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Mycelium Garden : Listening to and composing with the infra-world

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Title: *Mycelium Garden: Listening to and composing with the infra-world*

Building interspecific interactions

Listening to the “music” of living cells

Since 1873, we know plant cells conduct electrical signals. Burdon-Sanderson was the first to identify action potential (AP) in plants (Fromm and Silke, 2007).

Musicians and sound artists have used these electrical properties to build devices based on transduction systems for electrical signals (Agapea, 2021; Moore *et. al.*, 2016; Garcia, 2016).

***Fungi*, signals and symbiotic networks**

The mycelium is the underground vegetative part of *fungi* whose fruiting bodies are mushrooms. In the case of mycorrhizal *fungi*, the network can connect several root systems of sometimes different plants (Miyachi *et. al.*, 2020; Selosse, 2000). The result is a symbiosis: a lasting coexistence between organisms whose interactions are mutually beneficial (Selosse, 2000). Scientists have highlighted the action potential in *fungi*. Olsson and Hansson measured electrical signals in the mycelium of *Neurospora crassa* (Olsson and Hansson, 1995). Using a multichannel analysis, Dehshibi and Adamatzky discovered the complexity of signal systems in the mycelium network of *Pleurotus ostreatus* (Adamatzky, 2018). These studies show a diversity of protocols and representations. We must note the biases and methodological problems of some of these studies (Blatt, 2024). We took these elements into consideration in our research protocol.

Interacting with non-human beings

Beyond anthropomorphism

In musical composition, experiments exist with modular synthesizers using biodata sonification modules connected by electrodes to mycelial bags (Seraiah, 2023) or fungal sporocarps (Hissong, 2021). These experiments do not seem to account for the complexity of signals within a single mycelium. They also contribute to the simplification of an approach that aims to be interactionist. By removing uncertainties (Blatt *et. al.*, 2023) about the source of these sonification¹ from their communications, these artists present a simplified view of the possibility of hearing « the music of mushrooms² ». This anthropocentric approach can prove counterproductive³ in an ecological project (Castro and Selosse, 2019). Our project seeks to develop a device for sensitive and specific interaction modalities with mycelium, through an interpretation of the singularity of their electrical expressions (Berbara, 1995; Adamatzky, 2018).

Accounting for otherness

Our project aims to consider the singularity and multiplicity of a mycelium network. The aim is to make audible the complex, invisible dimensions of these beings often perceived as inert.

¹ Artist Noa Kalos uses Instruo's SCÍON module connected to a Eurorack modular system.

² Kalos describes her device as « mostly just mushrooms talking connected to synthesizers » (source: <https://www.youtube.com/channel/UCsmw-u-2kzPQPO5n9sTpcyA>)

³ See Marc-André Selosse's contribution to *Les plantes sont-elles des animaux comme les autres ?* [Online], URL: <https://youtu.be/y2qrvfMIqLg> [accessed January 10, 2023].

This model attempts to maintain the dimension of otherness in musical non-verbal interactions. This space will be understood as a process of building symbioses by adjusting differences (Guillo, 2019).

An « Objective process of knowledge »

In the construction of our experimental statements, we focused on a method of trial and error elimination, following the principle of « degree of corroboration » (Popper, 1985). Our research is based on an « objective knowledge process ». We rely on the principle of « verisimilitude » (Popper, 1985), in an attempt to get as close as possible to the truth while at the same time revealing the constraints and difficulties encountered in this process.

Paying attention to the living in a « mycelium garden »

The core of the project is the creation of an interactive sound installation in co-creation with a network of mycelium, whose emergence, development and living conditions have been organized by humans. In the MSH Paris Nord Garden we found an *Agaricus* which Stephen Withmarsh started to clone. He successfully reproduced the *Agaricus* mycelium. At this stage, identification was deferred to later observations⁴. We gave the cloned strain a specific name: *Hortus Annae*. *Hortus Annae* has its own characteristics that distinguish it from other mycelium, they make it a unique individual(s). Spora, an artistic collective dedicated to Funga, has then expanded the mycelium, moving from Petri dishes to “mycelization” bags. We established an interspecific relationship with this mycelium. For several months we took care of this mycelium and learned of its fragile constitution: an almost ephemeral structure.

