12.2021).

pose intuitive ways to orient oneself across different aspects of digital data: categories, features, similarity.

## Encountering radio signals

In the summer of 2009, at a workshop on *Data Forensics and Urban EM interventions* at Haus der Kulturen der Welt (HKW) in Berlin, participants learned to use open-source Wi-Fi network analysis tools and build *cantennas* from scrap material. Artists Martin Howse and Julian Oliver who led the workshop, problematized the 'leaking' of private, secured networks into public space, and access to networks more generally. Howse and Oliver were active within an artistic scene that explored networked media and communication through hacking, visualization and playful interference. As one of the participants at the HKW workshop, I became interested in materiality of wireless networks and other radio signals, which gradually developed into the research that addresses materiality of signals as data and energies, discussed in this book.

A couple of years after the HKW encounter, an important discovery hit network-aficionado communities. Engineers gathered around the open-source mobile communications project (osmocom)[5] found a way to turn small USB dongles, made for digital television (DTV) reception, into computer-based radio scanners. The discovery of this affordable software-defined radio (SDR) opened the specialized domain of electromagnetic engineering and research to tech-savvy radio amateurs. The use of RTL-SDR proliferated and a community formed around it, curious to explore the radio space.

The struggle to access and understand the propagation of Wi-Fi networks lead Carl Colena, a computer engineer and a student at the City College of New York at that time, to purchase a small electronic device

5 The project documents the way DVB-T dongles based on the Realtek RTL2832U can be used as a cheap SDR, as described here: https://sdr.osmocom.org/trac/wiki/rtl-sdr.

made for digital television reception (DTV) to understand the Wi-Fi environment at the college campus and orient himself towards stronger signals.[6] Gradually, his interest in radio signals lead him to become one of the main contributors and eventually the administrator of the Signal Identification Guide (SIGID) wiki website, which documents radio signals recorded 'in the wild'. The SIGID wiki project dates back to 2014, when Carl Laufer, the owner of the RTL-SDR radio amateur blog, started a centralized database of radio signals that could be recorded using this accessible equipment. The SIGID wiki website is a collection of all the information about radio signals that is held among a community of amateurs and enthusiasts, in form of a digital archive. It includes digital recordings of signals, as well as textual descriptions and meta-data in an online database. This digital archive is the starting point and the source of data for radio explorations discussed in this book.

## Encountering data: the architectonic disposition of a dataset

Different domains of theory and practice related to radio and telecommunications would approach the systematization of radio signals knowledge each with their own specific set of questions. An information studies scholar might focus on protocols and modulations, ways to keep track of different properties of signals and organize this knowledge in the archive. A data feminist might problematize these archival practices, looking into the way differences among signals have been naturalized (or not), as well as the presence of certain types of transmissions and certain archivists in the archive. A data visualization scholar could bring forward the importance of paying attention to methods that transform unobservable phenomena, such as radio, into visual systems that give us access to relationships between data on signals. What can recordings of radio signals tell us that we do not already know in theory? And how could we move across these different domains, without trading

6 See interview with Carl Colena in this volume.

the depth and span of expert knowledge for general understanding of communication technologies?

Large datasets form the basis of patterns and predictions identified in algorithmic operations of contemporary computational practices. In an article about historical technologies of information management, Shannon Mattern questioned if patterned data can ever be considered meaningful information. She noted that data, "in both its digital and analogue forms, has long been transformed into spectacle and packaged as a critical tool for cultural transformation."[7] What else, besides patterns or spectacle, might we see in data on radio signals?

Machine learning algorithms and artificial intelligence are often discussed in term of *black boxes* in engineering circles today. The *black box* articulation currently in circulation is rooted in post-World War II cybernetics and psychology research, where it was used to generalize a notion of systems so that the effects could be observed independently from their operation on an established consistency of inputs and outputs. Science and technology studies cultivated an interest in the black box of scientific facts, notably in the writings of Bruno Latour such as his collection of essays entitled *Pandora's Hope*.[8] With the box opened and absolute truth out of sight, Latour suggested, the only thing to do is to go deeper to reach the hope at the bottom. Importantly, Latour did not propose to simply smash black boxes open with hammers. Felix Stalder poignantly reminds us: "Treating complex systems as black boxes is a way of reducing complexity and this is often a very sensible thing to do."[9] Still, he continued, we can distinguish between an old and a new kind of black: between systems whose logic is accessible to specialized knowledge and systems whose elements are non-transparent even to the people who built them.

7 Shannon Mattern, "The Spectacle of Data: A Century of Fairs, *Fiches*, and Fantasies," *Theory, Culture & Society* 37, no. 7–8 (December 2020): p 136, https://doi.org/10.1177/0263276420958052.

8 Bruno Latour, *Pandora's Hope: Essays on the Reality of Science Studies* (Cambridge, Massachusetts: Harvard University Press, 1999).

9 Felix Stalder, "The Deepest of Black. AI as Social Power," *Entangled Realities – Living with Artificial Intelligence Exhibition Catalogue*, May 9, 2019, http://felix.openflows.com/node/539

The view of the process gets lost among layers of computational routines initiated with a couple of parameters and goals towards which to optimize the 'learning' or 'training' process. The question is, what should we do with these systems, given that they cannot be simply opened, while slowly creeping into every aspect of anticipation, without much accountability.

The method of working with digital data discussed in this book is inspired by the notion of *architectonic disposition*, articulated by Vera Bühlmann in *Posthuman Glossary.*[10] This method implies a volumetric thinking model that puts nature (the given or potential), the observable (a layout, a ground) and the viewing operation (perspective) into a volumetric relationship of proportionality. This method is inspired by a historical experimental approach of the ancient Greek mathematician Thales of Miletus to geometric measurement. Michel Serres described in the *Origin of Geometry*[11] how Thales measured the height of the Great Pyramid of Cheops. He established a proportionality between the height of a wooden stake and the height of the pyramid through the lengths of their shadows cast in the sand, establishing a space of similarity. The pyramid could not be measured directly, not only due to physical difficulty, but also because it would be considered a gesture of sacrilege to the pharaoh. Having no access to the pyramid itself, Thales turned to the sun to speak about it: "he asks the object in motion to provide a constant flow of information about the object at rest."[12]

Consider again the black box. As Latour pointed out, we might open it but find almost nothing there.[13] Serres' figure of the Harlequin, the Emperor of the Moon, is even more explicit: Harlequin's composite body dressed in a thick layer of coats, each made of thousand pieces and

10 Vera Bühlmann, "Architectonic Disposition: Ichnography, Scaenography, Orthography," in *Posthuman Glossary*, ed. Rossi Braidotti and Maria Hlavajova (London: Bloomsbury, 2018).

11 Michel Serres, *Hermes. Literature, Science, Philosophy*, ed. Josué V. Harari and David F. Bell (Baltimore: Johns Hopkins University Press, 1982) see Part II, chapter 10. The Origin of Geometry, pp 125–133.

12 Serres, p 87.

13 Latour, *Pandora's Hope*.

colours of clothes stitched together, withstands any methodical analysis: no amount of undressing will reveal its true nature.[14]

## Radio explorations and materiality of information

The book and the project *Architectonic Explorations of Radio* demonstrate ways to work with abstract datasets, computational training processes, and to understand situated yet invisible radio transmissions. The transmissions are situated by virtue of being recorded by specific people, on specific locations on Earth, and included in the database on radio signals, SIGID wiki. A wiki user can compare a signal they recorded in the wild to signals organized in the database, using some form of classification – according to the frequency band, or broadcast category – looking for a match. This identification process relies on profound and often implicit knowledge of signal engineering and experience of having 'heard' or 'seen' a signal before.

One of the premises of this book is to question the way we order things. This builds on the well-known work by Susan Leigh Star and Geoffrey Bowker[15] who saw classification as essential to any working infrastructure. With an interest in difference, or similarity, between the way people and machines perform intuitive pattern recognition, they propose a method for re-ordering digital information. This method is based on the development and use of *data observatories* to organize and explore concrete manifestations of radio signals, using the self-organizing map (SOM) – an unsupervised machine learning algorithm. The *digital observatories* enable the complex, mediated observation of radio sig-

14 Michel Serres, *The Troubadour of Knowledge*, Studies in Literature and Science (Ann Arbor: University of Michigan Press, 1997).

15 Susan Leigh Star, "The Ethnography of Infrastructure," *American Behavioral Scientist* 43, no. 3 (November 1, 1999): 377–91, https://doi.org/10.1177/00027649921955326; Bowker and Star, *Sorting Things Out*.

nals through publicly available web-based interfaces.[16] We can approach a *data observatory* more like an instrument rather than a tool – an instrument to measure and perform multidimensional information. Architect and researcher Miro Roman, one of the contributors of this book, articulated such an instrument as a 'double articulation' of algorithm and data[17], loosely based on Deleuze's and Guattari's notion.[18] The instrument brings into relationship the person playing it, the radio signals in the environment, and the digital data from the SIGID database. It is a partial and engaged method that brings out different voices from the dataset.

This book does not seek to lay open the black box of machinic reason performed by the SOM algorithm. Rather, it inquires into the possibility of "digital literacy": a sensorial and cognitive coupling with digital information which enables one to play with it like an instrument. Digital literacy is about practicing intentionality: articulating ways to index data by a situationally meaningful criterion.

This book and research project aim to facilitate speculation on the connection between signal representation and technical communication protocols, by shifting criteria of similarity from taxonomical and instrumental (e.g. used in military) or physical (e.g. high or low frequency), to properties shared across all signals – such as the probability of silence or noise in the signal. If the challenge today is not to separate artificial from natural or information from noise in banal or fixed ways, it is in the interaction with this information that we should look for the ways to articulate productive differences.

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16 The two *data observatories* developed in this project are available online, as *Descriptions* https://radioexplorations.ch/descriptions/ and *Projections* https://radioexplorations.ch/projections/ (accessed 21.06.2022).

17 Miro Roman, *Play Among Books: A Symposium on Architecture and Information Spelled in Atom-Letters*, Applied Virtuality Book Series 17 (Basel: Birkhäuser, 2022).

18 Gilles Deleuze and Félix Guattari, *A Thousand Plateaus: Capitalism and Schizophrenia* (Minneapolis: University of Minnesota Press, 1987) see chapter 3. 10,000 B.C.: The Geology of Morals (Who Does the Earth Think It Is?) pp. 39–75.

## Structure of the book

The special approach to radio signals, digital information and their materiality is introduced in a discussion with two interviewees: Douglas Kahn, the author of two books on the use of radio and energy more generally in the arts[19] and Carl Colena, the administrator of the SIGID wiki website. Douglas Kahn talked about the phenomenon of natural radio, its use in the arts as well as in climate science. Carl Colena introduced the background of the SIGID wiki project, related listening and knowledge practices and the community's archival strategies.

The second chapter presents essays that emanated from the research meeting on *Technicity of Listening* – knowledge, tools and approaches to digital data. Three invited guests, Carl Colena (SIGID wiki), Miro Roman (CAAD, ETHZ) and Simone Conforti (IRCAM) presented their current research into archives of radio signals, images, books and music, as well as strategies for articulating profiles and identities with data.

The third, intermezzo chapter documents the 'data observatories.' They were presented as a starting point for exchanges by the research team, Selena Savić and Yann Patricks Martins. The first *data observatory* called *Descriptions* was discussed at the first workshop meeting, while the prototype of the second data observatory, *Projections,* was discussed in terms of rewriting radio signals through different domains, such as music or sounds of nature.

The fourth chapter presents essays originating from the second research meeting, *Rewriting the Networks*. Together with three invited guests, Sarah Grant (Weise 7 and Kunsthochschule Kassel), Roberto Bottazzi (The Bartlett) and Miro Roman (CAAD, ETHZ), we explored the notion of *rewriting* in context of telecommunications and beyond: how to translate between domains, such as the natural environment and network infrastructures, digital and spatial, books and architecture.

19 Douglas Kahn, *Earth Sound Earth Signal: Energies and Earth Magnitude in the Arts* (Berkeley: University of California Press, 2013); Douglas Kahn, ed., *Energies in the Arts* (Cambridge, Massachusetts: MIT Press, 2019).

The final, post-scriptum chapter presents the findings and outlooks from the project, joined by an invited contribution by artist and researcher Lisa Müller-Trede. Her work is concerned with algorithmic order of difference within merged breath signals. Next to Müller-Trede's essay, this chapter presents the author's approach to understanding radio signal materialities and offers stories and resistance instead of hard discrete data, clusters and predictions.

# Interviews

# Nature of Radio Signals

*Interview with Douglas Kahn*

*Douglas Kahn is a historian and theorist, author of* Noise Water Meat: A History of Sound in the Arts *(1999), and* Earth Sound Earth Signal: Energies and Earth Magnitude in the Arts *(2013). He is Honorary Professor at the University of Sydney and Professor Emeritus at both the University of California, Davis, and the University of New South Wales, Sydney. The interview was conducted by Selena Savić in January 2021 and revised in March 2023*

**Selena Savić:** Your book *Earth Sound Earth Signal*[1] was one of the primary sources of inspiration for the project on *Radio Explorations*. Your writing on the way radio was heard before it was invented can be taken as the guideline for problematizing our knowledge of radio signals and the technicity of listening practices. Because radio can be 'natural' as in electromagnetic energy emitted by lightning, it extends beyond applied engineering knowledge. You mentioned, however, that it would be difficult to consider any radio signal 'natural' because the realignment of weather systems and increase in extreme weather events means a reconfiguration of the incidence of naturally occurring emissions, as discussed in the 1999 article by Reeve and Toumi.[2] Investigating correlation between global lightning activity and global temperature, the authors found a significant correlation between the global increase in temperature and in

1 Douglas Kahn, *Earth Sound Earth Signal: Energies and Earth Magnitude in the Arts* (Berkeley: University of California Press, 2013).

2 N. Reeve and R. Toumi, "Lightning Activity as an Indicator of Climate Change," *Quarterly Journal of the Royal Meteorological Society* 125, no. 555 (1999): 893–903, https://doi.org/10.1002/qj.49712555507.

lightning activity, in the Earth's northern hemisphere. Would you say that everything changes with global warming because all electromagnetic energy that affects the Earth is in a way 'filtered' by our ionosphere, whose properties are changing with increasing heat?

**Douglas Kahn:** The natural in natural radio denoted terrestrial radio that was not generated by humans, and it can refer to extraterrestrial radio in that respect. It was radio that could be heard and otherwise detected but not sent by anyone, radio using communications technologies but not communicating. *Sensing* is a better term and, indeed, so-called telecommunications technologies in the nineteenth century were used both wittingly and unwittingly, scientifically and aesthetically, as sensing devices within the frame of technological variability discussed in the book, that is, a technology designed for one function used for another. Early encounters with natural radio were on the telephone where, in effect, telephone lines and grounds became antennas before antennas. The 'natural' in this case was bolstered by how very low frequency (VLF) radio generated by lightning and other phenomena fell into the audio-frequency range of human hearing with only simple transduction available in preradiophonic technologies. It was heard while listening for other things. Naturalness was retained even after radiophonic technologies, no matter from where the original signal emanated with respect to normative hearing.

The full spectrum electromagnetic bursts of lightning strikes generate dominant forms of natural radio, travelling (transmitting) great distances, bouncing between the ionosphere high in the Earth's atmosphere and the surface of the Earth and, at times, catching a ride on magnetoionic flux lines out into the magnetosphere that reach out about six Earth radii into outer space, and then looping over to the opposite hemisphere, sometimes looping back. When transduced, these huge arcs can be heard as delicate glissandi, a crisp little whistle to the thunder's basso profundo. They are unlikely upper register products of the massive amounts of energy released with lightning. They can travel in the magnetosphere from one 'conjugate point' to another in the opposite hemisphere, a kind of conjugal planetary eroticism. At this very moment we stand one big spark away from gently whistling to our planetary partner, and vice versa. It is not a great relationship because they don't talk often. The flux lines are diaphanously transient and temperamentally dependent upon geomagnetic activity and solar winds, with weather and space weather twisted into an orbital torque. Whistling at Earth magnitude has many moving parts.

The redistribution and severity of weather events involving lightning within an anthropogenically changed climate is the main reason natural radio is less, or no longer, natural. Severity has not merely increased, as predicted decades ago, but accelerated on older models, and incidence of lightning, its spatial and temporal concentration, has changed accordingly. The static, sliding tones, and glissandi now have human content. Lightning's audible anthropogenesis in radio and thunder is an astounding transformation. Lightning was once associated mythologically with the destructive power and moralism of the gods; now it is more of a self-suicidal pact or, rather, asymmetrical omnicide carried on by a tiny class that ignores the logical conclusion of its own fate. The gods are now bourgeois, corrupt and criminal, with a political power that has mated with and mutated lightning to create monsters. They promise everything is under control, but they are not able to control something as down to earth as lightning. They have instead gone troppo, Australian slang for going mad due to hot tropical conditions, Doctor Moreaus in their troposphere. Their lightning makes it difficult to call this radio natural. What does the dry lightning igniting a forest rendered kindling by prolonged drought sound like, or the lightning generated by a pyrocumulus cloud fed by the forest creating its own weather? I saw one such cloud ten kilometres from my home in the Blue Mountains during the recent fires in Australia.

Like many I find natural radio beautiful, and I love lightning and thunder. One night where I live there was so much lightning, for several minutes it seemed like day interrupted by flashes of darkness. I was on top a hill running home, so danger pushed it into the sublime. During thunderstorms I sometimes tune an old transistor radio between stations to listen to the static bursts of lightning, which gives a feeling of being enfolded by weather beyond the horizon; as spatial experience it's much cheaper than wave field synthesis, and in a much larger space. Nevertheless, the beauty is like seeing a sunset and realizing its colours are due to air pollution from a factory in the region. The polluters of natural radio are global, with regional offices. Several years ago, climate modelling became sophisticated enough to validate climate attribution studies, that is, the ability to identify sources and degrees of responsibility for extreme weather events, narrowing it to certain industrial sectors, all of which have ensembles of power populated with individuals and family estates. Oceans tighten around their island tax havens. They have not merely stigmatized the sky and its radio, they are responsible for massive destruction, none of it with the old-fashioned moral authority of myth. They have removed weather events from the list of natural disasters, where earthquakes not caused by fracking remain. I discuss them in my essay, "What is an Ecopath?"[3]

Perception can shift technically, conceptually, and experientially to statistical and turbulent means adequate to hearing the toxicity of this (certain) human content. Playing with perceptual registers is what many artists do; others shift apperception to migrate content toward the tacit. Musicians not only sink sound into muscle memory, they sink hearing. Those who do not play also perform hearing. We are already thinking about and experiencing environments dynamically, in fields and systems, to be ecological in the first place. The frenzy of statistics in AI is already salting the daily lives of many, and quantum computing will begin to range influence once it quits perpetually promising. People hear and otherwise perceive adaptively in many models. In whatever trajectory, we should be able to sense intergenerationally and render dynamic homeostasis with the planet routine. A major experiential conundrum of climate catastrophe is its latency, the delayed effects of emissions released currently, or how ecopaths murder now but hide the bodies in the future. As kids we know the latency of lightning, the distance involved until the thunder arrives. Although we don't always

3 Douglas Kahn, "What Is an Ecopath?," *Sydney Review of Books* Climate Crisis (March 3, 2020), https://sydneyreviewofbooks.com/essay/what-is-an-ecopath

see the flash, the simultaneous static heard is beyond our sight. What is the human content, its care and corruption, across the land in the distance travelled? If music is the art of time, what of latency now that the storms have hit?

**SS:** The starting point for Henri Lefebvre's theory of rhythmanalysis had a medical connotation: it was about observing vibrations in bodily organs to detect anomalies. Do you think that has also changed?

**DK:** Lefebvre's rhythmanalysis had musical inspiration tied to his abilities as an amateur pianist of Western art music with Mozart at the top. His short book, co-written in part by Catherine Régulier,[4] was one of his last writings, so his lifelong musical loyalties would have ruled the day. Since he didn't have time to develop or demonstrate his analysis from closer examination of the sciences and (other) cultural traditions, he defaulted to an abstract and universalist approach. He talks about the rhythms or, rather, polyrhythms of the body as a garland of rhythms, which is merely a simple gesture to what occurs. I would recommend *Rhythms of Life* by Russell Foster and Leon Kreitzman for starters.[5] His own culturally-bound music was a triad of melody-harmony-rhythm, and he thought the third item was most neglected, so neglected that it deserved a new, dedicated branch of knowledge: rhythmanalysis. Another triad, time-space-energy, described the cosmos, and rhythm fit in thusly: "Everywhere where there is interaction between a place, a time and an expenditure of energy there is rhythm."[6] I don't live in that universe. Among the physical and conceptual fields of energies, repetition

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4 Henri Lefebvre and Catherine Régulier, "Le projet rythmanalytique," *Communications* 41, no. 1 (1985): 191–99, https://doi.org/10.3406/comm.1985.1616.

5 Russell G. Foster and Leon Kreitzman, *Rhythms of Life: The Biological Clocks That Control the Daily Lives of Every Living Thing* (New Haven: Yale University Press, 2005).

6 Russell G. Foster and Leon Kreitzman, *Rhythms of Life: The Biological Clocks That Control the Daily Lives of Every Living Thing* (New Haven: Yale University Press, 2005).

is common but not intrinsic and plenty of places among my musical loyalties where one or all of melody, harmony, and rhythm may go missing.

Lefebvre's concept appealed to Gaston Bachelard's earlier writing on rhythmanalysis. Bachelard in turn cited as his touchstone a Lúcio Alberto Pinheiro dos Santos text known only through his quotation of it, since nobody had seen it or could find it since (that may have changed). The 'vibrations in bodily organs' you mention are pharmacologically manifested in his discussion of Pinheiro dos Santos' 'wave biology,' a reference to homeopathy. Bachelard is rightfully suspicious but suspends his doubts to explore the abstract reasoning behind it. His thoughts on rhythmanalysis in general occupy a conflicting, if not convincing, meeting ground of his philosophy of science and elemental poetics, presuming rigor of the former and license of the latter, a schism that Michel Serres pointed out in his published conversations with Bruno Latour.[7]

Lefebvre's elaboration of Bachelard created its own fields of study. What his text lacked ecologically has been introduced by Gordon Walker in *Energy and Rhythm: Rhythmanalysis for a Low Carbon Future*, with the notable goal for remediation through a "general principle of reconnection and return to natural rhythm-energies."[8] It certainly has implications for design. Rhythmanalysis has also played a less practical role in cultural theory over the last decade too, where it has been coupled with 'vibrational ontology,' sound, and music. I distinguish this theory from cultural history in my essay "On Vibrations: Cosmographs."[9] Steve Goodman drew attention to Bachelard and Lefebvre by giving rhythmanalysis its own chapter in *Sonic Warfare*.[10] It is a long way from Mozart to Goodman's electronic dance music. Both moved into a discursive space

7 Michel Serres and Bruno Latour, *Conversations on Science, Culture, and Time*, trans. Roxanne Lapidus (Ann Arbor: University of Michigan Press, 1995).

8 Gordon Walker, *Energy and Rhythm: Rhythmanalysis for a Low Carbon Future* (London: Rowman & Littlefield, 2023), p 169.

9 Douglas Kahn, "On Vibrations: Cosmographs," *Sound Studies* 6, no. 1 (January 2, 2020): 14–28, https://doi.org/10.1080/20551940.2020.1713509.

10 Steve Goodman, *Sonic Warfare: Sound, Affect, and the Ecology of Fear* (Cambridge, Massachusetts: MIT Press, 2012).

that had been vacated by tropes of social harmony, frequency standing in for proportionality, and neither differ significantly from claims made by the Western symphonic repertoire of having privileged access to the universe. Goodman's 'ecology' is free of pollution, climate disruption, species extinction, etc., which would seem required for staging grand panoramas.

Moreover, having music as fundamental for rhythmanalysis seems reductive; energy positions it more appropriately. In Bachelard's *The Psychoanalysis of Fire*, in what may be a first appeal to Pinheiro dos Santos, the concept occurs within a discussion of how the unconscious may be sought in situ in two forms of 'primitivism,' the familiar colonial one, and another populated by those who try to make sense of new scientific and engineering developments without the proper education, laboratories, or professional networks to do so. [11] The latter primitivism mapped an elementary fire onto electricity that produces in the mid-eighteenth century an electrical fire and forms the basis for an electrical theory of the sexes, having the general outlines of those of Wilhelm Reich in the twentieth century derived from Freud's libidinal energetics.[12] Bachelard kindles his own flame explaining the thermal, kinetic, and sexual energies involved in how friction generates fire, whether flint producing a spark, rubbing sticks together long enough, in stormy winds rubbing trees together to set forests ablaze, in the warmth of a caress, or the to-and-fro friction involved in sexual copulation. The repetitive routine of the tasks of rubbing finally sets the stage for passing approval of Pinheiro dos Santos' rhythmanalysis. It seems like a stretch, but it is certainly less bizarre than Freud in *Civilization and its Discontents* talking about the homosexuality of 'primal man' pissing on the phallic flames of a fire while 'woman' is held captive physiologically bearing 'the hearth.'[13] Apart from Bachelard's brief speculation that it was during the prolonged 'gentle

11 Gaston Bachelard, *The Psychoanalysis of Fire*, trans. Alan C. M. Ross (Boston: Beacon Press, 1964).

12 Bachelard, pp 21–28.

13 Sigmund Freud, *Civilization and Its Discontents* (New York, NY: Norton, 2010), Section III, footnote 3.

task' of rubbing sticks together that "man learned to sing," there was no mention of music in this field of energies.[14]

There is also an idealization at the crux of Lefebvre's notion of rhythms that is no longer tenable. Ecological catastrophe hobbles it. In his attempt to get away from 'thingness,' he sought anchorage for rhythms in two grand cycles: the seasons and the diurnal (circadian). Without seasons only one remains. Since the circadian depends upon the rotation of the planet, and position (orbit, tilt) in relation to the sun, it has proven difficult to ruin, although it hasn't escaped entirely: shifts of weight due to melting glaciers and polar caps, and expansion of oceans, has resulted in minute changes to the wobble in the Earth's axis. On the circadian embodiment by humans, Lefebvre was too early and too abstract to integrate discoveries in sensory and corporeal rhythms. During the 1990s and early 2000s the existence of a third retinal cell was established, and a greater sophistication regarding circadian cells and processes throughout the body was developed. Rods and cones had been familiar to every school kid, but intrinsically photosensitive retinal ganglion cells were unknown to everyone. These *solar retinals*, as I have called them, are non-imaging receptors (actually, they have a miniscule role) that are the main mechanism to entrain, that is, sluggishly synch, our bodies to the sun. They were described with increasing detail just as synching with screens became obsessional.

The source of all but 1/4000 of the energy for life on Earth radiates from the sun. In the evolutionary biology of the eye, the sun was enfolded from the skin in response to its radiant and ambient light. In an odd Platonic way, the sun causes vision, causes time, but to see rhythm as primarily temporal is to forget that lived time is a spatial function of our position in the solar system. No need for clockwork time to be the straw dog for arguments about temporality when spatiality is absent. *Solarception* is the name I have given the sensory process of the internalization of the sun to locate this basic energy relation. Just as there is a way to hear statistically and turbulently, I also think there is a way of transfiguring the

14 Bachelard, *The Psychoanalysis of Fire*, p 28.

circadian from an autonomic to a somatic sense within an ecological effort. Long distance air travel already does this. It operates multimodally in the field notion of *transperception* introduced in *Earth Sound Earth Signal*. I first observed it in Henry David Thoreau hearing the sound of a train or bells over a distance, or seeing a mountain through intervening mist, and in Alvin Lucier hearing the enormous power and earth magnitude in the delicate glissando of a whistler, a type of natural radio. It supplements and supplants cause and effect, linearity, and indexicality found in models of perception and sensation with fields, and forces with energies. Again, transperception has and can become tacit. Lucier heard differently and transperceived sensibly in the mid-1960s due to geophysical radio science research from the previous decade. Solar retinals have had a quarter century head start.

**SS:** It is interesting to observe the engineering task in the medium of radio telecommunication, because radio signals are not flows or highways or any sort of linear information transmission channels, but a broadcast of energy going in all directions. This requires a different paradigm of control. Radio, at the same time, was always a very controlled medium, it was about broadcasting and receiving by engineering choice.

