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D7.1 - Sonification Platform and Training Courses v1

Work Package	WP7 - Increasing the senses, increasing inclusion
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Terminology

Terminology/Acronym	Description
ADSR	Attack, Decay, Sustain and Release
API	Application Programming Interface
CNRS	Centre National De La Recherche Scientifique
CONICET	Consejo Nacional de Investigaciones Científicas y Técnicas
CSA	Coordination and Support Action
CSV	Comma-Separated Values
D0	Project Deliverable + associated number
DoA	Description of Action
EA	Ellinogermanik i Agogi Scholi Panagea
EC	European Commission
EGO	European Gravitational Observatory
ERN	European Researchers' Night
EU	European Union
F2F	Face-to-Face meeting
GA	General Assembly
GWOSC	Gravitational Wave Open Science Center
IASA	Institute of Accelerating Systems and Applications
IBFI	Instituto de Bioingeniería, Facultad de Ingeniería, Universidad de Mendoza
INFN	Istituto Nazionale di Fisica Nucleare
ITDA	Instituto de Tecnologías en Detección y Astropartículas (CNEA, CONICET, UNSAM)
KPI	Key Performance Indicator
LC	The Lisbon Council For Economic Competitiveness

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	and Social Renewal
LRI	Large Research Infrastructure
M0	Project month + number
MIDI	Musical Instrument Digital Interface
OU	The Open University
PAB	Project Advisory Board
PDF	Portable Document Format
PNG	Portable Network Graphics
PO	Project Office
PTC	Project Technical Committee
QA	Quality Assurance
QUEST	Quick Unbiased and Efficient Statistical Tree
REA	Research Executive Agency
REINFORCE	REsearch Infrastructure FOR Citizens in Europe
RI	Research Infrastructures
SAAO	South African Astronomical Observatory
UNIPI	Università di Pisa
UOXF	University of Oxford
URI	Uniform Resource Identifier
WAV	Wave Audio File Format
WP	Work Package
WSGI	Web Server Gateway Interface
ZSI	Zentrum für Soziale Innovation

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1 Introduction

This document describes the work done in relation to deliverable D7.1 - *Sonification Platform and Training Courses v1* - of WP7 - *Increasing the senses, increasing inclusion* of the REINFORCE project.

The document is divided into the following core areas:

- an introduction and overview;
- the sonification platform;
- the training course being developed;
- the next steps.

2 The sonification platform: sonoUno

A key element in REINFORCE has been the development of the *sonoUno*[1] data-sonification software. *sonoUno* is a user-centered software package that allows people with different sensory styles to explore and analyse scientific data presented in tabular format; through both visual and sonified representations.

The *sonoUno* software was initially developed based on the study of other relevant software packages, such as Sonification Sandbox, MathTrax and xSonify, and following standards of accessibility like ISO 9241-171:2008 (Guidance on software accessibility). The first approach to the graphical user interface was developed through the use of a theoretical framework, based on a bibliography of user cases, focused on blind and visually-impaired people.

Within REINFORCE, two versions of the software have been developed: a browser-based version, accessible via the web; and a desktop version. Each of these versions of the software are described within this section, below.

In addition to the work done on these two individual versions, a project within WP7 is underway, to attempt to unify the code-base of the two separate versions, thus helping to streamline the development workflow. This effort, which aims to be ready for version 2 of this deliverable, due in M26 of the project, is also outlined later in this section.

[1] http://sion.frm.utn.edu.ar/sonoUno/

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2.1 The web-based sonoUno version

The main goal of *sonoUno* is to allow the user to open data files and to view the data within it in visual (graphical plots) or sonified (audio) formats, while allowing the user to vary the pitch, volume and the timbre.

Within the web-based version, users can:

- select specific ranges of data on the 'x' axis;
- mark and save points of interest in the data;
- apply predefined mathematical functions (for example, logarithm and square);
- and manipulate data arrays via an Octave interface.

They can also configure the plot and some features of the sound.

The various functionalities of the software are described in this section of the document.

2.1.1 The development framework

Angular[2] is used as the development framework of the web-based version. This choice was made as it promotes modularity, and facilitates collaborative work. Being web based, this version of *sonoUno* is, of course, accessible from most platforms, and accessibility has been at the forefront of the minds of the development team.

2.1.2 The code base

A dedicated gitlab repository[3] is being used to support community working within this deliverable.

[2] https://angular.io/
[3] https://gitlab.com/reinforceeu

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2.1.3 The web interface

Figure 1 – The landing page of the web-based version of sonoUno landing page.

Users first arriving at the web-based version of *sonoUno* are greeted by the landing page displayed in Figure 1. A Quick Start guide is available to them (Figure 2), in which a short explanation of each of the areas of the web interface and their functionalities are described.

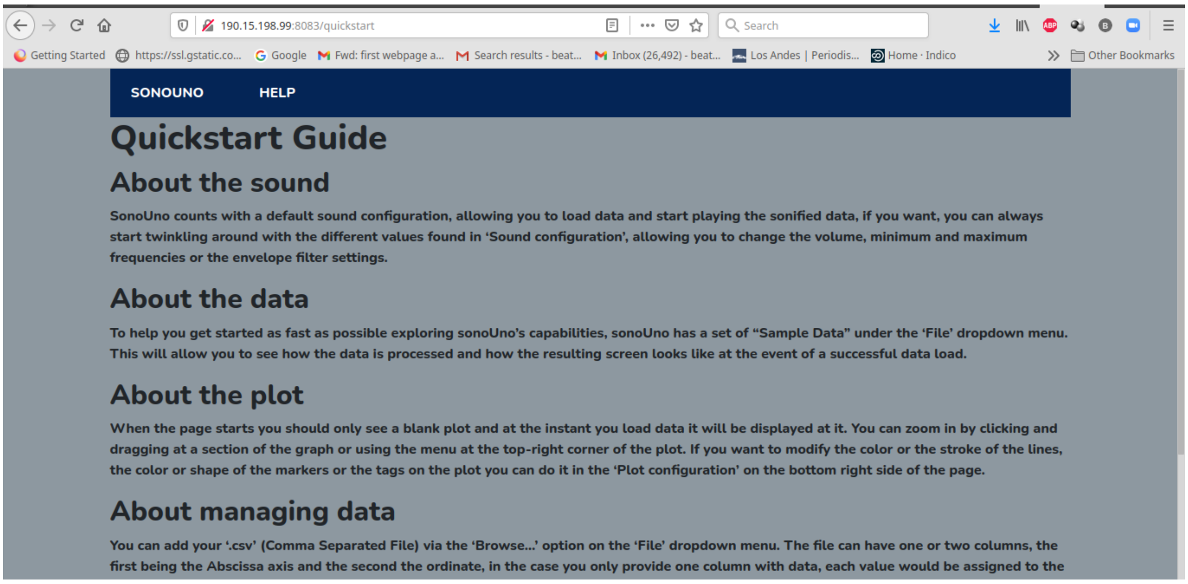

Figure 2 - The web-based sonoUno Quickstart Guide.

2.1.3.1 The homepage

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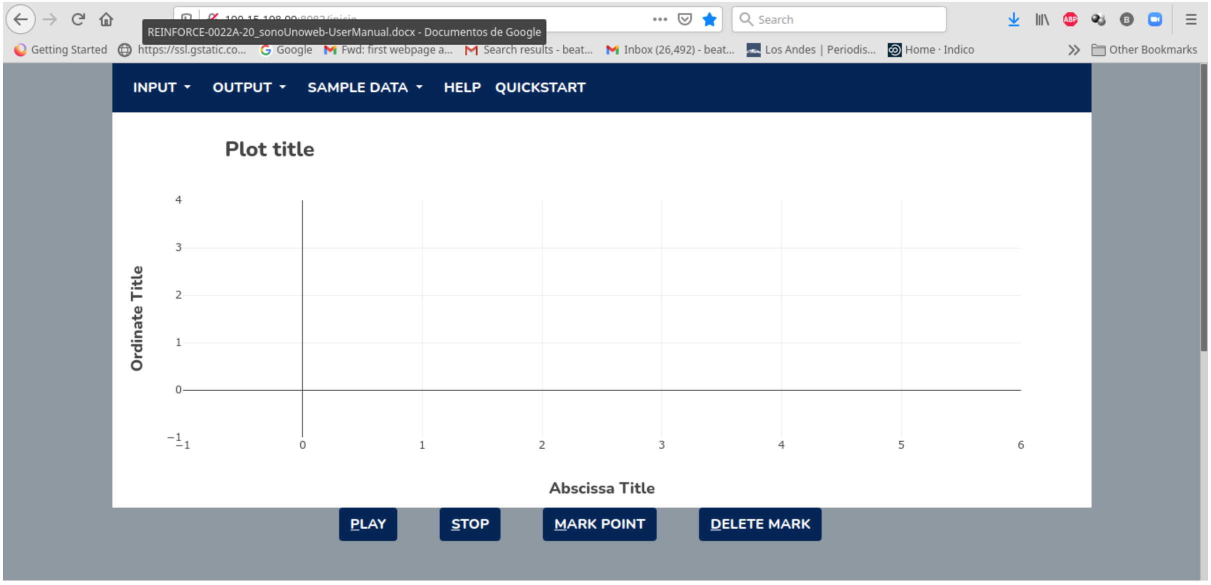

Figure 3 - The web-based sonoUno home page.

The home page of sonoUno greets the user with three distinct sections:

1. the **navigation bar**, providing access to the *File* functionalities, *Input/Output* functions, *Sample data* and access to the *Help* and *Quickstart* guides (Figure 3). The design of this element was based on a user case study conducted by Southampton University with both sighted and blind people, using the desktop version of *sonoUno*. The results highlighted the need for a simple interface that only shows the principal functionalities in the main framework[4];
2. the **plot area**, providing four control buttons: *Play/Pause*, *Stop*, *Mark Point* and *Delete Mark*;
3. and, below the plot, a **tools area** (Figure 4), supplying the following:
    - two sliders, with which to control the abscissa position and the tempo;
    - a Math Functions bar, permitting the selection of simple mathematical functions to be applied to the data (Figure 4);
    - a sound-configuration section, containing tools with which to modify the way audio is processed (Figure 5);
    - a plot-configuration section, which allows the user to modify the way the data is displayed in the plot (Figure 6).

[4] Casado, J., De La Vega, G., Diaz-Merced, W., Gandhi, P. & García, B. (2020). SonoUno: a user-centred approach to sonification. Proceedings of the IAU Symposium No. 367, Dec 8-12th 2020, Argentina, in press.

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Figure 4 - The lower area of the web-based sonoUno homepage, showing the plot area functionalities, the abscissa and tempo sliders, the math functions bar and the sound- and plot-configuration buttons.

Figure 5. The sound-configuration functionality available on the web-based sonoUno homepage.

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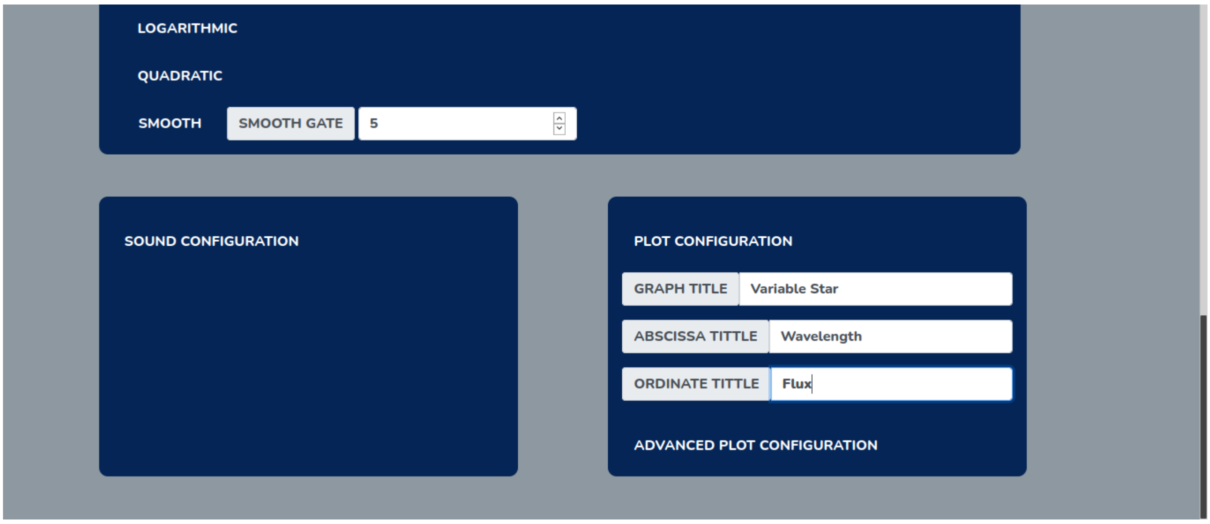

Figure 6. The plot-configuration functionality available on the web-based sonoUno homepage.

