

Sardine: a Modular Python Live Coding Environment

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ABSTRACT

Sardine is a live coding environment and library for Python 3.10+ focusing on the modularity and extensibility of several base components (clocks, parsers, handlers). *Sardine* has been designed to be easily integrated with existing live coding environments as both a tool for experimentation, and a demonstration of various live coding techniques: temporal recursion, patterning, integration in various hardware and software setups. Although the tool is still in active early development, it has already been used in multiple public performances and algoraves, partly enabled by its support for MIDI IN/Out, OSC IN/Out and *SuperCollider/SuperDirt* one-way communication through OSC. This paper is dedicated to the introduction of the *Sardine* system, and the explanation of the main guidelines currently followed by contributors to the project. It will also present the preliminary results of our work through practical realisations that served as experimental validation during the early stages of development.

1 Introduction

Sardine is a musical live coding library based on Python 3.10+ focusing on modularity and extensibility of several base components. Despite the fact that the project is not yet one year old, *Sardine* is already extensively documented on a [dedicated website](#) providing installation guides, documentation and tutorials. *Sardine* provides three main features built over the basic Python interpreter and linked together by the `FishBowl` – an environment handling synchronisation and communication between them:

- A *scheduling system* based on asynchronous and recursive function calls inspired by the concept of temporal recursion (Sorensen 2013). Calls can be scheduled in musical time either on an `InternalClock` or a `LinkClock` based on the Link Protocol (Goltz 2018).
- A *modular handler* system allowing the addition and/or removal of various inputs/outputs (e.g. OSC, MIDI) or base components through a central dispatch environment named the `FishBowl`. This allows the customisation of IO logic, without the need to rewrite or refactor low-level system behaviour.
- A *general purpose number-based algorithmic pattern language* with support for generative constructs. This language allows the playful manipulation of melodies, audio samples, synthesizers, synthesis parameters and data used by the various components to create algorithmic music.

Sardine, by design, is in the direct lineage of previously released Python based libraries such as `FoxDot` (Kirkbride 2016), `Isobar` (Jones, n.d.) or the very recent port of `TidalCycles` in Python, `TidalVortex` (McLean et al. 2022). At its inception, the *Sardine* project was thought as an attempt to provide a functional but barebones live coding library to be used for demonstration purposes in a dissertation manuscript. *Sardine* partially emulates some selected features from the previously mentioned libraries or from the dominant live-coding dialects such as the Tidal pattern mini-notation (McLean 2014) or the `Sonic Pi` imperative scheduling syntax (Aaron 2016). To serve its initial purpose, the library had



Figure 1: Sardine first algorave in Lorient (France), 2022, October 13th. Photography: Guillaume Kerjean.

to be capable enough for showing the impact of design and implementation choices on the possibilities of musical expression and on the expressiveness offered by a live coding environment. In consequence, Sardine has been designed as an agnostic framework for approaching live coding using Python. The library aims to support different writing paradigms and different approaches to live performance based on the manipulation of source code. The reliance on regular Python asynchronous functions for scheduling and music writing means that Sardine is particularly suited to let each developer-musician build their own personal coding style, providing a blank slate for experimental interface building. Furthermore, Sardine’s design has been strongly influenced by McPherson and Tahiroğlu’s concerns about the idiomatic patterns (McPherson and Tahiroğlu 2020) of usage enforced by computer music software, pushing users to repeat and strictly follow preferred patterns of usage. Sardine focuses on laying out the base infrastructure needed to support live coding in Python and wishes to encourage users to imagine diverse patterning idioms and live coding targets, mini-notations or user-facing scheduling mechanisms and syntax. The system’s modular architecture is a first step towards the inclusion of more targets and custom input and output handling. Initial work for the 0.1.0 has been based upon an older personal attempt at writing a live coding library, then named *ComputerTalk*¹. ComputerTalk’s base design was not suitable with Sardine’s goal, and so the base has quickly evolved after the first initial public tests, aiming for increased modularity of the system in order to maximise IO options.