**DK:** I wouldn't say paradigms of control are due to an intrinsic counter nature of radio signals. Radiation patterns are the basis of antenna design and there are ways to map and estimate the 'footprint' of broadcasts and narrowcasts. It used to be a dark art where steel suspension bridges and regional forests were influencing factors. I remember being in New York in the early 1980s and seeing the World Trade Center towers ghosted in a television image. Subtlety and precision are impressive now, and there has been a fascinating relationship between signal transmission with energy scavenging. It is a micro version of Tesla's free energy, yet still big enough for regulations against sapping signal strength. The patterns pertain to property rights, after all, let alone military dominion, national sovereignty, geopolitics, and other activities. As I discuss in *Earth Sound Earth Signal*, the surge in environmental sensing was a byproduct of military and intelligence activities during the Cold War. It was also part of an effort to control natural processes in weapons systems at local and planetary scales, as detailed in Jacob Darwin Hamblin's surprising and sobering book, *Arming Mother Nature: The Birth of Catastrophic Environmentalism*.[15]

Engineering has control issues, in that its native control paradigm has issued into places where it does not belong. For example, Friedrich Kittler's media theory was engineered, as it applied to knowledge, philosophy, history, literature, and media. Its importance, which is undeniable, was both validated by and contributed to a period of digital and media technological development, and no doubt will be revivified increasingly with the spread of AI. However, contemporary relevance is severely limited because of the negligible roles that ecology and the sciences played at the core of his work. In "The City is a Medium," published around the same year as US vice president Al Gore was talking about the information superhighway but before any Inconvenient Truth, Kittler wrote about all things related to the city as informational.[16] Everything is informational because there is control: "whether networks transmit information (telephone, radio, television) or energy (water supply, electricity, highway), they all represent forms of information. (If only because every modern energy flow requires a parallel control network.)"[17] His contest with humanism had no ecological impetus, which is a problem because there is no outside. Engineering put the post in his posthumanism, reinventing invention narratives in the progress of media studies and media theory founded on a fundamental sociality that had no nature. What other area of knowledge has shown such sturdy immunity to recent critiques of anthropocentrism? Its strength was legible in a media ecology with no ecological content. What is remediation now? Its strength is also measured in the lateness of any challenge in me-

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15 Jacob Darwin Hamblin, *Arming Mother Nature: The Birth of Catastrophic Environmentalism* (Oxford; New York: Oxford University Press, 2013).

16 Friedrich A. Kittler, "The City is a Medium," *New Literary History* 27, no. 4 (1996): 717–29.

17 Kittler, p 718.

dia theory, only a decade ago, with Jussi Parikka's *A Geology of Media,*[18] John Durham Peters' *The Marvellous Clouds,*[19] and my *Earth Sound Earth Signal.*[20] There is now no shortage.

**SS:** Michel Serres writes on noticing the balancing polarities: there is always softness and hardness to both matter and information, and these are the kinds of transformations that matter is going through. This is quite interesting and also very hard to make actionable in terms of engineering.

**DK:** When I presented a talk several years ago in Copenhagen about the *Earth Sound Earth Signal,* I was asked how it might relate to the digital in telecommunication and computation. I didn't have a good answer. Perhaps the expectation for expertise came from the earlier book I edited with Hannah Higgins, *Mainframe Experimentalism,* but that was on early computing and the arts, far from the digital we inhabit now.[21] I was planning to explore the notion of survivable communications, but that project went on the back burner as I took a step back as it became evident to me the engineering default of information as data and signals needed to go upstream scientifically to its physical status to dispose it differently to ecological understandings. The decentralization of the Internet was developed under this aegis of survivable communications in a military context. It was a means to foil the efficacy of a nuclear attack by structuring backup measures into the system. There is plenty of precedent in the history of military communications. George O. Squier was an officer rising in the ranks, although he is most known, oddly, for Muzak. He looked to trees as grounds and antennas when

18 Jussi Parikka, *A Geology of Media* (Minneapolis; London: University of Minnesota Press, 2015).

19 John Durham Peters, *The Marvelous Clouds: Toward a Philosophy of Elemental Media* (Chicago; London: the University of Chicago Press, 2015).

20 Kahn, *Earth Sound Earth Signal.*

21 Hannah Higgins and Douglas Kahn, eds., *Mainframe Experimentalism: Early Computing and the Foundations of the Digital Arts* (Berkeley: University of California Press, 2012).

the soil was too dry to form a good ground for his telegraphy gear, and then researched the possibilities for trans-Atlantic wireless tree communication.[22] The presence of trees does not make it ecological, but it is likewise not merely allegorical. Beyond carbon accounting, mineral extraction, and equations of infrastructure with materiality, what would survivability mean in an ecological rather than military sense?

After completing *Earth Sound Earth Signal*, I began reading Serres and he became important for my work, but I am a reader rather than a serious student of his work per se. I look to Christopher Watkin, Steven Connor, and others for a broader view. I haven't formed an opinion on his hard and soft tropes, just that they are at times at odds with one another, and because I am suspicious of polarities. Instead, I have spun his work to emphasize a conditionality associated with what he calls world-objects, and to amplify the energy in the triad matter-energy-information, which is something I do as a matter of course with other thinkers. 'Matter' is both a constituent of and collective term for matter-energy-information, so it can be confusing where and how its transformations might occur. I am interested in their configured activities rather than an umbrella of matter since it allows an analytical isolation of energy. Amplification is not dissimilar to Lefebvre singling out rhythm in the melody-harmony-rhythm triad on the basis of its neglect. If matter-energy-information were the Holy Trinity, matter and information are the two guys with beards who seem to be everywhere, but no one has a clue about the Holy Ghost. Lefebvre has a passage on the analytical advantages of such triads but, unlike Lefebvre's enterprising rhythm, no new branch of knowledge is necessary. Old-school energetics asserted a dominance or centrality of energy in something of a power play and generated plenty of intellectual paranoia in its wake. Historical and cultural analysis obviously has no such designs; scientism may be a topic, but not hardware to wave around. Philosophically, Michael Marder emphasizes that fundamentally challenging how energy is understood is of utmost

22 George O. Squier, "Tree Telephony and Telegraphy," *Journal of the Franklin Institute* 187, no. 6 (1919): 657–87

importance; perhaps his work could be called a 'survivable philosophy'? I agree but do not work in philosophy.

Tripartite configurations are convenient, crude emblems. Their legitimacy might be judged through their elemental status but, in any case, are preferable to poles and other binaries because they are more amenable to a type of field-thinking required to approach complex situations. It was routine in nineteenth century physics but doesn't often make its way into academic vernacular. The way Serres' writing resists pull quotes and epigrams is the result of field thinking, of saying several things at once. I first developed a preference for fields as a math major in university. It was a matter of words, concepts, events, sensations, etc. eventually adhering to the points and planes and vectors darting around in n-dimensions that I used to daydream about. Serres revels in a correlation of mathematics and the physical cosmos, and even starts his book on religion with the virtuality of mathematics, and incredibly finished the manuscript a day before he dies. The script would be too corny for Hollywood. Math lapsed for me when it proved to be an insufficient explanatory system for the systemic cruelty and violence I encountered while hitchhiking through the backroads of the United States. But I then found fields in Walter Benjamin's constellations, and both Benjamin and Serres keep power and trauma in focus. Benjamin finds barbarism in the documents of civilization, and much of Serres derives from Hiroshima, his metonym for nuclear annihilation.

Hiroshima was his first world-object. Although he didn't give credence to Bachelard's epistemological break, Hiroshima had a similar philosophical function for him in the break of humans facing for the first time a global self-realization for potential self-annihilation. This object belongs to his lexicon of objects, with Latour animating his quasi-objects in actor-network theory, along with the small class of cosmic objects. I have no idea why his world-objects never caught on, since they resemble Timothy Morton's hyperobjects, which made their way in the world. In *Hermes* Serres wrote about the world-object being the product of a thanatocratic expansion of capability arising from an unprecedented coordination of three socio-political players: the state/military, industry, and science – what Latour called the iron triangle. Sometime in the late 1980s, as far as I can tell, global warming becomes his other major world-object. Since Hiroshima is the planetary dimension of energy, the same would apply to global warming, one as instant incineration and the other a not-so-slow burn. Not all his world-objects would conform to annihilation at this scale, but his two main ones do. President Truman warned Japan hours after Hiroshima that the United States now has the power to bring the sun down to earth and unleash it once again, while now a revanchist sun comes down to earth to bake us. Under guises of mastery, these two dominant world-objects demonstrate a spasmodic lack of control. Their death reflex needs to be undercut with revised notions of energy, and triangulated with however matter and information may convert or relate to one another.

**SS:** When you speak of information pertaining to its physicality and the laws of physics, it seems to be about understanding data as found versus actively made. In pragmatic knowledge theories, such as the controversially hierarchical DIKW knowledge pyramid, information is simply the meaningful part of data.[23] But how could we really talk about the data? To go back to Serres, while I might not be able to get specific enough in terms of the way he talks about data, my impression is that data for him is this thing which is really dug up from the ground, and it is always material because it is always acquired through some kind of agency. It is the act of acquiring data that is giving it an 'orientation'; if data is always oriented, it is never 'neutral' nor inactive. Materiality of information therefore can be established with a quantum-physical understanding of communication theory. So rather than thinking of information with Shannon's information theory, I would be curious about other ways to address materiality of information. For example, we could say that the German

23 The Data Information Knowledge Wisdom pyramid is a model for structural and/or functional relationships between data, information, knowledge, and wisdom stacked in a hierarchical order that suggests increase in value through scarcity, from bottom (data) to top (wisdom): https://en.wikipedia.org/wiki/DIKW_pyramid [accessed 10.03.2021].

media theory addresses this materiality through the networks and technicality of mediating information. What is your take on this?

**DK:** There are many interesting artists addressing these issues, and no doubt enterprises that could mobilize them into media systems and engineering at scale. There is no shortage of talent and tools. I don't have anything to say beyond what others have said about the capitalist ecstasy of data mining having the same extractivist frame of transformations of matter at the root of environmental catastrophe. It would be interesting to apply Serres' notion of pollution as an expansion of territory rather than waste. The capitalist maw that chews up the Earth and spits it back out is a technique of possession in the manner that one owns someone else's bowl of soup by spitting in it. What does it possess after chewing up and spitting out data banks? He states advertising is pollution, which is hard to argue against, but it is just one form of monetization that wastes and possesses enormously for little social and ecological good. It is a question now whether non-extractivism occurs before catastrophe imposes it.

Materiality old and new is sold in so many flavours now, that the presumed virtues can be difficult to identify, and are often too simple when they can. For me, any smattering of matter needs to be accompanied by historical materialism, but also one not dependent on the archives that produce history. How 'data' exists and is produced by and against indigenous cultures, and what does and does not need to be known to survive and maintain integrity, are key, among all the records suppressed, destroyed, or never produced in the first place. I am living on Aboriginal land belonging to the longest continuing culture on Earth, over sixty thousand years, which makes this evident in a way that I don't know if Europeans who think of Greece as antiquity can appreciate.

I do find remarkable one understanding of an operative materiality of data. Key features of solar retinals I mentioned were hypothesized and validated among the circuits of data banks, long before weather research. The functional protein melanopsin active in solarception was shown that it had to exist, and it did, and its evolutionary biology was described in a similar manner. This is old news, of course, but as

Przemysław Prusinkiewicz and Aristid Lindenmayer signalled in *The Algorithmic Beauty of Plants*, it was inevitable that models in computational biology went past the point of scientists contributing their research to them, to conducting their research within them.[24] So, in a way, certain things exist more completely in data. The Delphic oracle of climate modelling is located there, Pythia proclaiming the future sitting on her tripod inhaling greenhouse gas fumes.

I am not familiar with the DIKW or its controversies but, if I had to choose among simple geometric explanations, I would go for the self-amplifying iron triangle. I find the wisdom placed at the pinnacle funny. Perhaps an eye could fit on top, like the pyramid on the US dollar bill? I wonder what self-abnegation and meditative practice of enlightenment is required to attain the wisdom of managerialist Bodhisattvahood? And what will shareholders think if it evaporates into full Buddhahood? Buddha will be fine because he comes from wealth, but what about the employees? Obviously, if this wisdom were truly wise, then it would already have the situation sorted out ahead of time. Somehow, I think it will end up instead in AI systems hacking each other's infrastructures.

I have failed to keep up with media theory from Germany since completing the book over a decade ago, so I am very much out of that loop. Even then it was primarily Kittler, whose historical basis for theorization I held in high regard, if not always the specific content. However, his penchant for engineering placed limits on the science, ecology, power, and trauma necessary to be broadly relevant. In a seminar I taught at University of California, we tested the limits of Kittler's ideas by examining war crime snapshots by American soldiers in Vietnam. Despite data, information, and knowledge, evidence has a hard climb to justice, let alone wisdom.

I wonder too what proximity experience would have in or with the DIKW pyramid. In my essay in *Energies in the Arts* I analyse the energy field performances of the Australian artist Peter Blamey through the notion of experiential physics. Other branches of science or forms of knowledge may become experiential through knowing or believing to know.

24 Prusinkiewicz and Lindenmayer, *The Algorithmic Beauty of Plants*.

You know that photosynthesis is occurring in plants, not just that they flower or are green. Photosynthesis may have initially leapt off a school desk, but it has since become tacit in what you can see (perceive, understand, experience) and what some sense without saying. Living in the sun moves without the baggage of a vital force. You can feel a forest as massive absorption, as an aspect of transperception. Fusing existing and new knowledges with tacit experience de facto exists in adaptative behaviours, but also in different cultures. The Wadjiginy, Emmiyangal, and Mendheyangal people on the coast of the Northern Territory of Australia, for example, see microseasonally where other cultures merely see weather. Knowledges built up in labs or data sets have certain advantages, but what informs knowledge built up over thousands of years? Just knowing that, it becomes clear that macroseasonal disruption is part of an ongoing dispossession and genocide.

**SS:** To wrap up, would you say that speaking of energy implies also always speaking of its manifestation as matter and information? Are they always present in your thought of how energy becomes manifested in the arts? In the case of Serres' world-object being in some extent created by humans, which is exceptional in the way it uses up life and resources: it is using all of it up, an ultimate reproduction.

**DK:** The matter-energy-information schema is productive in a theme-and-variation way that philosophers will stress test concepts with different classical elements. Marder did that recently with fire and political power in his *Pyropolitics*, instead of the presumed Earth with its territories, properties, sovereignty, and the geo- in geopolitics. Even Serres, who makes fun of Bachelard's schism between matter/energy (without the benefit of Shannon's information) and classical elements, makes recourse to them to replace the United Nations with "an objective institution, the WAFEL, whose initials would mean in English not men, nor nations, nor the species, but the world: Water, Air, Fire, the Earth, and the Living. One more step, and we have a cosmocracy."[25] For a physical model, I like to remind myself of their intricate relationships in Raman scattering, in the interactions of photons, electrons, molecular vibrations, and heat in the chemistries of why, in infinitesimal part, the sky is blue. Luckily, the sky is big enough to lend the infinitesimal some presence. I also like to think of the relatively free and easy energy ride of a photon from the sun, unencumbered by too much information, until it reaches the retina, whereupon it crosses into intricate information universe of ion exchanges, like a complicated knot at the end of a very long string, both for imaging in vision and for spatial-temporal position in the solar system. Perhaps because I concentrate on the arts and privilege (trans)perceptual matters, I limit energy and information interaction to the sensory membranes of the cochlea, retina, and skin, their cellular surface transduction and ion exchanges. The other huge matter-energy-information site is metabolism, but that would get too complicated too quickly for me at the moment, so I stay with the superficiality of sensory membranes.

Pia van Gelder from the Australian National University and I are presently completing a book collection, *The Energies Artists Say*, which is an exercise in engaging a physical, cultural, and linguistic breadth of energies in historical and cultural analyses. Artists said 'energy' in many ways during the twentieth century, but they did not mean fossil fuels and their alternatives until the 1970s, in the United States at least, in the wake of the Santa Barbara oil spill and the OPEC embargo, the so-called energy crisis. That is, artists did not say energy in the way energy humanities means it until recently, in an historical sense, and during and since this meaning has interacted with other energies and, in turn, matter and information, in specific ways. The book will introduce the energies artists say as one method within the development of an energy reading, which is beginning to take shape.

I wonder why Serres' world-objects began with Hiroshima. Its existential motivations make sense, but global telecommunications

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25 Michel Serres, *Malfeasance: Appropriation through Pollution?*, trans. Anne-Marie Feenberg-Dibon (Stanford: Stanford University Press, 2011), p 84.

unfolding in the mid-nineteenth century, its lines arcing over horizons, would be an obvious place to start. Natural radio has arced over the equator for about 3.5 billion years, but Serres' world-objects are human-made or -generated one way or another. The glissandi of whistlers generated along these flux lines were heard on early telecommunication lines, long perceived as nature, but now they broadcast their human content. If telecommunications require existential coordinates to be a world-object, then their deadly role in colonial expansion, military subjugation, and domestic repression, aided by messages at the speed of light, should suffice. If this is insufficient and global annihilation remains the metric, then we must wait for the DEW Line in the 1950s, which I believe was the largest media infrastructure up to that point. In the 1950s, militarized sensing at earth magnitude developed in parallel with an environmental sensing that itself hearkens back to the nineteenth century, when telegraph systems were used not only in communication but as large sensory arrays for the study of magnetic storms. Sensing and telemetry were on the same device, and there is no shortage of either at present. How to make them survivable is another question.

# SIGID Wiki Archival and Knowledge Practices

*Interview with Carl Colena*

*Carl Colena is a software engineer, digital signal processing hobbyist and the current administrator of the SIGID wiki website and radio signal digital archive. The interview was conducted by Selena Savić and Yann Patrick Martins in May 2020.*

**Selena Savić and Yann Patrick Martins:** The Signal Identification Guide (SIDIG) wiki is an organized database of information on radio signals. It contains data on signals' characteristics such as frequency and bandwidth, modulation type, as well as short descriptions, audio samples and waterfall plots. How was this project started and who supported it?

**Carl Colena:** A community of hardware hackers were able to turn the inexpensive digital television dongle (DVB-T) into a software defined radio (SDR) hardware. The discovery of these affordable TV dongles that can be used like a spectrum analyser, has significantly dropped the barrier of entry for amateur radio enthusiasts and other technically literate individuals, to explore radio signal reception and hacking.

Carl Laufer, the owner of the RTL-SDR blog,[1] started the Signal Identification Guide (SIGID) wiki[2] project in 2014. The goal was to create a blog for all interested people who were using RTL-SDR to look around the radio signal spectrum and understand what they are receiving.

1 RTL-SDR (RTL2832U) and software defined radio news and projects https://www.rtl-sdr.com/ (accessed 22.06.2022).

2 Signal Identification Guide wiki https://www.sigidwiki.com (accessed 22.06.2022).

There was previously no centralized database describing these signals. The SIGID wiki website started as a collection of the information about radio signals that was held among a community of radio enthusiasts who wanted to explore radio space and understand what they see and hear.

I was among the people who purchased an RTL-SDR enabled dongle around that time. I was interested in analysing Wi-Fi signals because I was having issues with network reception on campus where I was studying. I was planning to use the TV-dongle to search for a place on the campus to work from.

With my equipment, I could actually 'see' the radio spectrum, and I wanted to know more about all these different signals. I soon became fascinated with all these radio signals that exist around us, which we are not aware of. I had similar questions to many users of the RTL-SDR blog when I first came across SIGID wiki. I saw this as an opportunity to both find and contribute information from other sources. I added signals from my own research; I added signals which someone else would identify on another website, I added additional signal samples. Most of the signals that you see on the website today are pages that I have written. Eventually, around a year later, I became the website administrator.

I then started to work on reforming the website structure. I split the long list of all signals, which contained some 200 entries, and introduced categories.

## Known and unknown signals

**SS:** There are two major categories of radio signals on SIGID wiki: known and unknown (Figure 1). The first ones are those that serve identification. I could record a signal and turn to the wiki to compare it with those in the database to find one that matches. Or, if I do not find a match, I could upload my signal's data to the wiki as "unknown" and have it hopefully identified by someone else. How does this work in practice, how do you narrow down the search and how can you be sure you found a match?

**CC:** If someone recorded a signal and cannot find a match on the SIGID wiki, there is a number of different routes to take. Most people would create a page in the unidentified section, and upload whatever traits that they have recorded to help identify it. We provide a form to do this (Figure 2), and the more information you provide the easier it will be for other users to identify a new signal.

**SS:** This suggests that signals in the database are most probably "identifiable", just not yet identified. How do those in the unknown category pass to the known one? Conversely, how can one challenge a signal as incorrectly identified?

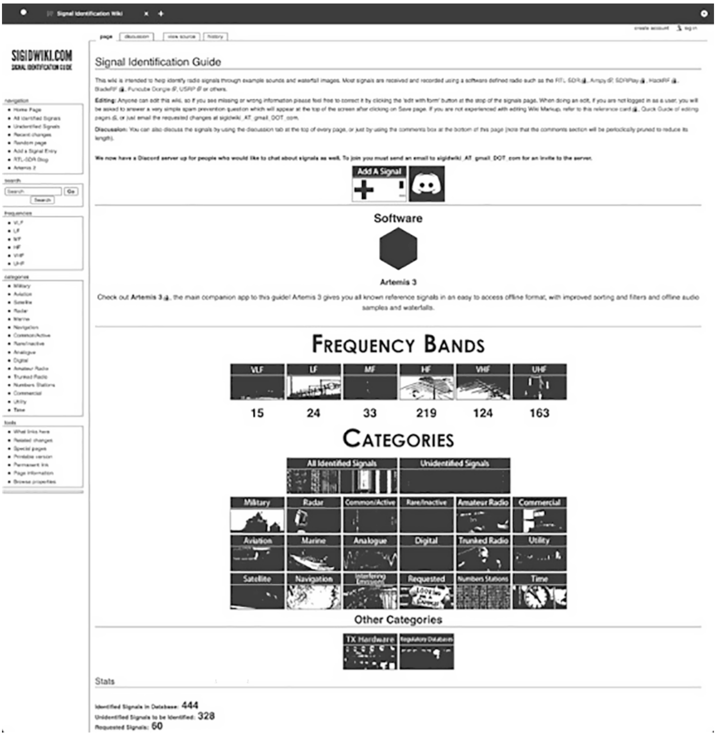
**CC:** Identification is a community effort. Someone from the user community, including myself, could look through unknown signals and recognize a signal they know. We often find out that a signal in the unidentified section corresponds to a newly identified signal on another website – it simply had not been identified at the time when it was added to SIGID wiki. We then add it to the collection of samples that showcase what this signal looks like in the environment. Most signals do not have a static representation, especially if they are transmitting data: they may have different modes and phases. Oftentimes audio samples on the SIDIG wiki are snippets of these transmissions, so there may be a mode or behaviour of the signal that is not captured within this short timeframe of the sample. Unidentified signal samples might therefore be a snippet of a known signals that was undocumented.

Contesting already identified signals happens as well in the user community. A user recently flagged a signal, stating which type of analysis they used and showing how these do not match up. This works on an evidence-based approach. If somebody would say that they have stronger evidence, demonstrating that a signal is not what it is identified as, that should be taken seriously to correct its identification.

**SS:** Is the aim, or one of the aims, of the SIGID wiki to resolve unknown signals' identity?

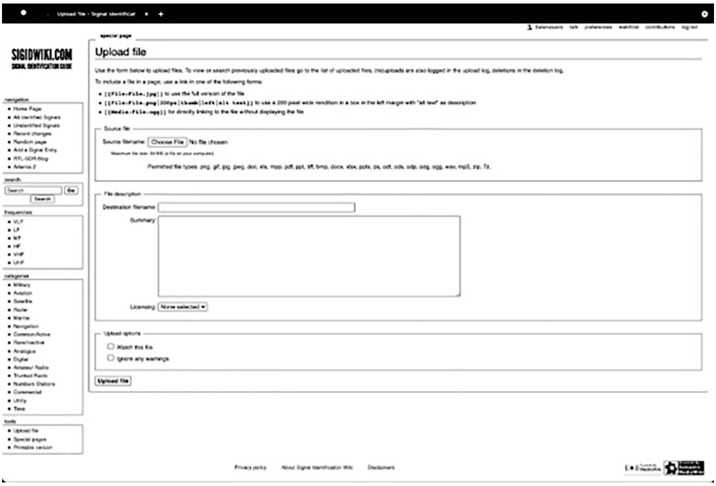
**CC:** Yes, that is certainly one of the aims. For the most part of the work that I did, the aim was also to serve as an archive for all of the signals that have been used for transmission, but also what could be natural emissions, like lightning spherics, for example. The SIGID wiki acts both as a holistic guide, as well as a kind of a 'museum' of different radio signals that have existed. We can observe in the archive how we have transitioned from lower band signals that are not able to carry as much information, to complex signals that can broadcast television.

*Figure 1: SIGID wiki website.*




Screenshot from 01.04.2022, made by Selena Savić

*Figure 2: SIGID wiki signal upload form.*




Screenshot from 01.04.2022, made by Selena Savić

## Signal knowledge

**SS:** How do conventions on archival techniques of tagging, categorization and metadata emerge in the SIGID wiki?

**CC:** The categories emerged out of a need for organizing signals we collected, trying to group them into meaningful sections. I first categorized them by application. This is reflected in the broader community of listeners, with groups that are specifically dedicated to, for example, satellite reception, or to public safety trunked radio channels. Categories are thus based on listener communities that emerged around certain types of transmissions. The question remains whether the users of a signal should define that signal. Categories are a conversation point within the community of users of the SIGID wiki. There are different proposals to update the categories to better align with objective metrics.

In terms of consistency, some of the categories are hard to disjoin. One such category is the digital. Radio signals are inherently not digital: they are continuous waves propagating in space. However, a large group of signals are digital in terms of the information that they transfer, such as cellular communication. Conversely, certain signals are used for digital purposes, but are analogue in nature. Telemetry devices can broadcast signals that are basically a tone, a sine wave whose frequency shifts based on changing pressure in a pipe. These are typically used in industrial systems, where the tone transmits the status of equipment: discreet analogue tones that could be purely analogue. Another example of an analogue signal is radar. Observations such as distance to buildings, or airplanes in the sky are not digital by any means. Signals are inherently not digital physically (in their transmission), but they can be used to communicate digital information.

**SS:** There is a lot of information on signals that is not quantitative, such as descriptions, application, historical use. Who writes these descriptions and other information, who checks if it is correct? Which resources are commonly used?

**CC:** I wrote the vast majority of signal pages on the SIGID wiki website. The descriptions are typically about answering high-level questions such as 'what is the signal used for?', 'who uses it?' and so on. It is similar to a Wikipedia article about fish, for example. I typically give an account of a signal's history, its' characteristics, any unique identifying trait. This knowledge is based on years of writing about signals. I include all additional information I might have, such as links to video samples on YouTube or the sources where I got information from, additional images or samples. I try to do as much fact checking as I can on my own.

The information comes from different places, typically second-hand sources like historical accounts. Some information, especially about commercial and military signals, tends to be quite opaque. It is hard to verify. Some information can be validated with first-hand sources, from a government or a technical white paper, but they do not always exist. There are certain companies that have heaps of information on radio signals and publish their databases of signals. I often used Wavecom[3] as a source of relatively reliable information. There are companies that specialize in signal intelligence (SIGINT), a field commonly used by governments and military to gather actionable data from emitted radio signals, for surveillance or intelligence purposes. Another source that I go to, at least in the United States, is the Federal Communications Commission (FCC). All telecommunication devices that are sold in the United States have to have an FCC ID which corresponds to a page with information about the manufacturer, the use of the equipment, frequencies and bands it is allowed to transmit on. Each government has their own regulatory agency, and you can use it to get information about anything that is wireless.

**SS:** Which properties do you look at in a radio signal?

**CC:** For each kind of signal there are different ways of finding out features. Sometimes I dive into the actual signal features, the structures. One of the features of communication-based signals is symbol rate. For example, Morse code is made of pauses and dots. With digital data, it is the timing between symbols that makes sense between two frequencies.