Each of these sections is explained in greater detail later in this section.

2.1.3.1.1 Using web-based sonoUno

Users can quickly get to grips with the functionalities provided through the homepage, via the Sample Data option in the navigation bar. Selecting any of the options under this menu to (Figure 7) automatically loads a dataset into the plot area and provides the audio version, ready to play.

Pressing the *Play* button starts a vertical line moving from left to right across the plot area, indicating progress along the x-axis. At the same time, the audio representation is played, with audible pitch variations matching the data point at the position on the x-axis. It is possible to jump to different points in the data by moving the progress vertical bar backwards and forwards.

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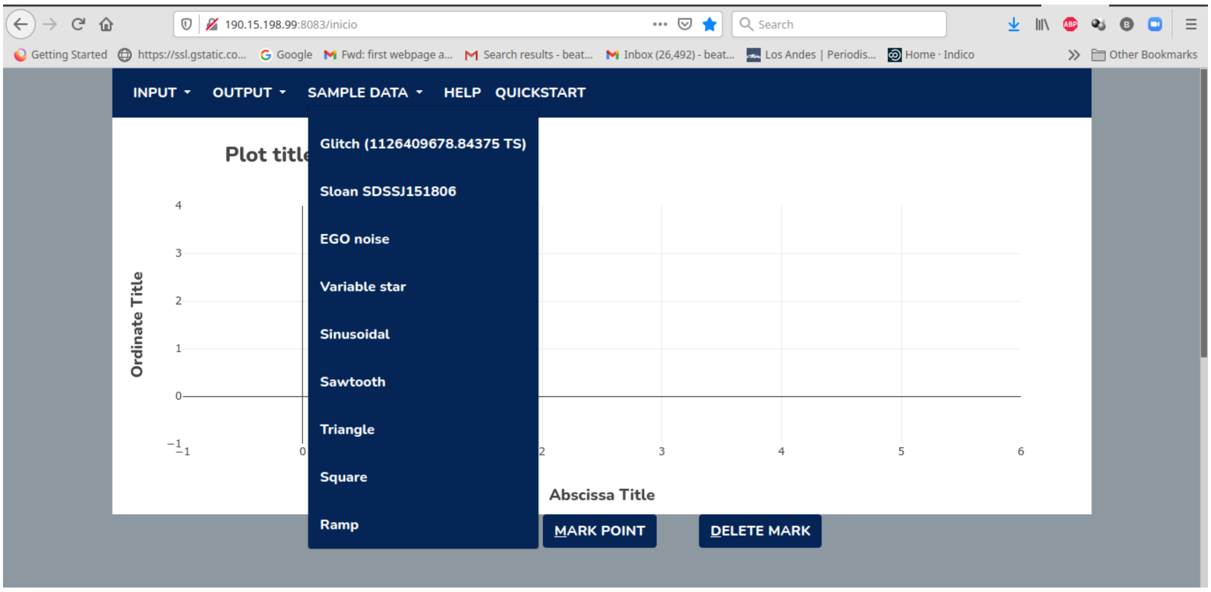

Figure 7 - The Sample Data menu.

2.1.3.1.1.1 Using custom data

In addition to the Sample Data functionality, users can also upload their own dataset, in comma-separated value (CSV) format (Figure 8), and take advantage of the functionality available within the interface to analyse it in visual and audio formats (Figure 9).

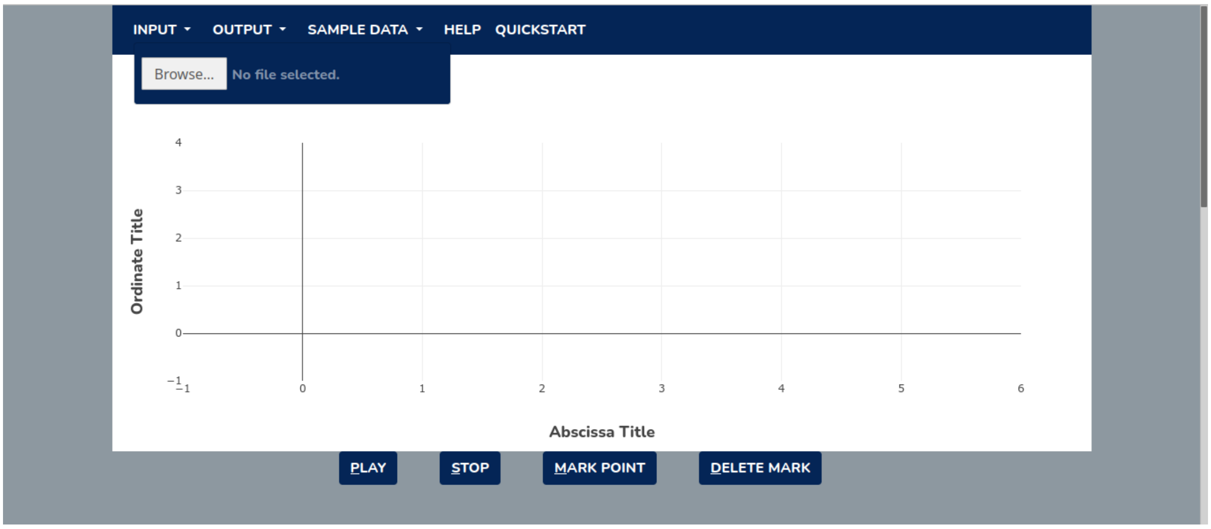

Figure 8 - The Browse functionality in web-based sonoUno, allowing users to upload custom datasets.

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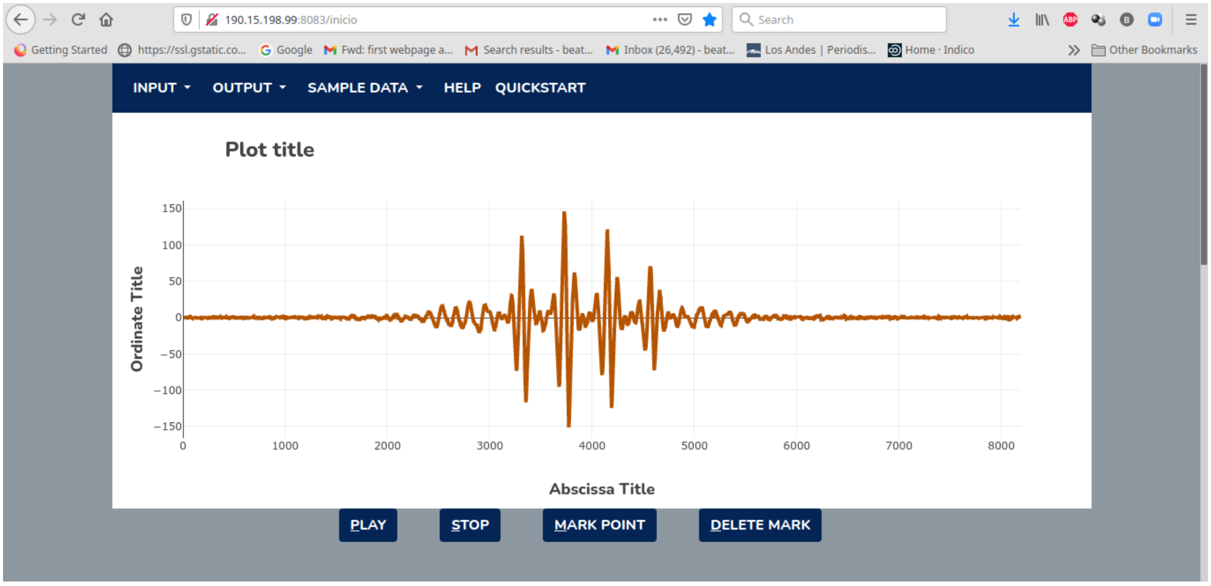

Figure 9 - Custom data, in this case a GW glitch, uploaded to the plot-area.

2.1.3.1.1.2 *Using Marks*

Users can mark and delete points of interest on the plot area (Figure 10) and store the associated coordinates in a vector or file.

Figure 10 - Points of interest, marked with blue circles, in the plot area.

2.1.3.1.1.3 *Saving outputs*

Web-based sonoUno also allows users to export data of interest, either for later or external use. Via the *Output* section of the navigation bar, users can save: sound, markers and plots (Figure 11).

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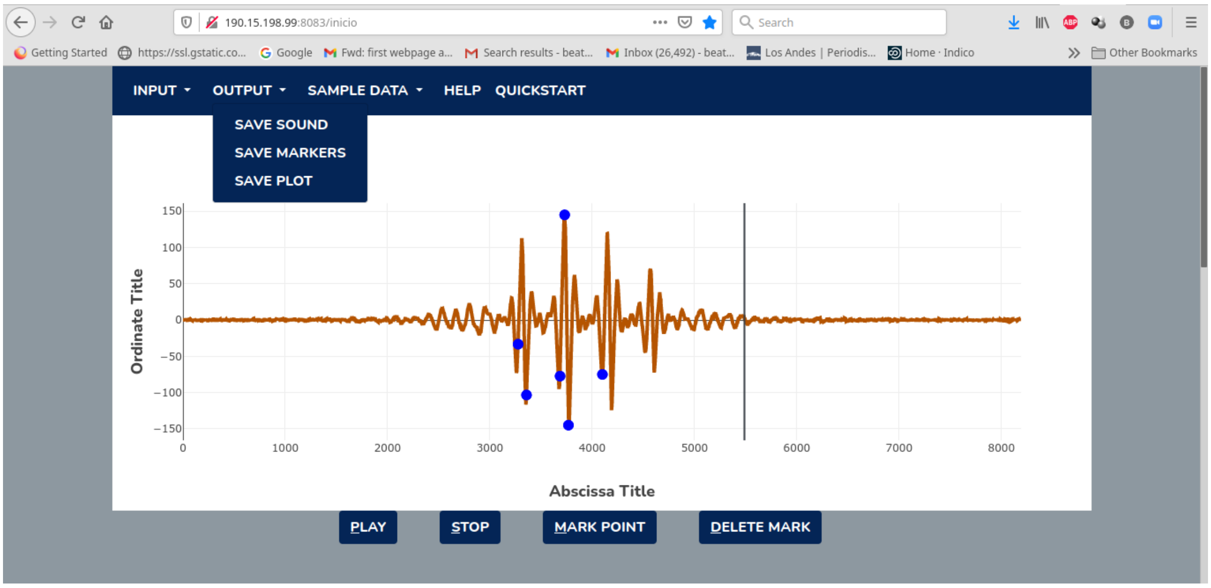

Figure 11 - The Save Sound, Save Markers and Save Plot options.

The *Save Sound* option allows the user to export the currently represented in the plot area, to be exported in a Waveform Audio File Format (WAV)-formatted file. The length of the time required to process the sound to this format is dependent upon the size of the data file and can take some minutes.

The *Save Markers* option exports the markers as an array of comma-separated x- and y-coordinates in a CSV file, formatted along the lines of:

59,20.633932,
64,20.249901,
67,20.700014,
77,15.293584,

2.1.3.1.1.4 Tools area functionalities

As mentioned earlier, the lower section of the homepage provides a range of additional tools for use in analysis of the data. These tools and their functionality are covered in this section.

Abscissa Position slider

The *Abscissa Position* slider (Figure 12) allows the user to shift the progress vertical line on the plot area to a precise point in the data. The current position, as a percentage of the length of the plot on the x-axis, is shown (Figure 13), along

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with the slider. This feature can be controlled with both the mouse and keyboard arrow keys.

Figure 12 - The Abscissa Position slider.

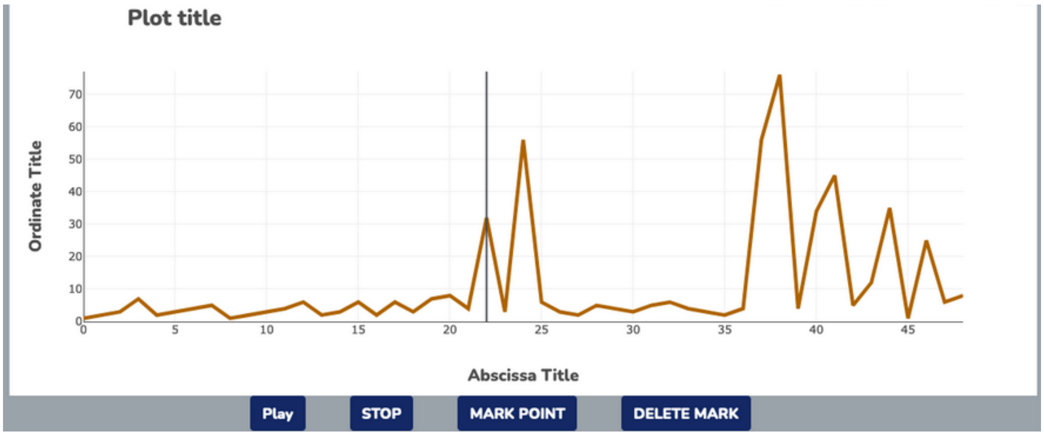

Figure 13 - The position of the progress vertical line corresponding to the position (46%) on the Abscissa Position slider (Figure 12).