The version hereby presented – v0.3.0 at the time of correction – offers a first look into the complete intended design for the library, and is a near complete rewrite over the 0.1.0 version previously used by members of the French live coding scene and by the first global Sardine users. It features two different clock implementations, multiple handlers for IO (MIDI, OSC, SuperDirt), a robust asynchronous temporal recursive scheduling system, and a reimagining of the Player system previously introduced by FoxDot (Kirkbride 2016). Since february 2023, Sardine also includes a prototype parser for the *Ziffers* language for musical pattern notation developed by Miika Alonen. Sardine’s originality lies in the implementation of its temporal model, strongly anchored in Python’s default mechanisms for asynchronous programming. It has been developed collectively with the help of John Phan, based on user requests and feedback gathered during a first period of experimentation that saw Sardine being used or integrated by musicians for several algoraves, network-based jams and musical performances. Sardine has been developed exclusively using the Python programming language.

Some libraries, providing critical functionality such as MIDI I/O or network synchronisation are obtained through Python bindings to C++ external libraries. Despite the known shortcomings of Python for interpreted real-time programming (incomplete support of dynamic programming, slowness relative to other interpreted languages), we believe that this language is suitable for the implementation of a live coding library. The large collection of available libraries and modules and the popularity of the language ensures the affordance of good tooling and rich customization and integration options for different text editors, running environments, and more. Sardine already takes advantage of a thorough ecosystem of libraries focused on data input/output, network communication and text manipulation. Moreover, thanks to its lightweight and clear syntax, Python can be read by programmers coming from various backgrounds, making it a convenient platform for collaboration and experimentation with bespoke features needed by performers.

¹Some videos of this older system can be found on Raphaël’s YouTube channel: <https://youtube.com/watch?v=MHGYtKibUo>

In the present article, we will introduce Sardine by detailing its goals (1) and base implementation centered on the scheduling mechanism (2), the environment/handler system (3) and the mininotation support (4). By doing so, we hope to highlight the basic principles of its inner workings, while providing some context on the current direction taken by the project and by its users.

2 Methodology and Objectives: a Framework for Exploring Live-Coding in Python

The development of Sardine began initially in a period of active collaboration and joint performances with the Parisian *Cookie Collective* (“Cookie Collective” 2016) and the *Digital Audio Community* from Lyon (France). Stemming from the demo and shader-coding scenes, *Cookie Collective*’s members are known for their complex multimedia performances. Each member typically relies on bespoke hybrid audio-visual setups ranging from low end computing devices to complex synthesizers and circuit-bent video mixers. The *Cookies* are also known for working in an improvised manner, customising setups for each venue depending on audience needs and expectations. This need for customisation gave rise to the idea of a modular interface that could be used and mastered by every member of the collective, while allowing for jam-ready synchronisation with other musicians and live-coders. The recent splitting of FoxDot’s development into several scattered branches reinforced the need for a central, customisable and easily editable Python interface, the library being used particularly in the French live coding community. Due to an open-ended development process, Sardine has been gradually shifting towards its current modular architecture, allowing each performer to refine the system, from simple MIDI note output to more convoluted SysEx and OSC handling. The invaluable help and expertise from John Phan has allowed for a rewrite of every base mechanism. The finalisation of Sardine’s new framework allows focus to turn towards introducing new features and improving existing ones, with users being encouraged to propose ideas and contribute code and documentation.

Having completed most of its initial objectives as a demonstration tool – the imitation and reproduction of known mechanisms – Sardine is now gradually shifting towards a more creative open-ended development process. This process is twofold: to facilitate the installation, learning and use of the software on the one hand, and to extend its expressive capabilities on the other. Although these two tasks can be seen as related, the former has more to do with the inclusion of new users, while the latter has to do with creative exploration for the more experienced users. In order to strengthen the accurateness of our aim, we have chosen to present Sardine to various audiences (at [PyCon France](#), in hackerspace workshops or informal musician meetings) in order to study user’s usage patterns and expectations when confronted to the software. This has led to many multi-platform support fixes and improvements. This has also led to improve the usability of Sardine without a dedicated text editor or to improve the quality and quantity of documentation provided with the software.