When analysing a signal, I look for its general characteristics, where it may be recorded, the type of modulation that it uses. I narrow it down further into specific features in terms of the spacing of tones, the speed at which symbols are being sent. Any unique characteristic that stands out is useful to both characterize a signal and potentially identify it.

**SS:** Which methods and tools do you use in signal analysis?

**CC:** Radio waves, an electromagnetic phenomenon, cannot be directly experienced by humans. We have to use extended methods of sensing to observe this domain. The first thing I always do is a visual and acoustic

3 See Wavecom online decoder website: http://www.wavecom.ch/content/ext/DecoderOnlineHelp/default.htm#!worddocuments/acars.htm (accessed 21.06.2022).

inspection. I can look at the waterfall plot live, as I am listening to the signal, establishing a connection between what I hear and what I see. Even though you are experiencing the signal through these proxy forms, you understand something about radio waves. I do not know if the other senses would make sense for that.

I mostly use free software tools for visual inspection, like SDR#,[4] or HDSDR[5] to replay the signal and look at its visual characteristics. I play with the Fast Fourier Transform (FFT) bin size to take a look at how this signal looks with inversed temporal resolution. The spectrogram, a short-time Fourier transform (STFT), can be a tool to derive different 'perspectives', on signals. Depending on the perspective you use, a signal will appear to have something distinguishing, or not. It is completely based on what you use to look at it. If you were to look at the signal itself, in raw I/Q recording of energy, the question would be what you could really understand. That is the reason we have tools, like the Fourier transform, to translate and understand the frequency components.

I could explain this through two primary forms of analogue radio communication: amplitude modulation (AM) and frequency modulation (FM). Depending on whether you use amplitude or frequency as a method for information transfer, you will look at the changes in the carrier wave differently. If we were to take a frequency modulated signal, and amplitude demodulate it, we will see in the spectrogram a simple straight line, no information at all. Thus, the reception mode, the perspective for which you receive the signal, enables you to observe whether and how it encodes and transmits information.

**SS:** On the Wiki, within first level categorization by application (e.g. military or aviation), there is second-level distinction between active and inactive signals. Are those still broadcast by some infrastructure that remains active but no longer serves any purpose? Could we still hear the inactive signals or is this archive material?

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4 See AIRSPY website, https://airspy.com/ (accessed 21.06.2022).

5 See High Definition Software Defined Radio (HDSDR) website, http://www.hdsdr.de/ (accessed 21.06.2022).

**CC:** Inactive signals are archival material. The recordings in the SIGID database were made years ago, in the 1990s or earlier. It is hard to say whether inactive signals will ever be transmitted again, given that some signals require specialized equipment that may not be around anymore. Whether a signal is considered active or not will depend on the community's input about the signal use by its designated user; and whether it can be received in the wild. There is an established community of listeners, both shortwave and more general amateur radio listeners, who monitor the amateur radio bands. Part of their interest is to keep unauthorized or problematic people off the amateur radio bands, since this space is kind of self-policed. They also listen to the whole band, and they note observations on transmissions they receive.

With regards to inactive signals, there is no hard threshold. A lot of the early signals on this page were used by diplomatic services in the '80s and '90s, before the internet became the principal mode of telecommunication. Diplomatic services used these dedicated radio channels because they needed a resilient and secure way of communicating back to the home country. I would not expect these to be used nowadays, given that you can send an encrypted email instead.

**SS:** Can you tell us more on the use of radio signals outside of transmitting information, such as for example for motion detection?

**CC:** A good example of this are ionospheric sounders. Similar to the way bats use the echo in a cave to orient themselves, radio waves can transmit signals to get the sounding of the ionosphere that surrounds the earth. This is typically done to understand the magnetic field of the earth at different points and time of the day, and in response to different stimuli. These systems use a big transmitter, broadcasting up into the sky. Receivers located at different locations pick up the reflections from these signals. They are not listening for the signal itself, but to see what the reflection from the signal looks like compared to the signal that was sent. This difference is then used to measure and characterize the atmosphere. Radio waves are used here purely as energy.

Amateur radio operators do something similar, which is called QSO.[6] They use low energy transmissions like a sport, trying to send a signal at the lowest energy possible to the furthest possible distance. They send out a short message identifying the operator, over and over again. It is not really useful in terms of information, but when someone receives it, they will note the distance and time period of the broadcast, giving a sense of local radio environment.

Research in the context of motion detection is typically interested in non-intentional emissions. These are emissions from things like a computer monitor, or the electrical wiring in a house, emissions that exist as a consequence of other processes (e.g. supplying energy to devices). This is typically used in the security field, both for information and physical security. Each key on a keyboard produces a distinct system interrupt in the computer circuitry, and it can be used to reconstruct the typing. This has been experimentally proven possible.

## Natural radio

**SS:** Could it be the case that some of the signals in the 'unknown' SIGID wiki category come from natural sources such as ionospheric emissions?

**CC:** Certain traits are unmistakeable signs that a signal is not a natural transmission. A signal with a strong wave patterns or complex structure is probably not natural, but it could be. From what I have seen, naturally occurring emissions are typically short. This depends on what one is listening to. For example, a meteor going through the Earth's magnetic field creates an electromagnetic wave at a given frequency with a drift in the frequency component.[7]

6 Contact (amateur radio) Wikipedia page: https://en.wikipedia.org/wiki/Contact_(amateur_radio) (accessed 21.06.2022).

7 See entry on Ionized Meteor Trails on SIGID wiki: https://www.sigidwiki.com/wiki/Ionized_Meteor_Trails (accessed 21.06.2022).

There might be some unidentified signals that are of natural origin. A ubiquitous radio signal that appears in high frequency range is called the 'whistler'. Similar to the meteor trails, electromagnetic discharges in the ionosphere generate whistling sounds that look like drifts of energy in terms of their frequency composition, sliding in and then disappearing. Those would certainly be natural phenomena.

There was another source that I found pretty interesting while looking at very low frequency emissions, singles of Hertz to sub-Hertz. A colleague of mine who worked at the South Pole on installing an extremely low frequency antenna, the purpose of which is to continuously record this frequency band. These antennas pick up a lot of natural phenomena like lightning, or earthquakes. Those are electromagnetic emissions coming from the Earth. Such natural emissions are typically longer than the ones at the higher frequencies, because they are actually slower. Higher frequencies tend to come from the outside of the Earth: pulsars, meteors, outer space phenomena, while very low frequency natural transmissions come from the Earth itself.

# On Technicity of Listening

Radio Explorations Workshop with participation of Carl Colena, Miro Roman, Simone Conforti, Shintaro Miyazaki, Yann Patrick Martins and Selena Savić.

This research meeting addressed the *technicity of listening*: knowledge, tools and approaches to sonic and other data. Three invited guests, Carl Colena (SIGID wiki), Miro Roman (CAAD, ETHZ) and Simone Conforti (IRCAM) presented their current research into archives of radio signals, images, books and music, as well as strategies for articulating profiles and identities with data. Participants of the meeting discussed their current work and shared interests in the context of radio, music and digital information. The team of the *Architectonic Explorations of Radio* research project, Selena Savić and Yann Patrick Martins, presented the first prototype of the *data observatory:* the possible exploration of the archive of radio signal recordings.

Essays that follow are written accounts of these presentations, as delivered by the authors.

Basel, 26.06.2020

# Technicity of Radio Signal Transmissions

*Carl Colena*

*Carl Colena works as a research engineer, running the Signal Identification Guide (SIGID) wiki as a hobby. His interest in signal identification developed during his studies in computer engineering at the City College of New York.*

The SIGID wiki website was started in 2014 during the so-called 'RTL-SDR boom': the discovery that small USB dongles, made for digital television (DTV) reception, could be used as computer-based radio scanners. Several people including Antti Palosaari, Eric Fry and group gathered around Osmocom,[1] hacked the driver on the RTL2832U chipset and found a way to access the raw IQ data from the analogue to digital converter, which samples the radio frequency space. The tuner on the DTV device can tune into a very wide range of frequencies. The discovery of this affordable software-defined radio (SDR) was still made in a professional research domain. Still, the use of RTL-SDR proliferated and a community formed around it, curious to explore the radio space.

The SIGID wiki website documented different signals that could be recorded using this equipment. Within three to four years, the wiki grew from about 80 signals to over 300. We have a community of individuals who use the website for a variety of purposes. There are amateur radio operators who focus on shortwave transmissions (SWLs). They listen for the purposes of listening, to discover new signals and track the patterns

1 See https://sdr.osmocom.org/trac/wiki/rtl-sdr (accessed 01.06.2021).

of different transmissions in their area. Other users come from the information security space, seeking to understand more on wireless and baseline some of their designs. Then there are tech hobbyists who are interested in the radio space in general, in radio frequency and the ability to transmit information in various different ways.

## Signal engineering

A comparison with acoustic waves is useful to understand radio signals: acoustic waves, such as the sound of the human voice, are generated by longitudinal waves, which transmit information by compressing air in the direction of travelling (Figure 2, top). Radio waves, a combination of an electric and a magnetic field, are transverse waves: they oscillate orthogonally to the direction to that which the wave travels. These are physically different phenomena, but they are both about the propagation of energy going in a specific direction.

We receive a radio signal in the digital domain using analogue to digital converters (ADCs) that sample the analogue space of the wave at a certain frequency. What is typically done in SDR, is to use an I and Q generator that takes the end phase component, and then simultaneously sample both in-phase (I) and quadrature (Q) waveforms as a single wave, saving the two pieces of data as a single sample in time. The digitally quantized form of the received signal is the accumulation of these samples. An IQ plot shows each individual component and complex form as a given magnitude: a polar circle of both magnitude and angle. This is the process typically used to sample and process signals.

Radio signals have a specific frequency associated with them, In the physical space, there can only be as many different signals as there are different frequencies, without interference. This is based on the Fourier theory of the frequency domain and the translation between time and frequency domains. When it comes to radio signals that transmit information, we can think of transmission frequencies as channels, and the derivatives of this frequency as bandwidth or the quantity of information being sent. In the domain of telecommunication and radio engineering, we talk about carrier frequencies. This is a baseband signal that has information embedded into it. It could be voice, digital data, or anything else. The bandwidth or the width of the signal, is usually much lower than the carrier frequency. Human voice, for example, is typically between 100Hz and 3KHz, making its bandwidth about 3KHz wide. The actual frequency of the signal partitions signal space, so that different transmissions can be individually tuned into and received without overlapping and distortion. Understanding carrier frequencies as 'channels' paints radio signals as a finite resource.

Consistent with the Fourier theory, instead of frequency, time division can be used to avoid interference and overlaps. Multiple signals could share the same frequency, sliced into different time chunks. Successful communication in this case requires coordination between operators.

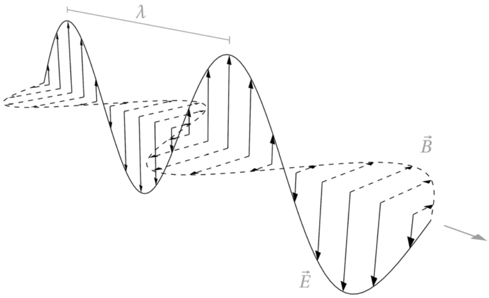
## Intentionality of radio signal transmissions

A radio wave is an oscillation of energy (Figure 1). Signal engineers have come up with ways to use this to transmit information by modulating the radio wave. Two very common types of modulation are amplitude (AM) and frequency modulation (FM). With AM, the channel is the carrier frequency at which this wave is actually oscillating, and then data itself is the overlaid signal, in form of a changing amplitude. With FM, amplitude is fixed and the frequency is changing: the compression between the oscillations gets narrower and wider, corresponding to the actual amplitude of the original signal.

By simply changing the domain at which the signal is transported, for example by using an FM demodulator on that AM signal and plotting the received information, we would just get a flat line because the frequency in AM is constant. The same would be the other way around, using an AM demodulator on the FM signal. If we were to receive the signal with incorrect or unintended method of reception, it would contain no information. Whether or not a signal has informational content, therefore depends on how it is received, and how the signal was intended to be transmitted.

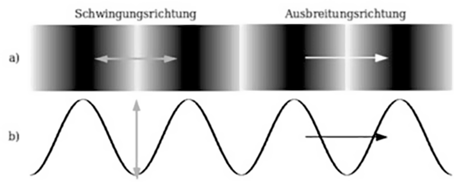
Two primary modalities that are used in signal analysis are acoustic and visual. Both are interpretations which can bring out different perspectives on radio signals, as we could see with AM and FM demodulation. It is important to gather multiple perspectives on a radio wave in order to fully understand it.

*Figure 1: Electromagnetic wave.*




Author Lennart Kudling, 2010. CC-BY-SA-3.0.

*Figure 2: Direction of oscillation and propagation of a longitudinal wave (a) and a transverse wave (labels in German).*




Author Debianux, 2018. CC-BY-SA-3.0.

*Figure 3: Three types of modulation. Left: Frequency-shift keying modulation. An example demonstrating binary FSK. Middle: Phase-shifting keying modulation. Right: Digital Amplitude Modulation Signals (OOK – On-Off Keying).*

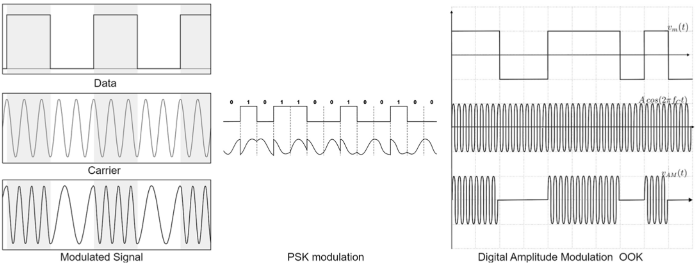



Image redrawn by Selena Savić based on sources: Left: Author Ktims, 2006, CC-BY-SA-3.0; Middle: Author Maria Moura Malburg, 2004 CC BY-SA 4.0; Right: Author Ramjar, 2014, CC BY-SA 4.0.

In terms of signal understanding, we typically try to look for patterns, signatures and tonalities that exist in the signal. This is combined with the visual component in order to have multiple perspectives on the signal at once, while also using a variety of modes, for example the upper-side band, which is probably the closest to raw listening or listening to the signal as it was sent. AM and FM modes are often used as well, depending on the way that the signal was meant to be received. With digital methods of signal transmission such as FSK (Figure 3, left), frequency shifts with respect to the carrier as the data is overlaid, resulting in periods of higher and lower frequency. In PSK (Figure 3, middle), frequency and amplitude stay the same, but the phase of the signal shifts (efficient for transmissions in a populated frequency space). In ASK (Figure 3, right) the signal can be modulated or not, it simply switches on and off.

One extreme perspective on radio signals is an encoding technique called 'spectrum painter', which uses the spectrum of a certain bandwidth and a digital analogue converter (DAC), to paint images on the spectrum. If we were to listen to this on the radio, it would sound like digital noise, but when it is received with a spectrum analyser tool, it plots a picture. With regards to intentionality, this signal is clearly not meant to be listened to, but it transports intentional visual information.

An interesting case of intentionality is the intention not to be seen, typically used for InfoSec such as pseudo random hopping signals. This makes it very difficult for a receiver to capture and decode a message broadcast on shifting frequencies.

Ultra-wide band signals lend themselves to another form of intentionality. These signals exist below the noise floor. For example, Driftnet Radio Buoys, used by fishing boats in open seas to locate and collect fishing nets. The beacon normally sends out a variety of dots and tones at a stable frequency, but the signal begins drifting, sounding almost like a dolphin, when the batteries become weak. A signal can therefore have many different forms, not just due to the intention of the transmission, but also to factors that may just be physical, such as battery power.

## Natural radio

Natural radio phenomena include spherics and whistlers. These are transmitted at a very low frequency (VLF) range and are purely natural transmissions. They are induced by natural events, such as lightning. Spherics come from lightnings which cause strong bursts of electromagnetic energy, such that you can actually hear them as simultaneous bursts in the acoustic domain. Their electromagnetic emissions sound like crackles. Whistlers are reverberations from lightning that have passed through the magnetosphere. You can think of them as shooting stars.

There are a lot of natural phenomena that produce radio signals at very low frequency (VLF) level. Two forms of listening are of interest here. One is media scattering: hobbyists listening for a manmade transmitter, one that they know they could not actually receive under normal circumstances, due to distance. They point their receiver up to the sky and they do something similar to passive coherent radar (PCR) technique, listening for reflections. This is typically done at a very high frequency (VHF), 141 MHz. When meteorites travel or burn up in the upper atmosphere, they leave behind this ionizing particle cloud. Under the right circumstances, the transmitted signals from the Earth hit this ionization cloud and bounce down, over the horizon, so that they can be heard on the other side of the planet. These are called meteor echoes, because a transmitter gets echoed off of a meteor trail. Whether or not this is a natural or manmade signal is an interesting discussion, but the role of natural phenomena in the transmission of a manmade emission is clearly important.

## Discussion

**Miro Roman:** I imagine taking the database of radio signals to compare all the sounds, or to create a context where they can live together. According to what Carl Colena is saying, the first move would be to translate them to the same modality. How would you work with sounds of different duration? I have an idea how to do this with text and with images, but not with sound.

**Carl Colena:** When it comes to comparison, you certainly want to compare signals from the same perspective. You do not want to compare the AM demodulation of one signal and the FM demodulation of another. But when it comes to what forms, what kind of signatures you can think of, look for, I know one of particular interest. It is the autocorrelation function (ACF), going into the order of frequency. You can compress the actual frequency of the modulating signal itself into a single number (or a much lower dimensionality piece of data), if a signal has that sort of periodicity. For example, what is the frequency of your modulating signal? That itself could be a single attribute. This is obviously depending on whether or not the signal has periodicity, as well as what is the form of this periodicity.

Some signals, like the FSK, have a minimum spacing between the tones, which could be considered a comparative attribute. There are certain things that we do in identification, we look for factors that would be common throughout the signals, and then use that to reduce the dimensionality space.

Signals that are not well structured, such as natural phenomena, make it hard to find a regularity because there may not be any periodicity in the signal. What you may need to do then, is look for signal differentiation: taking a derivative of the signal or looking at the rate of change of different properties throughout. For example, with the whistlers, there was a frequency change in the sound, which could be mapped as a function and as frequency of response in these signals. In spherics, there might be a high impulse between samples.

In general, you would look for different ways to 'signaturize' or come up with some sort of categorization that you can use upon multiple signals, such that you can find similar patterns in many signals. You first have to bring them to the same level and then, when it comes to radio, do the additional modality on top, so that you can process the sounds in a similar fashion.

**Simone Conforti:** If I were to compare radio signals to words, or other things with widespread accepted meaning, working with radio signals completely depends on what you are searching for. We can generalize and compare with looking for words and putting those words in a context or in another. This can give us something comparable.

# Digital Literacy and one of its Characters

*Miro Roman*

*Miro Roman is an architect and a researcher. He is an Assistant Professor at the House of Coded Objects at the UIBK Innsbruck, and a senior lecturer at the chair for Digital Architectonics at ETH Zurich. The following contribution presents his work on developing informational characters, drawing from an abundance of books and images. Text and visual information are rendered commensurable via artificial intelligence in a networked dramatization of data points. These data points are interconnected through sophisticated computational processes which Roman further relates to poetry and literacy. This approach creates informational characters that are relevant to the method of identifying radio signals proposed by the Radio Explorations project. This identification would be based not directly on the knowledge of radio amateurs and contributors to SIGID wiki digital archive, but rather on its mechanics, character and informational similarity between the digital recordings of signals and AI driven synthetic alphabets. The characters in Miro Roman's play are articulated in terms of the specific datasets he is working with, and they enable identification of qualities and relations within streams of data flow. They are at the same time a part of a dramatic play and a synthetic alphabet.*

I prepared a story to tell you. It is a short narrative in which I bring together images, texts, avatars and social media. I am interested in ways they relate to reality, to what we think is real. Are we real? Are avatars part of us? What is artificial intelligence? What is machine learning? Is it objective? How to encode things? In my understanding, it is always important to disclose a motivation, an interest for engaging with these questions. Not to stay on the level of techniques but motivate these techniques in a certain direction.

I would like to introduce you to *Alice_ch3n81*. *Alice_ch3n81* is an avatar of mine, and I would say she comes from the plenty, from the Wonderland. She is an avatar, a bot, an alien. She is a part of me, but she is not me, so we are in some kind of relationship. We are related, but she is independent of me. She deals with a lot and that is a thing that I really appreciate about her. She deals with a lot of information, with datasets, with abundance of objects, and in this case, images and text. This is the story of *Alice_ch3n81*, and how am I able to articulate a character, by playing with big libraries, together with her. This character has consistency, and it is related to me. I take these datasets and characters like *Alice_ch3n81*, and then try to give her a voice, for instance, on Twitter. We will get back to this later. What is interesting about *Alice_ch3n81* is that she plays with data independently of media. She can play with pixels and images, with rock, cells, and chairs. She can play with words, text, and letters. Since she is my avatar, she is, like me, interested in architecture. She talks about architecture by looking at all the images and all the texts I am working with.

This is the paradox of information: if you have enough information, you can stretch it, squeeze it, encode it and it will tell a story that you want to tell, rather than showing the objectivity of the world. This is, I think, important to note about the information space we live in today, with Trump and social media. It is a space in which we anchor in something and say: "This is the truth". All seems to be constantly changing depending on how we want to see. It is an interesting moment in which what is subjective and what is objective is not clear anymore. To call it fake news is simply misleading.

How to then talk about things that we care for? How to talk about things that we really like, if we have all the books, all the images, all this data. At the CAAD chair at ETHZ, we tried to push the idea that we can approach coding and computation from the concept of literacy. If you are literate in coding, you can write an email, you can write a book, or a poem. The idea is to see coding on a level which is not about problem solving, but about articulating: coding in the sense of writing books, books of a different kind. *Alice_ch3n81* is my story about becoming literate with coding. This would be an ambient where Alice_ch3n81 grew up, full of aliens, mutants, migrants, cyborgs, avatars. These creatures are neither mortal nor immortal. They are not from heaven, nor from Earth. What they share is a space of information and abundance they inhabit. I am interested in thinking about the kinds of objects these creatures use. What is their nature? How do we think of their nature? How do we then think of our nature? Are they related?

While there are more and more of these creatures, the more you focus on what they are, the harder it is to see them. They are never pure, but always a combination of different media, flavours, realities, fictions. There are no classical categories, labels, or boxes to contain them. One could say that these creatures live on a Google planet, they hang out among other avatars and aliens, and social media is the way how they transport themselves, how they render their faces. They like the web, they like information. Maybe they are information. In whatever way we look, they influence our world. They give us many faces. This, I think, is the beauty of social media. It gives us the ability to have as many faces as we would like to have. I can have many identities, and Alice_ch3n81 would be one of my other identities.

On Figure 1, I present *Alice_ch3n81*, and a chair that we designed together. This is the first meeting of me and Alice_ch3n81. This chair is similar to Alice_ch3n81, in the sense that it is composed out of other chairs. It has many faces, many identities in itself. This object is constantly morphing, and it is one click away from becoming real.

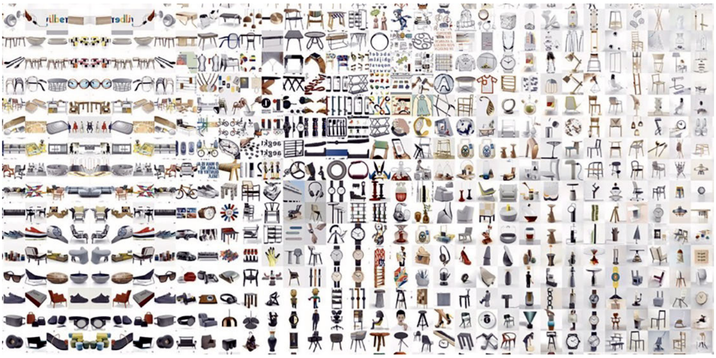
Alice_ch3n81 is my avatar and her biggest passion is architecture. When she is 'alone at home', she is addicted to surfing and navigating architectural blogs. She behaves like a search engine: snapping, indexing, filtering. She is doing this using small poems (scripts). With such a poem, she can scrape everything there is on popular architectural blogs like Dezeen or ArchDaily, all the posts that are posted today, and all the images of the first article. Then she can get the second article, and one by one she gets all of them. By running such a poem for one evening, Alice_ch3n81 gets everything that was ever published on the ArchDaily blog. One poem, one evening, half a million images. Two poems, two evenings, one million images. Ten years of online publishing. We are then in the noisy space of all the buildings that were built and published. All the furniture. All the drawings and all the architects, their publications and books. It is counted in millions, and it is just getting more.

*Figure 1: Alice_ch3n81 and the EigenChair, from Four Chairs and all the others.*


Courtesy of Miro Roman

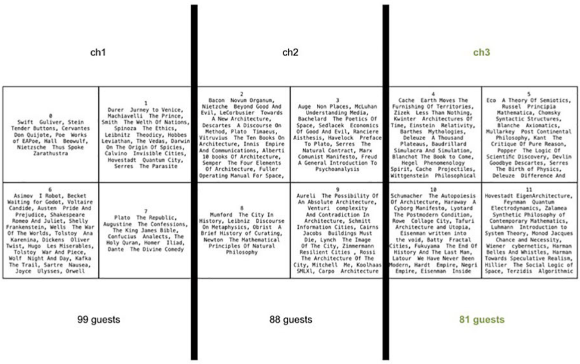
How could one think of encoding these images? I first bring them to the same resolution, into a square form and then start inventing stories. The most basic way how to transform an image into numbers is to reduce the resolution and read out RGB values. Another, slightly more sophisticated way is to search for the frequency of a structure in a specific part of a picture, by cutting the image into small squares, making an edge drawing of it, and then counting the number of white pixels. Mathematica software has different ways to measure common properties of images. You can measure the entropy of an image. You can transform this image using Fourier transformation, into complex numbers, and then take only their real or their imaginary parts. You can use feature extraction functions to extract features from six images of animals, and it comes back with a set of numbers. To encode images, you bring them to a space of numbers.

*Figure 2: Weather of images from Dezeen.*



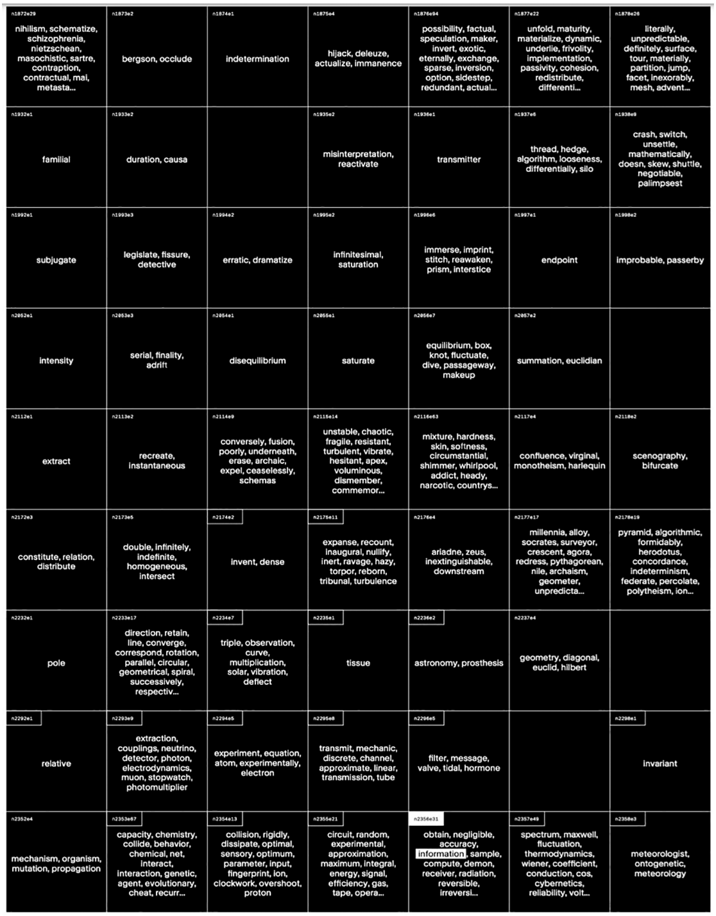
Courtesy of Miro Roman

*Figure 3: Cells with clusters of books in a self-organising map.*




Courtesy of Miro Roman

*Figure 4: Information Galaxy.*




Courtesy of Miro Roman

Interesting things can happen. I can say that one blog is one character and I talk to it, or I can mix these blogs, and make mutants out of them. I use the self-organizing map (SOM) machine learning algorithm for clustering. I take all the images of ArchDaily and Dezeen, and make a cloud, a weather of architecture in the past ten years, an impression or a face of it. It speaks of what has been happening in architecture in terms of weather. I can get a structure of images based on the colour of pixels, clustering images by structure and by form without having any input on what these elements mean. If we then take any two images, for instance a chair and something else, there will be infinite ways how we can relate them. We can relate them through the shortest path between them; or we can find random curves to relate them. The way we choose to relate the two images will be our story.