The abscissa position can be modified before, during and after the reproduction of the data. If the reproduction is in progress, after change the reproduction continues from the new set value.

Tempo slider

The *Tempo* slider (Figure 14) controls the duration of each tone in the sonified representation of the data. If ranges from 0% to 100%, with 100 being the shortest time and 0 the longest.

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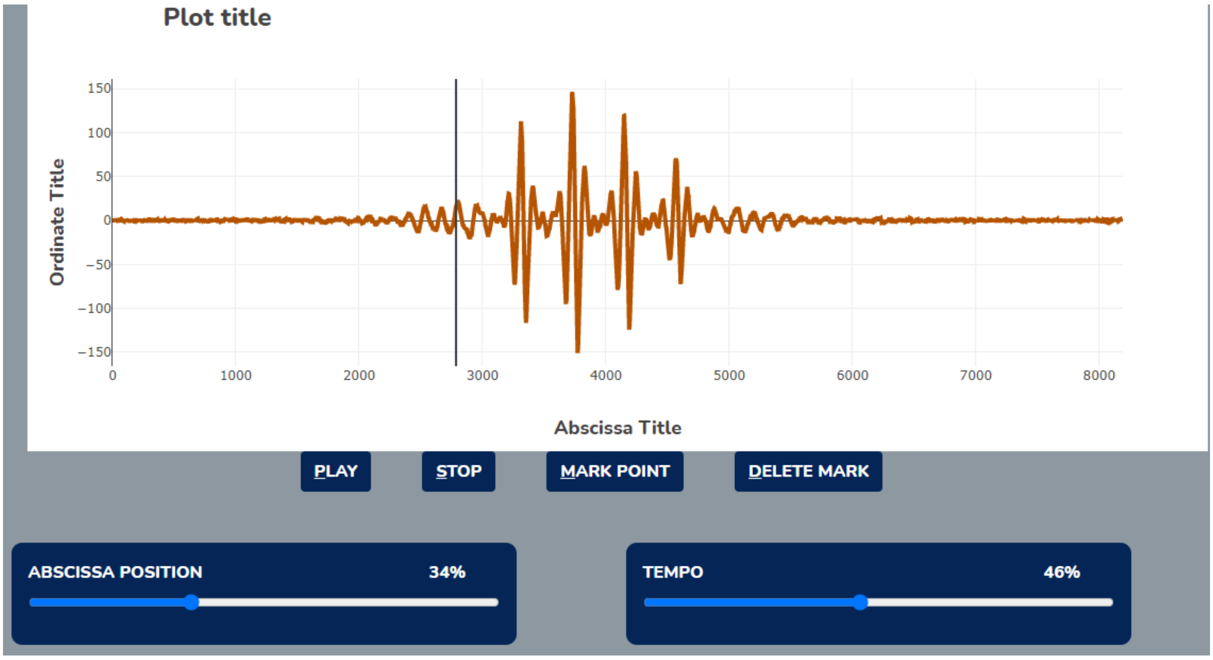

Figure 14 - The Tempo slider, in the bottom-right of the image.

Sound configuration

The *Sound Configuration* area is found at the bottom-left of the Tools Area on the homepage and allows the user to:

- set frequency range, by intervening in terms of minimum and maximum frequencies to be considered (Figure 15),
- change the volume and type of sound produced in the audio representation (Figure 16). The sounds listed are not intended to sound like real instruments, but rather to loosely recall those instrument sounds, in order to present the user with some distinguishable options;
- apply a linear or logarithmic scale (Figure 17);
- use discrete or continuous sound (Figure 17),
- apply a sound-envelope configuration, which, when activated, allows the user to use the *Attack*, *Decay*, *Sustain* and *Release* sliders, to modify the resulting sound.

All of the sliders inside the mapping configuration must be enabled and disabled with check boxes. This is to ensure a better navigation with the screen reader and a lower memory overload.

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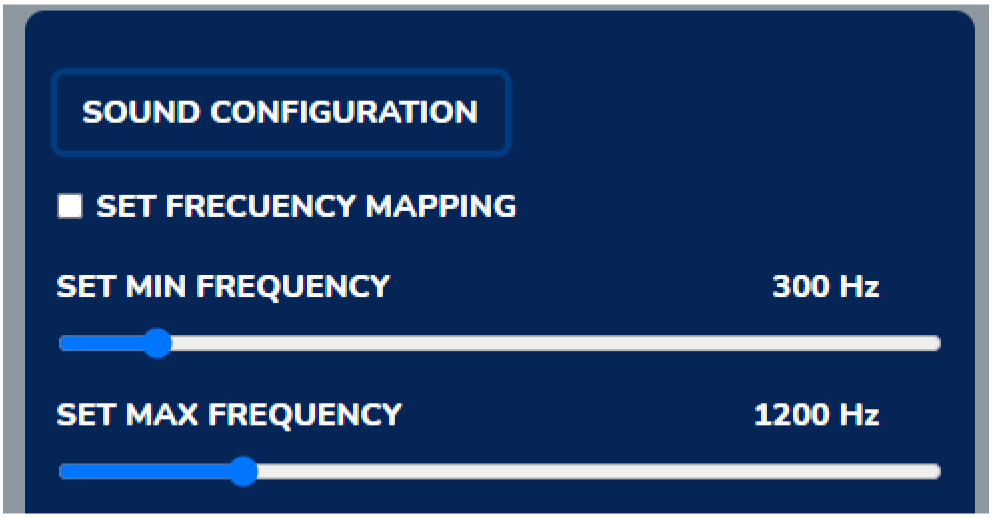

Figure 15 - Setting the frequency range.

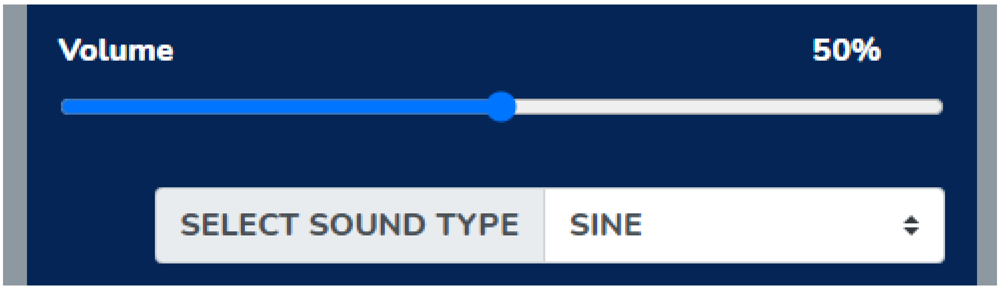

Figure 16 - The Volume slider and Select Sound Type drop-down menu.

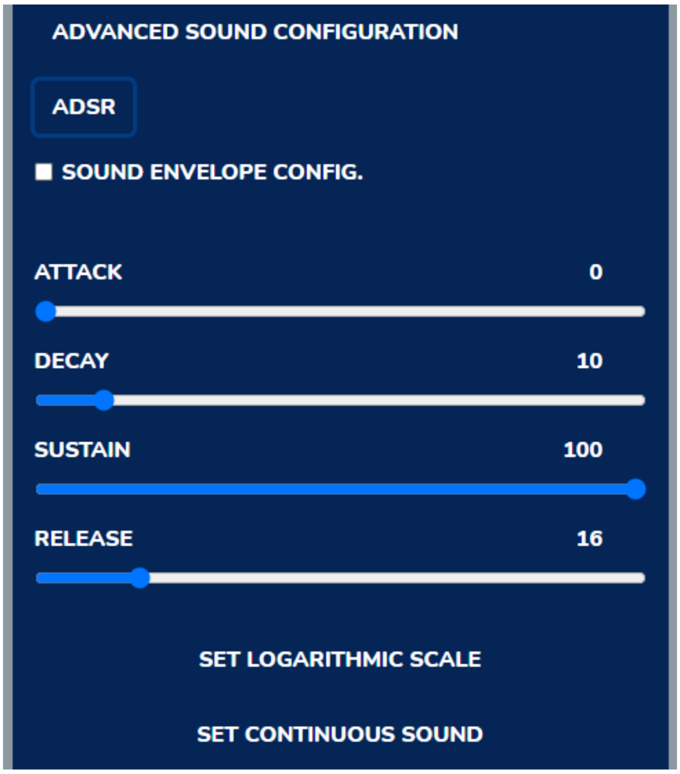

Figure 17 - The Advanced Sound Configuration options.

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Plot configuration

The Plot Configuration area is located at the bottom-right of the Tools Area and is described in this section.

The basic configuration area (Figure 18) allows the user to add the title of the plot as well as the names of the axes.

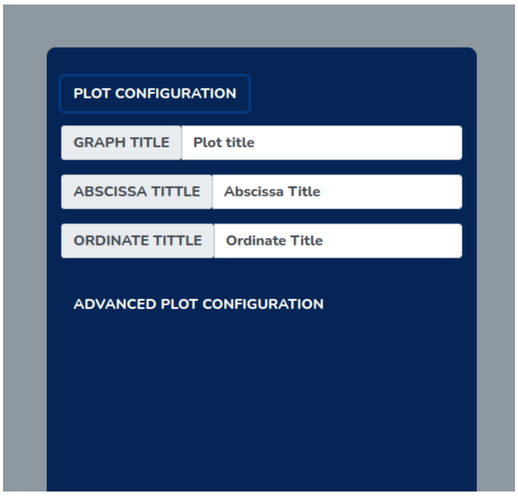

Figure 18 - The basic plot configuration section.

The advanced plot configuration area (Figure 19) allows the user to change the formatting and style of the plot area. Users can configure:

- the line style (solid, dashed, dotted, dashed and dotted);
- the marker style (x, star, circle, diamond);
- and the colour style (orange, blue, red, green, yellow).

An example of the plot area with non-default configurations applied can be seen in Figure 20, below.

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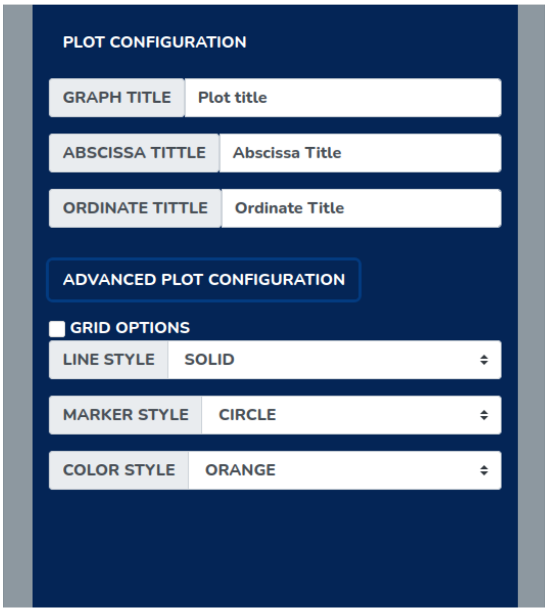

Figure 19 - The Advanced Plot Configuration area.

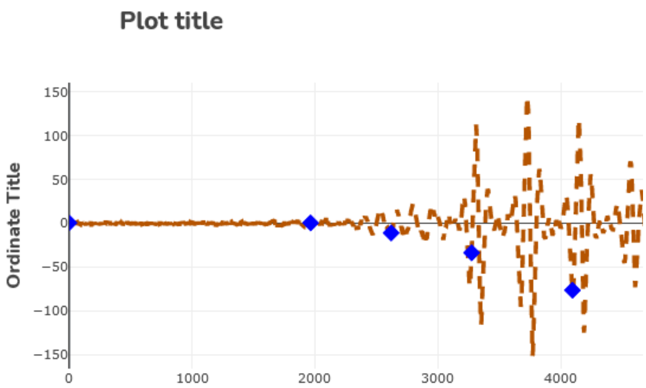

Figure 20 - The plot area with a non-standard configuration applied.

Mathematical Functions

The last version of the web-based version of *sonoUno* includes the possibility to apply predefined mathematical functions, such as *logarithm*, *square* and *smooth* to the data (Figure 21).

