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Alchemical Sensing: Creating an Embodied Experience of the Unseen Organism

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With a focus on the agency of the organism and a desire to develop a more embodied experience of microbial life, the artist, Louise Mackenzie wished to create an approach for 'listening to' the movement of microbial organisms. Having viewed a multitude of *Dunaliella salina* in one drop of medium under a microscope[1], Mackenzie was struck by their celestial resemblance and, having discussed this with scientists in the lab[2], was surprised to learn that they are rarely viewed in this way. Instead, visual information is generally taken at a higher resolution, or from more powerful microscopes that transfer data reflected from lasers directly to computer screens and interest tends to be focused on the genetic structure of the organism itself and the mechanics of the cell and flagella (the tail like structure with which the organism 'swims').

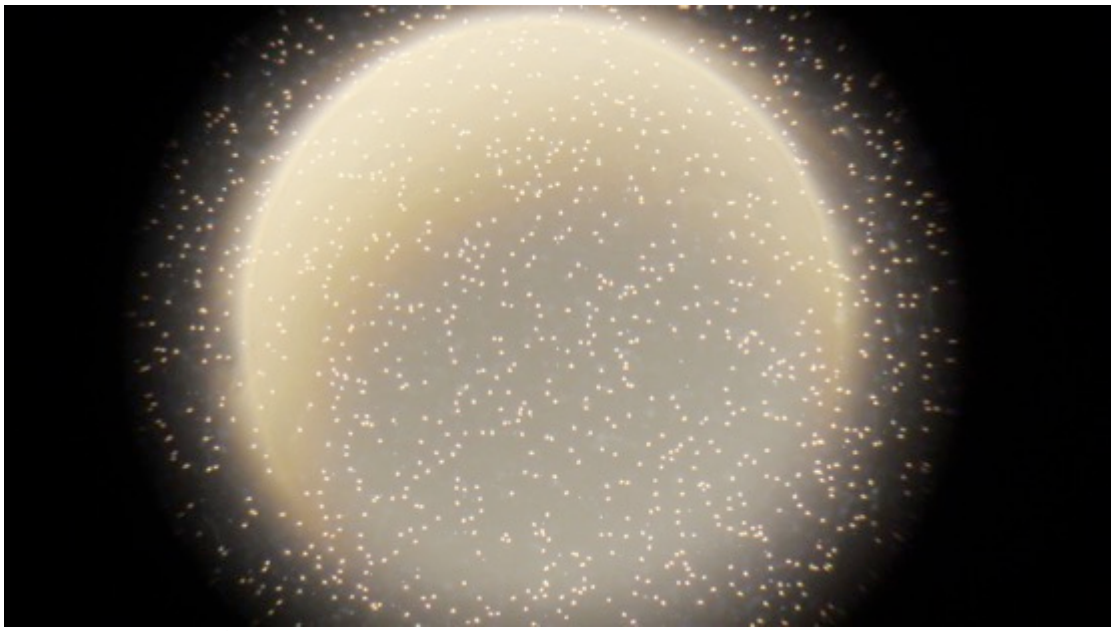

Figure 1. Louise Mackenzie, 2013. Dunaliella salina, Olympus CKX41, Bright Light

[1] Olympus CKX41 microscope, School of Marine Science & Technology, Newcastle University

[2] Dr Gary Caldwell and Dr Chelsea Brain, Newcastle University

This shift of context opened up possibilities in thinking about how scientific information is interpreted and whether one perspective is necessarily more 'true' than another. This visual referent, constructed through the microscopic gaze, of the motile *Dunaliella salina* has the same effect as gazing towards a night sky filled with twinkling stars. We are looking at things, but not seeing them. They are impossible to perceive other than with the senses available to us. In attempting to 'listen to' micro-organisms therefore, we might further extend the range of possible interpretations of the microbiological other[3].

Atomic Force Microscopy as a technique for 'Listening'

The motility of micro-organisms is described by E. M. Purcell via the phenomenon of the low Reynolds number (Purcell 1977). The size of *Dunaliella salina* (7.0–12.0 μm long and 2.0–5.0 μm broad), compared to the viscosity of their liquid environment results in negligible momentum, or a motion of 'going nowhere'. Thus movement is driven by a flagellum (a tail-like structure).

Given that the organism is motile, it should be possible to detect fluctuations caused by the propulsion of the *Dunaliella salina* and, after researching the work of Davis and Egan and Niemetz and Pelling, Mackenzie approached Richard Thompson of Durham University to discuss the possibility of studying the motion of *Dunaliella salina* using an Atomic Force Microscope (AFM). The AFM works by detecting deflections on a surface at the nanoscale. It is more commonly used for force measurement and imaging of materials. It uses a cantilever tip, which makes transient contact (a tapping motion) against the sample surface, and a laser is used to record any deflections in the beam as the cantilever tip scans across the surface of the medium.

[3] Recent turns in philosophical, anthropological, microbiological and neuroscientific theory point towards a holistic, symbiotic relationship between the human and the microbiological, and one might suggest that use of the term 'other' does not fit in this context. This must be balanced against the practice of scientific research, where the microbial is used as tool or scientific resource. The paradox is that in order to develop an understanding of the microbial as integral to the human psyche, the microbial has simultaneously become the 'slave' of the laboratory. It is suggested that this use of the microbial as resource, servant or slave to human endeavour maintains a definition of the microbial as 'other' that acts as a useful frame for discussing the organism in the context of scientific research.