Regardless of there being any truth in them, we can work with these relations. They are true and fake at the same time. They are true because there is a mathematical procedure how we got to them, but they are also arbitrary because everything is in some way connected to everything else. If I now take any of the clusters, if I unfold these images, I am extracting the atmospheres out of the weather. These atmospheres are super consistent in themselves. For some of them, there is a certain consistency of colours or structure, which goes beyond detecting objects or form. There is a consistency in them without us being able to pin down what it is. One could use this to make branding for celebrities or for rising stars in music. As an exercise, I can take a few flavours out of this, and make a kind of a 'brain': a brain for Alice_ch3n81. Or I can create a certain sensibility with which Alice_ch3n81 can look at images.

Out of the weather, I take specific flavours and I bring them into a profile. I can get a profile about patterns – here Alice_ch3n81 likes patterns. She likes textures. She likes complicated images. In another instance, she looks at drawings, it is a completely different profile. I can have one profile on Monday, another profile on Tuesday. I can play with them, and depending on this, Alice_ch3n81 can post different posts on social media.

The other hobby of Alice_ch3n81 is dealing with text. With information technologies, we can work with images and text in exactly the same manner. This should, in principle, work with sound as well. If we are with books, there is a library called Project Gutenberg,[1] containing all digital books that are free of copyright. By writing the kind of poems I mentioned earlier, you can get all those books. I am downloading all the books as we are speaking. I do not care what they are about. The same is with images. There is no need to look closely at what is there. From Project Gutenberg, I can get 60 000 books. Then I find myself in exactly the same setup as I described previously with the images. We have here financialization of housing, voodoo histories, coming to terms with suicide, politics, trauma, tea, Islamic philosophy, Slavoj Žižek, super random books.

In order to look at these books, we take the brain of Alice_ch3n81, which is made from text now. I use this brain in order to look at the books that I do not know. When encoding or making informational faces from text, I take the whole text of a book and it becomes a connectivity of its own words. I remove the stop words, lemmatize the text and turn it into a graph of words. I then make matrices. Speaking of what it means to articulate an object in its own terms, I can choose the way to approach the library, an object, via words. If we are with Google Books, then it is made of all English words. This would be the generic dictionary of everything. But if we are in a specific library, then we take only the words that really appear in its texts. I would call this articulating an object in its own terms: I am using the words that are in the books and I am abstracting from the length of the text. The articulation is accommodated inside the dictionary, and I am just counting. For instance, the word "say" appears in the first book 120 times, and in the second book 350 times. I do this counting for all the words. One word, in this way, reflects a book and the library at the same time. Vertically it is a book, and horizontally it is the whole library. The library gets something which I call an informational face. Then books are translated to another space. We pay attention to exactly which library and how do we encode them, which data we take, and how do we think of ways in which we encode the data. A library can be encoded in terms of words. You can have synonyms. You can have letters. You can have bigrams, trigrams. You can take Google ratings. It is

1 Project Gutenberg website, https://www.gutenberg.org/ (accessed 21.06.2022).

still open to think how this could be encoded. These two things are the double articulation. These processes give consistency to what we work with.

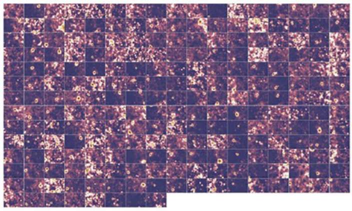
Once we have a library encoded in terms of books, it is important that I know something about all the books. I know that the Flat Land is a book about creatures in the flatland. I know Alberti. I know what a book by Žižek is about. I have not read all the books, but I have an idea what they are about. This library becomes a compass to look at the relations.

The library of books that I know, I call *Xenotheka*. I cluster the books in a specific way: in one cell there is Gulliver, Cervantes' Don Quixote, Asimov and Victor Hugo, James Joyce Ulysses, literary stuff. In the cell at the opposite side of the spectrum is Eco's Semiotics, Russel's Principia Mathematica, Chomsky with his language discussions. Then in another cell: mathematics and cybernetics. All of this clustering happened just by counting words. I then divide these into three characters (Figure 3). I am mostly interested in the third character: a technical way to think about language and architecture. I take all the books that I had from before and I project them on top of this. Then I know, for instance, that from the whole library, there are 81 books that came into the third character's cells. These books should have more in common with this character. They should somehow have similar flavours. If I unfold them, and I just take the titles of the books, I see that there is a lot about the 'digital'. Then I make word clouds, and I divide them again with SOM into four cells. The first is about 'design' and 'architecture'; the second is described by 'film', 'image', 'fashion' and 'cinema'; the third with 'digital technology', 'space', 'image', 'new'; the fourth includes a little bit on contemplation. In this way, I am getting a feeling of what this character might be about, even though I have never read the books.

This is the body of my new Alice_ch3n81. It is made of books. One thing was to cluster books, but if we invert the matrix, we can cluster words. This makes a brain for Alice_ch3n81: it is a kind of a galaxy of concepts. Each book can light up the galaxy in a specific way. If we look at, for instance, *information*, what we are going to get in this specific setting is not the definition of information, but what might information be in this context. It is close to Maxwell's 'demon', it is about 'radiation', 'spectrum', 'conduction', 'entropy', 'meteorology', 'filtering', 'transmission', and so on. We also have 'solar', 'electrons', 'electrodynamics', 'stop watch', 'photo multiplier', 'equation', 'atom'. It is about understanding information in the context of electricity and atoms: a kind of electric information.

The other term that I was looking for is *data*. It is related to information, but they have a completely different connotation in this setting. 'Data' here is around 'computer', 'airline', 'mail'; 'messy', 'keyboard', 'processor', 'laser', 'xerox', and so on. It is in the context of applications. In this setup, *information* is electric and atomic, and *data* is on the level of infrastructure and applications. I get all this just by counting words. What is important is that you find a way how to relate things to each other, to interpret what this might be about. Of course, these are arbitrary interpretations. But there is some consistency in what a cell is 'saying'. It is more complex than with images, with images we always see the whole thing. With words, the books and the words are coming, but you do not see exactly what is going on.

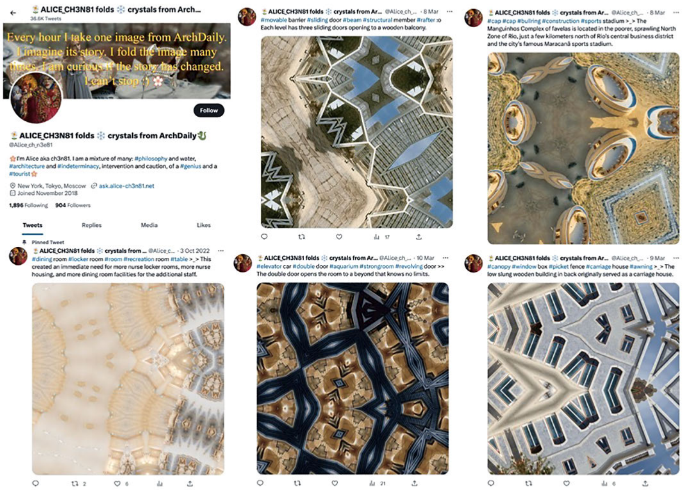
*Figure 5: Two brains of Alice_ch3n81: images (left) and books (rights).*



Courtesy of Miro Roman.

Later on, I start talking with Alice_ch3n81. I am developing an application where you can chat with this machine intelligence. You can choose to talk about information. Then we can ask Alice_ch3n81 about "articulating an object in its own terms" (see Figure 6). We can choose here different brains of Alice_ch3n81, different libraries. Alice_ch3n81 returns sentences from books which have something to do with the question we asked. There is almost an infinity of results that are coming. With K. Michael Hays, Architecture Theory Since 1968, for instance, the object language is questioned in its own term. You get the flavours of what is important for this concept for that galaxy.

*Figure 6: The Twitter account of Alice_ch3n81.*




Screenshot provided by Miro Roman.

Now, somehow, our Alice_ch3n81 has two brains. One is made of images, and the other is made of text. The brain of images is coming from half a million images I have never seen, and the brain of text comes from 13,000 books that I never read. Still, these books and these images have something to do with me, because I selected these 'flavours'. Alice_ch3n81 is a part of me but not really: we are related. It is a synthetic relation, and I can multiply it as much as I want. When I place these relations in time and space, I get a kind of consistency. This is what happens on Twitter: I take a random image from the brain of images, and I ask machine intelligence to recognize what is in these images, and to relate that to the libraries. I am getting Alice_ch3n81 to comment on the images. There are two sets of data which are related by a relation that I make. Alice_ch3n81 looks at this image using an image detection algorithm, and she says: 'scuba' 'ventilator' 'device' 'instrumentation' and 'artefact'. With this as a question, she is consulting the libraries. She gets all the answers, out of them she chooses one randomly, and posts this as a post on the Twitter. There, she has 1000 followers, and is following 2000 people, sending an image with a description once an hour. She is also able to retweet things.

Alice_ch3n81 is a character, able to act and talk, but unlike regular actors, she operates without a given script. She can find different ways of relating information. I think of Alice_ch3n81 as a character via which one can navigate the internet and play with these informational techniques.

## Discussion

**Simone Conforti:** We seem to be working with neural networks which are not doing deep learning. We are simply trying to classify stuff. But if we would do deep learning as engineers do now, we could understand more deeply why there is a relationship. The margin of interpretation would be smaller. Rather than just reproducing an organized space, deep learning is actually learning. I am wondering what would happen, in the case of Alice_ch3n81, if she would become an intelligent agent. At the moment, when we work with self-organizing map and other neural networks, we tend to think that the bigger the dataset, the better the result. But in my work with deep learning, I realized this to be false, because the point is in designing good datasets, rather than giving whatever to the network. I wonder if we can imagine the Alice_ch3n81 character operating through a network which is doing something more than organizing information, trying to really learn semantic relationships. Those networks could then also give us the reason why they create the relationship between the data, rather than just guessing.

**Selena Savić:** The way I see the specificity of this work with Alice_ch3n81 is in the question who do we want to do the work. Do we want the algorithms to generate things for us, or do we want to invent things in the organized space that the algorithms give us? In case of the latter, the importance is in understanding these techniques in terms of instruments: you can play almost anything on an instrument and you have to decide what this is going to be. This is perhaps comparable to how Carl Colena talked about reflections off the meteor: there is an active radio transmission, then there is a meteor coming at some point, we reflect on that, and we get some meaning. What I hear in the talk about Alice_ch3n81 is a proposal to work with the possibility to invent with these tools as instruments, as opposed to using them as tools to do something.

**Miro Roman:** This is the crucial difference. With both networks and deep learning, it is crucial how you collect the data: which data you take and how you will encode it. All this is subjective, dependent on our affinities, or feelings, on how you want to work. It is very important to stress that this does not reflect the world: it reflects me in the world.

If we would say that this is the world and go to policy makers to present them this as 'the truth', it would create a very aggressive setting. It would present itself as a scientific explanation for implementing a certain strategy. I think with data and AI we need to be much more sensitive and nuanced.

# Characterizing Aural Experiences

*Simone Conforti*

*Simone Conforti conducted his doctoral thesis within the research project* Radiophonic Cultures[1] *(2015–2019), which involved the Media Studies department at the University of Basel University, Experimental Radio department of the Weimar University and the Electronic studio at the Music Academy in Basel. He expressed his gratitude to his thesis advisor, the late Prof. Erik Oña, who pushed forward his understanding of music.*

I am going to talk about something that goes in a different direction from what we were discussing in the context of Miro Roman's work. My research is based on classification, or rather, clustering. It is really not about learning, in the sense of machine learning as a generative tool, but trying to understand if there is a way to use machine learning to make the life of musicologists and music researchers easier, in one specific case: sonic classification.

The starting point for the *Radiophonic Cultures* research project was the German experimental radio archive held at the Weimar University. With the sonic research team of the project, I considered using neural networks to create a tool capable of searching the archive without the need for human listening. The first question was, whether we were going to task the neural networks with analysing the sound in whatever form

1 The documentation of the SNSF-funded Sinergia research project Radiophonic Cultures is available at: http://www.radiophonic-cultures.ch/, accessed 21.03.2022

it presents itself, or try a more specific approach. We went for the latter, a specific approach based on the idea of *actual listening*, close to how humans listen to sonic facts. Actual listening means that we preserve an idea of what we heard in a longer time span, giving us the context for a sonic event. We focus on this context in which sonic events are happening, because otherwise sonic events remain unrelated to any musical development. A simple example: let us imagine we hear a voice speaking. We can analyse it in a very short amount of time. This short amount of time can tell us that this is a speaking voice or a singing voice, but it is not telling us anything about the context. Is this a voice speaking alone? Is this voice accompanied by an instrument? Does it belong to a radio drama?

We were searching for a way to represent how humans listen to sonic events, how we relate a sonic source to other sources and understand their meaning. We came up with a very simple idea: instead of analysing content as we would normally do, by slicing sounds in very small chunks and performing a spectrum analysis, we decided to look at bigger frames. A brief overview on the order of scales: if we perform a medium large FFT, we have 4096 bins, which corresponds to a duration of about 93 milliseconds at a sampling rate of 44.1KHz (CD quality). Considering that a $64^{th}$ note at 60 BPM corresponds to 62.5 milliseconds, we can get an idea about the length of the window from a musical perspective. Humans perceive this short note as a meaningful symbolic representation, but it does not give us enough musical information. If we were to analyse very large FFTs, within which varying sonic events happen, the resulting analysis gives us an average throughout the spectrum. This is interesting with reference to what Selena and Yann told us about Shazam (although the aim is different), the average time of listening chunks in the application being five seconds.[2] Without knowing this, I came to the same conclusion by listening and testing: within five or

2 In the presentation on Radio Explorations by Selena Savić and Yann Patrick Martins as part of this meeting, fingerprints and Shazam are discussed based on the 2003 conference paper by Avery Li-Chun Wang, who developed the Shazam application. The related paper by Wang is available under https://z

six seconds, we have enough time to acquire sufficient information on the kind of music we are hearing, from both high tempo and slow tempo music. For example, if we look at the first six seconds of the 1ere Gymnopédie by Eric Satie, which is in a very slow tempo, this is enough to understand that we are listening to a piano solo source.

In order to learn how to classify these sonic sources, I tried to work with very big FFTs, which requires computational power. In the case of the six seconds the FFT was made of 262144 bins. This was bringing out a lot of information that was complicated to handle, and it was not really representative of the human auditory model. There was not enough reason for making that computational effort.

I started looking for a way to compress this data. I tried many low-level descriptors, and I ended up with the Bark scale representation, which is a way to subdivide the audible frequency range into Critical Bands which are shaped according to the human auditory system. The Bark scale is divided into 24 Bark bands, which can be considered as band pass filters. These band pass filters are tuned on the way the cochlea, our inner ear, subdivides frequencies in space.[3] The cochlea is stimulated by the ear bones, pushing on the oval window – the external part of the cochlea. If we look at the cochlea not as a spiral but unrolled as a sort of cone, we observe that the frequency scale is logarithmically distributed and it is characterised by a more linear tendency towards the lowest frequencies and the opposite towards the high frequencies. This establishes a good relationship between what we hear and a sonic analysis. It is a way to translate the linear scale of the FFT into something that is closer to our auditory model.

When I decided to base my analysis on the Bark scale, I started looking for models that can give me a measure of similarity in order to compare and classify the sonic source. Bark analysis of the large FFTs win-

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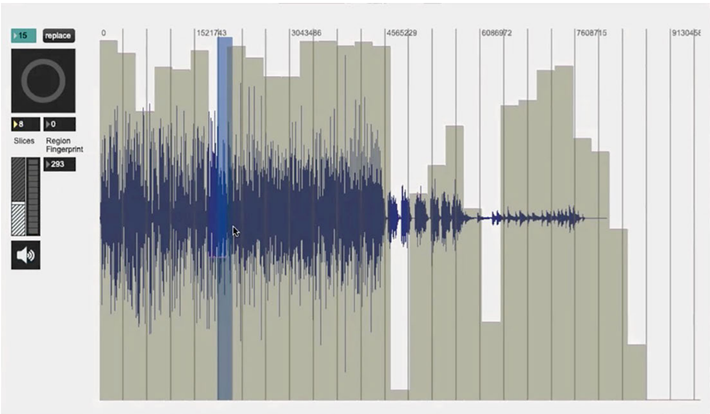
enodo.org/records/1416340, and within a Shazam github repository: https://github.com/bmoquist/Shazam

3 Eberhard Zwicker, "Subdivision of the Audible Frequency Range into Critical Bands (Frequenzgruppen)," *Journal of the Acoustical Society of America* 33, no. 2 (1961): 248, https://doi.org/10.1121/1.1908630.

dows are performed and compared each to the previous one, using cosine similarity in order to identify where to slice the sections according to their dissimilarities. The Bark scale fingerprints, obtained as the average of the sections, are then used to evaluate the distance from other sources using Euclidian distance. There are other measures of similarity, but this was already giving good results.

*Figure 1: The prototype tool for identification of changes in the mix.*




Courtesy of Simone Conforti

I have developed a tool prototype, a MAX/MSP patch. It demonstrates a way to measure similarity across audio recordings, and to understand if the idea of using the Bark scale is robust enough. It turned out to be reliable in automatic segmentation, even disregarding the fluctuations in energy of the content. I created a test sound mix. It starts with a radio program, talking with some background music. Then it shifts to dance music, in a more or less similar mood. Afterwards it moves to a solo female singing voice, and then from this moves on to Satie. The loudness is very different in different parts. My tool prototype compares all this through the Bark scale, creating a kind of a step map that represents the cosine similarity across steps. It identifies points in which we are expecting to have a change in similarity, when the sound content changes. We can then extract a fingerprint and analyse the distance between the chunks. I reduced my Bark scale into 22 bands, probably I can even reduce more, since we are dealing mainly with music or musical sources that present less relevant content beyond 6 or 7KHz. A future step in this research would be to gradually reduce the size of the FFTs, each time we find a change region, to really identify the exact point of change. For the moment, the margin is very large. Still, we can roughly identify the spots in which energy and frequencies characterize a radio talk show, dance music, a singing female voice and the piano. The idea is that we can use these extracted vectors, these fingerprints, as the training set for a self-organizing map. I would use these region fingerprints as the way to organize my map and afterwards I can use whatever input vector as a Bark scale vector to classify a new sound object.

My research so far was attuned to finding ways to classify sound. I think that we can probably reintroduce some more low-level descriptors in order to reinforce this classification. For now, the tool I demonstrated here is quite robust, but sometimes when we have very complex music, it becomes less meaningful or more difficult to interpret. Another relevant topic will be to understand how to shape the results of these comparisons in a way that can be considered meaningful for music researchers.

Finally, I was thinking about possible low-level descriptors for Selena's *Radio Explorations* project. This is also a question to Carl Colena, who understands the particular properties of radio signals and their demodulated audio samples. What do those sounds mean in terms of radio communication? What descriptors could we use to describe those sounds? In the self-organizing map of radio sounds Selena and Yann showed me in May 2020, I saw some inconsistencies, probably because too much was based on the spectrogram. The FFT tells something, but it is not clear what it means. For example, if there is strong energy in the high frequencies, in the case of a recording of instrumental music, perhaps it does not mean so much; it is probably just noise coming from electronic equipment. One question would be whether there is noise in the radio signal coming from interferences in the transmission, or is it part of the transmission. I was also thinking about the method of using only the FFT representation, with which we can actually get all the descriptions of the sonic source. But how to make good onset detection of an event? It could be performed through the measure of High Frequency Content or through the Spectral Flux, which is another way to not detect the onset but also to see the evolution of a sound within a timeframe. We then have, again, the issue of the time span. Different radio sources present specific patterns, which have different lengths. We can also think of an analysis that describes the source as it happens through Spectral Centroid and Spread, which can be useful because those are characterizing not the frequency in itself, but the energetic perceptual distribution of the sound: the barycentre of the spectrum and the standard deviation. All these features can be considered to define a sound and if needed the analysis can be extended by adding some more audio descriptors in our vectors of features to classify the sound sources.

# Data Observatories

*Data observatory* is a navigation apparatus which can be used to orient oneself in the vast landscape of data on radio transmissions based on computable similarity. The development of visual instruments, *data observatories,* is part of the method and ambition to organize data on radio signals according to properties of the dataset.

The dataset used by the *data observatory* comes from the Signal Identification Guide (SIGID) wiki: an organized collection of information about radio signals, held among a community of radio amateurs and enthusiasts. As of March 2022, there were 444 known or identified and 328 non-identified signal pages on the website. Known signals are divided into categories based on different listener community interests, such as the military, amateur radio, trunked signals or satellite reception. Each signal is characterized by its transmission properties, a short description and a recording sample with the spectrogram. Any radio signal that can be received and recorded can be included in the database.

The data itself mean very little in terms of human communication: it consists of demodulated recordings of radio transmissions pertaining to document the protocols rather than the content of transmitted messages. What was said is often a simple 'I am there', sent out by radio beacons, industrial and monitoring equipment. Partial access to this data means extracting specific features from the data, which gives access to a comparison across the dataset.

To render them comparable, or commensurable, a self-organizing map (SOM) machine learning algorithm was used to encode signals in terms of specific properties such as probability of silence, the level of noise in the audio sample, or an audio identification technique called fingerprinting.[1] Networks of machine learning algorithm train on each of these property sets and produce an organized space – a grid of 'codebook vectors'[2] – that can be navigated and explored in three dimensions: according to proximity of codebook cells (horizontally and vertically) as well as according to the content of one cell (depth). By doing this, the database gets an informational face, a different one for each of the properties. Signals are grouped with other signals in one cell of the grid (see Fig 01) when they exhibit strong similarity according to the organizing property. Signals that occupy opposing corners of the grid should in principle pertain to very different types, while types themselves are fluid across the grid – there is no hard cut to determine the area in which signals belong to any particular type.

The development of *data observatories* contributed to exploring ways to reorganize the digital archive on radio signals collected by radio enthusiasts and available online as Signal Identification Guide (SIGID) wiki.[3] This database documents listening practices of the community of radio amateurs and enthusiasts. In addition to radio amateurs, recordings of radio signals 'in the wild' can capture the interest of a telecommunications engineer and a media archaeologist, of a data scientist, and an ecologist, or a historian of science and technology.

The neural networks of the self-organizing map (SOM) lay down the ground, whose topology is rendered commensurable with an outside, intuitive domain: Descriptions and Projections.

1 Fingerprints are a sort of a condensed digital summary of an audio signal, based on peak points in the spectrogram which represent higher energy content. The technique is known for its use in Shazam music identification application. The related paper by Wang is available under https://zenodo.org/records/1416340, within a Shazam github repository: https://github.com/bmoquist/Shazam, and also within Columbia University repository of Dan Ellis, https://www.ee.columbia.edu/~dpwe/papers/Wang03-shazam.pdf

2 A codebook vector is a list of numbers that have the same input and output attributes as the training data.

3 Signal Identification Guide wiki is available at http://sigidwiki.com (accessed 17.02.2022).

# Data Observatory: Descriptions

*Selena Savić and Yann Patrick Martins*

All signals in the database have a textual description. These are short pieces of text describing basic properties, protocol-specific details, replete with technical jargon. Nevertheless, text is a domain that can give us meaningful access to signal qualities through an architectonic relationship. In this first study, we related the self-organizing map of spectral entropy in radio signal audio samples to a statistical model of text using Latent Dirichlet Allocation (LDA) algorithm, popular for topic modelling tasks.[1] We identified nine topics, each taking us to a group of signals that are most relevant to it (Fig 1, left).

I (Selena) began the Study 01 by expressing an interest in the relationship of radio and military. We know many telecommunication technologies, such as the Internet, were initially developed by the military, but is there something new and specific we can learn from this setup? I selected the topic that deals with things military (Fig 2, green highlighted text on the left) and looked at signals that are most representative of it.

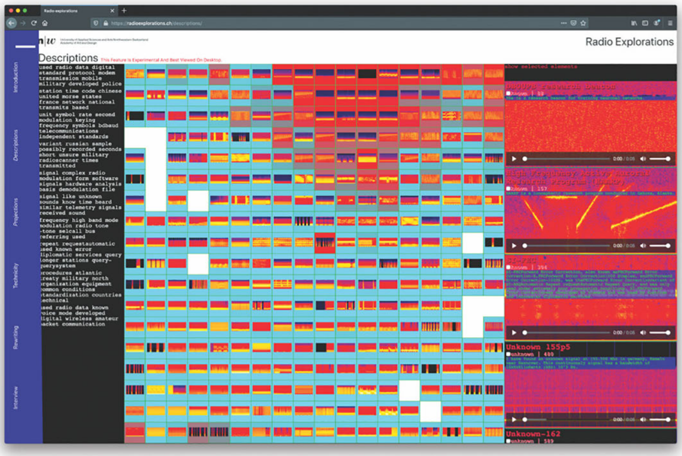
One signal with an interesting spectrogram, High Frequency Active Auroral Research Program (HAARP)[2] drew my attention (Fig 1, right side). It presents radially and diagonally propagating lines, like a drawing. According to the description, it belongs to a research programme

1 Latent Dirichlet Allocation (LDA) is a form of unsupervised learning that views documents as 'bags of words', in which order does not play a role. Topic modelling or topic detection is a machine learning method to discover human-readable topics in text.

2 More on this signal in the database: https://www.sigidwiki.com/wiki/High_Frequency_Active_Auroral_Research_Program_(HAARP), accessed 21.02.2022

studying the properties and behaviour of the Earth's ionosphere. Reading about ionospheric emissions, I learned that climate researchers used data on lightnings to measure the degree of climate change.[3] They found, back in the end of 1990s, a significant correlation between the increase in temperature and in lightning activity in the northern hemisphere of our planet. Within the fingerprint-based SOM, in a cell that is representative of the military topic, HAARP is similar to DUP-FEC-2 and RUM-FEC (Fig 2 and Fig 3, right).

*Figure 1: Study 01: Descriptions. Data observatory web-based interface. Topics are listed on the left. Data organized according to fingerprints.*



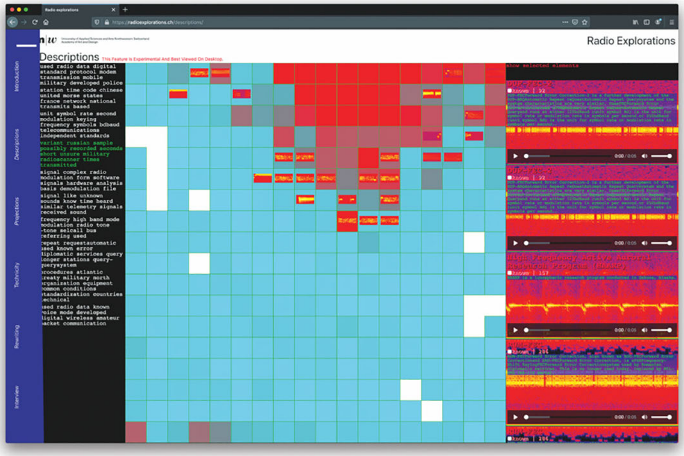

Courtesy of Selena Savić

The 'FEC' in the name of these signals stands for "forward error correction" – an error control method characteristically used in situ-

3 N. Reeve and R. Toumi, "Lightning Activity as an Indicator of Climate Change," *Quarterly Journal of the Royal Meteorological Society* 125, no. 555 (1999): 893–903, https://doi.org/10.1002/qj.49712555507.

ations where retransmissions are impossible. By now, what this cell tells us about military is: *Military communication is tightly connected with diplomacy and intelligence. The connection can be made through techniques of environmental listening (HAARP); the impossibility of retransmission (FEC) is characteristic of many military communication situations*.