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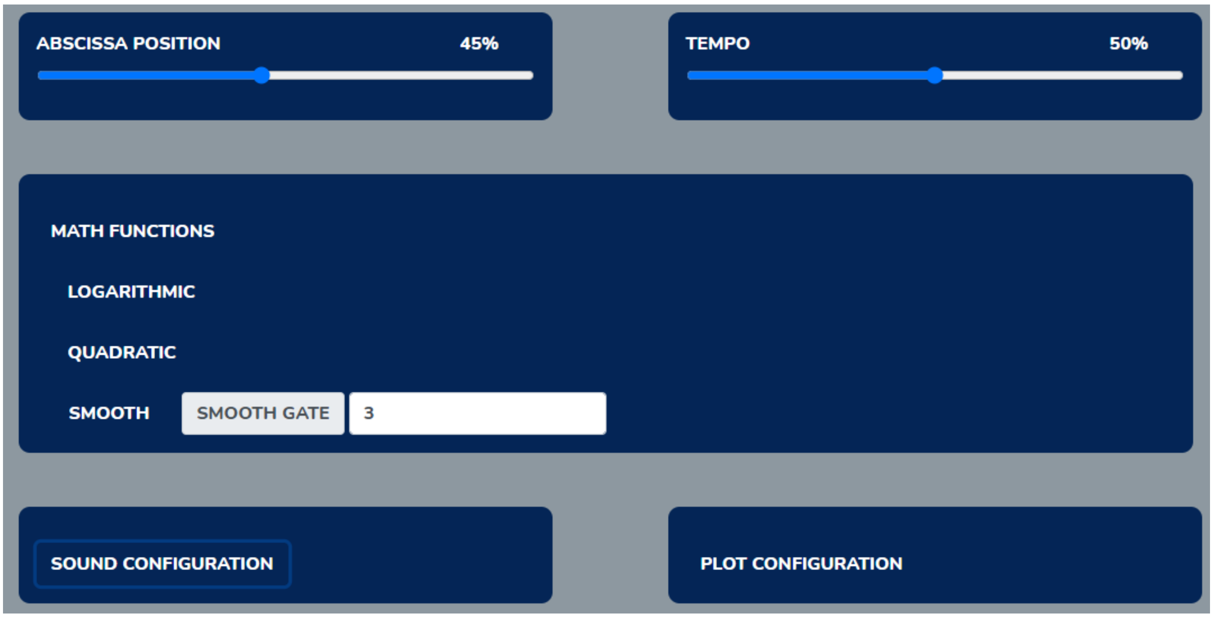

Figure 21 - Predefined mathematical functions.

The inclusion of mathematical functions is part of the aim to allow the possibility to apply external tools to the data, both in terms of the plot and the sound. The *logarithmic* and *square* functions were chosen because they are simple functions, with actions on the data that can be easily corroborated and tested outside of *sonoUno*, while the *smooth* function was selected because it is widely used by astronomers, who want to highlight relatively obvious features over noise, and is applied to data with a significant signal-to-noise ratio.

This is a first approach to this aspect, which, working towards version 2 of the software, will aim to permit the use of more complex functions, such as fast fourier transforms.

2.2 The desktop-based sonoUno version

The desktop-based version of the sonoUno software provides a more extensive range of functionalities than the web-based version. These are detailed in this section.

Developed in Python 3[5], the desktop version of the software has been tested successfully on recent versions of Ubuntu[6], CentOS[7] and macOS.

[5] https://www.python.org/download/releases/3.0/
[6] https://ubuntu.com/
[7] https://www.centos.org/

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2.2.1 Interface design

The initial window of the software (Figure 22) shows the plot area and the tools area, which contains the reproduction options for the data and the text-entry (Write) functionality. The other functionalities are hidden initially and can be accessed via the navigation bar at the top of the window. This is not visible in the image below, but will be covered later in this section. This simple and easy-to-understand design was based on a user case study and confirmed through focus-group analysis.

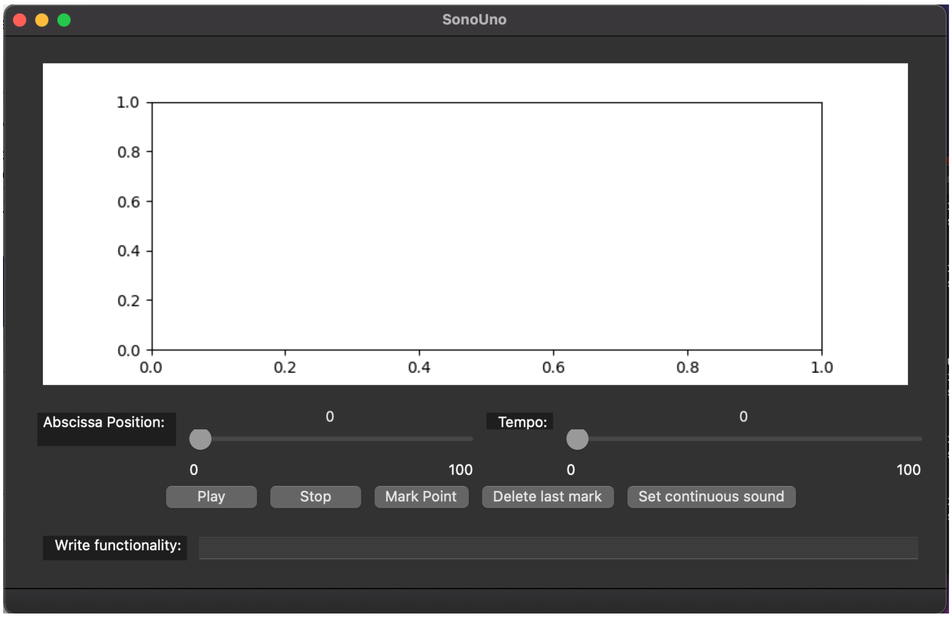

Figure 22 - The initial sonoUno window.

2.2.2 Using data

The desktop-based version of the software allows the user to work with either their own custom data (Figure 23) or to use sample data, already available within the package.

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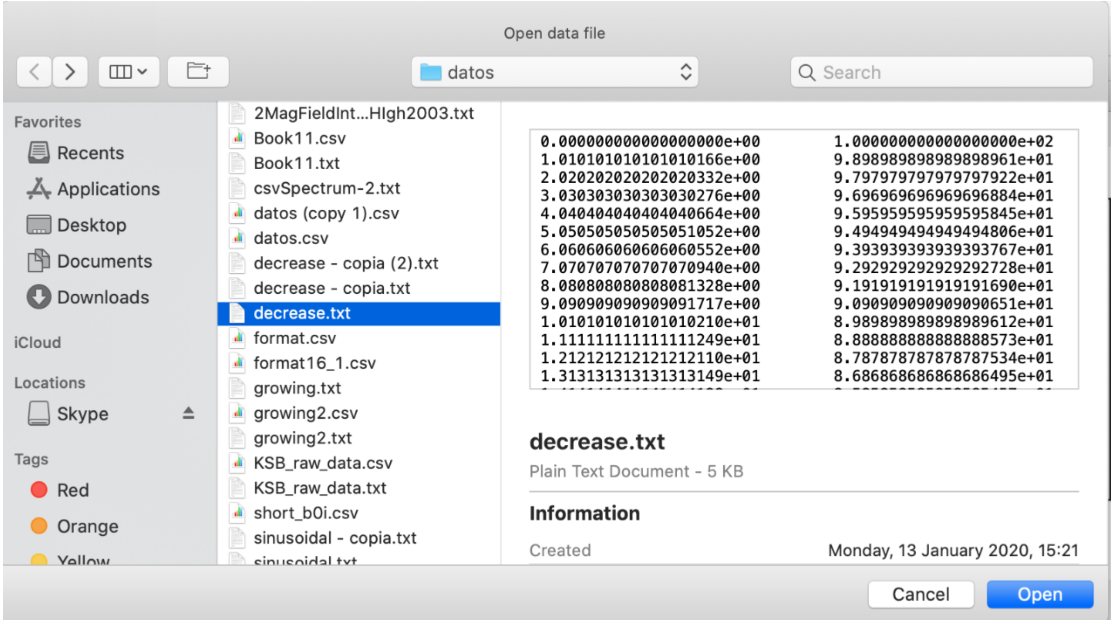

Figure 23 - An example of some custom data in a format usable by sonoUno.

Once selected, *sonoUno* interprets the data, shows the plot built in relation to it (Figure 24) and is ready to reproduce the associated sound. The *Play/Pause* and *Stop* buttons allow the user to navigate through audio representation of the data-points in the plot, while the red vertical line displays the position on the x-axis that is currently being played.

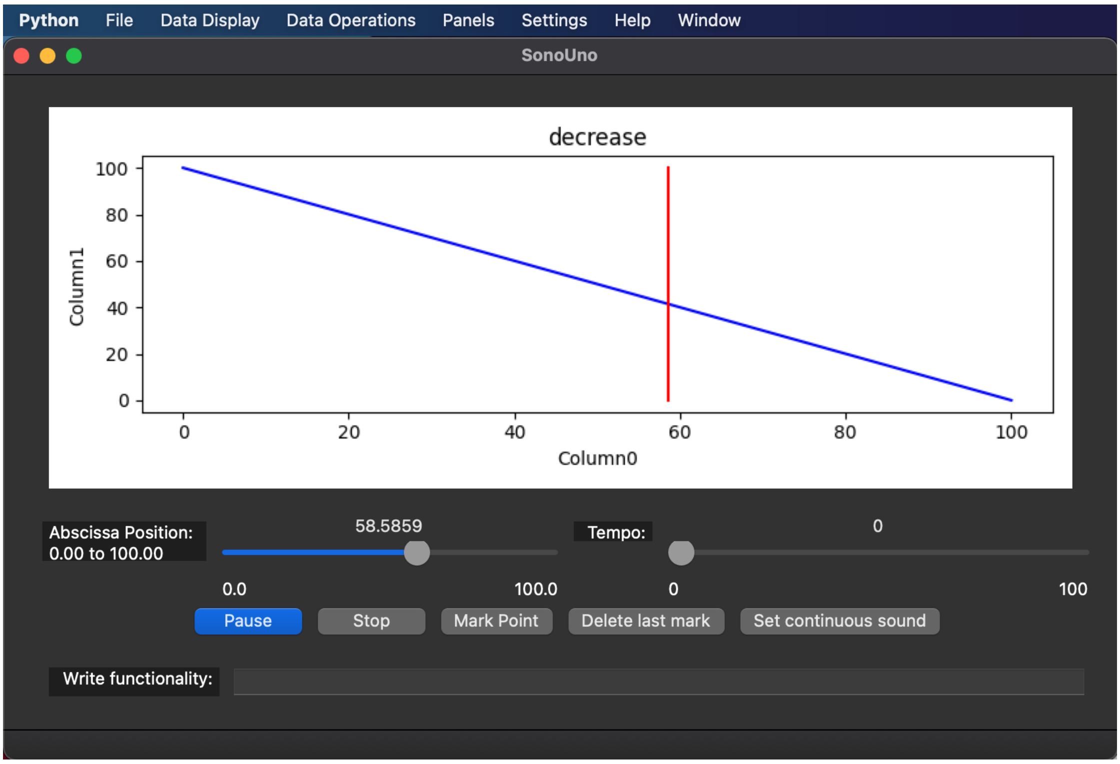

Figure 24 - Data loaded in sonoUno.

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Users can access additional options for use in manipulation of the data and plot area, via the *Panels* menu in the navigation bar (Figure 25).

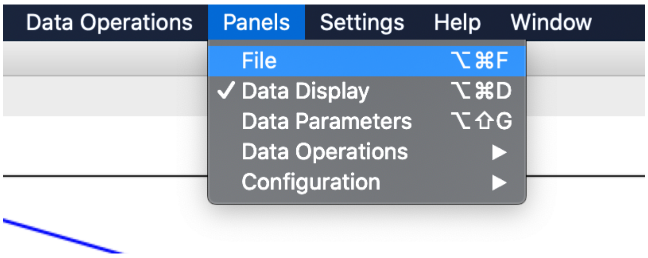

Figure 25 - The Panels menu.

The *File* option makes the *Open*, *Delete all marks*, *Save Data*, *Save Marks*, *Save Sound* and *Save Plot* options available (Figure 26). The functionality of these is detailed below.

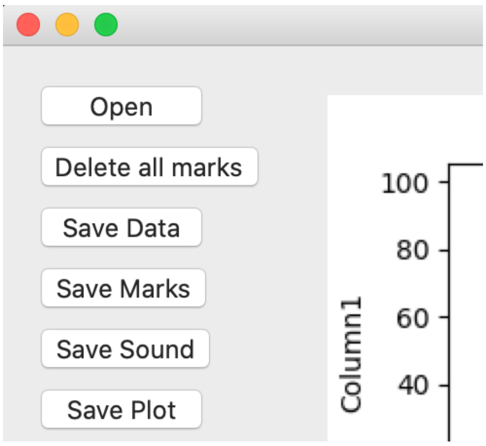

Figure 26 - The File options.