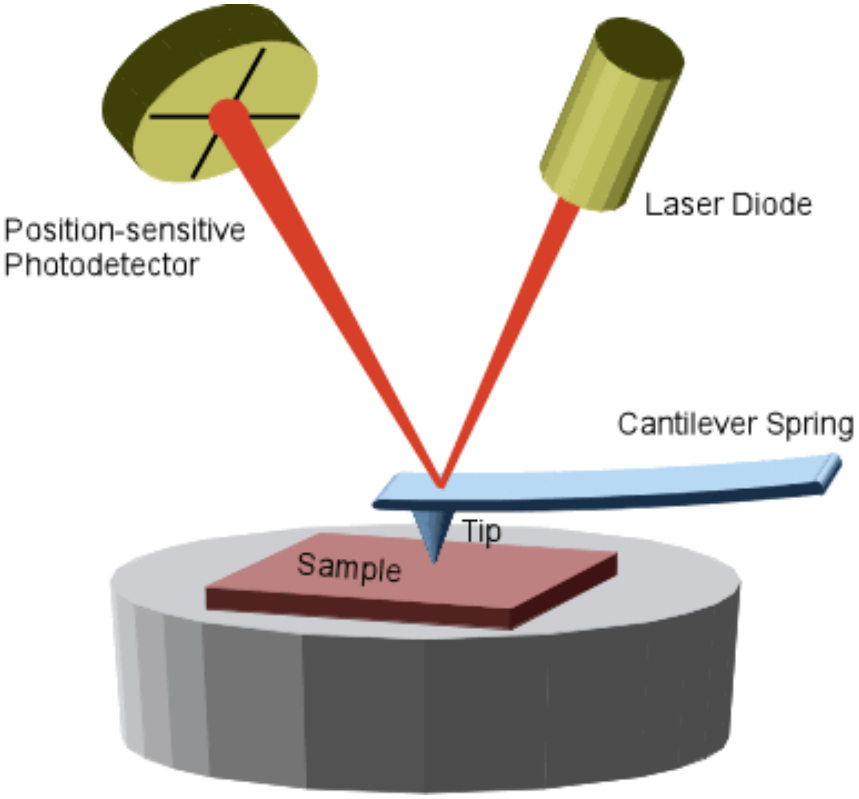

Figure 2. Mechanics of the Atomic Force Microscope

Source: http://www.physik.uni-greifswald.de/fileadmin/physik/ag_helm/Bilder/Methoden/AFM_laser.gif

After initial tests to determine the best approach to placing the micro-algae under the microscope, we set upon static use of the AFM with the fluid cell attachment that enabled us to pump the liquid medium (f/2 solution)[4] containing the *Dunaliella salina* into the chamber directly under the line of the laser. With this system, the micro-organism becomes the lens by which we perceive its motion. The laser beam used in the detection is approximately 30 microns diameter. This is large compared to the *Dunaliella*, which in turn is large compared to the wavelength of the laser. The natural consequence of this is that when the *Dunaliella* moves through the path of the beam, there is a significant disturbance to part of the beam. The interference of the scattered and non-scattered beams gives rise to periodic fluctuations in the locus of the detected beam. These fluctuations were recorded in high-speed capture mode exported as deflection versus time data. Using this approach, we identified fluctuations unlike those detected when analyzing inert material.

[4] Reference: Guillard, R. R. & Ryther, J. H. Studies of marine planktonic diatoms. I. Cyclotella nana Hustedt, and Detonula confervacea (cleve) Gran. *Can. J. Microbiol.* **8**, 229–239 (1962).