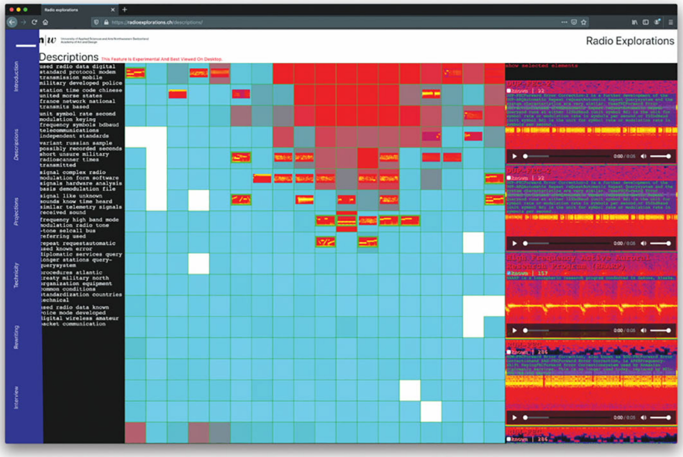
*Figure 2: Study 01: Descriptions. Data observatory web-based interface. Selecting a topic (green highlighted text) exposes the most relevant signals.*




Courtesy of Selena Savić

The setup of the *data observatory* renders these connections perceptible through an interest in the relation between sonic and textual representation of the signal. The use of a *data observatory* as an instrument to perform the comparison between the recording of a radio signal and its description, starts to unfold stories that would otherwise slip our attention.

*Figure 3: Study 01: Descriptions. Data observatory web-based interface. Chunks of one signal, HAARP, are highlighted throughout the map.*




Courtesy of Selena Savić

# Data Observatory: Projections

*Selena Savić and Yann Patrick Martins*

How can we compare radio signals to something that is meaningful to us? The second *data observatory* organizes radio signals by 'projecting' their properties onto musical genres. First, I let the self-organizing map give me a topology of audio samples from the Free Music Archive (FMA).[1] Then I projected radio signals onto this organization. Radio signals 'land' in cells where the music sounds similar to a signal. Some cells do not attract any radio signals. The music archive is organized into eight specific genres, and they can cast shadows onto the organized space of radio in a similar way the topics of textual descriptions do in the previous study. Certain genres share more cells with radio than others (see Fig. 1).

1 FMA: A Dataset For Music Analysis Github repository: https://github.com/mdeff/fma (accessed 21.06.2022).

*Figure 1: Study 02: Projections. Data observatory web-based interface. Radio signals projected onto a self-organizing map of Free Musical Archive. Highlighted cells (green) are representative of 'hip-hop' genre.*

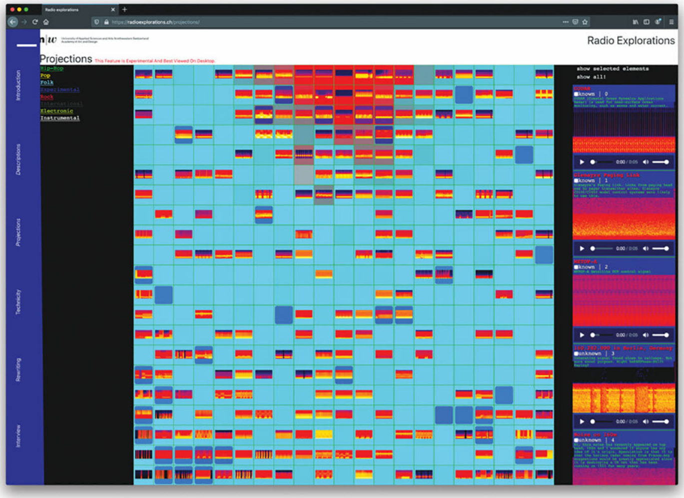

Courtesy of Selena Savić

Rhythmical characters emerge in the dataset: fast or slow-paced signals, narrow and wide. Signals that are grouped together according to their similarity to songs, demonstrate consistency in rhythmical and spectral components. This similarity is not arbitrary, and it strongly suggests the possibility to use this organization to identify unknown signals. Signals that pertain to video link transmissions, PAL broadcast[2] and an unknown satellite-like signal are grouped together in three neighbouring cells. It should be noted that some of this rhythmicity comes as an artefact of signal recording, limiting the reliability of sim-

2 PAL Broadcast entry on SIGID wiki: https://www.sigidwiki.com/wiki/PAL_Broadcast (accessed 21.06.2022).

ilarities to infer signal identity. The dataset would require cleaning to remove such false consistencies.

*Figure 2: Study 02: Projections. Data observatory web-based interface. Radio signals projected onto a self-organizing map of Free Musical Archive. Cells that are representative of the 'experimental' genre are highlighted (blue).*




Courtesy of Selena Savić

# On Rewriting Networks

Radio Explorations Research Meeting with participation of Sarah Grant, Roberto Bottazzi, Miro Roman, Simone Conforti, Yann Patrick Martins and Selena Savić

The second research meeting in the *Architectonic Explorations of Radio* research project addressed the notion of *rewriting* in context of telecommunications and beyond: how to translate between domains, such as the natural environment and network infrastructures, digital and spatial, books and architecture. Three invited guests, Sarah Grant (Kunsthochschule Kassel), Roberto Bottazzi (The Bartlett) and Miro Roman (CAAD, ETHZ) presented their current research in nature of networks, cryptographic writing and the design of search. In the space that is marked by the three interests, the *Radio explorations* team presented the first data observatory *Codebook*: reorganized archive of radio signal recordings, explored through text, topics and keywords identified in a statistical model (LDA) of signal descriptions. A prototype of the second data observatory, *Projections* was discussed in terms of rewriting radio signals through different domains, such as music or sounds of nature.

Essays that follow are written accounts of these presentations and discussions, as delivered by authors.

Basel, 24.11.2020

# The Art of Networking

*Sarah Grant*

*Sarah Grant, visiting lecturer at Die Angewandte in Vienna and previously guest professor for New Media at the Kunsthochschule Kassel, has a background as a professional web developer and an artist. She studied art, in particular sculpture and printmaking, completing a masters from NYU at the Interactive Telecommunications Program in media arts.*

Even though I have a technical background as a programmer, my relationship to antennas, radio waves, and the electromagnetic spectrum is experimental rather than practical. When I say experimental, I mean working somewhere at the intersection of bio art and networking engineering. When I work with electromagnetic waves, specifically within the Wi-Fi bands, or with the design and construction of antennas, it is from an exploratory point of view. I started exploring antennas as sculpture in a project with my partner Danja Vasiliev, called *LANscapes*. It is a research project in merging the practices of environmental art and network engineering. We started this work at a residency at Ljudmila in Ljubljana, Slovenia.[1] We chose a landscape and studied it in order to design experimental antennas and other potential components of network infrastructure, for example signal paths. Our goal was to create an envi-

1 Documentation of the residence is available on the website of Ljudmila: https://wiki.ljudmila.org/Rezidenca:%20Grant%20&%20Vasiliev (accessed 22.03.2022).

ronmental network as an art installation, with bio-electrical hybrid versions of infrastructure.

Following this experimental approach to reimagining communication networks, I visited the Critical Media Lab to collaborate with Selena Savić and Yann Martins to model cooperative housing with the assistance of an organism called *Physarum polycephalum*, or slime mould. Slime moulds are single cell amoeba creatures, that creep around forest floors looking for food. Once they find food, they surround it with their cellular body and create networks of protoplasmic tubes between all of the food sources. I was interested in slime mould because it is known for creating efficient resource distribution networks. I wanted to see if I could model different kinds of networking topologies with how I placed food on a surface. As you can see in this picture, the oat flakes have been dyed red and so as the slime mould consumes or breaks down the oat flake, it distributes the nutrients and food pigment throughout its body. I used food dye as a visual marker for tracing how information flows within a slime mould's protoplasmic tubes. At the conclusion of this project, Selena and I wrote an article summarizing the results of our experiments using slime mould as a computational resource distribution network.[2]

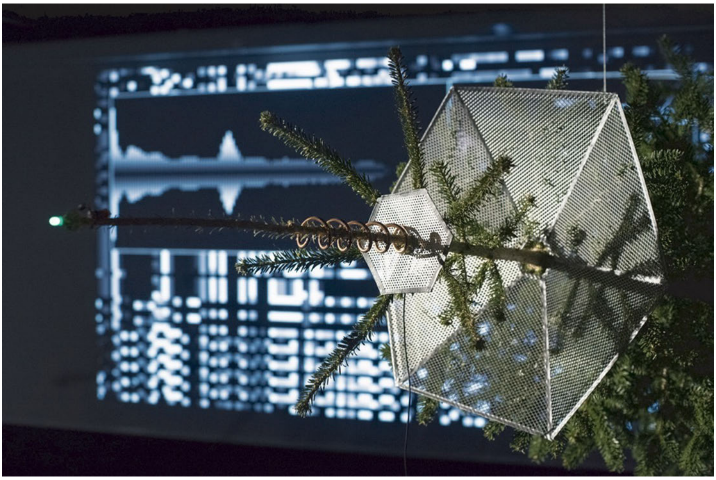
From a broad perspective, I am interested in thinking about how connections are made, specifically about data transfer using an organism like slime mould or a physical phenomenon like electromagnetic waves. However, since EM waves are intangible and given my background in sculpture, I am left longing for some kind of texture or tangible interface for understanding and interacting with this medium. This is part of the reason for why I am drawn to looking for models of networks within nature.

When we went to Ljubljana to for the *LANscapes* residency, we had this very abstract idea inspired by the fact that network infrastructure,

2 Selena Savić and Sarah Grant, "Slime Mold and Network Imaginaries: An Experimental Approach to Communication," *Leonardo*, July 21, 2022, 462–67, https://doi.org/10.1162/leon_a_02248.

data centres, antennas and wires, are usually just dropped into a landscape without much regard for the environment. We wished to identify processes or features found within the environment that mirror network infrastructure. We looked for a way to work together in collaboration with a given environment in order to make designs inspired by and in partnership with nature, such as new kinds of antennas or other parts of network infrastructure. In Ljubljana, we first tried to make the tree itself an antenna. We came across some very old papers from the time of World War I when people had already been trying to do this with some degree of success. We planned to follow what we were reading in these papers in order to replicate the experiments. However, we were blocked from pursuing this by city regulations; we were forbidden from doing things like inserting metal stakes into the tree trunks, which unfortunately was going to be part of the process of turning the tree into an antenna.

*Figure 1: LANscapes installation at Ljudmila, Ljubljana, December 2019.*



Courtesy of Sarah Grant

We decided to make our own reflective dishes that the tree could 'wear'. Additionally, since we were not able to get the permit in time from the city to do any work in a public space, and because this was as well happening in December with Christmas trees for sale everywhere, we ended up using a Christmas tree as our test tree for which we designed experimental kinds of antennas. This was not the direction I had originally envisioned, as in doing this we are still placing manmade infrastructure on top of nature – literally dressing a tree up in a spiral coil and collar – but it was all we could work with.

In the end we set up a stage performance with a few different trees wearing various antennas that were designed for them. This one in particular is a Wi-Fi antenna. It is really the very beginning of these experiments because after all, we only were able to scratch the surface of this line of thinking and prototyping.

## Discussion

**Selena Savić:** Speaking of antennas, what I understand as a very general working principle is that electrons in the metal are getting excited and moving through the material in a sort of a pattern that creates the electromagnetic field and transmits this pattern to another antenna. This is actually the information. What is it that you can do in this engineering space? What is it in the antenna that lets you do different things, working at different frequencies? Or what do you need to know about antennas that lets you play with them?

**Sarah Grant:** My relationship to antennas is more about the forms that they take. It is a sculptural point of view, although I also take seriously the fact that they have to transmit properly at their assigned frequencies. Antennas are typically designed to transmit information as efficiently as possible. They are designed for a very specific use. My work here is not art for art's sake: what I wanted to intervene with, as an artist who also appreciates the technical qualities of an antenna, is to think of experimental forms an antenna can take while still performing its intended function. It is more about reimagining how the antenna looks, than about its electromagnetic properties, while still keeping those in mind because I want to make antennas that actually work.

**Selena Savić:** This reminds me of DIY projects that teach you how you can extend your Wi-Fi network range by making antennas and other kinds of things. I have tried to make such antennas a while back, and I remember that there were very precise instructions about dimensioning their square wave shape, how to bend the wire at precise distances relative to the wavelength of that signal. And then there were other materials that had to be introduced on top. I remember from that design that I would not be able to intuitively figure out how to make such an antenna, or why the antenna I made is not doing what I am expecting it to do. In other words, the form of an antenna matters for its operation. You were obviously able to make antennas that work, so I was wondering, how do you know what you can change, where you can intervene?

**Sarah Grant:** I appreciate the fact that there is a lot of skill and training that goes into designing an antenna. I am typically on the software side of things, and I have lots of experience dealing with different kinds of software issues. When it comes to doing things like building antennas, I take a completely experimental approach, and I think it is good to be kind of naive. When I do not know what I am doing, it does not hold me back from trying unexpected things, and figuring out how to make it work.

On the other hand, of course, I kind of know what I am doing. I understand the basic idea about how certain antennas for certain frequencies should look like. One thing that is important for my practice and also for all other members of our art studio Weise7, is that we do not want to just play around with something. We actually do want things to work. This is because we all have these deeply technical backgrounds. It would bother me to make something that spoke to an idea, but did not really see it through all the way to the end of actually working.

**Roberto Bottazzi:** What is the link between slime mould and antennas? Is it something that you want to or have been pressing further?

**Sarah Grant:** My work with slime mould is not an antenna experimentation. The work with slime mould is in the domain of network topologies and attempts to model what happens in software in terms of creating efficient networks. I rely on what seems to be innate to the slime mould nature, to know how to do that.

**Roberto Bottazzi:** Do you think that because slime moulds were used to model cities, such as for example in the Tokyo rail network experiment? Would you say that is the nature of radio signals that makes the slime moulds incapable of modelling a network like a network of antennas?

**Sarah Grant:** I think slime mould is capable of modelling any network. But the thing that is interesting about it, is that the slime mould obviously does not know what I am trying to model with it, a computer network or a city. The way it behaves could be applied to all kinds of networks and at the end of the day, it does not actually matter what kinds of networks we are talking about – if it is about railway stations or the design of a freeway or a computer network or a network of antennas. A network is a network and it has its particular computational function. Slime moulds are an interesting creature to work with when exploring how to model networks under different environmental conditions.

Importantly though, we cannot just cut and paste slime mould's behaviour into a human experience or a human reality. It is not a one-to-one relationship. What I do is to take a phenomenon which is in this typically technical realm, for instance a network, and step to the side to see how a network manifests in a slime mould when it is trying to eat food. I observe any insights that I can gain from that. I intentionally put myself in these situations where the outcome is uncertain. It is possible that something really amazing would come out of this or that absolutely nothing would come out of it. I am looking for bridges: modelling a distributed network with slime mould, seeking to observe something of interest, which I can then take back into computer networking, but which maybe just would not fit.

**Roberto Bottazzi:** It is totally right what you said about that slime mould, it does not really care if you are using it to simulate a city or anything else. That is also the case for a Turing machine. A Turing machine is not built to model or simulate anything in particular. I wondered whether, in case of radio signals, an attempt to model them with slime mould would be problematic because they are essentially not the same kind of thing. In fact, the opposite could have posed an interesting condition: to model radio signals with something that was not thinking that way. Because slime mould still thinks, but it does not think in radio waves, it does not think of space in that kind of format.

**Sarah Grant:** Maybe there is some other creature that would be suitable to model radio waves. It seems to me like a lot of engineering problems that we face have been solved by different creatures and organisms in biological processes that have existed for millions of years. It sometimes feels like we are reverse-engineering the world so that we can use these behaviours or phenomena to control things for our own ends.

**Selena Savić:** It is a very interesting problem to think about, looking at the way you present your interests in engineering: engineering practice being a code that you apply to the question of networking. Networking taken as an abstract term, which happens in the body of the slime mould, or which happens also in our engineered network infrastructures for communication. I think this material practice of making an antenna somehow encodes it in a certain way and also distances itself from pure efficiency. Technical problems of communicating across a distance have been solved in many ways, and while it can always be made more efficient, the question is what do we actually know about it? How do we organize this knowledge of telecommunication? To what extent do you know what is going to happen and how do you make something happen? It is a process of distancing from simply solving the problem.

**Sarah Grant:** I think about this quite a lot. If you remove the requirement that something is perfectly efficient, it opens up a lot of possibilities for other forms that something like at an antenna could take. The other reason I am drawn to doing experiments like this, even if it results in a less efficient antenna, is an attraction to knowing how these particular technologies work. I would say this is my aesthetic. Not everyone cares to think about all those things, even though communication networks and antennas are so present in our environment. It is not even that they are embedded in our environment, we are embedded in their environment really. I do like to make work that brings some of these things to attention in a way that is more visually appealing, in a different visual language, in a way which might cause people to think about these networks as part of themselves, something we are born into, and participate in.

# Cryptographic Rewriting across Domains

*Roberto Bottazzi*

*Roberto Bottazzi is an architect by training and Associate Professor of Master in urban design at the Bartlett School of Architecture in London. He is the author of Digital Architecture Beyond Computers (Bloomsbury Visual Arts, 2018). He writes on the history of digital design and the role AI plays in the design process.*

From the discovery of the Anthropocene, and the consequent decentring of humans, to the rapid diffusion of novel forms of rationality represented by Machine Learning (ML) methods, or the exploration of radio waves as in the Radio Explorations project, the present condition of all creative disciplines continuously confronts domains that escape human senses and cognitive abilities. The apprehension of these beyond-human domains relies on the implementation of technological prostheses, be it in the form of algorithms or physical devices. In all these instances, the recurrent issue at stake is the development of instruments and theoretical frameworks to orchestrate communication and exchange across domains. This chapter focuses on the evolution and significance of instruments and ideas in the field of computation, a domain that through the invention of abstract signs and operations has been developing a rich history of techniques dealing with what lies beyond both the perceptible, and, as we shall see, the intelligible.

The branch of computation that has been specifically tasked with the translation of signals or messages between domains is cryptography. The history of cryptography, in fact, provides a vast repertoire of techniques whose application impacted several fields and that will constitute the central focus of this discussion. Though we will briefly survey some methods developed to safely transmit diplomatic secrets, the aim of the discussion is to think cryptography in broader terms, that is, to unpack how a series of abstract and arbitrary operations can resonate with and foreground aspects of complex, beyond-human phenomena. I will concentrate on architecture and urbanism (my area of research) as, with the penetration of machine learning methods in this field, a series of issues have come to the fore that benefit from being discussed through the lenses of cryptography. The aim of this discussion is to foreground a way of thinking about exchanges between domains that could also be relevant to grasping what issues and opportunities could characterise the *Radio Explorations* project.

In wider and more theoretical terms, cryptography in fact is a discipline that conjures up methods to create communication channels between what is inaccessible (noisy, in information theory parlance) and what is intelligible (and therefore amenable to manipulations). In the hands of philosophers such as Ramon Llull or Francis Bacon, cryptographic methods became bridges between what 'there is' (nature, in classical terms) and what can be created (in contemporary computational parlance, cryptography had 'generative' qualities). To devise the right cypher (the actual bridge between two or more domains) had the wonderous ability to let nature speak (Bacon) or a whole metaphysical system to reveal itself (Llull). Thought of along these lines, cryptography can be seen, as I will argue, as an object of design that can be conceived, tuned, and played with in order to move a certain domain in and out of intelligibility. As such, the theme is relevant to the Radio Explorations project as part of the issues dealing with radio signals also involves thinking how the inaccessible can be interfaced by humans, how an eminently non-human domain should be approached for it to speak, and what implications to creative processes it could have. The construction of notational systems to deal with abstraction and creativity and the individuation of a balance between prescriptive and aleatory procedures are some of the themes along which cryptography can provide fruitful insights for design and artistic endeavours as it deals with forms of rationality that are not human.

No matter which historical period we concentrate on, cryptography remains a central tenet of computation. Besides the preservation of diplomatic secrets, cryptography was also understood as a key, a cypher, to unlock nature's secrets. Today, one of the most powerful operations Machine Learning (ML) methods enable is to extract functions (cyphers) from heterogeneous sets of data and, perhaps even more remarkably, project cyphers onto any other dataset, teasing out potential correlations.

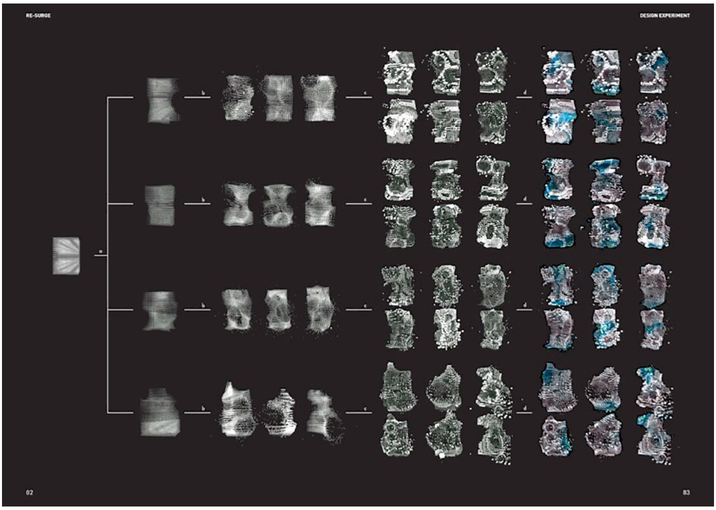
To give specificity to the arguments put forward, the discussion will focus on architecture and will briefly conclude by describing some of the projects developed within the Master in Urban Design which I direct at the Bartlett School of Architecture in London. The approach proposed here is also consistent with what is put forward in *Digital Architecture beyond Computers,*[1] which proposed a massively expanded historical perspective in order to grasp what is at stake when designing with computers, one in which the technical operations enabled by computation constitute the 'materials' digital designers need to think through.

The arguments presented in this chapter broadly divide into two parts. Each part is distinct as it addresses different historical moments and technological conditions, with no like-for-like comparison between the two being suggested. The first section outlines some paradigmatic conditions that emerged from the introduction of Machine Learning (ML) models in design disciplines. This part is firmly anchored in the present and, rather than dwelling on the technical aspects of ML, it concentrates on how ML models are changing design culture. The second segment focuses on the late Middle Ages and Renaissance when notational systems emerged in cryptography to affect fields as diverse as architecture, mathematics, and writing. The common thread linking these two distant moments in the history of cultural production is the role that cryptographic methods played. Designing with ML models demands a continuous exchange with systems that operate outside the

1 Roberto Bottazzi, *Digital Architecture beyond Computers: Fragments of a Cultural History of Computational Design* (London New York Oxford: Bloomsbury Visual Arts, 2018).

limits of human cognition. Operations of retrieval, translation, and rewriting are constantly performed to make intelligible the abstract space of massive data organised by automated algorithmic processes. These operations have been fairly common for cryptographers. The comparison between the present and early modern condition is obviously not literal, rather it exploits the distance in time to widen our perspective on the present. Cryptography is here understood as a paradigm; that is as a "single element within a set."[2]

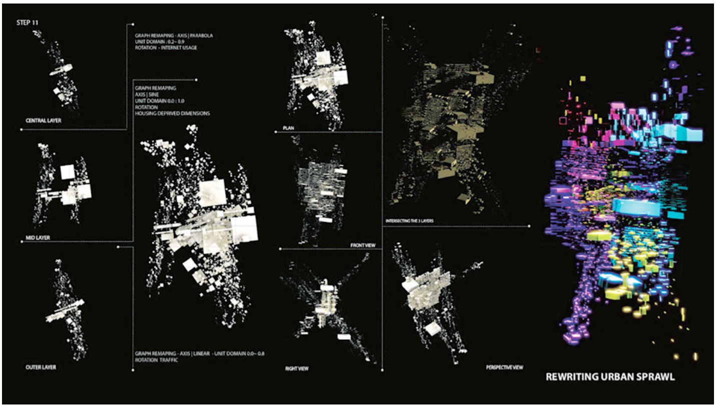
*Figure 1: Rewriting. ReSurge (Abdimajid Aden, Su Keyu, Yubin Liao, Mohammed Puthiyaveettil, Zhou Zhou), Research Cluster 14 2019/20, B-Pro MArch Urban Design, The Bartlett, UCL.*




Courtesy of Roberto Bottazzi

2 Thomas S. Kuhn, *The Structure of Scientific Revolutions*, Second Edition, Enlarged (Chicago: University of Chicago Press, 1970).

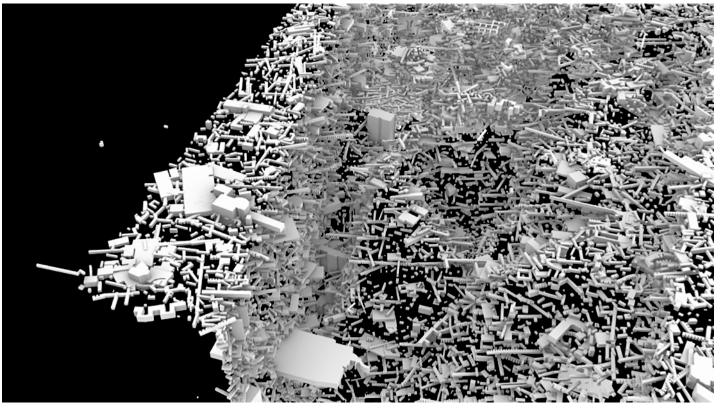
*Figure 2: Rewriting. Flora Amritt, Research Cluster 14 2020/21, B-Pro MArch Urban Design, The Bartlett, UCL.*




Courtesy of Roberto Bottazzi

Seen through the lenses of paradigms, cryptography is explored both ontologically and epistemologically. In the first case, cryptography helps identify a series of experiments in different fields such as philosophy, art, and language that resonate with present design issues. Secondly, by considering the examples chosen as a part of a single set, cryptography provides a new angle through which to read them. Therefore, the essay should not be read as a manual, a piece of technical literature, a complete account of what either ML models or cryptography are, and, even less so, as a ready-made design methodology to deploy. The essay juxtaposes cryptography and ML models so that, despite their obvious differences, common themes and concerns can resonate one another. This is the task of the conclusive part which draws out some final considerations that, whilst having first emerged some six or more centuries ago, could be useful to reconsider in the current debate on ML and design and in *Radio Explorations* project.

*Figure 3: Rewriting. Halfway between data visualizations and spatial compositions, rewritings are design exercises through which students develop a technical and aesthetic literacy towards working with large databases. Alankrita Amarnath, Research Cluster 14 2020/21, B-Pro MArch Urban Design, The Bartlett, UCL.*



Courtesy of Roberto Bottazzi

## On the introduction of machine learning models in design

There are two aspects of computation, in general, and Machine Learning, in particular, that are useful to foreground to define the argument of this paper.

First, computation can be thought of as an infrastructure to move signals between domains. Jean-Michel Salanskis pointed out that the fundamentals of modern computation, as laid out in close succession by Gödel, Turing and Church, did not constitute an exact language.[3] Each method proposed different approaches to computation, so much so that they could only be compared at a schematic level. More importantly for

3 Jean-Michel Salanskis, *Le monde du computationnel*, À présent (Paris: Les Belles Lettres, 2011).

this discussion, Salanskis contends that what unified all three methods was the focus on establishing syntactical rules which allowed them to function whilst bypassing semantic questions. In other words, the three computational procedures formalized an 'infrastructure' of calculation; that is, they prescribed *how* signals could be transmitted, not *what*. ML algorithms such as classification algorithms constantly reorganize input data by compressing or expanding them or by seeking correlations. In doing so, they move signals between domains based on statistical distributions that bypass issues of meaning. At the same time, they encrypt and decrypt data to extract relevant features assimilating the work of the designer to that of a curator that oversees these operations of compression and organisation.