3 Sardine Implementation and Installation

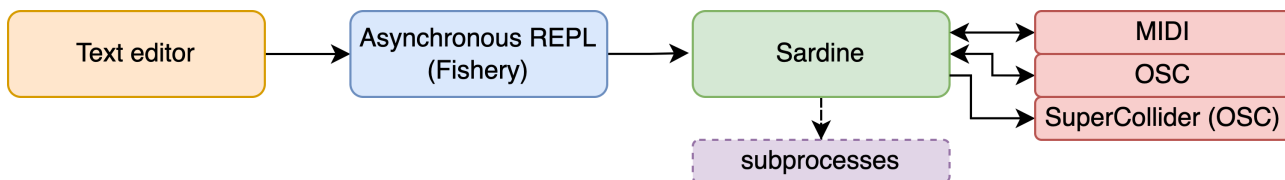


Figure 1: Software layers of the Sardine system stack.

Sardine is implemented and distributed as two complementary Python modules: `sardine` and `fishery`. The `fishery` module is a modified version of the base Python asynchronous REPL². Starting `fishery` automatically imports `Sardine` and starts a new live session. To facilitate configuration and orchestration of the various components of the system, a terminal based configuration client, `sardine-config`, is also provided. This tool is designed as a user-friendly interface for the editing of configuration files. Configuration files are stored in a single folder inside a OS-specific default standard location (e.g. `.local/share` on UNIX systems), and include a main JSON file, a blank `.py` file used for loading custom Python code among other files needed to properly configure a `SuperCollider` or `SuperDirt` session. Despite its initial complexity, this approach makes Sardine more accessible to novice users who may not be familiar with the command line, with Python development tools or with plain-text editing of configuration files. In order to encourage modularity in user’s configuration, many of the input and output components are disabled by default. This makes the installation of

²*Read, Eval, Print, Loop*: mechanism used by most interpreted languages to process user input from the command line and return textual output.

other programs like SuperCollider entirely optional while also encouraging users to consider their needs for a successful interaction with their own instruments and softwares.

Sardine does not require usage of a specific editor or text-editor plugin. Any IDE³ or coding environment capable of spawning a command line interface and sending code to it is sufficient. Fortunately, these features are usually included by default in most popular code editors or Python-specific plugins⁴. With this approach, Sardine has been successfully tested with Atom, VSCode, Emacs, Vim/Neovim and Jupyter Notebooks. Sardine uses the Python interpreter mainly as a code receiver and a monitoring tool for displaying useful information to the user, such as the state of a SuperCollider sub-process, or of an event loop. Since January 2023, some effort has been put into the development of an internal text editor named fishery web for its reliance on web technologies. This editor uses the Flask Python web application framework to serve a text editor web application composed using the Svelte frontend library and WebSockets (Fette and Melnikov 2011) for communicating between the web browser and the local fishery instance. This text editor, fully dedicated to newcomers, already includes automatic handling of text files and quick access to documentation.

Reliance on an audio backend requires booting another application. So far, SuperCollider and SuperDirt are natively supported to do this by their own Sardine components. Even though the installation of these backends is still necessary for users willing to use them, integration is done in such a way that there is no need – later on – to actively take care and monitor any of these dependencies. A basic interface to SuperCollider is offered through the SC() function, allowing to run arbitrary sclang code in the subprocess session. A more thorough integration with SuperCollider is planned for inclusion in future versions of the software. Clever usage of the provided tools for MIDI and OSC communication already allows users to generate custom mappings to other custom audio custom backends (Max/MSP patches, DAW, etc).

Sardine is packaged as a regular Python module, making use of the pyproject.toml module configuration and packaging format defined by PEP 660, meaning only a base Python 3.10+ runtime is required for installation. Sardine has recently been packaged and released on PyPi, allowing installation using a simple command: `python -m pip install --find-links https://thegamecracks.github.io/python-rtmidi-wheels/ sardine-system`. All C++ dependencies and wheels – binary distribution of compiled packages – are available for every major platform. This also means Sardine is compatible with the recent release of Python 3.11.