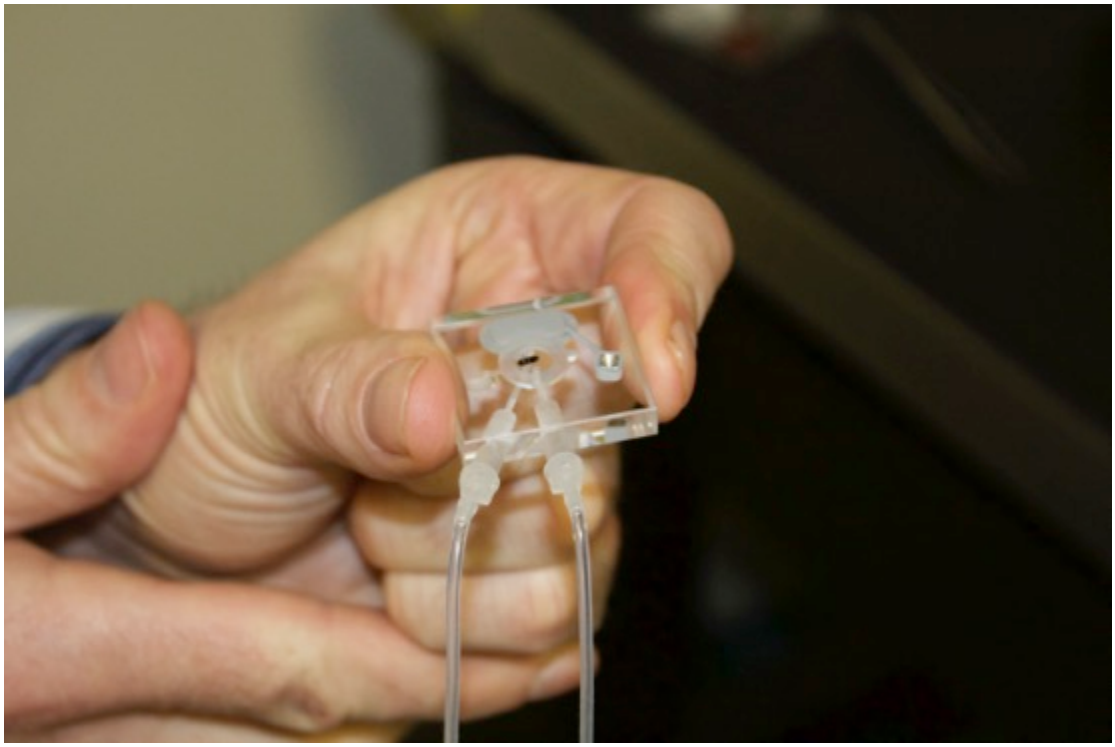

Figure 3. Louise Mackenzie, 2015. Fluid cell attachment for Bruker MM8 Multimode AFM

Running a control experiment by passing pure water (in the absence of *Dunaliella salina*) through the same system, the signal was entirely absent, leading us to believe that the data reflected the presence of movement. What was not initially known was whether the vibrations detected were due to the *Dunaliella* colliding with the cantilever or simply traversing the beam. Since the signal was often seen to crescendo, then diminuendo, this would be consistent with the microbe entering then leaving the beam path. For a collision, a 'hit' then a rapid diminuendo would be expected, as the motion of the cantilever in a fluid medium is highly damped. Thus we perceived the data as representation of the nanoscale phenomenon of the *Dunaliella*'s motility.

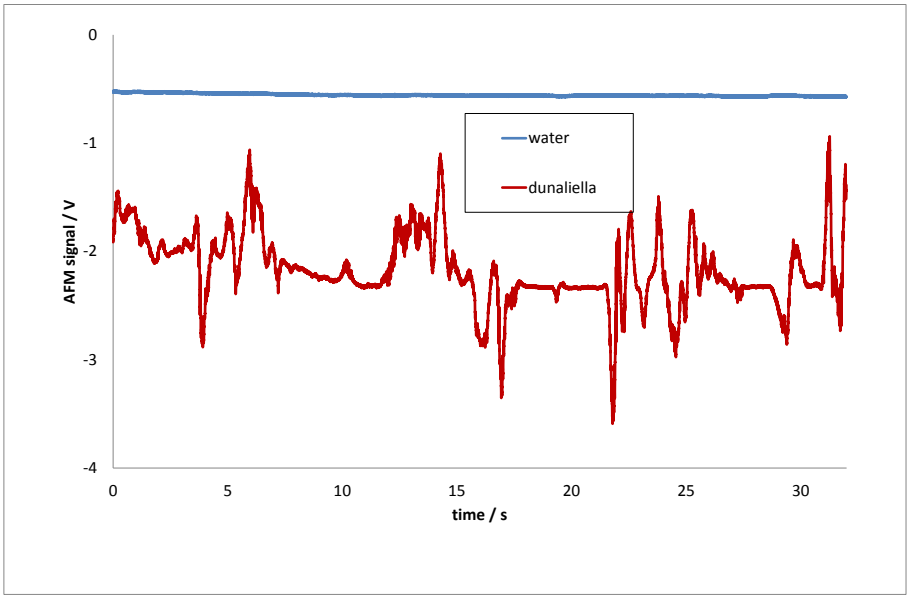

Figure 4. Richard Thompson, 2015. Readings with water as control (32 seconds) and *Dunaliella salina* (32 seconds)

Further research to confirm the cause of the fluctuations has been identified, for example it would be possible to identify the speed of the flagella (the whip like tail structure that causes motility) of *Dunaliella salina*, and compare this to the rate of fluctuation identified.

A double blind experiment, with additional researchers, further samples and another AFM microscope in a different setting, would also serve to validate the results.

The data gathered from the phenomenon observed using the AFM is still a number of levels removed from sound as perceived by the human ear. To convert the data obtained via the AFM to sound requires more layers of technology, further distancing the micro-organisms' agency from what one hears.

Listening to the Microbial Other

In translating the data captured by the AFM, it was important to find as linear a method as possible, one that, whilst requiring aesthetic decisions, enabled a clearly defined path through the layers of additional technology. Thus revealing the choices within each layer that contribute to the outward spiral of possible interpretations. The information gathered is translated through the following sequence of events:

1. Movement of *Dunaliella salina* in medium f/2
2. Deflection of laser beam by *Dunaliella salina* in the AFM detection system
3. Variation in beam deflection represented numerically over time
4. Numerical representation of distance plotted graphically

5. Graphical representation depicted as sound wave

This final step, the depiction of the data as sound, was achieved in three different ways, each requiring additional technological layering.