2.2.2.1 Using Marks

sonoUno allows the user to mark points of interest on the data in the plot area. These marks are represented by a vertical black line (Figure 27) and the associated coordinates are stored in a vector.

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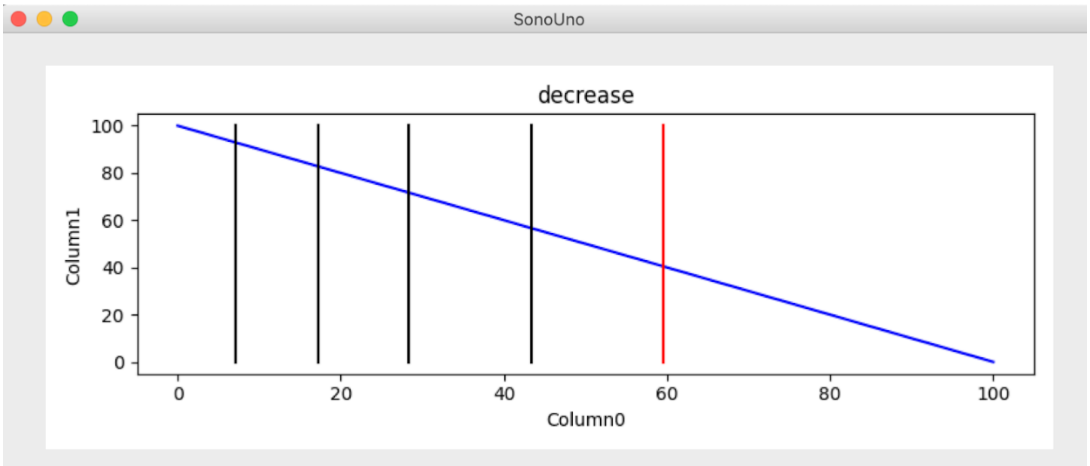

Figure 27 - Desktop-based sonoUno interface with an open data file, one vertical red line (the position of the playing coordinate on the x-axis) and several vertical black lines (coordinates of the mark points).

The *Delete all marks* option simply empties the vector containing the mark coordinates.

2.2.2.2 Saving data, marks, sound and plot

Users can save various parts of their work in sonoUno for external reference or later use. Data and marks are saved to CSV-format files (Figure 28), while sounds are saved as Musical Instrument Digital Interface (MIDI) files and images are stored as Portable Network Graphics (PNG) files (Figure 29).

marks

x	y
56.56565656565657	43.43434343434343
10.101010101010102	89.89898989898988
29.292929292929	70.7070707070707

Figure 28 - A representation of a saved-coordinates CSV file.

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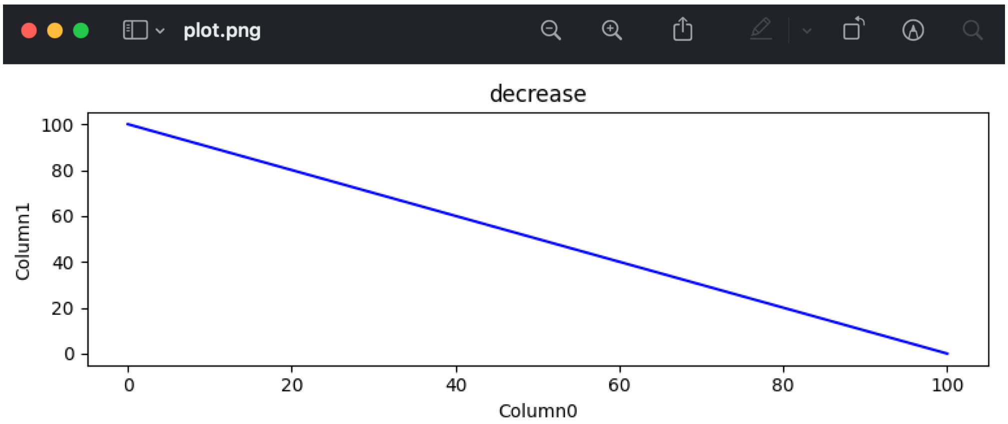

Figure 29 - The plot area saved to PNG format.

2.2.3 Reproduction options

A number of options are also available to allow the user interact with and modify the way in which data is represented.

2.2.3.1 Abscissas position

A slider is provided (Figure 29), which allows the user to move the position of the vertical red line indicating the point on the x-axis that is currently being played in the audio representation of the data.

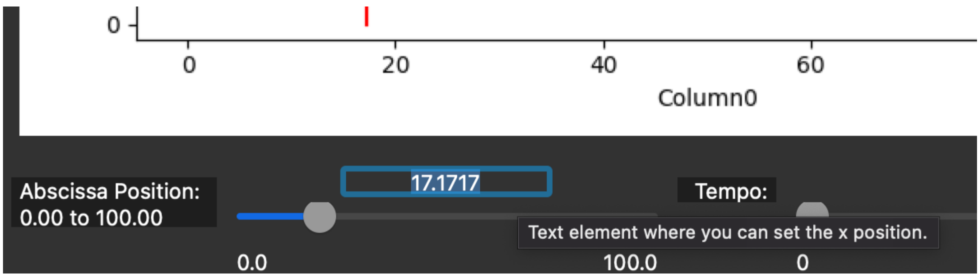

Figure 29 - The Abscissas Position set to 17.1717 on the slider.

2.2.3.2 Tempo selection

This functionality allows the user to select the tempo of the reproduction of the sound, varies between 0% and 100%, being 100 the fastest and 0 the slowest reproduction speed.

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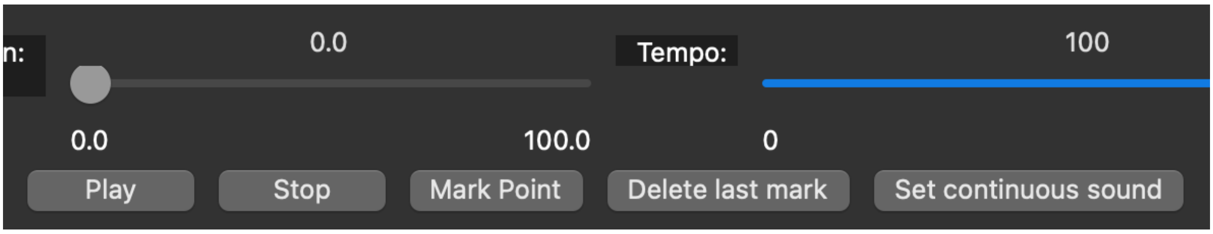

Figure 30 - Tempo set to 100.

2.2.4 Data management options

Desktop-based sonoUno provides a number of additional data-management options. These are detailed in this section.

2.2.4.1 Data parameters

The *Data Parameters* item, available in the *Panels* menu of the navigation bar, displays the data file in columns to the left of the plot area (Figure 31) and allows the user to change the title of the data, change the column titles and select which column to plot on the x-axis and which on the y-axis.

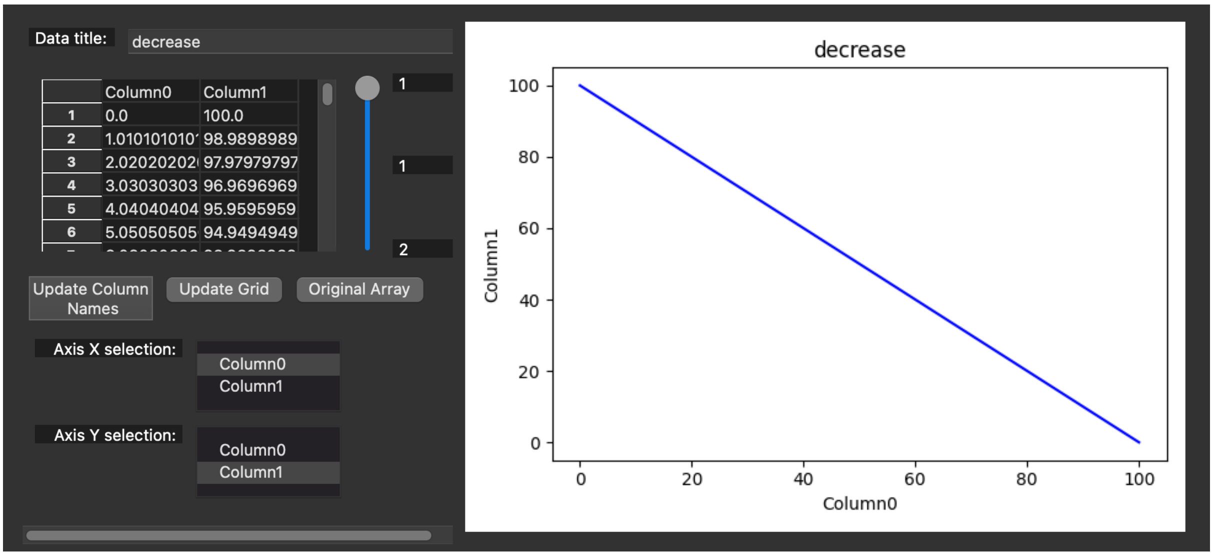

Figure 31 - The Data Parameters area.

The Update Grid button plots the data visible in the two columns, which may have been modified within the interface, while the Original Array button allows the user to restore the original values.

When the data file contains more than one hundred rows, the software loads the data in pages, with one hundred values per page. A vertical slider bar becomes visible to the right of the data grid, with an index of the available page numbers to its immediate right (Figure 32).

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Figure 32 – The vertical slider bar allowing navigation between pages, used when more than 100 values are provided in the dataset. It is currently set to page 14 of 39.

This functionality has so far been tested with two-column datasets containing one million rows.

2.2.4.2 Data operations

In addition to parameter setting, it is also possible to undertake certain operations on the data.

2.2.4.2.1 Horizontal limitting

The Horizontal Limit operation enables the user to use a slider to cut the abscissas axis between an upper and lower data limit, thus selecting only a range of interest (Figure 33).

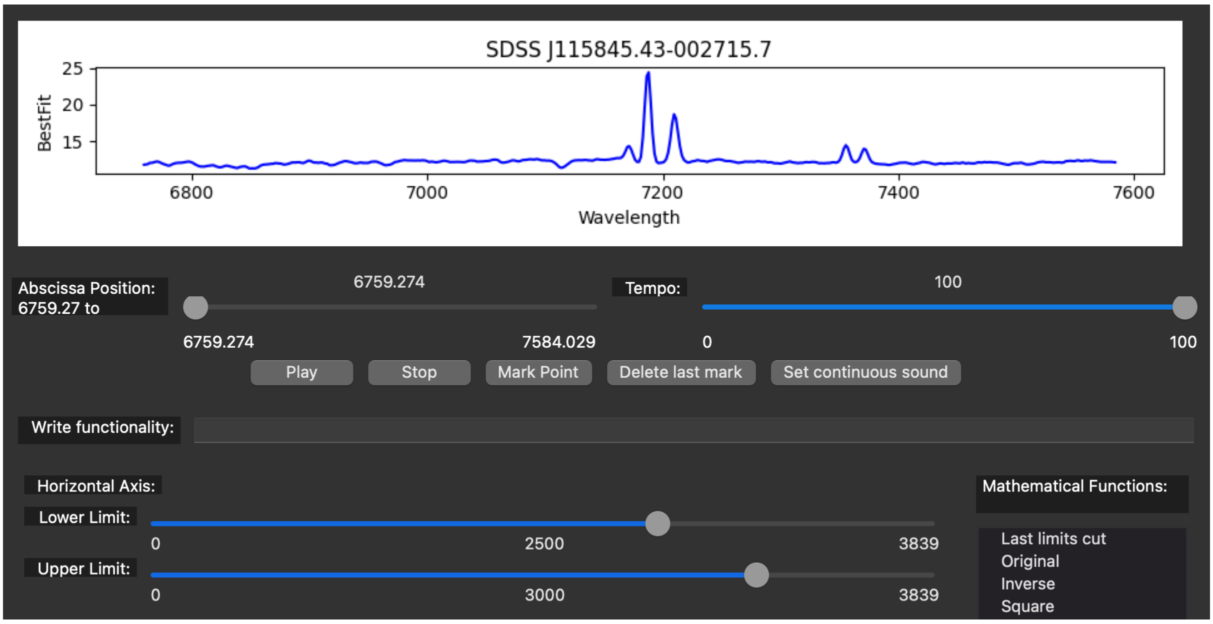

Figure 33 – A lower limit is set to data point 2,500 and an upper limit is set to 3,000. The updated scale on the x-axis can be seen in the plot area.

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2.2.4.2.2 Mathematical functions

2.2.4.2.2.1 Predefined functions

Six predefined mathematical functions are available in the desktop-based *sonoUno* (Figure 34).