Recording the mycelium signal: trials and protocols

Adapting a device designed for humans

To facilitate a co-composition environment between three agents (mycelium/IA/human), we established a protocol to measure the intrinsic signal’s variations while avoiding as much as possible instrumental noise. Mycelial electrical signals can vary in amplitude and dynamics. However, they have a low intensity and a slow evolution over time (Slayman *et. al.*, 1976). Depending on the strains and protocols, activities are in the millivolt range⁵ and in a frequency range between 0,004 Hz and 0,6 Hz⁶. These characteristics pose a technical challenge when it comes to capturing them. Therefore, we adopted EEG and EMG⁷ capture technologies. They share a good signal-to-noise ratio, high amplification capacity and the ability to filter instrumental noise (Metting *et. al.*, 1994). As part of the ANR BBDMI project⁸ prototypes to measure muscle and brain electrical signals (EMG and EEG) were developed. We built on these technologies to develop sound mapping of the mycelium activity for our installation. Using two EAVI board (Di Donato Balandino *et. al.*, 2019) and subdermal needle electrodes, we tested the feasibility (Klejchova *et. al.*, 2021) and accounted for the diversity of the mycelium electrical expressions. Given the equipment available, we are not measuring true AP, but local voltage changes, « field potentials » (Bodis-Wollner, 1982) that reflect the behavior of several cells. It is an indirect measure of cellular activity.

⁴ Mycologist Aurélie Sanchez, identified the clone as an *Agaricus xanthodermus*.

⁵ Slayman Clifford L., Long W. Scott, Gradmann Dietrich (1976), « “Action potentials” in *Neurospora crassa*, a mycelial fungus », *Biochimica et Biophysica, Acta* 426, p. 732–44. DOI : [https://doi.org/10.1016/0005-2736\(76\)90138-3](https://doi.org/10.1016/0005-2736(76)90138-3)

⁶ See Slayman *et. al.* (1976) ; Olsson and Hansson (1995) ; Adamatzky (2018).

⁷ Electroencephalogram/Electromyogram

⁸ ANR-21-CE38-0018, <https://bbdmi.nakala.fr/>

The signals we measure are the result of a complex interaction between the mycelium and its environment (Blatt *et. al.*, 2024).

Recording mycelial signals, protocols

Careful analysis is required to ensure that the signals measured originate from the mycelium and not from external noise. Two test protocols have been established to measure electrical signals from our model organism *Pleurotus ostreatus* while minimizing interference. The first protocol⁹ uses subdermal needle electrodes¹⁰ chosen for their sterility and precision, and copper electrodes. The second protocol places the mycelium and a control object (a damp sponge) in a Faraday cage to minimize electromagnetic noise. Needle electrodes, which are more sensitive to interference because they are unshielded, are used in conjunction with noise protection measures. The sponge is used as a control object to compare signals and identify disturbances.

First phase

Electrical signals were recorded from the mycelium of two types of mushroom, *Pleurotus ostreatus* and *Agaricus « Hortus Annae »*. The *Pleurotus ostreatus* signal showed sporadic disturbances that resembled electromagnetic noise, suggesting the presence of both useful information and instrumental noise. It should be noted that the ADS1294 integrated circuit on the EAVI board introduces a small electrical current into the system, which can affect measurements. This is considered in the data analysis. The signal from *Agaricus « Hortus Annae »* is similar to that from *Pleurotus ostreatus* but without voltage peaks, noting a difference that could be due to the phase of mycelium development at the time of recording. We used advanced analysis methods to separate and identify significant signal elements.