a. Photosounder

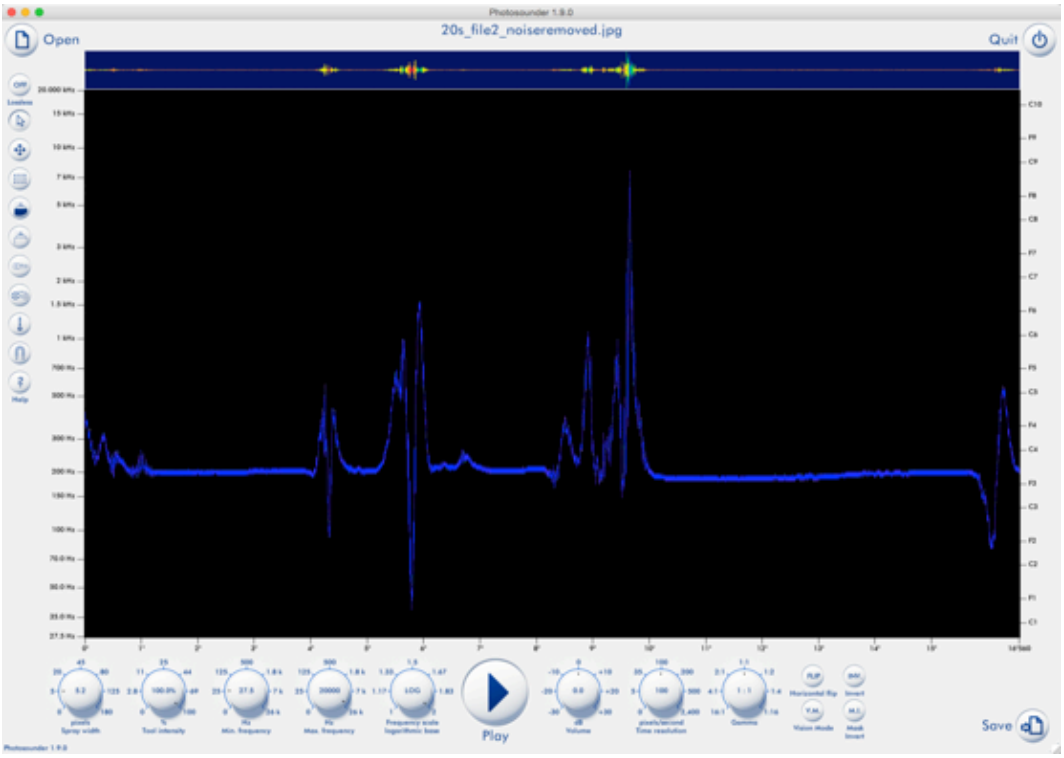

Figure 5: Louise Mackenzie, 2015. Photosounder, Inverted image of raw data file from AFM, 20 second clip.

Photosounder is an audio editor/synthesizer that is capable of converting a photographic image to sound, thus *sonifying* the image data. Created by Michael Rouzic in 2008, Photosounder uses synthesis algorithms to take the digital information of an image and convert this into sound frequencies. By taking the image of the graph from step 5 above into Photosounder, the application reads the image and converts it directly into frequencies. From this point, it is possible to use Photosounder to alter the resulting sound using a variety of parameters to achieve desired acoustic effects.

Photosounder is an extremely flexible tool for visual artists working with sound. Mackenzie has previously used Photosounder to generate sound from photographic images as a part of *Heartisanorgan* (2014), an installation and social media website that enabled the public to exchange stories with fictional characters represented by photographs of historic members of a former church congregation, developed by the artist as a part of the *transformation content* exhibition[5]. With Photosounder, visual data can be manipulated directly within the application, to create abstract sounds that map to the pixels comprising the image.

[5] Transformation content, Louise Mackenzie, Holy Biscuit Gallery, Newcastle, 2014

Figure 6. Louise Mackenzie, 2014. *Heartisanorgan*. Holy Biscuit Gallery, Newcastle, UK. Organ wood, social media website

In order to generate a sound based on the data from the *Dunaliella* alone, rather than all of the image data, adjustments to the image (adding to the technical layering) were required. Firstly, the graph was removed by cropping and raising the contrast (using the Curves tool) in Photoshop. Secondly, it was found that with a white background there was no audible correlation between the data generated and sound produced, only a single constant noise was audible. By inverting the image using the Photosounder application, a clear correlation between data and sound resulted.

Photosounder gives a reasonably direct mapping of data to sound. It is close to *audification* of the data, but it is audification of the visual data (pixels) rather than the AFM data. The data is mediated through the image and technological layering is necessary to remove noise generated by pixels not relevant to the AFM data.

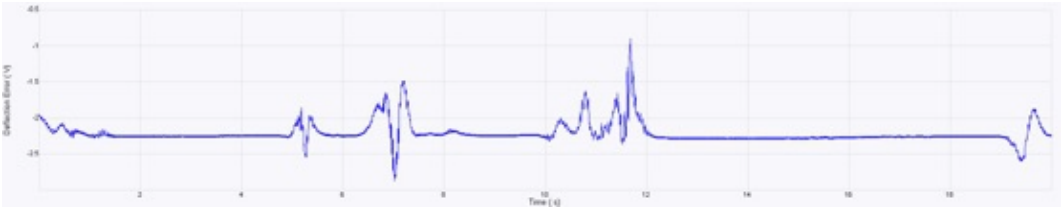

Figure 7. Louise Mackenzie, 2015. Raw data file from AFM, 20 second clip

The resulting sound can be heard here: https://soundcloud.com/louise-mackenzie-1/dunaliella-salina_20s_photosounder_noiseremoved

b. Sonification using MAX/MSP

An alternative approach to representing the AFM data was carried out in the form of parameter mapping sonification (PMSon). In PMSon the dataset is used to control the parameters of an audio signal. For example, Vickers, Laing, and Fairfax (2016) used the differences in four different measures of network traffic volume over 1 second intervals to control the amplitude and timbre of four separate audio streams in order to monitor the load on a computer network in real time.