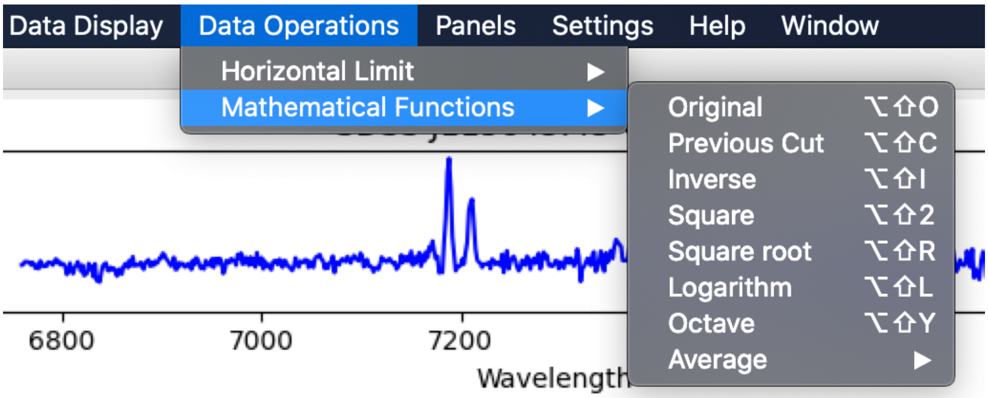

Figure 34 - The six predefined mathematical functions in desktop sonoUno.

The predefined functions are:

- the **inverse** function, which reverses the y axis (Figure 35);
- the **square** and **square root** functions;
- the **logarithm** function (Figure 36);
- the **average** function, which uses the number of points entered by the user to group the data and calculate the average over the original data (Figure 37);
- and the **octave** function. When the user opens some data in the software, the first two columns of the data are automatically sent to octave with the names x and y. In addition, all of the columns are sent to octave with the column names as variable names. Then, when the user makes some changes to the data, the variables x and y are updated in octave. This is important, because the user does not need to make any steps to send the plotted data to octave, instead the software performs this task automatically, and conserves the original data with the column names.

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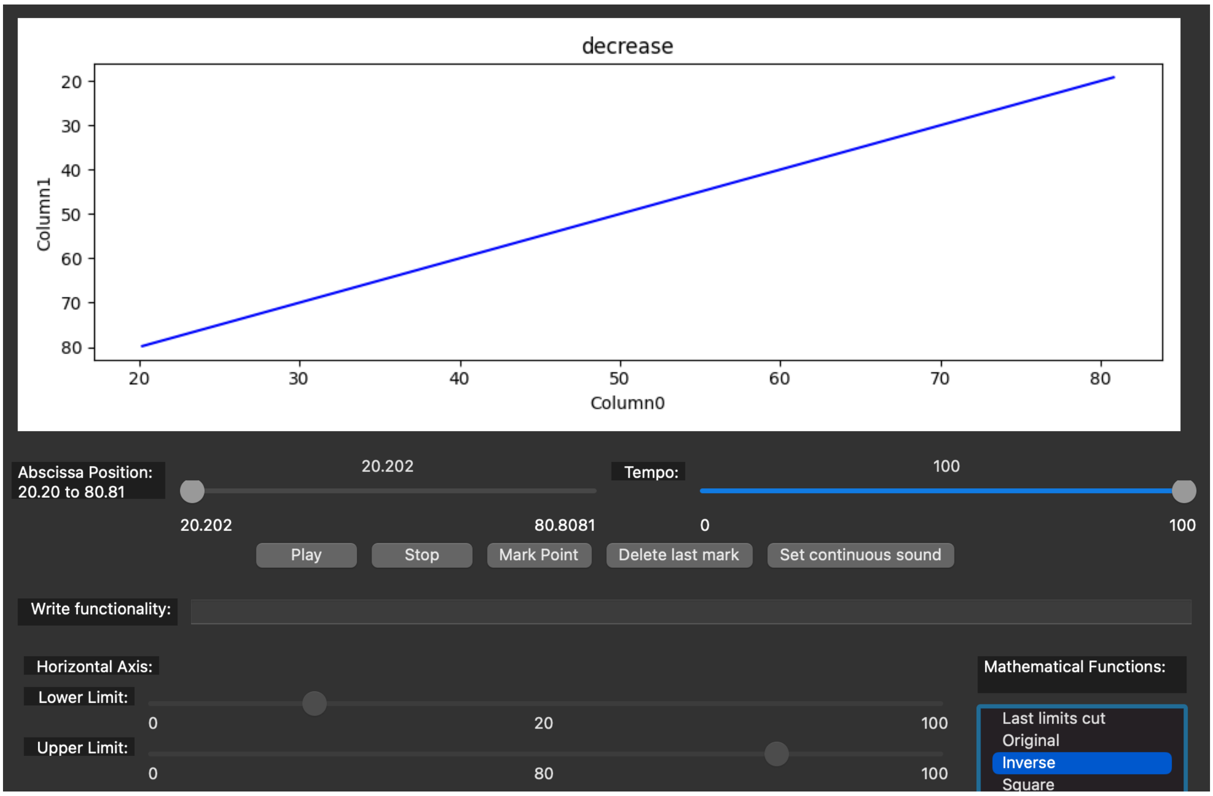

Figure 35 – The reversed y-axis following application of the inverse function.

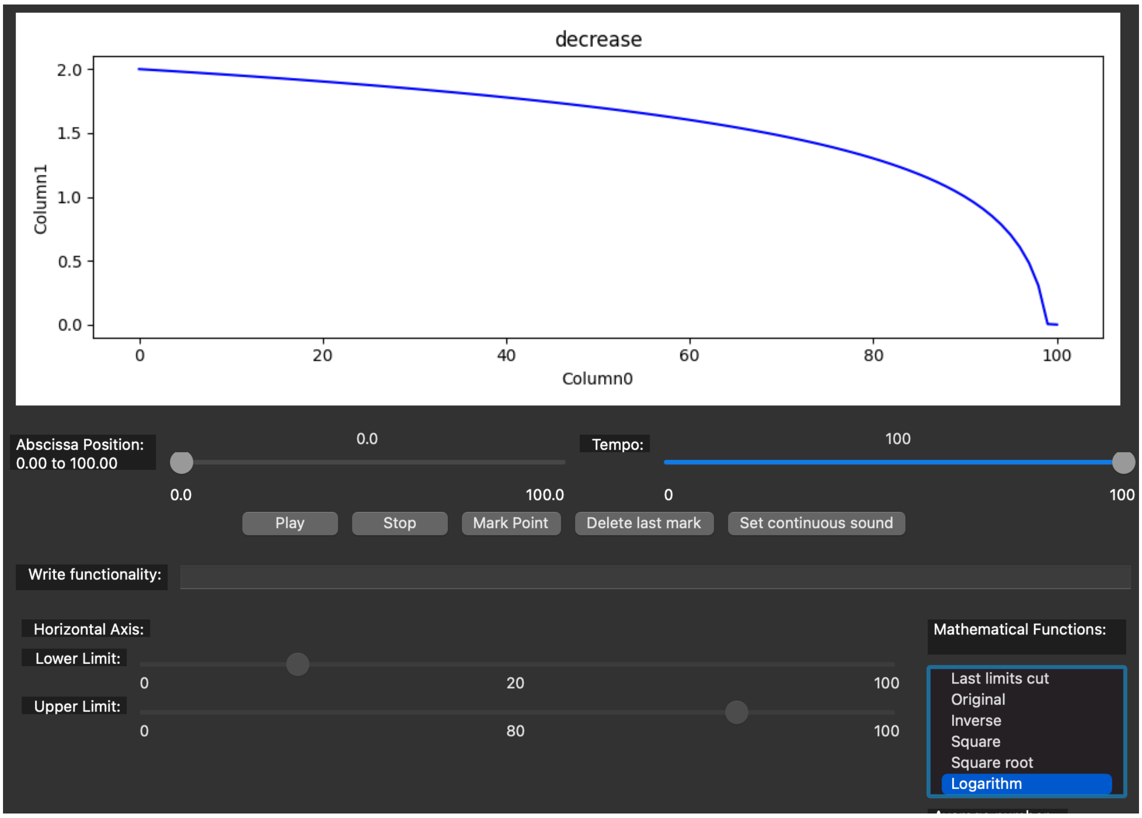

Figure 36 – The logarithm function applied.

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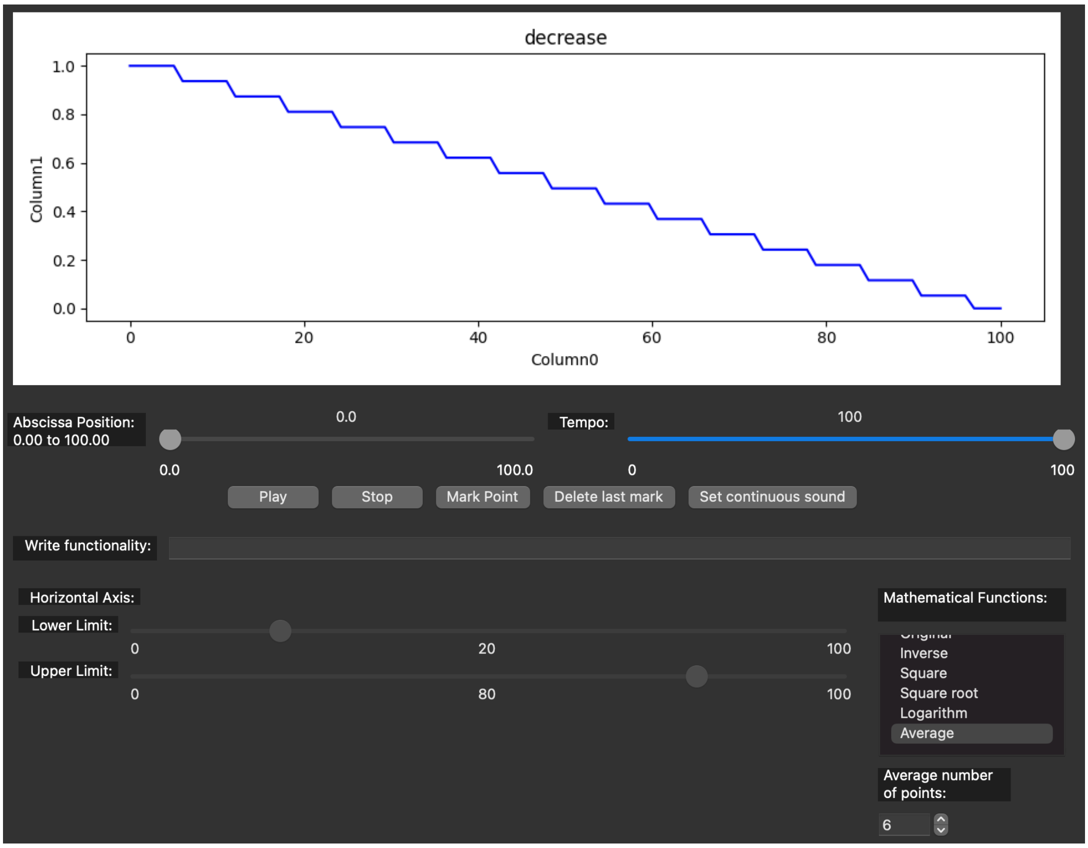

Figure 37 - The average function applied.

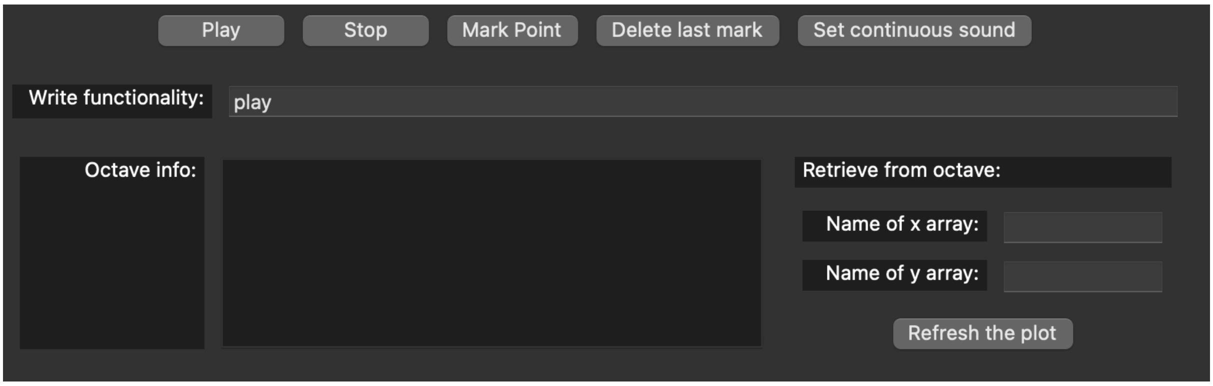

Figure 38 - The octave function panel.