Filtering and classifying mycelial electrical expression

We employed machine learning techniques to filter and classify the mycelium's electrical behavior. Machine learning adds a layer of uncertainty to our practice with the mycelium through its probabilistic framework. We decided to include this feature in our practice, by considering it as a form of computational agency (Scurto *et al.*, 2021). We first filtered the mycelium signal using a wavelet analysis (Françoise *et al.*, 2022), which revealed constant spectral components, undoubtedly due to the instrumentation of the measurement, as well as low-frequency components typical of mycelium's electrical activity. We then used a shallow Gaussian mixture model (Françoise *et al.*, 2014) to classify mycelial electrical expression filtered by wavelet analysis. We built a small database with two classes: an example with low-frequency components labeled "mycelium", and an example without these components labeled "noise". While low-frequency components were mostly detected, we testified of occasional errors produced by classification, typically detecting mycelium activity when there is none. We decided to include these computational errors in our practice, as a way to attend and respond to the materiality of machine learning.

Second phase

In the second phase of the project¹¹, we modified the recording protocol on the EAVI board. We deactivated all the filters that had been set on the card and took the signal directly without processing or filters. In line with the observations detailed in our study, it was identified that

⁹ 34 hours of recordings between December 21, 2022 and June 15, 2023.

¹⁰ « Disposable Subdermal EEG needle electrode ».

¹¹ 11 hours of recordings made in September 2023.

the integrated circuit responsible for capturing mycelium signals introduces an electric current into the system. Although this current is small (200pA), it has effects on long-term measurements, revealing the presence of DC voltage components in our data. This discovery necessitated an adaptation of our analysis methodology to take account of these alterations. With this new configuration we discovered a signal much closer to the state of the art: with a very slow evolution and a very low frequency range.

Co-composing with mycelium

Synthesis and « sonic archaeology »

We asked ourselves how we could connect the mycelium signal to our human musical world; what sensitive mediations and compositional choices could we propose?

In the first stage of composition we used the recording of the noise (the mycelium and its environment) as material. Using FFT analysis we looked for frequency singularities. Within the noise, we were able to identify rare but remarkable intensities in frequency bands below 50 Hz. Based on this analysis, we developed sonic poetics inspired by the mycelium and its environment: the underground. Using the sonographic transformation synthesis technique (Roads, 2015), we sought to highlight the low frequencies, acting on the graphic representation of sound¹². Considering this first step as an initial sound substrate, this raw material was transformed in Max using BBDMI¹³ and abclib¹⁴ libraries in order to compose long harmonic and inharmonic sequences¹⁵ as well as a multitude of short granular and rustling sound objects¹⁶. This work is an exploration of what could be the poetics of an underground polyphony, as well as the development of composition through what we define as « sonic archaeology¹⁷ ». These samples then serve as the sound substrate for a Max patch whose variables are modulated in real time by the activity recorded from electrodes attached to the mycelium.

Making audible, adaptive assemblages

The installations produced are a combination of several technologies, human expertise and living mycelium. Two diffusion systems were tested. Each allowed us to experiment with composing sound spaces and test the adaptability of the model.

A hybrid system

The first diffusion of the mycelium/human co-composition was made on a Wave Field Synthesis/Ambisonic hybrid system thought by Adrien Zanni, comprising 11 in-line loudspeakers, 4 subwoofers and 4 loudspeakers¹⁸ placed in a semi-circular pattern. For this set-up, the low-frequency composition work was part of the hypothesis of establishing

¹² Samples composed from the noise recorded from the mycelium:

https://dianeschuh.fr/02_48Khz_Mycelium_sonographic.wav and

https://dianeschuh.fr/03_48Khz_Mycelium_sonographic.wav

¹³ <https://gitlab.huma-num.fr/bbdmi/bbdmi>

¹⁴ <https://github.com/alainbonardi/abclib>

¹⁵ Example of one track composed for *Mycelium Garden*: https://dianeschuh.fr/MyceliumGarden_1piste.wav

¹⁶ 43 pointillist sound objects composed for the *Mycelium Garden* installation:

<https://mycelium.hypotheses.org/composer-le-substrat-sonore>

¹⁷ We define sonic archaeology not as a reconstruction of past soundscapes, but as a way of extracting from the noise the singularities of what we imagine to be the frequency expression of the mycelium signal.