3.1 Event Loop and Scheduling System

3.1.1 Event Loop

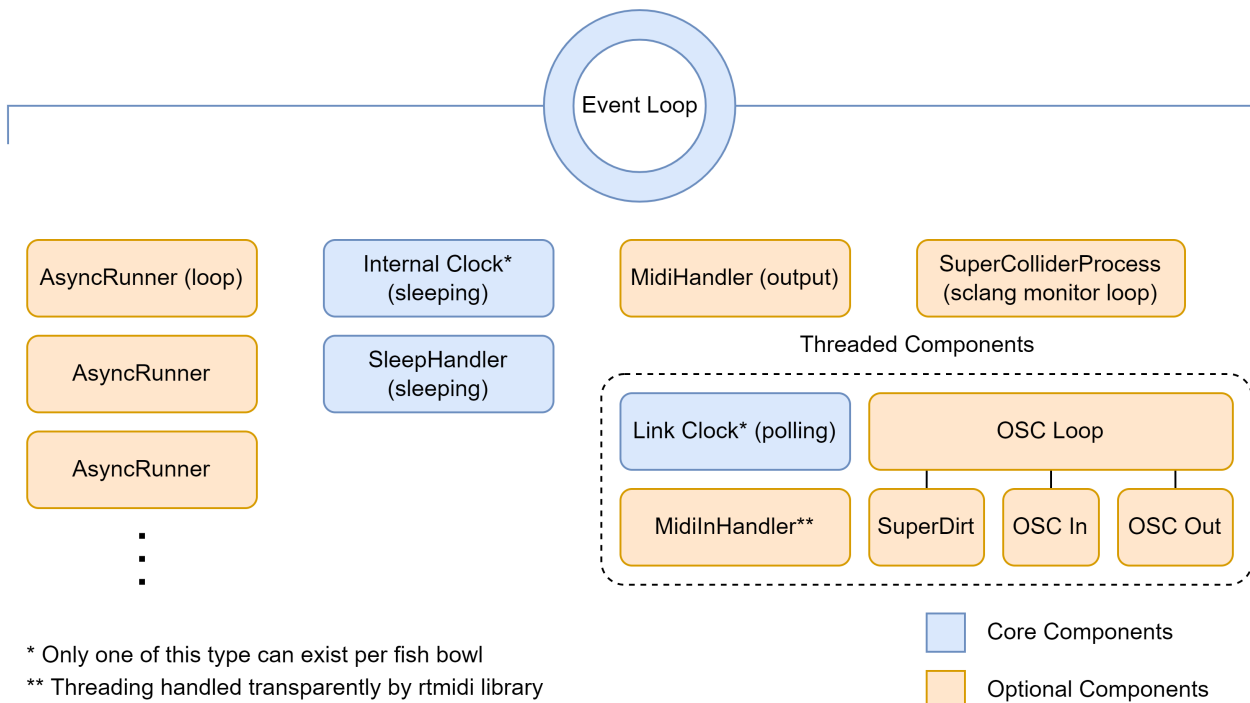


Figure 2: Architecture diagram of the customised asynchronous event loop.

³Integrated Development Environment.

⁴The process for setting up various interfaces is extensively detailed on Sardine’s [website](#).