2.2.4.3 Configuration options

sonoUno allows users to adjust some sound and plot settings, these functionalities are available in the *Settings* menu in the navigation bar and are described in this section.

2.2.4.3.1 Sound configurations

Various sound configuration settings are available (Figure 39), which can be accessed via the *Sounds* area of the *Settings* menu in the navigation bar.

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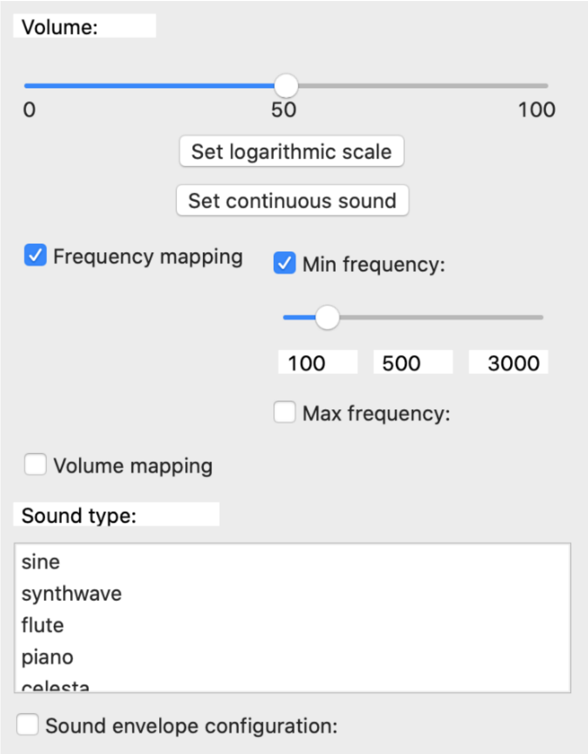

Figure 39 - The sound configuration panel.

These configuration options include:

- a slider that controls the volume of the sound played;
- a button allowing the application of linear or logarithmic mapping of the represented variables into a sound feature (frequency or volume);
- a button to load some sound preset configuration, potentially better suited for use in playing continuous sounds or discrete sound steps;
- a checkbox for the selection of frequency mapping (at a fixed volume);
- two sliders for setting minimum and maximum frequency, for use with the variable mapping;
- a checkbox for mapping to volume at a frequency that can be selected with a slider, as well as the minimum and maximum volume to use for the variable mapping;
- a combo box, with a list, which allows the user to choose between different sound types.

2.2.4.3.1.1 Sound envelope configuration

A standard approach to wave envelopes, called ADSR, is adopted. It provides controls for four variables:

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- **Attack**: the time it takes for the wave intensity to rise from silence to the peak volume. The shorter this time, the more the sound resembles a strike or percussive sound (like a piano, or xylophone). A longer attack will result in a softer sound;
- **Decay**: right after the peak is reached, the intensity takes this time to fall to a sustained level. A short decay time results in a more discrete sound, whilst a longer decay gives longer, yet not continuous sound;
- **Sustain**: once the decay time ends, the intensity is held at this value. It gives the sensation of instrument resonance. A high sustain level will yield a continuously playing sound, as the volume will not get low. This value can even be set to zero, so that the sound will just seem like something is hit, with no resonance at all;
- **Release**: ending the sound abruptly not only generates artifacts in the sound hardware, but also sounds odd. The release time is the time the sound takes to fade from the sustain level to silence.

Figure 40 - The sound-envelope configuration panel.

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2.2.4.3.2 Plot configuration

The line, marker, colour and grid styles can be modified in the desktop *sonoUno* (Figure 41).

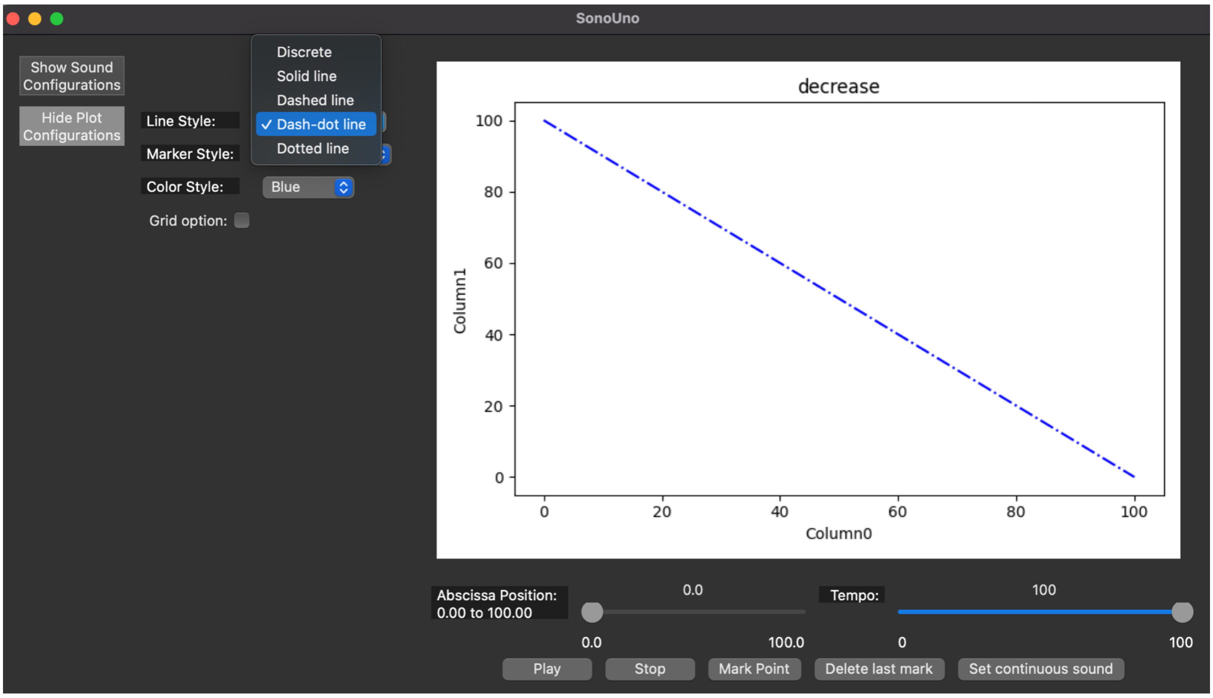

Figure 41 - The Plot Configuration area.

The line, marker and colour options are analogous to those in the web-based version of *sonoUno*, while the grid options are unique to the desktop versions and allow the user to configure the colour, line type and width of the background grid in the plot area (Figure 42).

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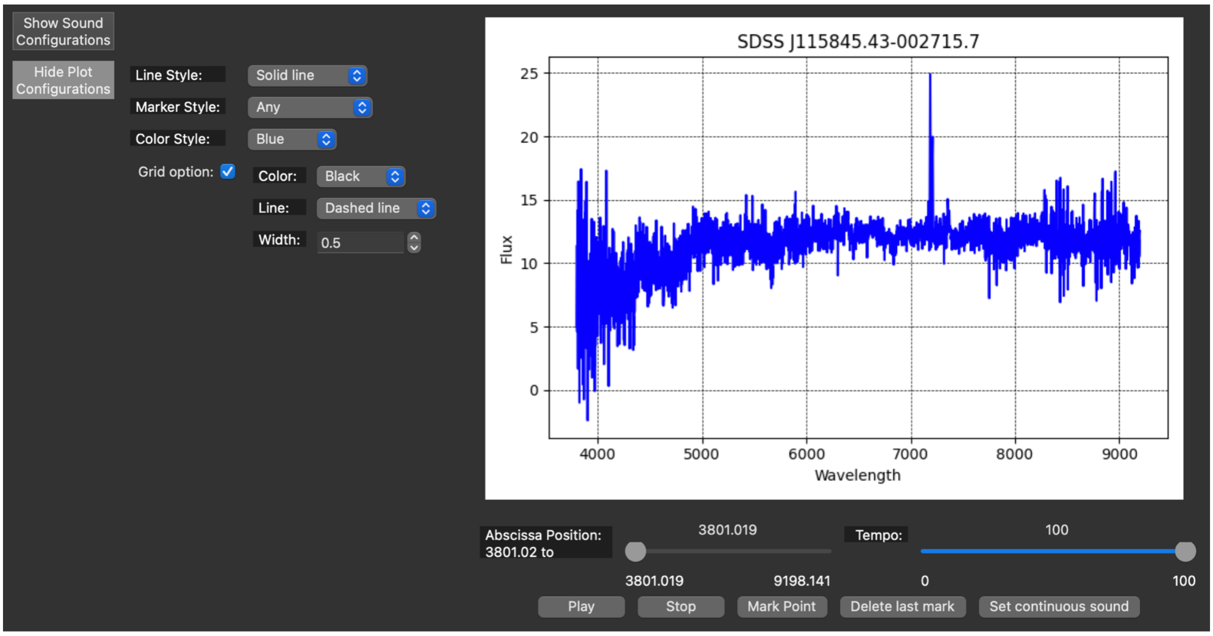

Figure 42 - The Grid Options area.

2.3 A unified version?

As part of version 2 of the *sonoUno* deliverable (D7.2), work will proceed towards the achievement of two goals:

1. making the software more versatile in handling sonifications beyond a single time-series;
2. and providing an open sonification as a service platform.

This will add complexity and, in order to avoid the duplication of effort, it will become cost-effective to unify the web and desktop versions of *sonoUno*.

Within WP7, the novel idea of embedding a Web Server Gateway Interface (WSGI) application containing the *sonoUno* Python library in the browser using *WebAssembly*[8] is being investigated. An interesting benefit of this approach is that the sonification requests from users, such as Zooniverse citizen scientists, would be served locally, without drawing resources from institutional computing centres. For researchers or intensive batch jobs, institutions could set up dedicated sonification servers that would serve the same *sonoUno* WSGI application as the one running in the browser.

[8] https://webassembly.org/

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This part of the project is currently at a feasibility-study stage. If the approach proves not possible, it will fall-back to using a classical client-server architecture.

2.4 Integration

In addition to the work carried out, and which is still being carried out, in relation to *sonoUno*, a way to integrate it fully into the Zooniverse demonstrator projects has also been studied. The architecture proposed following a study of the requirements, can be seen in Figure 43, below.

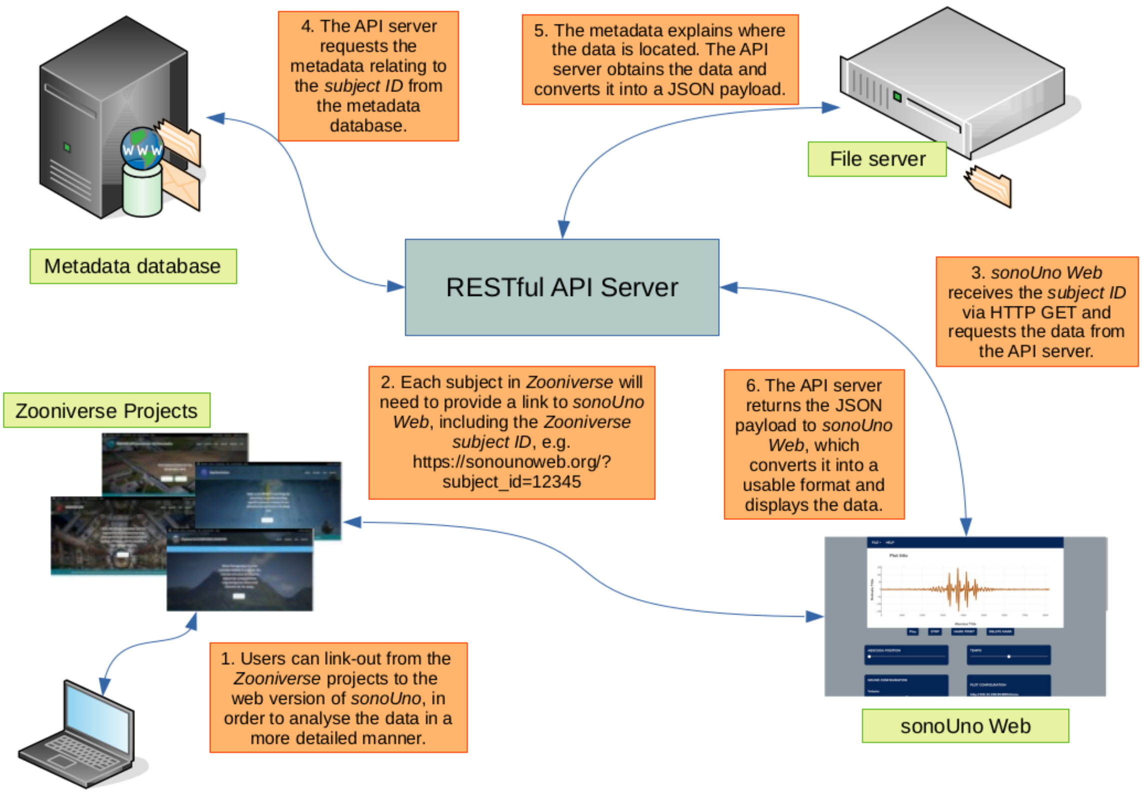

Figure 43 - Proposed architecture for a RESTful API server enabling connection of REINFORCE Zooniverse demonstrator projects to sonoUno.