The crucial difference between sonification and audification is that sonification imposes a mapping on the data. These mappings can be fairly low level (such as using the changes in value of a variable to alter the frequency of a sine tone) or they can be much more metaphorical (e.g., the use of melodic phrase structures to represent the various activities of a computer program - see Vickers & Alty, 2006).

This means that the relationship between the audio and the data is less direct. Whilst PMSon offers much more flexibility over how the dataset is rendered in sound one needs to be aware of the imposed mapping and that features of the audio could lead to erroneous inferences being drawn about the underlying data. For example, rapid increases in pitch might be interpreted as panic or distress when no such phenomenon exists in the dataset.

Because the AFM datasets comprise only a single variable (the sensor value) it was decided to use a simple sonification technique to represent them. A patch was built in MAX/MSP that used the AFM sensor values to control the frequency of a sinusoidal oscillator. In the presentation mode view of the MAX/MSP patch, the user can choose between an oscillator running at 220 Hz, 330 Hz, and 440 Hz (see Figure 8). The sliders allow the output frequency range to be widened or narrowed by the user depending on the variation in the data stream.

The input sensor values were scaled to the range [1..2], which means that with the patch's default values, the largest value in the AFM sensor file would cause the oscillator's frequency to double (an octave increase) while the minimum value would cause it to play at its default value. The sliders in the central box in Figure 8 let this range be extended or contracted as the user wishes.

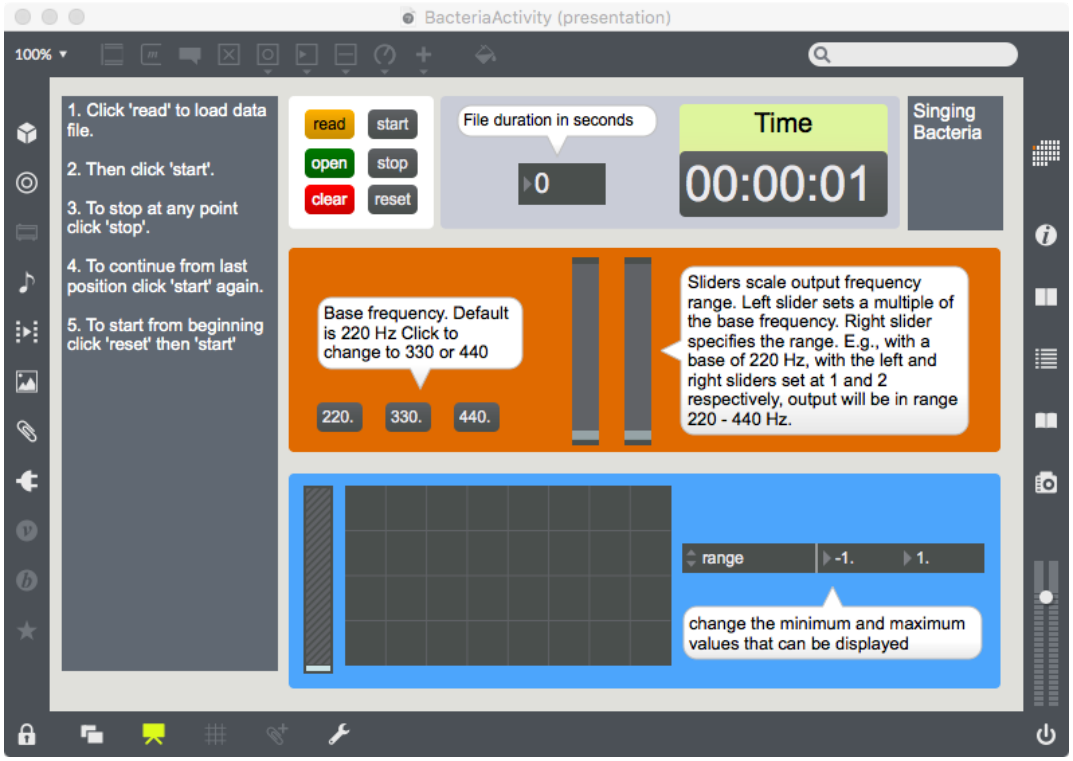

Figure 8. Louise Mackenzie, 2015. MAX/MSP patch in presentation mode.