Sardine makes use of Python’s asynchronous programming features, specifically the `asyncio` REPL prototype introduced by Python 3.8 (Selivanov 2019). The `UVLoop` (Selivanov 2016) drop-in replacement event loop is also used in order to speed up asynchronous call scheduling (except on Windows). Several hot-patches to the asynchronous loop have been introduced by John Phan (*thegamecracks*) to make its behaviour consistent on every major OS platform. Sardine is laid out as a series of abstractions built on the base loop, making it aware of tempo and timing. Sardine’s clock (either internal or link) automatically starts whenever the system is imported, but pure asynchronous calls can still be handled even if the clock is stopped. The `LinkClock` allows Sardine users to connect their session to a global tempo on a local network, enabling networked synchronisation of several Sardine instances and/or other Link-enabled devices⁵. All Sardine clocks provides the same interface, allowing the system to retrieve the current bar, beat and position in musical time. Time drift compensation and time shifting needed by some features is handled by the low-level event loop system. Asynchronous clock consistency is covered by tests (in the `tests/` folder) and favourably compares with alternatives offered by similar, more widely used threaded clocks. Development of such a feature has proven to be a difficult technical challenge due to the specificity of the task, and of the relatively obscure and scarcely documented inner workings of each OS’s internal schedulers. Threaded components are still used for various IO operations to lighten the load of the event loop and to alleviate the temporal cost of message processing. Many Sardine components are optional and can be activated on demand by the user, apart from the `clock`, `AsyncRunners` and `SleepHandler` core abstractions needed for `asyncio` loops. Basing Sardine’s custom event loop on Python’s asynchronous interpreter allows for the evaluation of any top-level asynchronous `await` instructions that would be forbidden by the main interpreter. However, Python `asyncio` ultimately behaves differently on every major OS due to its binding with system-level mechanisms, and more empirical testing is needed to document OS-specific limitations of this approach.

3.1.2 Scheduling

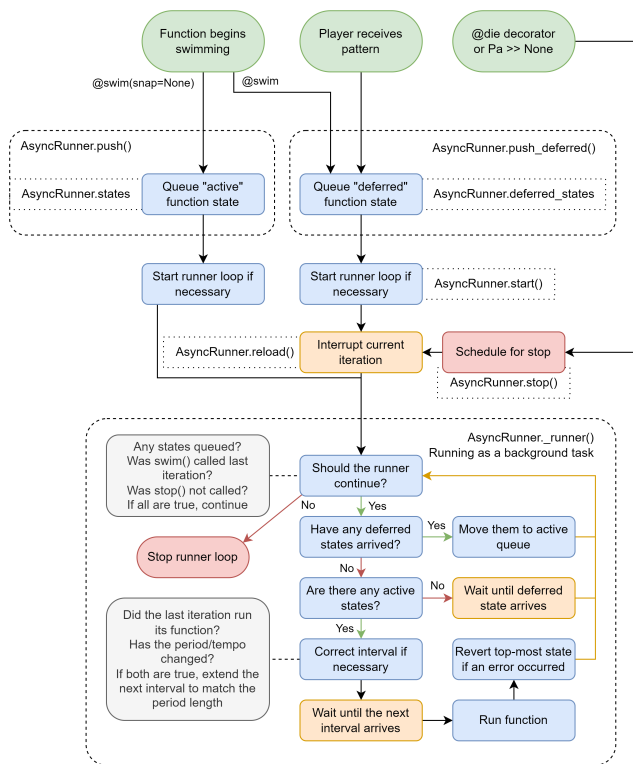


Figure 3: Lifetime of an asynchronous ‘swimming function’.

Python does not feature native tail-call recursion support (Rossum 2009a, 2009b), making the infinite recursion of a function, as Sardine requires, a delicate task. Support for this central feature is based on John Phan’s `AsyncRunners`, which is the basis for every repetitive operation – such as a repeating pattern – scheduled within Sardine. In the spirit of the nautical theme of Sardine, a temporal recursive function is called a *swimming* function and is labelled in code as an `AsyncRunner`. Swimming functions can be started using the `@swim` decorator⁶, stopped using the `@die` decorator, and can receive updates throughout its lifetime on the scheduler (see Figure 3).

Decorated asynchronous Python functions are passed to the scheduler, making them repeat every `p` (for period), a time measured in beats relative to the clock currently in use. The content of a given function will be re-evaluated for every recursion cycle and state can be preserved either by passing arguments to a subsequent call or by relying on global state. Swimming functions are a powerful construct for building abstractions dealing with time, code re-evaluation and dynamic lifetime management of code components. Iterators, for example, can be built by incrementing a variable passed as an argument. Random generators can be built by calling a simple native random function whose result will be dynamically updated for each recursion.