Furthermore, some ML algorithms, such as the ones used for classification, allow designers to project datasets onto each other; that is, to remap a particular set of data onto a different one. This capacity of ML algorithms has genuinely radical implications for design as it allows designers to consider and work with domains and themes that have traditionally been intractable to design. The curatorial and infrastructural aspects of design become even more relevant in this context. In urban design, this shift opens up the possibility to work with aspects of cities that have not been traditionally considered by urbanists as well as simultaneously focusing on how functional, material, temporal aspects of city life interact. Issues of compression, translation, remapping and rewriting can be enriched by thinking of them through the lenses of cryptography. To think of data compression and projectability in infrastructural terms allows us to shift the focus away from single aspects of the city towards connectivity, and, consequently, framing the problems in terms that could also be useful for the analysis and representation of radio signals.

The second point concerns the relationship between intelligibility and representation that is at the core of both cryptographic and ML methods. Again, it is useful to frame the argument from an historical perspective as it offers a richer context to map out the discussion whilst giving a better sense of the scale of the disruption presented by the introduction of ML models in design. In very schematic terms, we could broadly define the history of the epistemology of representation by three areas. The first one is characterised by reduction: the task of representation is to reduce the complexity of signs that make up our world in order to foreground new insights. This is, for instance, what maps perform through the depiction of selective aspects of reality. We could say that the greater the compression, the better the map (that is, more legible, more specific, etc.). The second phase is that of approximation. Once we accept that representation is a compression of reality, we can work towards reducing the gap between the two in order to generate 'high-fidelity' renditions of reality. This intellectual project had an enormous traction for several centuries across the whole of Europe.[4] In this group we could include the search for so-called perfect languages (whose development was also influenced by cryptography) or encyclopaedias which introduced the format of the open list to approximate as closely as possible the distance between knowledge and its classification. ML models usher in a new phase in which representation exceeds reality. Though ML models are trained on data coming from reality, they perform many mathematical and statistical operations that massively increase the complexity of the representation of the initial datasets. Tangible examples of this phenomenon abound. Though never fully confirmed, it is rumoured that each Facebook user is described by 52,000 types of data.[5] A hypothetical spreadsheet of all Facebook users would therefore consist of 2.96 billion rows (approximate number of Facebook users at the time of writing) and 52,000 columns or dimensions. Beside the impossibility for human cognition to navigate such a vast data space, it is plausible to imagine that the parameters do not represent sensory qualities of each user or even intelligible ones. More recently, Open AI's ChatGTP-3 model processes training data through

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4 Paolo Rossi, *Clavis Universalis. Arti Mnemoniche E Logica Combinatoria Da Lullo A Leibniz* (Milano; Napoli: Riccardo Ricciardi editore, 1960).

5 Green, A. (2018). "Facebook's 52,000 data points on each person reveal something shocking about its future". Available at: https://www.komando.com/social-media/facebooks-52000-data-points-on-each-person-reveal-something-shocking-about-its-future/489188/ (accessed on 20.03.2023).

175 billion parameters. Again, cryptographic thinking and techniques can be useful to problematize these technologies and think of working with them as issues of translation of signals between domains, between reality and representation and between humans and machines. As Salanskis noticed, questions of meaning are irrelevant to procedural calculations. This new 'infrastructural' condition is what gives rise to a new paradigm of representation that we are seeking to problematize in this discussion.

## Cryptography and machine learning

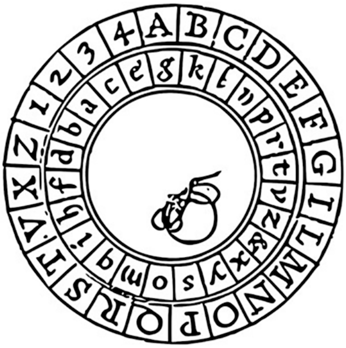
The branch of computation has historically been tasked with the translations of signals between domains of cryptography. The cryptographic paradigm is also useful as ML models can solve very complex tasks (well beyond what humans can achieve) without availing themselves of any elements that we have associated with human intelligence. So, rather than dwelling on whether a computer is more or less intelligent than a human (an irrelevant question as both conditions are true), we should recognise the emergence of a different type of rationality and establish methods to communicate and interact with it; hence, the focus on cryptography.

Foregrounding the infrastructural condition of computation leads us to focus more on the connection between different domains and how they can be interacted with. These observations shift the focus from identity (form) to communication (infrastructure). The introduction of ML models in design has reinforced such a condition: ML models are proving to be incredibly effective in managing unprecedented amounts of complexity, be it about working across scales, timelines, or disciplines. In this new condition, form decreases its importance to make room for organization and curation based on mathematics and statistics. Though the field this piece is preoccupied with is urban design, these observations can be extended to radio signals and communication. To think of the relation between design and ML models through the lenses of cryptography not only provides a novel perspective, but it also mobilizes a set of computational techniques and ideas that have a very central place in the history of computation and yet have been overlooked. The first element to consider is that cryptography firmly places us outside anthropocentrism and the temptation of considering ML methods in relation to human intelligence. Cryptographic problems are animated by mathematical, logical, and semiotic concerns which clearly distance them from psychological or anthropocentric ones. Secondly, the particular examples from the history of cryptography will show how they operated relationally. Relationality can be understood in two ways: first, as we shall see, early cryptographic methods intersected many fields ranging from mathematics to language and philosophy. Also, cryptography can also be defined as the art of finding relations across different domains: namely, the encrypted text (ciphertext) and decrypted one (plaintext).

These points also help move the conversation on ML models beyond purely technical concerns characterized by functionality and optimization to include cultural ones. To progress the understanding and applicability of technical instruments it is often more fruitful to shift our point of view; that is, to widen the frame of reference rather than narrowing it down. To do so, we ought to develop a literacy for ML models in design: again, not so much focus on the actual ability to master ML methods, but rather on providing a historical (what place ML methods occupy in the history of representation techniques) and a conceptual framework to operate within (which fields and knowledge are useful to mobilize).

We will explore the cultural dimension of cryptography by focusing on a specific moment in its history: the early Renaissance and the emergence of non-mimetic cryptographic methods. This transformation will also involve Leon Battista Alberti whose contribution to architecture included, amongst many things, the conceptualization of notational drawings (in addition to representational ones). Notational drawings like cryptographic methods lack mimetic qualities: they do not employ iconic signs (in the sense that Peirce defined them) and, consequently, require encoding and decoding. Once again, notions of literacy, translation, and mathematics are at work enabling architectural representation to avail of properties that had pertained to cryptographic methods.

*Figure 4: Diagram of Leon Battista Alberti's cipher as described in the De Cifris (1466).*




Courtesy of Roberto Bottazzi

*Figure 5: Diagram of Ramon Llull's wheels as his Ars (1283–1308).*


Courtesy of Roberto Bottazzi

## Early cryptographic methods and notational representation

First, we should understand cryptography beyond its use in diplomacy where it had been used to transmit cables and preserve secrets. We are rather drawn to cryptography because of the rich series of techniques deployed when confronted with beyond-human conditions. Framed along these lines, cryptographic techniques initiate a process to mobilize and elicit the emergence of knowledge in a non-mimetic fashion, that is, by solely availing of mathematical and logical means. On these premises, therefore, cryptography resonates with the kind of issues arising from engaging with the classification and translation of radio signals or ML methods in design as they both deal with signals that lie beyond our immediate sensorial perception and challenge what can be intelligible. The bridge between these different domains is the cipher: the actual instrument which tunes plaintext and ciphertext.[6]

6 Roberto Bottazzi, "Crypto Architecture: Notes on Machine Learning and Design," in *Ghosts of Transparency: Shadows Cast and Shadows Cast Out*, ed. Michael

Ciphers can be understood as infrastructural elements that bridge between domains. The etymology of the word 'cipher' derives from the French *chiffre*, denoting 'the arithmetical sign for zero', which in turn descends from the Arabic *sifr* and the Hindu *sunya* 'zero, empty, nothing'. In identifying the empty set and consequently the 'zero' sign, ciphers reorder different domains. Brian Rotman showed how the introduction of the 'zero' sign in Western culture (which also took place in the Renaissance) reconfigured disciplines as different as mathematics, finance, and art.[7] Ciphers are artefacts, they are designed objects, that is, the rationale to account for their mechanics needs to be invented. Such mechanics will have to negotiate between syntactic rigour and semantic intelligibility. A cipher may not signify in itself, but it makes a whole domain speak; that is, its infrastructural qualities are the means by which we can appreciate it. Ciphers have had an important role in history of philosophy, art, and computation as they were part of the techniques developed in the quest for the mechanization of thought and its augmentation to venture into beyond-human domains. Thought of along these lines, ciphers were popular intellectual and practical instruments that intrigued many thinkers in different periods (from Ramon Llull to Francis Bacon, Gottfried Leibniz, and Michel Serres)[8] and cultures (though not the main focus of this essay, there is an equally rich literature on Middle Eastern and Asian ciphers and their influence on European cryptographers).[9]

The Renaissance is often a misunderstood historical period as well as largely neglected from the point of view of computation. If Eugenio Battisti's *Antirinascimento*[10] challenged the image of harmony and balance associated with it, more research still needs to be carried out to grasp its

R. Doyle, Selena Savić, and Vera Bühlmann (Birkhäuser, 2019), https://www.degruyter.com/document/doi/10.1515/9783035619171-002/html.

7 Brian Rotman, *Signifying Nothing: The Semiotics of Zero*, Language, Discourse, Society (Houndmills, Basingstoke, Hampshire; London: Macmillan Press, 1987.

8 Michel Serres, *Hominescence* (Paris: Edition Le Pommier, 2001).

9 For instance, the King Faisal Center for Research on Arabic Origins of Cryptography located in Riyadh tasked to collect all the majors works on cryptography in the Arabic region.

10 Eugenio Battisti, *L'antirinascimento* (Milano: Feltrinelli, 1962).

relevance in the history of computation. To best appreciate the innovations that the Renaissance helped develop in the field of cryptography, we ought to take a step back and consider cryptography in the Middle Ages. Most cryptographic methods prior to the late Middle Ages were still relying on mimetic representations by utilizing visual images as ciphers. Though not technically a cryptographic method, the visually stunning *De Laudibus Sanctae Crucis* (810–814) by Rabanus Maurus already featured an overlay of letters and figurative and ornamental elements to encrypt his poems.[11] His work exhibited a complex relation between text and images indicative of a different sensibility. The proto-computational work of Ramon Llull constituted a significant turning point in the evolution and application of cryptography. Llull's tasked notational representation and cryptography to articulate its metaphysics: by spinning a series of concentric wheels with engraved letters (from *b* to *k*), the user would obtain strings of letters that could be decoded with the help of Llull's own charts, de facto giving rise to a semantics. The whole system as explained in Llull's *Ars* (from 1283 to 1308) replaced entirely any reliance on images in favour of a non-mimetic (notational) form of encryption/decryption that provided access to the order of the universe. Llull's ambitions were far greater than perfecting cryptographic techniques. His machines could reveal the hidden order of the cosmos beyond its potentially deceiving appearances. Though using a limited number of signals in form of letters, Llull's wheels already encountered what in computation is termed a combinatorial explosion. This is the computational phenomenon describing the exponential growth of possible combinations generated by a comparatively small set of signals.[12] As a result of it, the computational system quickly stepped into beyond-human domains

11 Katherine E. Ellison and Susan M. Kim, eds., *A Material History of Medieval and Early Modern Ciphers: Cryptography and the History of Literacy* (New York, NY: Routledge, 2020).

12 Daintith, J. and Wright, E., eds. (2008). Combinatorial explosion. In: *A Dictionary of Computing*, 6th ed. [online] Oxford: Oxford University Press. Available at: https://www-oxfordreference-com.libproxy.ucl.ac.uk/view/10.1093/acref/9780199234004.001.0001/acref-9780199234004-e-857?rskey=LRpMhl&result=959 (accessed 18.03.2023).

for which Llull had limited instruments or desire to manage. Llull's response was to eliminate all combinations which could potentially contradict the initial assumption of his metaphysics which was premised on the superiority of the Christian doctrine. Leibniz, who showed great interest in Llull's wheels, disappointingly noticed that curbing the number of possible combinations contradicted the potential of the very method adopted. Llull did not set up a system for searching, for venturing outside what was known or understood; rather, his proto-computational wheels were a verification device, a way to mechanically prove a thesis that had already been predetermined.

Leon Battista Alberti's *De componendis cifris* (1466) also made use of concentric wheels (very similar to Llull's) for his cryptographic method. More sophisticated than any method known at the time, Alberti's cryptography was polyalphabetic: that is, it made uses of multiple ciphers that changed numerous times throughout the encoding/decoding process. Particular alignments of the concentric wheels would provide a cipher for substituting letters in the ciphertext (or encrypt the plaintext). The problems caused by combinatorial explosion were even more pronounced than in Llull's system as every time the cipher changed, the size of the combinatorial space of all possible combinations also exponentially increased. On the one hand, the system immediately ventured into a territory that exceeded human capacities (a useful quality for a cryptographic method); on the other, mathematics became the only instrument to navigate the vast space of signals combinations and to make intelligible and, as we shall see, perceptible the abstract domain of encrypted signals. Notational systems also opened new ways of thinking that Alberti could take to art, whilst philosophers, such as Francis Bacon, would task cryptography to decrypt the Book of Nature. Notational systems no longer pertained to mimetic representation and allowed designers to design with the artificial. Notation allowed artists to implement the combinatorial methods of cryptography that the emergence of mobile characters printing had also made materially visible.[13] Alberti used a simi-

13 Quinn DuPont, "The Printing Press and Cryptography: Alberti and the Dawn of the Notational Epoch," in *A Material History of Medieval and Early Modern Ciphers:*

lar device as the one illustrated in the *De Cifris*, albeit in a modified version, to survey the city of Rome[14] or the human body as he explained in his treatise on sculpture *De Statua*. Through operations of translation, substitution, and rewriting, ciphers generated intelligible sets of signals out of random ones (and vice versa). Such operations relied on syntactical rigour to establish a meaningful relation between noise, intelligibility, and perceptibility. Though manipulation of signals did not belong to mimetic representations, the outputs produced by the wheels did give letters an aesthetic quality, which also contributed to making them amenable to further transformations. The aesthetic dimensions of the cryptographic methods work of both Alberti and Llull is also detectable in the way in which letters, charts, and devices are presented in the actual manuscripts.

As we have seen the adoption of cryptographic methods based on notation distanced representation from the mimetic tradition and embraced mathematics as an orientation instrument. These two conditions were explored further by Pico della Mirandola, the famous Renaissance philosopher, who conceived them as instruments for surveying uncharted domains: a sort of literacy for the unknown. It is along these lines that it is useful to approach our final example, as Pico della Mirandola is not usually evoked in discussions on cryptography or computation. However, his last work, the *Heptatlus* (1489) which focused on a philosophical account of the creation, is relevant to this discussion as his combinatorial logic bridged between domains in a way that is analogous to cryptography methods. Pico did know Llull's work on combinatorial logic which he had dubbed *revolutio alphabetaria*, once again highlighting the relation between notation and language. However, whilst Llull's letters had only a symbolic value as the actual elements to be manipulated was the content of his metaphysics, Pico,

*Cryptography and the History of Literacy*, ed. Katherine E. Ellison and Susan M. Kim (New York, NY: Routledge, 2020), 95–117

14 Leon Batista Alberti, *Descriptio Urbis Romae*, trans. Mario Carpo and Martine Furno, Cahiers d'Humanisme et Renaissance 56 (Genève: Droz, 1999)

who was much closer to the cabbalistic tradition, thought of combinatorial logic as applicable to the substance of expression, that is, to the actual letters without referring to secondary meanings. Umberto Eco observed that Pico's approach could no longer be described as an *ars combinandi* but rather as an *ars inveniendi*, that is, a generative system. Whereas in the former system combinatorial logic offered innumerable ways to reach the same, predetermined conclusions, in Pico, letters were rigorously combined to search for a truth that was yet unknown.[15] Eco drew attention to a passage of the *Heptatlus* in which Pico "launches in the most uninhibited permutational and anagrammatical operations" to manipulate the words of the *Bereishit*.[16] Pico finally exploited the

15 Umberto Eco, *From the Tree to the Labyrinth: Historical Studies on the Sign and Interpretation*, trans. Anthony Oldcorn (Cambridge, Massachusetts: Harvard University Press, 2014).

16 The precise passage quoted by Eco is: "Applying the rules of the ancients to the first phrase of the work, which is read *Beresit* by the Hebrews and "In the beginning" by us, I wanted to see whether I too could bring to light something worth knowing. Beyond my hope and expectation I found what I myself did not believe as I found it, and what others will not believe easily: the whole plan of the creation of the world and of all things in it disclosed and explained in that one phrase. Among the Hebrews, this phrase is written thus: בראשיח , *berescith*. From this, if we join the third letter to the first, comes the word אב , *ab*. If we add the second to the doubled first, we get בד ב, *bebar*. If we read all except the first, we get ית ראש, *resith*. If we connect the fourth to the first and last, we get שבת, *sciabat*. If we take the first three in the order in which they come, we get רא כ, *bara*. If, leaving out the first, we take the next three, we get אש ר, *rosc*. If, leaving out the first and second, we take the two following, we get , ,אש, *es*. If, leaving out the first three, we join the fourth to the last, we get ,שת, *seth*. Again, if we join the second to the first, we get רב , *rab*. If after the third we set the fifth and fourth, we get יש א, *hisc*. If we join the first two to the last two, we get ית בר, *berith*. If we add the last to the first, we get the twelfth and last word, which is תב , *thob*, the *thau* being changed into the letter *thet*, which is very common in Hebrew. Let us see first what these words mean in Latin, then what mysteries of all nature they reveal to those not ignorant of philosophy. *Ab* means "the father"; *bebar* "in the son" and "through the son" (for the prefix *beth* means both); resit, "the beginning"; *sabath*, "the rest and end"; *bara*, "created"; *rosc*, "head"; *es*, "fire"; *seth*, "foundation"; *rab*, "of the great"; *hisc*,

full potential of combinatorial logic and notational representation. In doing so, we begin to appreciate what the project of cryptography and computational literacy implies. Eco noticed that with Pico "… we pass from the idea of man as subject to the laws of the cosmos to that of a man who constructs and reconstructs without fear of the vertigo of the possible, fully accepting its risk."[17]

## Working across domains

Several aspects of this short overview of Renaissance cryptography can resonate with our contemporary condition vis-à-vis designing with ML models. Cryptography is in fact syntactical and algorithmic and requires the presence of a grammar robust enough to be shared by both sender and receiver. By extension, similar operations can be performed on visual documents such as drawings or computer renderings, whose signs can be manipulated and generated through algorithmic operation, as in the case of mathematical perspective. Cryptographic techniques work across domains and are instrumental to seek intelligibility where one can only see noise. ML models not only work across domains, but the recent emergence of cross-modal ML models provides much wider range of inputs and outputs superseding the distinctions between different fields.

The exchange between mathematical operations and visual representation is also an important aspect that is at work in both ML design and cryptography. Here the work of Sybille Krämer helps us structure this relationship in order to expose the sensuous side of mathematics

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"of the man"; *berit*, "with a pact"; *thob*, "with good." If we fit the whole passage together following this order, it will read like this:
"The father, in the Son and through the Son, the beginning and end or rest, created the head, the fire, and the foundation of the great man with a good pact." This whole passage results from taking apart and putting together that first word." *Ibid.*, p. 412. Giovanni Pico della Mirandola, "Heptaplus," in *On the Dignity of Man, On Being and the One, Heptaplus*, trans. Douglas Carmicheal (Indianapolis: Bobbs-Merril, 1965). pp. 171– 172.

17 Eco, *From the Tree to the Labyrinth*, p 414.

and, conversely, the intellectual aspect of visual representation.[18] In challenging the assumption that "computation is a nonsensual kind of operation,"[19] Krämer identifies three moments in which mathematics and visual representation intersect to offer us three trajectories along which to articulate the relation between cryptography, ML models and design. The first one concerns the relation between imagination and intuition. When performing mathematical operations, such as the decryption and encryption of strings of signals, visualizations should not be relegated to *after* having understood or resolved the problem; they would merely be illustrative gestures. Rather, visualizing aspects of mathematical problems is part of the instrumentation necessary to trigger intuition and imagination and, in turn, to make strings of signals intelligible and solvable. The sensual and visual dimension that drawing in the past or computer visualizations today adds to algorithmic operations is an essential step to navigating complex and abstract domains of cryptography or the latent space generated by ML models. Visual operations such as data visualizations are necessary to move from the particular to the general or to foreground specific aspects of the data analysed. The second aspect highlighted by Krämer is that of perception. Here the use of visual operations to translate between different data domains and media is essential to getting accustomed to the abstract space of ML models and beginning to develop a design sensibility towards it. Finally, Krämer foregrounds the role the symbolic representation can have in generalizing knowledge. In discussing Descartes' work, she uses the examples of algebraic notation as a generalizing system that makes all quantifiable objects comparable to each other and therefore computable. These considerations can be extended to the cryptographic examples we surveyed in which ciphers were the instruments through which signals moved across domains and could be made amenable to further manipulations. In ML design classification,

18 Sybille Krämer, "Mathematizing Power, Formalization, and the Diagrammatical Mind or: What Does 'Computation' Mean?," *Philosophy & Technology* 27, no. 3 (September 1, 2014): 345–57, https://doi.org/10.1007/s13347-012-0094-3.

19 Ibid., p.345.

algorithms perform analogue operations allowing for the projection of datasets onto each other and the expansion of the remit of what can be analysed and designed. By simultaneously playing with mathematical and artistic conventions, cryptography offers a material approach to abstract, intellectual problems that resonate with the ones designers are confronted with when designing with ML methods. The examples from cryptography and literature we discussed showed a playful relationship between mathematical operations and visual and material artefacts. They charged the physical act of writing or combining symbols with the possibility to launch a bridge towards what cannot be perceptible.

Finally, the examples from cryptography all required the intervention of humans. Early modern literature on cryptography did emphasize the importance of intuition and agility. After all, the whole idea of cryptography is to present humans with "situations… in which traditional rules of behaviour, or even the typical choice of tools, no longer applied."[20] Working with ML models, or radio signals, is also characterized by a breakdown in communication resulting from the innovation that a new technology introduced. Intuition, agility, dexterity are useful skills to make use of in order to orient ourselves in a new context. They are not purely intellectual skills, rather, they are hybrid, since moving between software, code, renderings, and models necessitates different sensibilities.

Cryptography is essentially relational. Deciphering messages requires constructing a network of relations between disparate signals through different instruments. Crypted strings of signals remain meaningless until the identification of the right grammar will begin to return intelligible messages. Again, these are operations that not only resonate with those developed by linguists and artists, but also with ML models. The emphasis this paper puts on the cultural dimension of ML stresses the importance of framing ML models within a broader, diverse, and sophisticated cultural milieu. To think of design as a series of operations to let data speak and to embed it in the long tradition of cultural tech-

20 Ellison and Kim, *A Material History of Medieval and Early Modern Ciphers*, p 18.

niques developed to deal with unknown domains is both a promising and exciting prospect for ML methods in design.

## Discussion

**Selena Savić:** This resonates with some of the problems we are encountering, namely the fact that radio is in a domain beyond our sensory and cognitive capacities and that the recordings of the signals we work with do not mean anything to us. What and how can we know about them? Framing things as 'search' opens quite an interesting, if rather obvious, realization about the extent to which combinatorics of search determine what you can know. The same applies vice versa too. The search results themselves get organized through search. Both directions of searching for and having found organize that which we know.

**Roberto Bottazzi:** Search is very easily understood as an open search when perhaps it is not. This is implicit in graphs, for example. When we speak of graphs in a historical context, we often speak of search too. The graph itself always implies some sort of pre-existence of the nodes. This notion of search needs to be problematized.

**Selena Savić:** Another important thing is your notion of cryptography as a way to establish communication. How can one establish communication between the domain of human knowledge and radio signals? We know that radio signals are happening in a purely technical domain, broadcast by antennas somewhere in the world and received by other antennas to be decoded by electronics or software. Radio signals are intentionally encoded on carrier waves, as part of human telecommunication activities. It is about bringing together aspects of technology being in the environment and being instrumental to our exchanges, as highlighted by Sarah Grant, with the way to understand that which is already there through abstraction and cryptographic movement across the data that is always partial, but also always complete.

**Miro Roman:** The stories about ways to classify knowledge are very relevant to the discussion on computation, big data and machine intelligence today. I fully agree with you on the level of cryptography. Could you expand on the kind of knowledge they were trying to classify? I think there is a difference in scope between the earlier work with memory palace and Camillo's Theatre. A memory palace would be a kind of a personalized algorithm while the theatre would be an algorithm searching for the underlying structure. If we were to apply the logic of Facebook and their databases, in principle, we would not care about underlying structures. Some of them even do not care to classify knowledge: they 'just work' with knowledge to produce new correlations. With Shannon or Markov, on the other hand, it is about the mechanics of knowledge rather than classifying or ordering.

**Roberto Bottazzi:** We could exclude Llull's wheels as they would not serve particularly well in this kind of conversation. In terms of the scope of these experiments, Pico della Mirandola's poems are no longer about knowledge within a predetermined scope, but an opening to the generation of new kinds of knowledge. More contemporary projects of search are naturally very different in scope. The problem of meaning gets totally removed here. Markov and Shannon deal with knowledge on a purely mechanical level, and it does not need to mean anything. In the older examples that I showed, the starting point and the body of knowledge had to be meaningful, which is perhaps the largest difference. A way to continue the conversation today could be to remove any kind of criteria, any parameter. Anything becomes possible. The experiments I discussed are interesting because they try to reason about some sort of commonality. If you destroy commonality, there is no knowledge either. It is knowledge that has to have a public face. It has to be shared, otherwise it is just my opinion. It is not a form of knowledge. This is a big political question today.

Here I would like to introduce a thought that comes from Massimo Cacciari.[21] If we were to contextualize the work of Pico della Mirandola work within the Renaissance, the argument Cacciari makes is that his efforts emerge out of the desire to find a form of publicness, of shared communication between the three major religions that surround the Mediterranean. The reason for this is that the late 15th century was a period of incredible difficulties to establish this form of communication. It is also the period when a truly multicultural Europe ended with the Expulsion of the Moriscos from Spain. Pico makes use of Kabbalistic methods and combinatorial logic within his project. These techniques are integral to the project of searching for a plan for peace that is grounded on philosophy. He was aware that if he would have grounded such a project in politics, it would have to result in war. But if it is indeed possible to argue philosophically, it turns entirely into a problem of interpreting and exchanging between different kinds of cultures. Pico della Mirandola was one of the few people in Florence that mastered Latin, Greek, and Hebrew, he could speak all three of them. And the reason was that if literacy were the first step towards peace, you would have to be able to speak the other's language in order to strike a philosophical plateau on which to confront differences, which goes into the 900 theses that Pico wanted to discuss with the Pope. I think mediation speaks towards them in a deeper, or bigger motivations that animate this kind of work.

21 Palazzo Ducale (2015). "Massimo Cacciari Oration de hominis dignitate di Pico della Mirandola. Available at: https://www.youtube.com/watch?v=DvMzSK8anHQ&t=3863s (accessed on 16.03.2023).

# Navigating across Galaxies of Concepts

*Miro Roman*

With my previous presentation on *Alice_ch3n81* in mind (see: "Digital Literacy and one of its Characters" in this volume), I will show how this project evolved and present a search engine that came out of it. The way this relates to your project in principle, is that it is about the constitution of a database and the way how to navigate this database. In navigating this database, we can search for problems you are encountering with radio.

At the Digital Architectonics chair at ETHZ, we have an internal library of more than 1000 books. One can download a book as a PDF, read it as HTML, as individual images. You can download the whole library. When students come to the architectural department, they have 1000 books ready for reading: they can read them page by page, or they can start playing with them on a computational level.