¹⁸ Binaural mix of an iteration of the *Mycelium Garden* installation broadcast on the WFS/Ambisonie hybrid system: <https://mycelium.hypotheses.org/ecouter>

“contact” with the mycelium. We were working on the possibility of this organism reacting to low-frequency vibrations, thus establishing an initial feedback loop through the mycelium’s reaction to the composition, which would then modulate differently by new peaks of electrical activity.

Composing a milieu

The second iteration of the installation, was composed for a 2d-order ambisonic three-dimensional sound space¹⁹. This diffusion set-up, designed by Paul Goutmann, consisted of 11 loudspeakers and a subwoofer. We worked on ways of scaling the temporal dimensions of the captured signal in order to compose hybrid music, human music transformed by non-human processes: mycelia and machines. The possibility of composing with rings of loudspeakers enabled us to test the composition of a diversified sound space conceived as a milieu²⁰.



[Fig 1. Second presentation of the *Mycelium Garden* installation at « Rencontres ArTec », on the 15th and 16th of November 2023 in Paris, photo © Université Paris 8 / Service création audiovisuelle - Patrick Masclaux]

Adjusting temporalities

The control of these sound synthesis and the activation of certain samples are modulated in real time by the electrical activity monitored from the mycelium bags. We conceived this device as a mixed composition relationship between linear times determined and composed by a human and the indeterminate temporalities of a mycelium that activates and transforms sounds in unexpected ways. In addition, voltage micro-variations measured from the

¹⁹ Adding the dimension of elevation to the composition of sound space.

²⁰ Binaural mix of an iteration of the *Mycelium Garden* installation broadcast on the 3d ambisonics system: <https://mycelium.hypotheses.org/ecouter>

mycelium's eight monitoring points modulate in real time the decorrelation and feedback factors of various decorrelation modules as well as trajectory modules, thus constructing a diversified sound space in motion.

AI, introducing a new agent

The use of generative artificial intelligence was another aspect of the project, using deep learning to generate images from the mycelium signal. A GAN algorithm developed by Salim Aissi was employed. This algorithm involves training two adversarial networks: a generator and a discriminator. They are trained jointly, where the generator attempts to deceive the discriminator's prediction, and the discriminator tries to detect the truth of the image. This process enabled us to obtain realistic images²¹ as the training progressed. For *Mycelium Garden*, our generator neural network was trained on the mycelium signal as input and produced an image simulating the shape of a mushroom. The discriminator was trained on a dataset of real mushroom images²². This conditions the generator to produce images similar to those. The following figure illustrates the process: each cell represents a generated image based on a part of the mycelium signal.



[Fig. 2 Generating images from mycelium recordings during the AI re-training phase ©Salim Aissi]

²¹ We did not overtrain the model in order to keep a dimension of otherness in the representation.

²² The project created its own photographic database by collecting thousands of photos and some videos with the help of volunteer photographers to retrain the AI model.

Building symbioses by « adjusting differences »

The objects and installations developed in this project are built as a basis for rethinking the question of inter-species interaction, conceived not as a process based on shared culture and intentionality, but as a form of co-production of meaning by « adjusting differences » (Guillo, 2019). In this project, the rhythm of the mycelium guided each of our actions. This required adaptation and the ability to adapt, to readjust our expectations. The result of this research is a process rather than the production of an object. The multispecific assemblages built during these experiments have led us to develop a methodology of attention that tends towards the search for objective knowledge, built up over the course of experimentation. This experience led us to reflect on the notions of interface, translation and scaling of data between different systems/ecosystems: humans, non-humans, machines and AI. In this work, we highlighted all the stages in this translation that enable us to access an auditory dimension of a mycelium/human relationship. Uncovering these processes and sharing this approach with the public has enabled a communication about mycelium and engaged a critical dialogue about interfaces. The study of the notion of symbiosis and its application served as a tool to shed light on the notion of complexity. This installation invites us to question the aesthetic stakes of forms generated automatically or, in this case, guided by non-human processes, showing the fragmentation and dissolution of intentionality in this type of production, which synthesizes and explores unexplored niches in our cultural spaces.

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