Swimming functions will automatically start on-the-beat. The start of a function can target a specific point in musical time by specifying a special `snap` argument that is interpreted as an offset in beats from the beginning of the next bar. The `until` keyword can also be used to give to each *swimming* function an explicit end after `n` iterations. The

⁵Sardine has also been integrated with `Flok` (<https://github.com/munshkr/flok>) made by Damián Silvani. This tool for remote live-coding allows any number of users to play by sharing the same code and code evaluation events remotely through the network without sharing the same clock or local audio backend.

⁶Decorators in Python are used to add a behaviour to an object such as a function without modifying the base object itself.

period argument of a given function is the only required argument for a function to be considered as a valid swimming function. All Sardine components are based on the assumption that their evaluation context will be as a swimming function. They can receive any arbitrary Python code and/or call the various players defined by the Sardine system to handle IO operations. Thus, the prototype of a basic musical function using the previously defined model looks like the following:

```
@swim
def swimming_function(p=0.5, i=0):
    print('I am swimming in time.')
    D('bd hh cp hh', i=i)
    ...
    again(swimming_function, p=0.5, i=i+1)

silence(swimming_function)
swimming_function.stop()
```

Figure 4: A commented complete example of a 'swimming' recursive function.

Multiple abstractions can be built on top of the basic swimming function mechanism, allowing for a terse user-facing syntax. Building abstractions on top of @swim is helpful to allow newcomers to grasp the system's temporal model. The FoxDot-inspired *surfboard* mechanism is the first available abstraction demonstrating this principle. It automatically handles its own scheduling logic and provides its own iterators to the default parser. As demonstrated by the following example, it also provides customised musical logic, thus adding a completely new flavour of patterning and scheduling over the basic *swimming functions*. Following this model, Sardine future versions are likely to include user-based playing modes built upon the basic abstractions provided by the library. The experimental Ziffers notation integration to Sardine relies on a similar design pattern, the customization of *swimming functions*.

```
Pa >> d('bd hh cp hh', p=0.5)
Pb >> d('voodoo', span=2)
Pc >> d('voodoo tabla', legato=0.1, span=2, p='1 2 3 4')
Pc >> None
Pc.stop()
```

Figure 5: A 'surfboard', custom FoxDot-like emulation adding a new playing mode to Sardine.

Worthy of note is Sardine's `sleep()` method, which has been overridden from the default Python `time.sleep()` function that would, if used, block the event loop. This function defers the execution of any statement or expression defined thereafter to x beats in the future, even if these events take place after the next recursive call, a phenomenon known as oversleeping. Unlike `time.sleep()`, Sardine's `sleep()` does not block the function from running to its end, instead it temporarily affects the value of `clock.time` and extends the perceived time of methods using that property. This mechanism mimics the `sleep()` statement found in other live coding tools such as Sonic Pi (Aaron, Orchard, and Blackwell 2014). This mechanism can be used explicitly by the user or implicitly by functions implementing algorithmic transformations of a simpler event.

```
@swim
def sonorous_cake(p=2, i=0):
    D('jvbass!4 jvbass:4', midinote='C Eb G D', i=i)
    sleep(1)
    D('jvbass:4!4', midinote="C' C''!3", i=i)
    again(sonorous_cake, p=2, i=i+1)
```

Figure 6: Usage of the 'sleep' method to defer execution, mimicking Sonic Pi.

3.2 Environment, Dispatch and Handlers

3.2.1 The FishBowl

While scheduling takes an important role in the overall modular design of the Sardine library, its logic wouldn't function without a central piece of the system called the FishBowl. The FishBowl is an environment for software components, and handles synchronisation and coordination between all the different pieces composing a Sardine system. It is designed so that every component of the system can talk and instantly access data held by any other component. The FishBowl allows components to subscribe to it through hooks, and to react to messages through a dispatch system. The `FishBowl.dispatch('stop')` message is an example of such an event which stops the clock and requests for the collaboration and immediate response of multiple components. Naturally, some components are more important than others and can thus be considered as hard dependencies. Other soft dependencies, mainly the various IO handlers available, can be added and removed from the environment or session at any point in time. The clock and the parser are two hard dependencies that cannot be completely removed, but can be swapped. They provide the basic mechanisms needed by other modular components to properly function. The fluidity of the FishBowl mechanism allows for the addition and removal of modular logic to any Sardine system capable of answering to any message currently being dispatched to other components. One can switch from the internal to the link clock on-the-fly if the need arises to synchronise with other players, or add a new OSC receiver.

```
bowl = FishBowl(clock=clock(tempo=config.bpm, bpb=config.beats)) # declaring the bowl
...
midi = MidiHandler(port_name=str(config.midi)) # instance of new component
bowl.add_handler(midi) # adding to the environment
M = midi.send # aliasing for playability
```

Figure 6: Excerpt from Sardine boot process, addition of a MIDI Output.