To start playing with this now, I developed a search engine called *Ask.Alice_ch3n81*. As a search engine, *Alice_ch3n81.net* embodies a kind of a personalized Google for people who like to write. What Alice_ch3n81 can help you to do is write together with thousands of books. We have exercises as part of, for example, our design studio where people are asked to write about their ideas in someone else's terms. What Alice_ch3n81 offers, just like any search engine, is never an explicit answer but always a spectrum of different possibilities and ways to look at things. Under Alice_ch3n81's 'brain', we have the different kinds of libraries: one of them is the Xenotheka library, another is the library on architecture. Then we have a dedicated master's library: Serres, Foucault, Deleuze and Derrida, whom you can always ask about tricky questions. In a special library for our current design studio at the ETHZ Architecture Department, we have most of Alberti's works and four or five translations of Vitruvius. You can also look at the body of each library: what is the content, what are its main works, and then one can start asking questions to Alice_ch3n81.

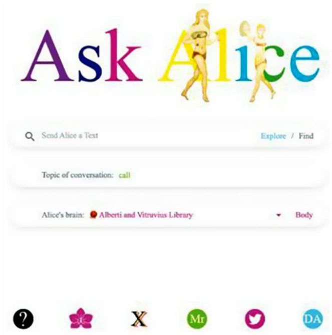
Today we want to talk about signals. We want to talk about 'radio signals' from the perspective of a specific brain, which is Xenotheka. This is a topic of conversation which will arrange books, their order and excerpts as the answers of Alice_ch3n81. What Alice_ch3n81 offers us towards the question of 'radio signal' is more than 10,000 results, 10,000 associations of what this 'radio signal' might be. For instance, if you want to write a text about your research on radio signals, you can play with Alice_ch3n81 and use these quotes to expand your ideas or even to write texts in this way. For instance, here we have a quote from Hofstadter's *Gödel, Escher, Bach*:

> "Radio signal is composed of symbolic constituents whose symbolic meaning mentors the case of youth rather than mentioned."

Then, you can look at the context in which it is. You can go directly to this book on Xenotheka and start working with these games. If you like Hofstadter, you can keep reading his books, there is a lot about radio signals. There is another book by him, *I Am a Strange Loop*. If you want to search in a more explicit way, you can use 'Find' rather than 'Explore' which is a fuzzy search looking for synonyms, antonyms; with 'Find' you get an exact search, returning 16 results which all have the query, 'radio' and 'signal'.

If then you want to see, what does this mean, what is the context of the signal, you can expand the context from the book. If this is not enough, you can check, for instance, in which ways Hofstadter is looking at the signal or, for instance, which concepts would be important for him. If we are with Hofstadter, it is about the stream, the template, the program, symbol, and this kind of thing, systems. This is one of his focuses, and then he has many different ones. Then, Alice_ch3n81 creates another set of associations for further queries and plays with this setting.

*Figure 1: Ask Alice_ch3n81 search engine interface.*




Courtesy of Miro Roman.

Can you have the galaxy of concepts? Here, I wanted to show you how Alice_ch3n81 developed into something which is now a usable search engine. It is important that I set it up in a way that it can host different characters. I would like to mention another character, *Homo Effluviens*, which I set up for a friend that was working on a conference. It is currently exhibited at the Taipei Biennial. At the conference, we recorded all the talks, transcribed them automatically, then added the books which are relevant for the discussions and created a small database that you can talk to. Another example of a character is *Think SOLL*, for a fashion brand. We have here his favourite books. Here we also have a collection of subtitles of movies. So, you can start talking with different movies and so on. I find very promising the idea to create custom databases and their digital characters, as an important way to balance, challenge, and start talking to big Ai-s like Google, OpenAI and similar.

# Post-Scriptum: Radio Otherwise

The texts in this chapter came after the experimental project was completed. They contribute a post-scriptum commentary on digital information and computer networks.

# Sonic Symbiosis Beyond the Symbolic

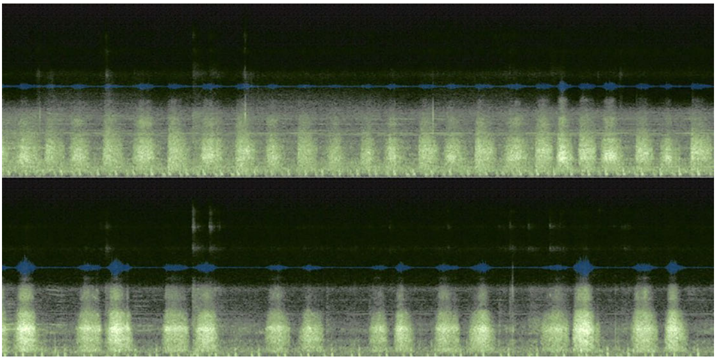
*Lisa Müller-Trede*

If relationality is exchange, attentiveness might be its currency. In this text, I discuss non-verbal exchanges of attention along a gift economy that assumes giving to be a creative act with inherent intra-relational rewards. To reify attention and relationality, I listen to and visualize interlocutors' breaths in the form of spectrograms. Breathing is linked to non-verbal communication in that changes in bodily motion are traceable within the sounds of breathing that occur as air flows into and out of the body while muscles are supplied with oxygen. After synthesizing the audio recording of each body's breath into one monophonic channel, I analyse this flattened visual representation with the help of a signal processing algorithm, which, as opposed to the human ear, can assume a single input while human listeners continue to hear two bodies breathing regardless of whether the data is monophonic or stereophonic. The algorithm isolates recurring sonic patterns which point to body movements that would not be decipherable in individual breaths. Through this synthesis, I have found that minute relational gestures like twitches, weight shifts, and kinaesthetic reorientations recur between dyads that share a space. Their joint breathing during these gestures sounds similar as the gestures recur.[1] This renders breathing a semiotic process that

1 In an example I discuss in detail elsewhere, I analysed the spectrograms of two people's merged breaths alongside the video documentation of their movements. It turned out that by attending to bodies as literally joined in process rather than as individual agents, a nexus of gestures that mark a form of non-verbal communication was revealed, which would otherwise go unnoticed.

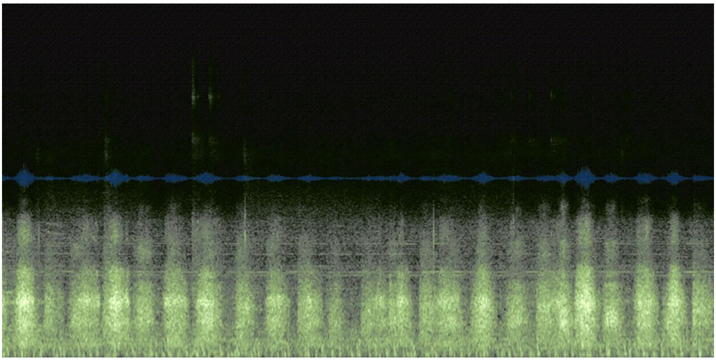
reveals a code by which bodies navigate their literal and affective proximity.

*Figure 1: Stereophonic representation of two breath recordings.*



Courtesy of Lisa Müller-Trede

*Figure 2: Merged monophonic representation of the two breath recordings above.*



Courtesy of Lisa Müller-Trede

The non-verbal and non-haptic exchanges of gestures as they are captured in joint breathing, do not rely on a symbolic order such as words or the negotiation of pressure in haptic exchanges. Instead, the coordinated expressions remain ephemeral without concrete semantic values attached to them. Searching for repetitions follows a positivist practice only insofar as it exposes patterns of relational behaviours. These, however, cannot be mapped as a concrete signifying system and remain singular clues for each particular dyad. The patterns seem to typically remain subconscious markers that occur too subtly and are too tailored to each individual partner to be named within theories of emotion or linguistics. Specifically, the simultaneous reciprocity of the exchange that operates beyond notions of active versus passive or giving versus taking, and the literal synthesis of merging the breath patterns into one joint signal reifies relationality. It demonstrates that the relation literally creates new data which constantly updates and thus defies categorization. For each dyad, these often subconscious gestures nevertheless operate as a form of orientation. Attentiveness renders this mode of communication more effective, and mutual recognition – not to be confused with agreement – seems to register as rewarding.

With regard to exchange systems, the reward tied to reciprocal kinaesthetic acknowledgement does not depend on symbolic orders such as words, objects, or pressure (haptics). Devoid of signification, these subtle joint gestures do not denote values but rather impulses and directions that express both a literal and an affective negotiation of distance and proximity. Since this negotiation remains largely ineffable, it is impossible to assign to it specific notions of giving or receiving. Marcel Mauss[2] states that the process of giving and receiving, in other words, gift economies, arrange social relations around a pressure of returning the gesture, acknowledging value, and indebtedness. While gifts strengthen social organizations by establishing predictable behaviours that enable reliable, personal bonds, giving seems most often tied to tak-

2 Marcel Mauss, *The Gift: The Form and Reason for Exchange in Archaic Societies* (London: Routledge, 1925).

ing.[3] Typically, gifts are either material objects or deeds, signified and concrete. The temporality of exchange commonly involves concepts of past, present, and future. Jacques Derrida[4] specifies Mauss' notion of the gift as a "force"[5] which nevertheless remains tied to signifiers that need to be graspable as concrete elements in space and/or time:

> However the *syn-*, the *syn*thesis, the *sys*tem, or the *syn*tax that joins together gift and exchange is temporal—or more precisely temporizing—differance, the delay of the term or the term of delay that dislocates any "at the same time." The identity between gift and exchange would not be immediate and analytical. It would have in effect the form of an *a priori* synthesis: a synthesis because it requires temporization and a priori—in other words necessary— because it is required at the outset by *the thing itself*, namely by the very object of the gift, by the force or the virtue that would be inherent to it.[6]

I propose that the patterns which become visible and audible in the synthesis of breaths and movements within the spectrograms mark a symbiosis that is graspable, yet independent of conscious "a priori" activities and, hence, independent of specific virtues and inherent expectations. Without a "term" an "at the same time" is indeed possible, and the joint signal aids grasping and analysing this simultaneity. Foregrounding the immediacy of the encounter and singling out minute, subconscious, yet recurring gestures that, because of their recurrence, can be placed, even contextualized, yet not interpreted, allows a focus on that which might comprise the notion of giving. The spectrograms materialize bodies' gestures of becoming legible for one another without an a priori activity – without a term or point of reference for expectations. Sociologist David Cheal describes the impulse of giving embedded within

3 Mauss, p 85.

4 Jacques Derrida, *Given Time. I: Counterfeit Money* (Chicago: University of Chicago Press, 1991).

5 Derrida, p 40.

6 Derrida, pp 39–40.

moral economies of the contemporary West as a sentiment of friendship, love, and gratitude. He writes that notions of giving as social exchange "involve the actor in identifying with others, so that for certain purposes the boundaries between self and other are denied, and a collective identity is defined vis-a-vis outsiders. The enclosure of persons within these supra-individual boundaries makes possible a characteristic mutuality of assistance between members."[7] I wonder whether the reward of recognizing the recurrence of somatic articulations is a "characteristic mutuality of assistance" active while navigating the immediacy of space and time kinaesthetically. I suspect that, whenever the minute recurring patterns in joint movements and breaths are recognized, this "mutual assistance" registers as a sentiment akin to that of friendship, love, or gratitude while they are being contextualized through brief and ephemeral gestures rather than the symbolic constructs and the naming conventions of "friendship, love, or gratitude" that tend to entail expectations and potential debts.

If, in the context of kinaesthetic recognition debt is disregarded, the notion of a conventional economy might not provide suitable terms to further develop a vocabulary around this ineffable exchange. In *Valuing Dance*, Susan Leigh Foster[8] explains that energy transfer does not operate according to an economy conditional on limitations and demands because the energy that passes from one body to the next is abundant. She describes the energy behind kinaesthetic articulations as the source for "psychological and social spaciousness" because it is readily available and not part of a scarcity paradigm.[9] Spacious perhaps because it does not adhere to definitions, objects, or pressures but, instead, to attention and the recognition of patterns that point in certain directions as they recur.

The spatial and affective direction, the distance or proximity that results from recognizing joint kinaesthetic expressions remains a ne-

7 David J. Cheal, *The Gift Economy* (London: Routledge, 2016 (1988)), p 18

8 Susan Leigh Foster, *Valuing Dance: Commodities and Gifts in Motion* (New York: Oxford University Press, 2019).

9 Foster, p 77.

gotiation of space and affect that does not stand for anything but the distance or proximity itself. Beyond, prior, next to, or below the symbolic, kinaesthetic symbiosis is not concerned with points of reference in time or space other than its present expression of relationality that, even though it is being refined by recurrences, tends to happen too immediately to rise to consciousness. The subtleties of these non-verbal accentuations are surfaced by turning breath sounds into electric energy and these currents further into visual representations that can be deciphered by a pattern recognition algorithm. As long as the accentuations remain non-symbolic in their representation, the interpretation of currents and exchanges of energy remains unfazed by expectations and notions of debt – of giving more or less than the "other." Even though bodies give themselves away as they express information about themselves in relation, the simultaneity of moving and being moved that is inherent to kinaesthetic correspondence can only provoke a sense of mutual indebtedness, or in Cheal's words, a "characteristic mutuality of assistance." This symbiotic means of communication establishes a sense of stability, predictability, and possible trust without expectations and may reorient the notion of gift exchange beyond economic terms.

# The Urban, The Classified, the Coupled

*Selena Savić*

## Weird urbanity of radio signals

Radio signals manifest as 'weird' materiality when observed from a position within the classical human/nature divide. In Parikka's articulation of new materialist concerns as media theory, weird materialities designate that which escapes direct human perception, and is irreducible to categories of 'soft' or 'hard.'[1] Radio signals are 'simply' energy, but they have a material and symbolic importance for human societies, both as environmental radiation and as messages they transmit. Contemporary feminist and new materialist thinkers, such as Donna Haraway, Rosi Braidotti, Vicki Kirby, ecofeminist Val Plumwood among others, took issue with the deep rootedness of nature/culture and body/mind divide

1 Parikka specifically refers to Serres' distinction between 'soft' and 'hard' as mutually exclusive levels of materiality, to which, he claims, weird materialities of contemporary technological culture cannot be reduced; Jussi Parikka, "New Materialism as Media Theory: Medianatures and Dirty Matter," *Communication and Critical/Cultural Studies* 9, no. 1 (March 2012): 95–100, https://doi.org/10.1080/14791420.2011.626252. While I agree with such a view on weirdness, it is important to note that contrary to Parikka's reading of Serres, 'hard' and 'soft' are for Serres indeed a continuum, as discussed in Vera Bühlmann, *Mathematics and Information in the Philosophy of Michel Serres*, Michel Serres and Material Futures (Bloomsbury Academic, 2020). Parikka's interpretation draws more closely on Serres articulation of pollution in *Malfeasance: Appropriation Through Pollution?*, while materiality of communication and communication physics for Serres are based on the irreducibility of communication or physics to hard and soft.

in Western thought and proposed ways to articulate inseparability of naturalized differences. The same dualism is the object of Bruno Latour's critique of the 'modernist settlement.'[2]

Radio is an interesting phenomenon to challenge dualisms and hyper-separations. "Radio was heard before it was invented [...] telephone users listened to radio for two decades before Guglielmo Marconi or anyone else invented it."[3] wrote Douglas Kahn in his comprehensive exploration of artistic engagements with radio signals. *Hiss, Whistler, Dawn* chorus are some of the names given to naturally occurring electromagnetic phenomena that can be 'heard' with specific receiving equipment. Kahn challenged the distinction of nature and culture on the premise that media (as in telecommunications media) do have nature and are undetermined. If radio has nature, how could we observe its materiality? Beyond sprawling transmission equipment, radio signals can be considered as what Keller Easterling termed an *active form* in an *infrastructure space*[4]: an organization of a large collection of humans and nonhumans co-opting the electromagnetic spectrum into the domain of human politics. Radio signals are one way the city leaks into nature.

When we speak of cities and infrastructures, it might be useful to reflect on the mid 20$^{th}$ century writing of Lewis Mumford and his influential *Myth of the Machine.*[5] Mumford's focus on city and civilization is sustained by his analysis of the *Megamachine*: a complex mechanism of message transmissions, passing from the top to the smallest working unit, able to mobilize a large body of individuals and coordinate their activities for a clearly envisaged and calculated purpose. In antiquity it appeared as a vast human organization that built the pyramids; in the 20th century, *Megamachine* featured the neatly automated organization

2 Bruno Latour, *Pandora's Hope: Essays on the Reality of Science Studies* (Cambridge, Massachusetts: Harvard University Press, 1999).

3 Douglas Kahn, *Earth Sound Earth Signal: Energies and Earth Magnitude in the Arts* (Berkeley: University of California Press, 2013)

4 Keller Easterling, *Extrastatecraft: The Power of Infrastructure Space* (Brooklyn: Verso, 2014).

5 Lewis Mumford, *The Myth of the Machine*, vol. 1: Technics and Human Development (San Diego: Harcourt Brace Jovanovich, 1967).

of humans and technology that provided us with the atomic bomb and telecommunications. A lesser-known fact is that Mumford was a radio amateur himself and had ambitions of studying electrical engineering. Having become instead a thinker of civic relations and a fierce critic of capitalism, Mumford theorized the link between technics and civilization not in terms of life processes, and not in terms of determination or shaping. Technologies have nature.

How might we think this nature of technology, networks, and signals? A key distinction that remains to be unfolded here is that between nature and city. Presumably, the city is the manifestation of culture, and is therefore the opposite and exclusive of nature. Nature, in this account, only appears outside of the city, at least if we talk about 'true' nature that cannot include parks and urban forests. In contrast, with contemporary theorists of the city and technology, the interest is to recognize the entanglement of human with non-human or more-than-human, to characterize the posthuman relationships. This relationship is founded on including politics in what we consider 'nature' or 'wild'. In Braidotti and Hlavajova's *Posthuman Glossary*, Paulo Tavares gives an account of the term *Forest*, its' role in the history of Western thought and expansion projects such as colonization.[6] Tavares insists on reading the forest as always already cosmopolitan, inhabited by beings (trees, jaguars and people) that form a large political space. "Instead of seeing the forest as an environment lacking the city, it is the very concept of the city that has to be widened and transformed to incorporate the constructed, political nature of the forest"[7] Towards a different, informational understanding of the city, Vera Bühlmann put forward an urban philosophy of potentiality that relates form and materiality through the concept of the informational motor.[8] Technology, mediating information by means of electrical

6 Paulo Tavares, "Forest," in *Posthuman Glossary*, ed. Rosi Braidotti and Maria Hlavajova, Theory (London Oxford New York New Delhi Sydney: Bloomsbury Academic, 2018), 162–67

7 Tavares. pp. 165–6.

8 Vera Bühlmann, "III. Primary Abundance, Urban Philosophy — Information and The Form of Actuality," in *Printed Physics: Metalithikum I*, ed. Ludger Hov-

networks becomes variably composable out of mediality which unfolds within logistic networks (social, political, economic). Benjamin Bratton put focus on the logics of the logistical activity of the planetary network of infrastructures, the *Big Machine.*[9] This machine, according to Bratton, might not see humanity as distinct among the stuff of the world. While the imaginary of such a relationship certainly facilitates a certain withdrawal of the human subject from the anthropo-scene, as discussed by object-oriented thinkers, I propose that the way to think the nature of technology is not to withdraw, but rather to think about indexing materiality of information and practice intentionality.

## The challenge of classification

The work on materiality of information is premised on data. Positivist ontology posits that data exists independently of an interpretive frame, waiting to be 'collected' by a human or a machine. This is untrue for both qualitative and quantitative data, obtained through measurement and/or observation. Contrary to its Latin name in the singular, 'datum,' data is never simply ‚given' but produced in complex processes. Cultural and literary studies scholar Elizabeth Adams St. Pierre wrote on understanding the appearance of data, which requires asking "when, where, why, how, and by whom data is called into being to do some work [as well as] what data looks like when it appears, in what counts as data."[10] According to recent accounts from philosophy and history of science, which are informed by contemporary quantum theory, data

estadt and Vera Bühlmann, vol. 1, Applied Virtuality (Berlin, Boston: Ambra Verlag, 2013), 113–53.

9 Benjamin H. Bratton, *The Stack: On Software and Sovereignty*, Software Studies (Cambridge, Massachusetts: MIT Press, 2015).

10 Elizabeth Adams St. Pierre, "The Appearance of Data," *Cultural Studies ↔ Critical Methodologies* 13, no. 4 (August 2013): 223, https://doi.org/10.1177/1532708613487862.

is not discreet but a continuous discreetness obtained through measurement.[11] Once data is acquired through some form of observation or measurement, to be put to use, it must be classified in some way. In their well-known work on classification and its consequences, *Sorting Things Out*, Geoffrey Bowker and Susan Leigh Star discussed classification as essential to any working infrastructure.[12] Datasets and digital archives provide comprehensive lists and a systematization of details that document diverse natural and social phenomena (for example, a dataset of European animals, of world temperature and precipitation measurements, or social media interactions dataset, or a corpus of European Parliament transcripts). Once the system works, its organization becomes 'naturalized'.

Diana Coole and Samantha Frost challenged the common sense that the 'real' material world consists of solid bounded objects with predictable and controllable behaviours. In the tradition of New Materialism, they insisted on new materialist suspiciousness towards fixed, predetermined categories and modes of existence. Contemporary critique of database ontology challenges their universal aspirations for "carefully and hierarchically represent[ing] knowledge according to a singular logic of the world, with embedded ontologies that exclude others."[13] The authors note that: "within databases […] we construct categories of normativity, singular ways of commanding the logic of the world". From a media-theoretical position, Posner and Klein extend this critique to emphasize that everything we encounter is already categorized in some way, which further propagates the presumption these

11 Karen Barad, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning* (Durham: Duke University Press, 2007).

12 Geoffrey C. Bowker and Susan Leigh Star, *Sorting Things out: Classification and Its Consequences*, 1st paperback edition, Inside Technology (Cambridge, Massachusetts London, England: The MIT Press, 2000).

13 Linzi Juliano and Ramesh Srinivasan, "Tagging it: Considering how ontologies limit the reading of identity," *International Journal of Cultural Studies* 15, no. 6 (November 1, 2012): 619, https://doi.org/10.1177/1367877912451684.

categories are meaningful.[14] Connecting to one of the author's works on *Data Feminism*,[15] Posner and Klein rely on feminist theory (in particular the work of Butler, Haraway and Barad) to challenge classification's repressive systems.[16]

Another relevant problematization of classification is Roberto Bottazzi's chronologically-ordered treatise on computational mechanics, *Digital Architecture Beyond Computers.*[17] Bottazzi traced the undulating trends of proof- and search-oriented combinatorics. He recounted the case of Ramon Llull's wheels of *Ars Magna*, as a mechanism for disseminating the author's doctrine and religious beliefs. Giulio Camillo's articulation of *L'Idea del Theatro* and Leibniz's *Ars Combinatoria* are discussed as methods of search. Aby Warburg's *Mnemosyne Atlas* was a pioneering way to organize large collections by purely visual means. Contemporary design work with machine learning is a culmination of these trends, a way to investigate datasets in search for patterns or sources of intuitions that can be used in the architectural or urban design process, for example. In further pursuit of this thread, Bottazzi put forward a provocative proposal to consider cryptography to venture into domains beyond human cognition (such as abstract data, or recordings of radio signals) by carefully constructing a system of signs that move in and out of the realm of human legibility (encryption and decryption) and moving productively across different domains.[18]

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14 Miriam Posner and Lauren F. Klein, "Editor's Introduction: Data as Media," *Feminist Media Histories* 3, no. 3 (July 1, 2017): 1–8, https://doi.org/10.1525/fmh.2017.3.3.1.

15 Catherine D'Ignazio and Lauren F. Klein, *Data Feminism* (Cambridge, Massachusetts: MIT Press, 2020).

16 Posner and Klein, "Editor's Introduction: Data as Media," p 4.

17 Roberto Bottazzi, *Digital Architecture beyond Computers: Fragments of a Cultural History of Computational Design* (London New York Oxford: Bloomsbury Visual Arts, 2018) See also the text by Bottazzi in this volume.

18 Roberto Bottazzi, "Crypto Architecture: Notes on Machine Learning and Design," in *Ghosts of Transparency: Shadows Cast and Shadows Cast Out*, ed. Michael R. Doyle, Selena Savić, and Vera Bühlmann (Birkhäuser, 2019), https://www.degruyter.com/document/doi/10.1515/9783035619171-002/html.

Andrew Lisony addressed the question of search in his introduction to *Archives*[19] a book about alternative, self-organized, contested archival practices. We often take availability of archives for granted and equate availability with access. Lison connects access to search, inextricably linked to retrieval of information, whose privatization he problematizes as "a totalizing expansion of knowledge retrieval under the privatizing conditions of neoliberalism", operated by Google for example. He proposes unconventional archives to contest this dominance by privileging a more eccentric curatorial touch.

Intersectional feminism poses important questions to methods for working with data and classification. In *Data Feminism*, Catherine D'Ignazio and Lauren F. Klein,[20] the authors engage with an intersectional analysis of the ways in which systems for counting and classification perpetuate oppression. They recognize an initial impasse of having to classify data in some way to work with it. To question classification is a feminist concern: how are people divided in categories of, for example, men and women? Data feminism is concerned with uses and limits of data, informed by direct experience and by intersectional feminist thought and paying attention to power and privilege.

I extend the data feminist intersectional approach to knowledge of radio signals and focus on the way data classification encodes power in this database. Whose power organizes the knowledge on radio signals? Which knowledge counts? What is considered as optimal or efficient organization? These are not easy questions to ask, as they require opening large avenues of thinking about what it means to apply the matrix of domination optics onto radio signals. It is an inquiry into the ways we gather around a technical artefact, and how this in turn organizes our knowledge of it.

Artificial neural networks of the SOM machine-learning algorithm extract whatever can be essential information from the data, but they do not give us any *reason* for it: reason itself stays in a kind of a black box.

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19 Andrew Lison et al., *Archives*, 2019, https://meson.press/wp-content/uploads/2019/08/978-3-95796-150-1-Archives.pdf

20 D'Ignazio and Klein, *Data Feminism*.

Reasoning *with* ML algorithms therefore becomes interesting if it is not used to explain how the world *is* or *will be* (as in predictions), but if we take its outputs as an incentive to make another translation. I am not suggesting that ML algorithms are not efficient in making probabilistic predictions, such as which books one might want to buy, or which advertisement is most effective for a certain user profile. However, the interest here is in exploring the possibilities of working with machine learning 'humanistically', without delegating human responsibilities of reasoning with and making sense of data to algorithms. The challenge picked up in this book and this research project is to take the network topology (the two-dimensional distribution of network nodes) as an invitation to rethink the way to talk about these engineered energy transmissions.

## Sensorial coupling with radio signal data

Radio signals cannot be known through engineering knowledge alone or indeed a single disciplinary perspective. They are part of the natural environment but are also made with broadcasting equipment; they are energy transmissions but also material,[21] they are technical artefacts but also information. The data on radio signals collected in the SIGID database, even if mainly intended to circulate among communication engineers and radio amateurs, illustrates well how these aspects are entangled.

Digital data such as pixels embody certain logics but also lend themselves to the logics of computational processing. The research discussed in this book suggests that travel and vision constitute methodical tools to unfold disciplinary concerns starting from something specific, such as a single radio signal recording or a group of pixels. In working with computation to preserve, rather than suspend richness in interpretations, such an observation describes a concrete imaginary of interdisciplinarity.

21 Art historian and theoretician Douglas Kahn talks about artistic use of radio as material in Kahn, *Earth Sound Earth Signal*.

The book documents a method of working with this database with an emphasis on preserving the complexity and entanglement of information. Sensorial coupling with radio signals is about practicing intentionality: articulating ways to index data by something meaningful and deliberately chosen. With such multiplicity of relationships comes a potentiality and responsibility to follow through ensuing narratives.

In *Earth Sound Earth Signal*, Douglas Kahn challenged the distinction on nature and culture in the instrumentalization of radio signals, on the premise that media (as in telecommunications media) do have nature and are underdetermined.[22] Jussi Parikka focused on the joint history of media and nature to tease out senses and rationalities inherent in the logic of life and technic, as in 'bio-logy' or 'techno-logy.'[23] In this parallel between media and nature, Parikka creates room to discuss natural technics in the context of organization and architecture, such as insect-builders or self-organized swarming systems. A new materialist media theory recently proposed by Vera Bühlmann, engaged Michel Serres' philosophy of natural communication to speak of the mediality of public knowledge.[24] The double articulation of time as/in space, of physics of communication as a communication of physics, requires attending to materiality of time that passes (commutes), to its communicative materiality. In the ways highlighted here, technicity and communicative capacity of radio signals are expressed as nature, but also have nature. Radio is not passive energy waiting to be put to use, but active energy, whose materiality unfolds in time and space.