Through this architecture it would be possible to link individual subject sets - individual event datasets - in Zooniverse directly to *sonoUno* and vice-versa. It would be necessary to set up a few software components not initially foreseen in the project, such as a server to field application-programming interface (API) requests, as well as the definition of the API itself, but it would bring significant added value. With its implementation, users would be able to listen to an audio representation of a dataset in Zooniverse and from there link-out to the same

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dataset in *sonoUno* and amend the pitch, timbre, tempo, etc., thus making it more accessible.

3 The training course

This section details each of the individual modules under development within the training course delivered as part of the first version of deliverable D7.1. Twelve modules are under development in total; three modules for each of the four demonstrator projects developed within REINFORCE:

- a module on the use of the demonstrator project in Zooniverse;
- a module on usage of the Zooniverse demonstrator project within *sonoUno*;
- and a separate module on data-analysis using data from the demonstrator project.

Together, these modules will build the following course:

- Module 1 - Using the GWitchHunters Zooniverse demonstrator;
- Module 2 - Using GWitchHunters gravitational-wave data in *sonoUno*;
- Module 3 - Using GWitchHunters gravitational-wave data;
- Module 4 - Using the Deep Sea Hunters Zooniverse demonstrator;
- Module 5 - Using Deep Sea Hunters data in *sonoUno*;
- Module 6 - Using Deep Sea Hunters data;
- Module 7 - Using the New Particle Search at LHC Zooniverse demonstrator;
- Module 8 - Using New Particle Search at LHC data in *sonoUno*;
- Module 9 - Using New Particle Search at LHC data;
- Module 10 - Using Cosmic Muon Images Zooniverse demonstrator;
- Module 11 - Using Cosmic Muon Images data in *sonoUno*;
- Module 12 - Using Cosmic Muon Images data.

The methods to be used in each of these approaches is detailed in the following section, along with the provision of specific details for the individual demonstrators. The document treats the modules related to the Zooniverse demonstrators separately to the other two modules, as these - the *sonoUno* and data modules - sit more comfortably together.

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3.1 The Zooniverse demonstrator project modules

Modules 1, 4, 7 and 10 are dedicated to using the demonstrator projects developed within REINFORCE, within the Zooniverse[9] platform:

- GWitchHunters;
- Deep Sea Hunters;
- New Particle Search at LHC;
- Cosmic Muon Images.

These modules will provide students with a grounding in the science behind the demonstrator project, as well as information on the collaborations that carry the science forward. They will use walk-throughs of the demonstrators and explanations of how the classification procedure within them works. The individual Zooniverse demonstrator modules are detailed here below.

3.1.1 Module 1 - Using the GWitchHunters Zooniverse demonstrator

In Module 1, students will be introduced to the *GWitchHunters*[10] demonstrator project, developed within WP3 of the project, on the Zooniverse platform. They will receive an introduction to the physics behind the project and an explanation of how and why the classifications they undertake will prove beneficial to the Virgo Collaboration.

Students will also be able to follow classification walk-throughs, using both the audio and visual representations of the gravitational-wave data within the project and be trained how to identify glitches in both the main Virgo *strain* channel, $h(t)$, and to look for correlations in auxiliary channels.

3.1.2 Module 4 - Using the Deep Sea Hunters Zooniverse demonstrator

In Module 4, students will be introduced to the *Deep Sea Hunters*[11] demonstrator project, developed within WP4 of the project, on the Zooniverse platform. Students will be introduced to the science behind the project, as well as receiving an introduction to the KM3Net collaboration, detectors and experiment.

[9] https://www.zooniverse.org/
[10] https://www.zooniverse.org/projects/reinforce/gwitchhunters
[11] https://www.zooniverse.org/projects/reinforce/deep-sea-hunters

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The module will involve a walk-through of both of the workflows - bioluminescence and bioacoustic - but will then concentrate almost entirely on classifications in the bioacoustic workflow, using available audio representations of the data to help students understand the difference between the different species and noise signals.

3.1.3 Module 7 - Using the New Particle Search at LHC Zooniverse

In Module 7, students will be introduced to the *New Particle Search at LHC*[12] demonstrator project, developed within WP5 of the project, on the Zooniverse platform.

Students will be given a grounding in the background to the demonstrator, including the workings of the ATLAS detector and collaboration, as well as the physics involved in high-energy particle physics.

Beyond that, the module will concentrate on walk-throughs of the different workflows in the project, both within the Zooniverse platform itself and in the HYPATIA[13] platform.

3.1.4 Module 10 - Using Cosmic Muon Images Zooniverse demonstrator

In Module 10, students will be introduced to the *Cosmic Muon Images*[14] demonstrator project, developed within WP10 of the project, on the Zooniverse platform.

Background information will be provided on the instrumentation used in the collection of the muon data and students will receive a walk-through explanation of the introductory and advanced workflows in the project.

3.2 The sonoUno- and data-related modules

Within the *sonoUno* and data modules - Modules 2, 3, 5, 6, 8, 9, 11 and 12 - students will be introduced to the *sonoUno* software and concepts and will receive a walk-through of the functionality, prior to concentrating on an analysis of sample data from the individual demonstrator projects. The core objectives of these modules are to:

[12] https://www.zooniverse.org/projects/reinforce/new-particle-search-at-lhc
[13] https://hypatia-app.iasa.gr/Hypatia/
[14] https://www.zooniverse.org/projects/reinforce/cosmic-muon-images

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- develop experiments that are designed to research perception techniques;
- develop experiential-hands-on modules targeting peoples with disabilities and senior scientists;
- encourage engagement;
- to develop trust, to make students feel welcomed, focussing on the person and on their abilities;
- to promote acceptance of the multi-sensorial exploration of data and detection and identification of signals and events.

3.2.1 The framework

The framework presented in relation to these modules concentrates on those areas identified by WP9 - Impact Assessment, in relation to persistent involvement by citizen scientists in the work of REINFORCE. Specifically, these are:

- the importance of receiving feedback on progress;
- developing an understanding of the scientific impact of the work they are carrying out;
- the importance of receiving training;
- and the use of an interface that is easy to manipulate.

One of the principal objectives of the framework is to help participants to understand the theoretical knowledge surrounding the demonstrator project datasets and perception methods. Building on experience gained with previous experiments on training based on error, the modules will focus on perceptions of noise against signal. Generally, participants will be engaged by having them think about:

- What is a signal?
- What is noise?
- How is it possible to identify how long a signal lasts?
- How to identify amplitude?
- How to identify the signal length?
- How to identify its frequency?
- How is that information important?
- Links to daily life events, multi-sensorially.

More specifically, they will study:

- different typologies of noise features (instrumental, environmental);

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- how noise can impact upon a scientific measurement;
- how to recognise and classify both visual and audio data patterns.

Students will be involved in the categorisation in three different ways. Some will categorise only images (as lights and shadows), others will categorise only sounds, while others will categorise both. This will give scientists an insight into the pros and cons of each method.

These modules aim to provide a simple experience for citizens that may have a multiplicity of disabilities. To teach how to identify basic parameters from frequency-versus-time plots and how to do calculations and share them with scientists. They will be placed online and will be simple and easy to understand. At their essence, they target citizens with disabilities in an informal setting.

3.2.2 Signal and time interval versus signal and trajectory

For the purposes of the training course, the modules relating to the *GWitchHunters* and *Deep Sea Hunters* projects will be approached differently to the *New Particle Search at LHC* and *Cosmic Muon Images* projects. This difference in approach is because, in the former, the data comprises a signal and a time interval ('glitches' and 'clicks'), while the data in the latter grouping, require the sonification of an event and its arrival trajectory. In this sense, it is possible to transform the 3D path of the particle into a 2D path and thus determine its direction, in the same way as they are presented in the visual representations; the plots. The trajectory can be sonified because of the different times the moments it hits the different parts of the detector.

3.2.3 Calibration

The module-preparation has so far made use of gravitational-wave data available via the Gravitational Wave Open Science Center (GWOSC), as well as with simulated data. This data is being used to help test and calibrate software at the core of the modules *sonoUno* and data modules. The idea being that, at the end of the experience, students should have enough of a basis to be able to use spectrogram plots to work on the determining of the following in relation to the source data; in this case, gravitational waves:

- the mass of an emitter;
- the gravitational-wave frequency;
- gravitational-wave orbital-frequency;
- gravitational-wave orbital velocity;
- and orbital energy.

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3.2.4 Training paradigms

Training paradigms based on transfer, attention modalities and working memory tasks have been used. An experimental module has been designed in which participants may accessibly use multi-sensorial perception to explore supplied data. The training is based on the ability to identify the presence of signals and to calculate parameters. A threshold-analysis algorithm, called QUEST, (Quick Unbiased and Efficient Statistical Three) (Loh & Shih[15], 1997), is used to calculate the accuracy of thresholds and sensitivities as participants experience the training and the experiences contained in the module.

The modules are then composed of two parts: a training paradigm; and a practice experience. In the training, a staircase algorithm monitors participant responses and dynamically varies the amplitude and position of a simulated Gaussian signal until a threshold at which participants respond correctly to 70% of the trials can be ascertained. This actually determines each subject's 70% threshold sensitivity for the correct identification for each condition. A Bayesian adaptive staircase procedure (Watson & Pelli[16], 1983), which uses all of the previous trials to estimate the parameter *T*, the threshold, of psychometric function, is used to measure signal-to-noise sensitivity thresholds in the signal identification task for each of the presented conditions in the task.

3.2.5 Visual representation

Because the visual noise triggers attention mechanisms that inhibit peripheral sensitivity in the task, for the purposes of this training, it was decided for, the visual representations, based on the paradigm designed by Diaz-Merced, to show the signal as white lines (with a luminance of 360 cd/m^2) on an otherwise black screen (3 cd/m^2). The width of this line is approximately 0.1° of the visual angle, and the graph subtends 30° horizontally and 3° vertically.

In 'noise-only' stimuli, the vertical position of the graph at each horizontal pixel position is determined by Gaussian noise, and the graph is scaled to subtend 3° vertically. In 'signal' stimuli, a signal consisting of one, or two or more (up to 4) positive, upward peaks was added to the noise before the scaling is performed. These peaks are modeled by identical Gaussian functions with standard deviations of 0.5° and variable, but equal, peak elevation. The quotient of peak

[15] Loh W-Y, Shih Y-S. Split selection methods for classification trees. Statistica Sinica. 1997:815-840

[16] Watson, A.B., Pelli, D.G. Quest: A Bayesian adaptive psychometric method. Perception & Psychophysics 33, 113–120 (1983). https://doi.org/10.3758/BF03202828

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elevation and standard deviation of the Gaussian noise in a given stimulus is operationally defined as its signal-to-noise ratio. If more than one peak occurs, the peaks will occur to the left and to the right of the centre of the visual field, at identical eccentricity. The span from the centre may be 8° , 16°, or 24°, with random jitter in the span modelled by the Gaussian noise with a random diminishing jitter standard deviation beginning at 1.0°.

3.2.6 The modules

3.2.6.1 Modules 2 and 3 - GWitchHunters

Modules 2 and 5 will be based on the use of gravitational-wave data. They will involve providing several examples of files with gravitational-wave signatures via the Gallery. Students will be asked to analyse each of them in *sonoUno*, to compare them and to recognise the differences between them.

They will then be asked to select specific component features within the data, again comparing examples, with the intention of leading the student to being able to detect GW signatures.

3.2.6.2 Modules 5 and 6 - Deep Sea Hunters

In Modules 5 and 6, students will use *sonoUno* to analyse the bioacoustic signals provided in the Deep Sea Hunters project. The modules will involve distinguishing signals - 'clicks' - over indeterminate time intervals.

3.2.6.3 Module 8 and 9 - New Particle Search at LHC

In the case of the LHC data, the sonification will be related to the identification of the type of particle detected (electrons, photons, muons), the energy deposited in the calorimeter or linked to the particle, and the clusters that appear as a consequence of the interaction of the primary particle (the proton) with the detectors.

Finally, for the sonifiction of the trajectories, experiments will be carried out based on stereo perception, a characteristic of the auditory system. Part of the activity will also require special training.

3.2.6.4 Modules 11 and 12 - Cosmic Muon Images

Similar to the work students will undertake in Modules 8 and 9, in relation to the New Particle Search at LHC project, Modules 11 and 12 will involve identification and classification of signal and trajectory information.

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