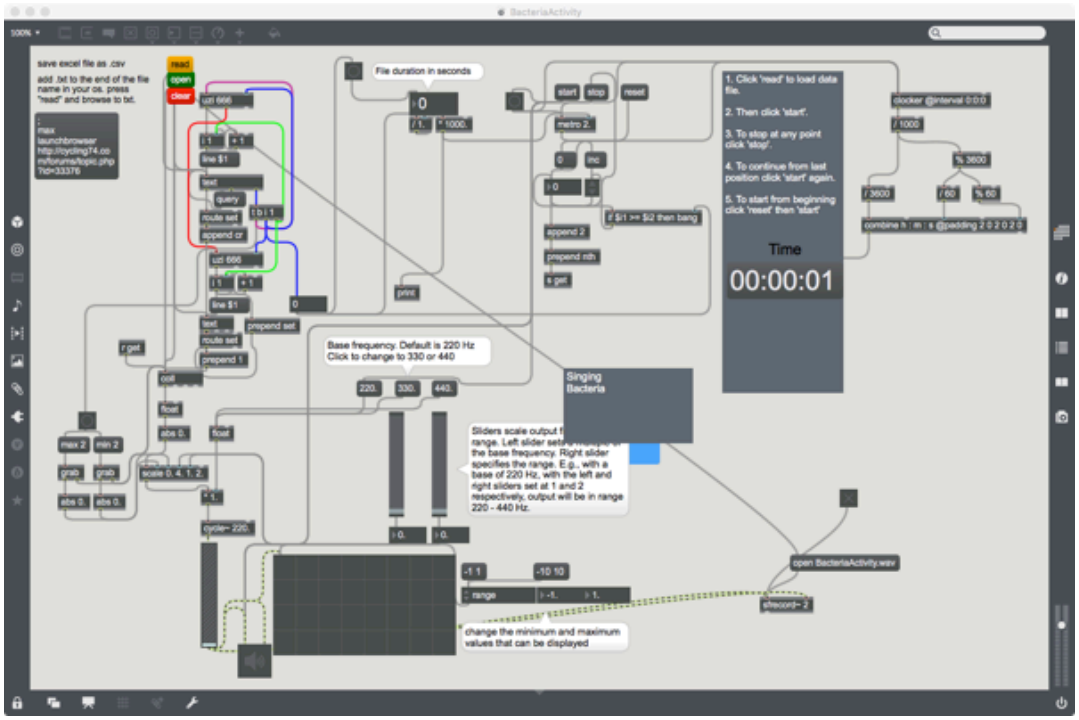
Figure 9. Louise Mackenzie, 2015. MAX/MSP patch in editing mode.

Using the PMSon approach, the additional technological layering is limited to the parameters set in the creation of the patch, in our case a sinusoidal oscillator operating at a base frequency of 220 Hz, 330 Hz or 440 Hz with an input range of 1..2 and an output range of up to twice the base frequency. Using such a simple mapping as the method of sonification reduces the distance between the original phenomenon and the resulting sound, however the use of the sinusoidal oscillator means that the sound is still not as close to the organisms as it could be.

The resulting sound can be heard here: https://soundcloud.com/louise-mackenzie-1/maxpatch-microbialsensing-test2 and the MAX/MSP patch can be accessed via Github (Vickers 2016).

c. Audification using Python

In the third option, a Python script was developed that translated the numbers from step 4 into frequencies of a sound wave. Each measurement in step 4 represents a sensor displacement recorded at a specific time. Knowing the total number of measurements recorded (94,820) and the length of time that the data was recorded over (328 seconds) enabled us to determine the frequency of oscillations and thus determine the audible range of the data in Hz (approximately 290 Hz in this case[6]). No parameter mapping takes place in this option; the dataset is translated as directly as possible into sound, thus the data is *audified*.

Audification involves only transposing the frequencies of the data to the human-audible range and occasional filtering to remove unwanted linear distortions (and in rare cases dynamic range compression to remove very large level variations). Therefore the process is more direct than other than other auditory display processes, which generally rely on mappings (e.g., data to pitch) to effect the auditory output. In discussing the representational aspects of auditory displays, Emily Caddick-Bourne observed:

> …[that when] a work represents some data then it seems that the data must, in some more substantial way be part of how the representation is properly experienced, so we somehow experience the thing in terms of what it represents (Caddick-Bourne, 2014)

The Audification Process

The data sampled by the AFM was encoded as two-value tuples[7] and stored in a tab-delimited text file. The first column contains a time stamp and the second column the value of the AFM sensor at the time indicated by the time stamp.

Figure 10 shows a graphical plot of a typical set of sensor readings. In this case it is the plot of a series of samples taken over a 20 second period. Because the sample data constitute a simple one-value time series the graphical plot resembles the visual representation of a digital audio file. Therefore, the audification process is a straightforward matter of taking each of the sample values in turn and scaling them to a signed 16-bit integer, thereby transforming them into digital audio sample values. These sample values can then be written to a digital audio file for playback.

[6] The range of human hearing is around 20 Hz to 20 000 Hz.

[7] A tuple is an ordered data structure consisting of multiple parts, a list in effect. It is commonly used in Python programming language.

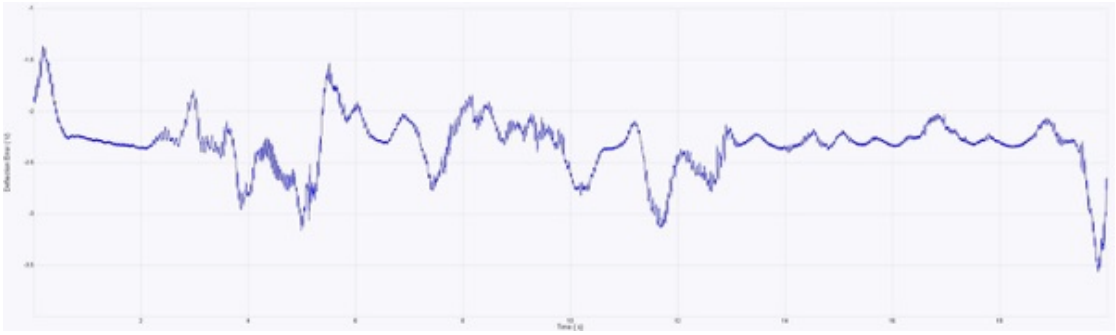

Figure 10. Louise Mackenzie, 2015. Atomic Force Microscope samples of Dunaliella collected over a 20 sec. period.