The outputs of this research aim to facilitate speculation on the connection between signal representation and technical communication protocols, by shifting criteria of similarity from taxonomical and instrumental (e.g. used in military) or physical (e.g. high or low frequency), to properties shared across all signals – such as the probability of silence or

22 Ibid.

23 Jussi Parikka, *Insect Media: An Archaeology of Animals and Technology* (Minneapolis: University of Minnesota Press, 2010).

24 Vera Bühlmann, "In Medias Naturae," *Media Theory* 5, no. 1 (September 25, 2021): 231–52.

noise in the signal. It remains clear that the SOM is simply sorting high dimensional data in the space of possibilities that are always/already encoded. Nevertheless, it is in the interaction with this information that we should look for the ways to articulate interdisciplinary knowledge.

# Pixels and Bandwidth: On Imaginaries of Travel in Data

*Selena Savić*

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## The image of an incomplete message

An imaginary attempt to read an incomplete message can illustrate the interplay between aesthetic, semantic and epistemic concerns for interdisciplinarity. French classical author Jules Verne wrote a novel about the adventure of rescuing a captain of a sunken ship. Verne's novel *In Search of the Castaways* (*Les enfants du Capitaine Grant*) begins with the protagonists, future rescuers of the captain, considering how to read a message that reached them on a damaged piece of paper. The message was packed in a bottle, swallowed by a "balance-fish," and subsequently recovered by a small group of wealthy Englishmen on a yacht. The "balance-fish" is a hammer-headed shark found worldwide in warm waters. This detail speaks of the impossibility of tracing the bottle back to its origin: it could come from any sea at any longitude. Three sheets of paper in the bottle preserve parts of a message translated into English, French and German. Most of the letters are erased, and it is impossible to make sense of the text using any of the sheets individually. The three sheets complement each other to some degree of certainty to give possible directions for search. Jules Verne presents three different readings, determined by additional constraining factors of departure time, complemented with their travel worldwide. Each of these readings takes the passengers of the rescue ship to a different location and enables Verne to englobe the planet and tell stories about the wonders of travel and adventure. The rescue team, including the captain's two children, sails to Patagonia, then to Australia, before successfully locating the lost captain at the Tabor Island, a phantom reef in South Pacific.

This opening vignette speaks of the challenge of interpreting incomplete messages and the different places an interpretation can take us, literally. The story's protagonists fill in the missing letters with those most likely to make sense, according to some known determinants, such as the departure time, destination, and a possible route the ship could have taken. They rely on their knowledge of geography, sailing and navigation, lines of international trade, and proficiency in different languages. Verne's story suggests thinking of travelling and navigation as an empirical method for exploring hypotheses. French philosopher Michel Serres, an avid reader of Verne, offered navigation as a metaphor to expound the problem of interdisciplinarity more broadly. In his fifth book on communication, *Hermes V*, *Le Passage de Nord-Ouest,* Serres portrayed the shipping passage in northern Canada, which connects the Atlantic and the Pacific, as an image of instability and risk in passing between the natural sciences and the humanities.[1] The Northwest Passage changes with freezing water and melting ice every year and must always be discovered anew. It is equally challenging to find or invent methods for passing between different domains of inquiry and knowledge, according to Serres.

Interdisciplinarity is a concern inherent to Science and Technology Studies (STS). From the volume that became the first handbook of STS, *Science, Technology, and Society: A Cross-disciplinary Perspective,*[2] through

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1 Michel Serres, *Le Passage Du Nord-Ouest. Hermès V*, Collection "Critique" 5 (Paris: Editions de Minuit, 1980).

2 Ina Spiegel-Roesing and Derek de Solla Price, *Science, Technology, and Society: A Cross-Disciplinary Perspective* (Beverly Hills, CA US: SAGE Publications, 1977), https://www.osti.gov/biblio/6890751.

subsequent handbook volumes and articles concerned with characterising the field,[3] the concern for interdisciplinarity is mentioned in the first page, paragraph or sentence. This chapter engages with travelling as an imaginary interdisciplinarity trip: a way to articulate multiple perspectives when interpreting data, their relations across datasets and the disciplinary knowledge they draw upon. An approach to visual data exploration is introduced, inspired by the reading of Jules Verne's literary images of search and ambiguity. This approach is applied to a digital archive on radio signals within a research project, *Architectonic Studies of Radio*.[4] The search for meaning is at the core of this research endeavour, aspiring to demonstrate multiple ways of sense-making. Furthermore, following Haraway's attention to the embodied, positioned subject who, when perceiving and understanding the world, has a partial view and perspective,[5] this research locates concerns about telecommunications and its digital traces in a complex interplay between data, navigation and imaginaries of visualization.

This work with radio signal datasets forms a complex relationship with several specific fields of inquiry. It is rooted partly in digital humanities research methods for working with digital tools and large datasets, partly in media-theoretical concerns for communication technologies, and partly in feminist intersectionality. With interest in the materiality of radio telecommunications and digital technologies, the

3 Sheila Jasanoff et al., eds., *Handbook of Science and Technology Studies*, Rev. ed (Thousand Oaks, Calif: Sage Publications, 1995); Edward J. Hackett et al., eds., *The Handbook of Science and Technology Studies*, 3rd ed (Cambridge, Massachusetts: MIT Press: Published in cooperation with the Society for the Social Studies of Science, 2008); Knut Holtan Sørensen, "Disciplined Interdisciplinarity? A Brief Account of STS in Norway," *Tecnoscienza, Italian Journal of Science & Technology Studies*, 2012, 49–61; Ulrike Felt, ed., *The Handbook of Science and Technology Studies* (Cambridge, Massachusetts: MIT Press, 2017).

4 For more on the research project *Architectonic Explorations of Radio*, see the project archive: https://radioexplorations.ch/ (accessed on 07.02.2022).

5 Donna Haraway, "Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective," *Feminist Studies* 14, no. 3 (1988): 575, https://doi.org/10.2307/3178066.

approach taken in this research demonstrates the importance of an interdisciplinary and intersectional perspective on radio signals and technical artefacts more generally.

## Seeing and moving across data

At the end of the 20th century, before the massification of computational power and data processing, science fiction authors imagined gifted persons with visual faculties capable of reading patterns in data, making sense of relations that appeared (or were) meaningless. William Gibson, for example, explored this idea with the character of Colin Laney. The latter, in Gibson's words, "had a peculiar knack with data-collection architectures, and a medically documented concentration-deficit that he could toggle, under certain conditions, into a state of pathological hyperfocus."[6] This capability enabled Colin Laney to intuitively spot patterns of information in vast 'floes' of abstract, undifferentiated data. Laney's skill was not explainable: it represented implicit knowledge Laney was inclined to acquire through careful and persistent practice.

Visibility haunts our idea of knowledge and has found particularly fruitful ground in empiricism. If knowledge arrives at the mind through sensory experience, what we see, we know. Philosopher Susanne Langer observed in the late 1950s how evidence derived from sense-dominated natural sciences.[7] The argument has a basis on observed and identified facts. We believe what we see. At the same time, Langer continued, the observation space in laboratory experiments has shifted from direct experiences accessible to our senses to phenomena that are increasingly mediated by visualization and assessed with different measuring instruments. We can observe objects that have never been experienced through instruments and devices that give access to the space of the experiment

6 William Gibson, *Idoru*, Berkley Novel (New York, NY: Berkley Books, 1996), p 30.

7 Susanne K. Langer, *Philosophy in a New Key: A Study in the Symbolism of Reason, Rite and Art*, 3. ed (Cambridge, Mass.: Harvard Univ. Press, 1993).

or dataset, which is too small and too dynamic to be observed by human eyes.

A universally objective position implies the rule of having access to everywhere equally. Donna Haraway called this "the God trick of seeing everything from nowhere."[8] To counter this myth, she claimed it is necessary to embrace the idea that having a body means having a finite and partial point of view which determines and enables our freedom. This view embodies what, for a universalist, objective position would be the disqualifying and polluting bias. In laying out tensions between the two movements that challenged such 'inexplicable scientific objectivity', Haraway disagreed with the relativism that informed both the social constructionists' and feminist empiricists' critique of objectivity.

On the one hand, Haraway challenged the strong social constructionist argument in STS that painted the scientific method as primarily ideological and saw the drawing of knowledge boundaries as moves towards power rather than truth. On the other hand, standpoint theories, together with 'feminist empiricism', remained focused on legitimate meanings of objectivity. Haraway also criticised feminist literature and writing in History and Philosophy of Science for exhibiting a special kind of essentialism, which divides 'them' and 'us' and entraps two poles of a tempting dichotomy regarding objectivity (one either is objective or is not). Against all this, Haraway sought a way to go beyond simply exposing the existing bias in science. She theorized vision to avoid binary oppositions such as being either biased or objective. Instruments of vision always mediate vision, including our own eyes and the 'eyes' of modern technologies like photographs, space probes, and microscopes. Their embodied nature can address varying scales and contexts. It would be useful to extend Haraway's insistence on the importance and persistence of vision in matters of objectivity to the interdisciplinarity of vision and the imaginary of navigation to trace the movement across disciplinary knowledges in a non-reductive way.

Vision is about making phenomena publicly visible and taking responsibility for drawing boundaries of public knowledge. Since vi-

8 Haraway, "Situated Knowledges," p 581.

sualization as an idea and practice emerged in the 19th century in the work of literary criticism by Samuel Taylor Coleridge,[9] scientists and designers maintained the interest in the capacity of graphical analysis to offer a more efficient evidence base to observe data than abstract calculations would do. In writing a history of co-construction of vision and cognition, historian of science Orit Halpern traced the transformation of ideas of mechanical objectivity, questioning the transformation of knowledge formation from discovery to analysis.[10] She focused on cybernetics, with interest in its resonance with 'governance' through the etymological origin of the term and post WWII projects of technological fixes. Visualization is a term derived from the concern for observation and vision, for rendering visible that which is not available to sight, by using machines, scientific instruments and numeric measures and making new relationships, new objects and spaces of action appear.[11] Halpern pointed to the aspirations of mathematician and cybernetician Norbert Wiener to render the world into an accumulation of records, with nothing left 'unknown' and only new degrees of comprehension left to achieve. With this, cybernetics proposed an end to the discovery of the world, and we could thus say the end of travel. The way screens and digital interfaces are used today hinders our desire to explore the world, as Halpern and others noted. Nevertheless, we could consider how different kinds of exploration enabled by these same digital interfaces could promote a sustained interest in the world in re-reading and re-interpreting records and articulating new perspectives. Such explorations are based on reprograming the information processing and display, which is the starting point for the studies of radio signals

9 The Online Etymology Dictionary documents the first recorded use of the term and suggests that Coleridge coined or first used it in the sense close to how we talk about visualizing data https://www.etymonline.com/word/visualize#etymonline_v_30876 (accessed on 17.02.2022)

10 Orit Halpern, *Beautiful Data: A History of Vision and Reason since 1945* (Durham: Duke University Press, 2014).

11 Halpern, p 21.

discussed later in this text, and the development of experimental tools to reorganize and navigate data.

As in the travels that Jules Verne wrote so extensively about, moving the point of view includes being accountable for this movement. It means assuming intentionality and keeping a record of it. The power of sight and the violence implied in visualizing practices sustain the heritage of the conquering, wandering Western eye and its' travelling lens. Science and optics are closely connected: optical metaphors such as 'reflection' or 'diffraction' serve as models of scientific practice. The former relates to Western philosophy and classical critical practice. At the same time, the latter emerged in feminist materialist circles, which included Haraway and Karen Barad, who wrote extensively on diffractive science and sought "an optical metaphor for the effort to make a difference in the world."[12] Earlier, in *Situated Knowledges*, Haraway generalized optics as a politics of positioning, "the key practice in grounding knowledge organised around the imagery of vision."[13] Positioning is not only optical. As the opening vignette about Jules Verne's lost captain illustrates, interpretation and translation take us to different places. Can we aspire to develop visual systems that would be legible to people without the talent of Gibson's Colin Laney? How might we consider information that circulates in pixels? The following text will offer partial answers to these questions.

## Data observatories: following patterns in data

To illustrate possible ways of travelling in data, we will take a brief detour to consider the concept and experimental design of *data observatories* developed within the research project *Negentropic Explorations of Radio*. Conceived as an intuitive tool for orienting and navigating datasets, a *data observatory* is a computational instrument that provides measurements

12 Donna Haraway, *Modest_Witness@Second_Millennium. FemaleMan_Meets_OncoMouse: Feminism and Technoscience* (New York; London: Routledge, 1997), p 16.

13 Haraway, "Situated Knowledges," p 587.

of similarities among data points and enables multiple perspectives on data. The development of *data observatories* contributed ways to re-organize the digital archive on radio signals collected by radio enthusiasts and available online as Signal Identification Guide (SIGID) wiki.[14] This database documents the listening practices of the community of radio amateurs and enthusiasts. The archive's primary purpose is identification: radio amateurs and enthusiasts compare a signal they recorded to the archive of known signals, searching for a match. In addition to radio amateurs, recordings of radio signals 'in the wild' capture the interest of telecommunications engineers and media archaeologists, data scientists, ecologists, and historians of science and technology. *Data observatories* enable the navigating of radio signals datasets from a specific point of view of a disciplinary, interdisciplinary, other kind of interest.

*A data observatory* is a navigation apparatus that can orient oneself in the vast landscape of data on radio transmissions based on computable similarity. The development of *data observatories* as optical instruments is part of the method and ambition to organize data on radio signals according to the dataset's properties. The data itself means very little in human communication: it consists of demodulated recordings of radio transmissions about the document and the protocols rather than the content of transmitted messages. A self-organizing map (SOM) machine learning algorithm encoded signals in specific properties to render them comparable or commensurable. These were: the probability of silence, the level of noise in the audio sample, or an audio identification technique called fingerprinting.[15] Networks of machine learning algorithms

14 Signal Identification Guide wiki is available at http://sigidwiki.com (accessed on 17.02.2022).

15 Fingerprints are a condensed digital summary of an audio signal, based on peak points in the spectrogram, representing higher energy content. The technique is known for its use in Shazam music identification applications. It was introduced by Avery Wang, as discussed in his invited lecture at the 4th International Conference on Music Information Retrieval in 2003 and the accompanying unpublished paper referenced here, available to download from https://zenodo.org/records/1416340, as well as a Shazam github repository: https://github.com/bmoquist/Shazam, and also from the Columbia University reposi-

train on each of these property sets and produce an organized space – a grid of 'codebook vectors.'[16] – that can be navigated and explored in three dimensions: according to the proximity of codebook cells (horizontally and vertically) and according to the content of one cell (depth). The database gets an informational face, a different one for each property (see Figure 1).

*Figure 1: A data observatory interface. The 'informational face' of the radio signal digital archive: Descriptions overview with detailed view of one cell (middle, highlighted).*


Courtesy of Selena Savić

tory of Dan Ellis, https://www.ee.columbia.edu/~dpwe/papers/Wang03-shazam.pdf

16 A codebook vector is a list of numbers with the same input and output attributes as the training data.

We previously explored how data observatories can be used to establish radio signals' identities and trace digital information's materiality.[17] The focus here is on how such explorations constitute an act of travelling, which is not unproblematic, and which suggests a way to unfold the interplay between images (i.e. of a radio signal spectrum or a *data observatory* informational face) and navigational imaginaries as a form of scientific communication.

## Travelling across data

The *data observatories* enable complex, mediated observation of radio signals through web-based interfaces.[18] We will discuss the travel across textual descriptions of radio signals written by contributors to the SIGID wiki (Figure 1). Data on radio signals are organized according to how we talk about the signals. One moves across the dataset by clicking and accessing information in a browser, observing pixels on a screen that represent relations extracted from radio signals recorded 'in the wild'. We can orient ourselves in this organized space according to specific terms and characteristics of 'clusters' of descriptions that we could call 'topics'. For example, a topic could be determined by the list of words:

> 'data', 'digital', 'standard', 'protocol', 'modem', 'mobile', military', 'developed', 'police'

Or:

> 'variant', 'Russian', 'possibly', 'unsure', 'military', 'radioscanner'

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17 Selena Savić, "Articulating Nomadic Identities of Radio Signals," *Matter: Journal of New Materialist Research* 3, no. 1 (February 2022): 56–81, https://doi.org/10.1344/jnmr.v3i1.38959.

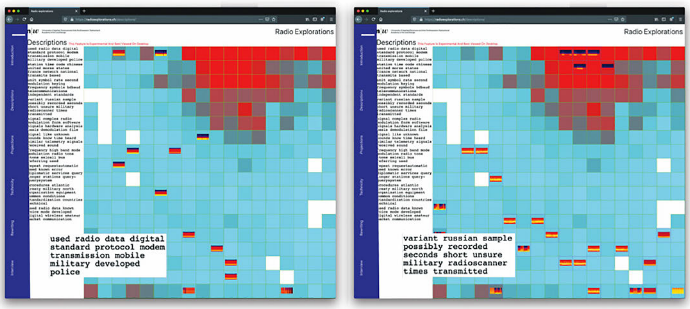
18 The two *data observatories* developed in this project are available online as *Descriptions* https://radioexplorations.ch/descriptions/ and *Projections* https://radioexplorations.ch/projections/.

Or:

'complex', 'modulation', 'form', 'software', 'hardware', 'analysis'

These words direct us towards different imaginaries. The first one speaks of digitality ('data', 'digital') and mediation techniques ('modem', 'mobile'). The second one resonates with international intelligence concerns ('Russian', 'variant'), probably including signals used by military and diplomacy for jamming and spying ('radio scanner, 'unsure'). The third topic resonates with listening techniques, tools and activities for signal analysis. A topic is characteristic or characterized by a group of signals (see Figure 2 for the two topics discussed here), organized on the map of the *data observatory*. This organization is based on similarity across all signals regarding a specific signal property – for example, signal fingerprints. Within a map, signals get 'highlighted' by a topic. In each cell, segments of signals of equal duration are grouped when they exhibit close similarity. Making visual and sonic comparisons of signals in a cell is the endpoint of a movement across the map. The figurative 'depth' of a cell (number of signal segments present) relates to the noisiness of a place. Exploring the overlapping visual and sonic segments informs us of the character of a cell, similar to the way we can experience a location. It also suggests unique connections across cells. For example, different segments of an exciting signal can be found in neighbouring or very distant cells (Figure 1, right vertical area), inverting the informational face of the library, encoded in terms of a signal and directing movement across the dataset. One can choose to visit other cells that host the exciting signal. Exploring one cell in-depth extracts relationships and the essence of a place. This 'essence' can be interpreted further in the topic that highlighted the initial exploration.

*Figure 2: Two informational faces of the dataset according to Descriptions, each representing a topic.*




Courtesy of Selena Savić

## Imaginary, narrative: encoding, decoding and practicing interdisciplinarity

Travel is directly related to privilege: to travel is to have the ability and resources to navigate the world, like Marco Polo or Christopher Columbus did on their trips to extend colonial relations to the 'unknown' world: a world unknown to them while home to others. However, ending exploration and discovery suggests an even more problematic form of appropriation of the world. The movement across the dataset described above is a form of discovery informed by computational measurement of similarity in data points. It is equally accessible to a scholar in political sciences and a communications engineer. This cross-disciplinary access, however, is not enough to constitute interdisciplinarity. Knut Sørensen made this observation in his overview of STS in Norway, using interdisciplinarity as an accounting device to question what is meant by "interdisciplinarity" in STS and to propose four (or more) ways of understanding STS as an interdisciplinary effort.[19] The combination of con-

19 Sørensen, "Disciplined Interdisciplinarity?"

cerns preserved in the digital 'shadows' cast by radio signals transmissions in the form of recordings stored in a digital archive brings together the different disciplinary concerns, including engineering, politics, history, and sociology of technology. The imaginary of travel offers consistency to the interaction between these different fields of expertise. The travel articulates techniques of passage between topics as an interdisciplinary challenge.

Data observatories are based on the SOM algorithm: the artificial neural network introduced by the Finnish professor Teuvo Kohonen in the 1980s as a cybernetic approach to unsupervised machine learning, inspired by biological neural networks.[20] Artificial neural networks of the SOM extract whatever can be essential information from the data, but they do not give us any *reason* for it: reason itself stays in a kind of a black box. The outputs of these computational processes are often used to explain how the world *is* or *will be* (as in predictions), in policymaking, and data-powered business models such as online marketing or surveillance. However, reasoning *with* ML algorithms becomes interesting for humanities when we take its outputs as an incentive to do another translation, to raise new questions through careful interpretation of patterns and clusters observed in data. This is not suggesting that ML algorithms are inefficient in making probabilistic predictions, such as which books one might want to buy, or which advertisement is most effective for a specific user profile. However, we are interested in exploring the possibilities of working with machine learning 'humanistically' without delegating the human responsibilities of reasoning and making sense of data to algorithms. The network topology (the two-dimensional distribution of network nodes) is an invitation to rethink the way to talk about radio transmissions.

Digital data, such as pixels, embody specific logic and lend themselves to the computational processing logic. The main argument in this

20 Teuvo Kohonen, "Self-Organized Formation of Topologically Correct Feature Maps," *Biological Cybernetics* 43, no. 1 (January 1982): 59–69, https://doi.org/10.1007/BF00337288

chapter suggests that travel and vision constitute methodical tools to unfold disciplinary concerns starting from something specific, such as a radio signal recording or a group of pixels, favouring interactional expertise. In working with computation to preserve, rather than suspend richness in interpretations, such an observation describes a concrete imaginary of interdisciplinarity.

## Conclusions

Radio signals cannot be known through engineering knowledge alone or a single disciplinary perspective. Signals are made by broadcasting equipment, but they are also part of the natural environment: energy transmissions and material.[21] They are technical artefacts but are also information. The data on radio signals collected in the SIGID database, even if mainly intended to circulate among communication engineers and amateurs, illustrates how these aspects are entangled.

This chapter documents a method to work with this database, while preserving the complexity and entanglement of information. Similar to Gibson's character Colin Laney, neural networks of the SOM algorithm identify patterns in the data on radio signals, but they do not give us any reason for it: reason itself stays in a kind of a black box. However, we do not seek to open this box but acquire digital literacy to play with it like an instrument. Digital literacy is about practising intentionality: articulating ways to index data in meaningful and deliberate ways. With such a multiplicity of relationships comes potentiality and responsibility to follow ensuing narratives.

The dataset that we worked with is not just simply a database. It testifies to a knowledge community that has developed around the technical literacy of telecommunications.

The outputs of this project aim to facilitate speculation on the connection between signal representation and technical communication

21 Douglas Kahn, *Earth Sound Earth Signal: Energies and Earth Magnitude in the Arts* (Berkeley: University of California Press, 2013).

protocols by shifting criteria of similarity from taxonomical and instrumental (e.g. used in the military) or physical (e.g. high or low frequency) to properties shared across all signals – such as the probability of silence or noise in the signal. It remains clear that the SOM is simply sorting high dimensional data in the space of possibilities that are always/already encoded. Nevertheless, in the interaction with this information, we should look for ways to articulate interdisciplinary knowledge.

# References

# Contributors

In order of contribution

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**Douglas Kahn** is a writer, historian and theorist of energies in the arts, sound in the arts, and media arts from the late-19th Century to the present. His books include *Energies in the Arts* (MIT Press, 2019); *Earth Sound Earth Signal: Energies and Earth Magnitude in the Arts* (University of California Press, 2013); *Noise, Water, Meat: A History of Sound in the Arts* (MIT Press, 1999); *Mainframe Experimentalism: Early Computing and the Foundations of Digital Arts*, edited with Hannah Higgins (University of

California Press, 2012); *Source: Music of the Avant-garde*, edited with Larry Austin (University of California Press, 2011; and *Wireless Imagination: Sound, Radio and the Avant-garde*, edited with Gregory Whitehead (MIT Press, 1992). He received an Australian Research Council Future Fellowship, Guggenheim Fellowship, and an Arts Writers Grant from Creative Capital/Warhol Foundation. Douglas Kahn is Honorary Professor, Sydney College of the Arts, University of Sydney; Professor Emeritus at University of California at Davis; and Professor Emeritus at University of New South Wales, Sydney.

**Carl Colena** is the administrator of the Signal Identification Guide, a large open database of radio signals and their recordings. Carl has administered the database since 2015, enriching the database with a wide set of radio samples and descriptive analyses, and fostering a community of signal identification hobbyists and professionals. Carl earned his Bachelor's degree in Computer Engineering from The City College of New York in 2013 and is currently a graduate student at the Georgia Institute of Technology, pursuing a M.S. in Computer Science. Carl works professionally as a Software Engineer, with a focus on improving the performance of computing systems. His most recent publication introduces a novel computational signal processing algorithm which was published and presented at the 2020 IEEE HPEC Conference.

**Yann Martins** is a coder, debugger, artist and doctoral candidate of the Make/Sense PhD Programme. His practice rooted in programming, and his doctoral research looks at the ways in which the capitalist mode of production and machine learning are re-enacting forms of inequality and discrimination. In his practice he develops tools for Critical Debugging, by subverting the canonical use of browsers and using them to investigate how algorithms operate in the background. He has also pioneered a teaching format at the Critical Media Lab that links technological education and cooking practices. He naively believes that alternative and sustainable modes of living outside of neoliberalism are still possible and contributes actively to projects that deal with Commoning and the Commons.

**Miro Roman** is an architect and a researcher. He is an Assistant Professor at the House of Coded Objects at the UIBK Innsbruck, and a senior lecturer at the chair for Digital Architectonics at ETH Zurich. His focus is the overlap of information technologies and architectural articulations. Miro explores, designs, codes, and writes about architecture while playing with a lot; with 'all' the buildings, books, images; with clouds, avatars, streams, lists, indexes, and pixels. What is this abundance of information about, how to handle it, and how does it shape the way we think about the world? To navigate and surf these vast flows, Miro codes and articulates synthetic alphabets. From 2004 to 2017 he was a part of the project romanvlahovic. From 2013 to 2015 he was a part of the Future Cities Laboratory, the interdisciplinary research programme of the Singapore ETH Centre for Global Environmental Sustainability (SEC). His books include *Play Among Books* (De Gruyter/Birkhäuser 2022) and *A Quantum City* edited with Ludger Hovestadt, Vera Bühlmann, Diana Alvarez-Marin and Sebastian Michael (De Gruyter/Birkhäuser, 2015).

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**Sarah Grant** is an American media artist and educator based in Berlin. She is a member of the Weise7 studio in Berlin, founder of the interactive media studio Cosmic.Berlin and has held visiting professorships for universities across Europe. She holds a Bachelors of Arts in Fine Art from UC Davis and a Masters of Professional Studies in Media Arts from New York University's Interactive Telecommunications Program. Her teaching and media art practice engages with the electromagnetic spectrum and computer networks as artistic material, habitat, and political landscape. With a focus on radio art and computer networking, she researches and develops artworks as educational tools and workshops that demystify computer networking and radio technology. Since 2015, she has organized the Radical Networks conference in New York and Berlin, a community event and arts festival for critical investigations and creative experiments in telecommunications. She recently published the article "Slime Mold and Network Imaginaries", co-authored with Selena Savić, in *Leonardo* journal (MIT Press, 2022).

**Roberto Bottazzi** is an architect, researcher, and educator based in London. He is Associate Professor at the Bartlett School of Architecture, UCL, where he directs the Master in Urban Design. He studied architecture at University of Florence (Italy) and University of British Columbia (Canada). He lectured and exhibited internationally including the Pompidou Centre and Ars Electronica. He has been Visiting Professor at the Politecnico of Milan and Visiting Tutor at the Innovation Design Engineering [IDE] at the Royal College of Art. His publications include *Digital Architecture Beyond Computers* (Bloomsbury, 2018), *Walking Cities: London* (Camberwell Press, 2017; Routledge, 2020, co-editor) and *Architecture, Energy, Matter: DS18* 2013–2015 (University of Westminster, 2016, co-editor) along with numerous articles on architecture and computational design. His research analyses the impact of digital technologies on architecture and urbanism.

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