3.2.2 Case-study of a component: the MIDI sender

In the previous code example, a MIDI handler was added to the FishBowl, giving access to a new MIDI output. *Senders* are one type of Sardine modular components which requires the collaboration of multiple parts of the system to function properly. The `N(midi.note_send)` is one of the possible outputs and user interface offered by this component. To operate efficiently, it requires an access to the parser for patterning and composing a valid message, to the clock for sending its message in musical time, and to the SleepHandler to precisely time calls between a Note On and Note Off message. By declaring itself to the environment, it gains access to these required features, that will be accessed transparently without having to deal with lower-level logic. Consequently, user interaction can be implemented through one minimal function only, letting the system handle the hard and slightly convoluted asynchronous scheduling calls taking place in the background.

```
# basic MIDI note scheduling (duration handled by bowl.SleepHandler)
N(note=60, velocity=100, channel=0, dur=0.25)
# patterning a similar call with added component-specific logic (strings parsed by bowl.parser)
N(note='C@penta C.. G3', velocity='80~100', channel='[0:10]', i=i, r=2)
```

Figure 7: Sending MIDI using multiple components of the bowl.

Similar senders or handlers can be implemented for various operations requiring collaboration between multiple parts of the system. Given that each one of these adhere to the BaseHandler abstract base class, adding a component to Sardine does not require refactoring of the base system. Most of the internal critical components of Sardine work by taking advantage of interconnection of every component, allowing one component to affect the behaviour of the whole environment, if needed. Given that handlers generally implement one specific input or output protocol, one handler is generally responsible for providing many different senders (e.g MIDI note, MIDI control change, MIDI program change, etc) as well as custom variants (Ziffers SuperDirt interface, etc).

3.3 Sardine Pattern Language

3.3.1 Sardine Sefault Pattern Language

Initially for demonstration and usability purposes, a small domain-specific language (DSL) for musical patterns has been developed for Sardine using [Lark](#) (Shinan n.d.) for LALR parsing. The DSL's source code is directly included in the sardine module, in the `sequences/` directory. A DSL was needed to deal with the limited support provided by Python for syntactic macros (à la Lisp) and operator overloading. The use of the hard parser dependency is limited to parsing string arguments provided to any handler's `send` methods. These `send` functions, common to any sender, act as its principal interface for patterning and output alike, enabling the creation of complex data and music patterns, evolving over time in the context of a swimming function. Patterns play an important role in the workflow of audio/visual live coders, allowing them to define rich evolving structures spanning over time (Magnusson and McLean 2018). A generic interface `P()` is also available to increase the patternability of Python code or function calls done in the context of recursive swimming calls. This basic pattern language is best defined as a rich and terse interface dealing with lists of arbitrarily typed elements ranging from numbers to MIDI notes, samples or synthesizer names, or even OSC addresses. Pattern strings given for each keyword argument provided to a `send` method are resolved by the parser as arbitrarily-nested lists, which are in turn used for composing an output message. Quite possibly, multiple connections to different parsers will be supported in future versions as a way to vary the idioms available for composing patterns. For now one parser is supported in each instance of the `FishBowl`, and its use is optional.

```
# standalone call to the parser, yielding one value per iteration (i acting as the index)
P('1 2 3 2~40 5!4 C@fifths', i=i)

# several calls nested inside a more densely composed call to SuperDirt.
D('amencutup:[1:10]', legato='0.1~0.8', room='0.5', dry='[0.1,0.5:0.05]', i=i)
```