A Python script called *Audify* (available from Vickers & Mackenzie, 2016) was written to carry out the audification process. The script is controlled by several run-time arguments, which govern how it processes the AFM sample data (see Figure 11).

```
usage: Audify [-h] [-i INPUT] [-o OUTPUT] [-d] [-f] [-n] [-s {tab,comma}] [-m]
              [-S] [-r RESAMPLE]
optional arguments:
  -h, --help            show this help message and exit.
  -i INPUT, --input INPUT
                        Name of input CSV data file.
  -o OUTPUT, --output OUTPUT
                        Name of output file. If none specfied will have same
                        name as input but with .wav extension.
  -d, --debug           Turn on print statements for debugging.
  -f, --fade            Turn off the default addition of fade in and out to
                        prevent pops at start and end of audio.
  -n, --noskip          Do not skip header row in spreadsheet. Off by default,
                        use -n or --noskip if no header row present.
  -s {tab,comma}, --separator {tab,comma}
                        Specify the type of input file: comma separated or tab
                        separated. Default is tab.
  -m, --mono            Specify mono output. Default is stereo.
  -S, --Stats           Show basic sampling stats of the data file, do no
                        audio processing.
  -r RESAMPLE, --resample RESAMPLE
                        Resample the generated audio to the sample rate
                        specified by the argument's value. Default = 0 which
                        results in no resampling. Sample usage: Audify -r
                        44100 would generate a 44.1 kHz audio file.
```

Figure 11. Paul Vickers, 2015. Run-time arguments for Audify audification script

Data Analysis

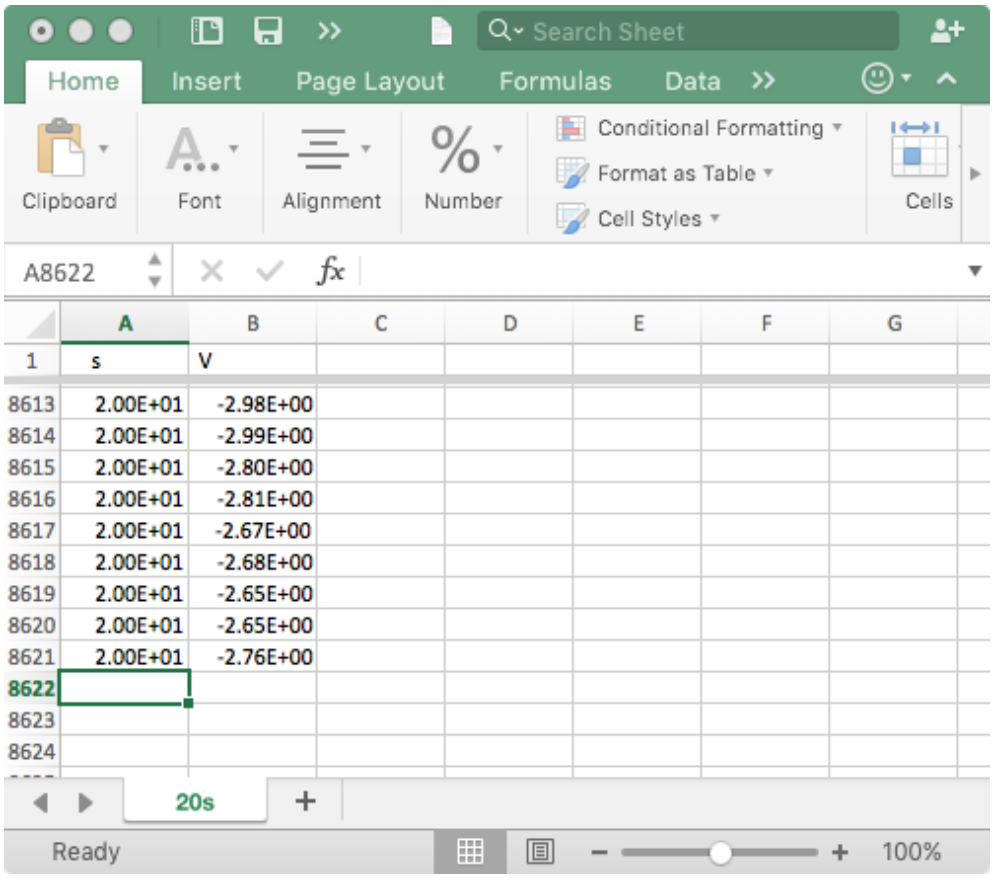

Figure 12. Paul Vickers, 2015. Extract of 20 sec. sample data file. Column headers stand for time stamp (s) and AFM sensor value (V).

Figure 12 shows the last few rows of the file 20s.txt, which contained 20 seconds worth of tab-separated AFM sample data. The time stamps are cumulative starting at 0 s (row 2) and ending at ~20 s (row 8621: the actual value is 19.99375). Because the first row of each file contained column headers the number of sample values was one less than the total number of rows. Knowing the duration of the file and the number of samples, the sampling frequency, f, used to collect the AFM sensor data is determined by dividing the number of samples by the duration. In this case that is:

$$f = \frac{8620}{20} = 431 \text{ Hz}$$

From this we can calculate the sampling period (the time difference between successive samples) as:

$$\frac{1}{f} = 0.0023202 \text{ s}$$

Inspection of the data file reveals that the sample periods are not demonstrating significant fluctuation. The smallest period between successful samples was 0.000004 s and the largest was 0.00743 s. However, the average period was 0.002320 s, which compares favourably with the theoretical period given above.

Given that the data files contained samples whose mean period equated to the sampling period required they were deemed suitable for direct conversion to audio samples. For a given data file the Audify script carries out the following steps:

1. Calculate the sampling frequency of the data file
2. Calculate the sampling period
3. Convert each sample value to a signed 16-bit audio sample (i.e., to a value between -32768 and +32767. This is done by determining the minimum and maximum data values and rescaling each value to the new range.
4. Add 0.25 seconds of fade-in and fade-out to the beginning and end of the new audio data (to avoid unwanted clicks when playing it back).
5. Write the new audio samples to a mono or stereo audio .wav file (as determined by the '-m' run-time argument). (Note, the stereo is simply a two-channel audio file which will sound the same as the mono file as both channels are identical).
6. Optionally resample the output file to a new sampling rate (as determined by the '-r' runtime argument.

For example, to process the input file 20s.txt and produce a 44.1 kHz 16-bit two-channel audio file one would invoke the Audify script thus:

```
Audify –i 20s.txt –r r44100
```

This would generate two audio files:

1. 20s.wav which is a 20 second two-channel audio file with a sampling rate of 431 Hz (the samling rate of the original data file) and
2. 20sR_44100.wav which is a resampled version of the audio at a sampling rate of 44.1 kHz.

The reason for offering the resampling option is because not all computer media players can playback audio files at non-standard sampling rates. As can be seen from Figure 13, the shape of the output audio waveform closely resembles the plot of the original AFM sample data (see Figure 10). Playing back the audio file one hears a low rumbling sound. This is the most direct auditory representation of the AFM data possible.

A goal of audification is to apply as little processing of the data and resultant audio as possible in order to retain as direct a representation as possible. Small data differences are more difficult for the human auditory system to perceive at lower pitches and so if this means that one cannot detect sufficient details in the data by listening to the audification then, as with the Photosounder option outlined above, further technological layering can be carried out.

Höldrich and Vogt (2015) outline techniques for allowing auditory 'zooming' to be carried out if closer inspection of the data is needed. For example, applying a five-semitone upwards pitch shift in the free Audacity audio editing tool brings a degree more clarity to the AFM sample data. Further processing such as applying some

audio compression to narrow the dynamic range of the file and then applying normalization would make the file sound louder but would reduce the difference in loudness of the loud and soft parts of the file. To provide an embodied experience of the phenomenon of the motility of *Dunaliella* however, it was deemed that no further processing was necessary.

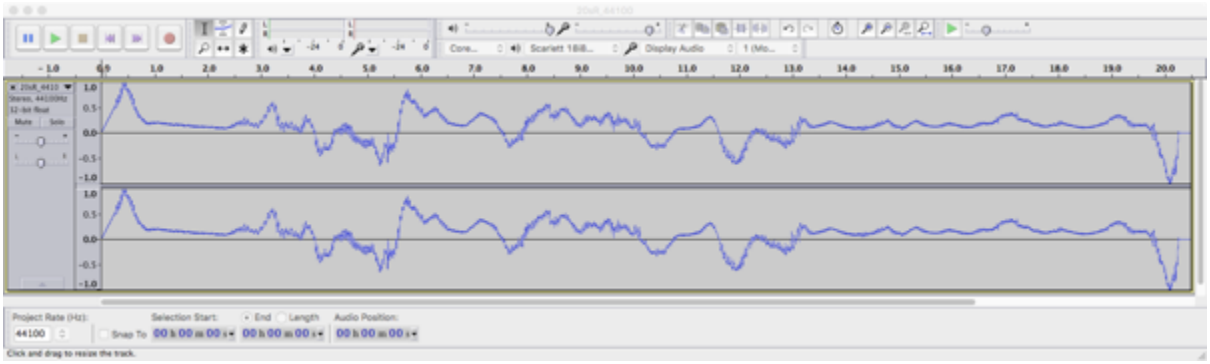

Figure 13. Paul Vickers, 2015. The resultant two-channel audio file.

Choosing Constructs Mediated by Technological Layering

Having listened to the results produced using all three methods above, Option c, the Python script, gave the sensation of presenting the most direct translation of the data. Something that not only captured the *Dunaliella*'s liveliness, but that appeared to place the listener physically within the same space as the organisms.

Whilst all three methods created the same peaks and troughs of pitch as the oscillating data changed, the Python script helps to construct an *audification*, rather than a sonification, and the closest representation of the data, thus a more direct translation of the original phenomenon to sound. This gives a *sense* of the organism that does not carry the added layer of interpretation created through *choosing* a sound to represent the organism. Gratifyingly, the sound generated using the Python script presents as a deep, almost 'watery' rumbling, that could be construed by the human ear as the sound of creatures moving (even swimming). The sound possessed a resonance befitting of the other-worldly quality of the *Dunaliella* that Mackenzie has previously alluded to, adding to the construction of an alchemical sense of the organism.

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