Figure 8: Several calls to the parser spread in different Sardine methods

Extensive support has been dedicated to list-based operations for the composition of sequences. Binary arithmetic operators such as `+`, `-`, `*` and `%` can work either on single tokens or on lists (on both sides). Lists can be arbitrarily nested. List slicing and value extraction has been re-implemented in a fashion similar to that of Python. Unary operators such as `(abs x)`, `(sin x)` or similar scientific calculation functions work in a similar way, with the function being mapped to each element of the list if needed. Basic function calls are available, opening the pattern language to more complex operations. Functions can support arbitrary number of arguments and keyword arguments (e.g. `(disco F A C E ::depth 2 ::cond (beat 1))`). Custom operators have also been defined such as `x~y` (choosing a number in range), `x|y|z` (choosing between x elements). Other operators have been borrowed to similar pattern languages such as `Ziffers` (Alonen n.d.) and `TidalCycles`: `'` for octave up, `.` for octave down, `:` for sample choice, `!` for repetition, among many others. Basic music notation is handled through the conversion of specific tokens to single MIDI notes (`C#4` or `D#4` parsed as 61), silences (a full stop `.` or variable size ellipsis `...`), list objects (`C@penta` parsed as `[60, 62, 64, 67, 69]`) with support for transposition, chord and structure inversion. A complete list of all supported operations is provided to the user through Sardine's documentation. Support for random and generative structures, albeit basic, has been implemented. Again, the implementation of this feature has been facilitated by the definition of the parser as a component of the `FishBowl`. This allows the parser to query the environment and `owl.clock` in search of semi-random number generators, such as the measure number (`$.m`), phase (`$.p`) or current beat since the origin of time (`$.`). Similar functions, such as `(phase 0.25 0.5)` are implementing conditional operations based on the available timing information.

```
# Middle-C MIDI Note with default velocity and channel (N, alias for midi.send_note)
N(60)
# C major natural seventh chord with velocity in between 80 and 120, channel either 0, 1 or 2
N('{C:maj7}', vel='80~120', chan='0|1|2', i=i)
# SuperDirt call, picking samples '0' to '20' in order in the 'drum' folder. Speed parameter
# ramping from 1 to 10 in increments of 2, shape is the sin function of current time divided by 2.
D("drum:[0:20]", speed='[1:10,2]', shape='(sin $)/2', i=i)
```

Figure 9: Various commented examples of Sardine patterns.

3.3.2 Iteration and pattern querying

Querying values from the possible multiple patterns per *swimming function* is done by providing a single pattern-wide iterator (labelled *i*) as an argument to each sender. Indexing errors are taken care of by making this index cyclical over the length of each pattern. The design of the iterator is a key creative choice for the user. Hence, the preferred method for browsing through the reduced list patterns can be chosen depending on context: sequentially, in reverse, or using a random number generator. Additional arguments, namely *rate* and *div*, can help in specifying how the iterator will be applied to the gathered patterns, adding another quickly accessible layer of patterning. The *rate* argument (aliased to *r*) is used to compress or extend the number of iterations needed to move from a list index to the preceding/next. It is best understood as a way to slow down or speed up the iteration over patterns. The divisor argument (aliased to *div* or *d*) is a modulo operation between the iteration count and *div* that will determine if the current event is to be played. Other sender-level functions, similar in functionality to high-level functions applied to musical patterns from live coding languages such as TidalCycles, have also been experimented with in the most recent versions of Sardine. While the querying of pattern information is done by usage of iterators, this new set of function will use other available temporal information – such as current bar or phase – to apply transformations to patterns based on a temporal condition.

```
@swim
def querying_flavors(p=1/2, i=0):
    D('bd cp sn hh', i=i, r=0.5, d=2) # simple iterator: 0, 1, 2.
                                     # Custom rate and div
    D('linnhats!4 jvbass', i=-i)     # reversed iterator: 0, -1, -2
    D('bongo bongo:2', i='rand*50') # random iterator: 0, 24, 5
    again(querying_flavors, p=1/2, i=i+1)
```

Figure 10: *Querying pattern values using iterators in swimming functions*

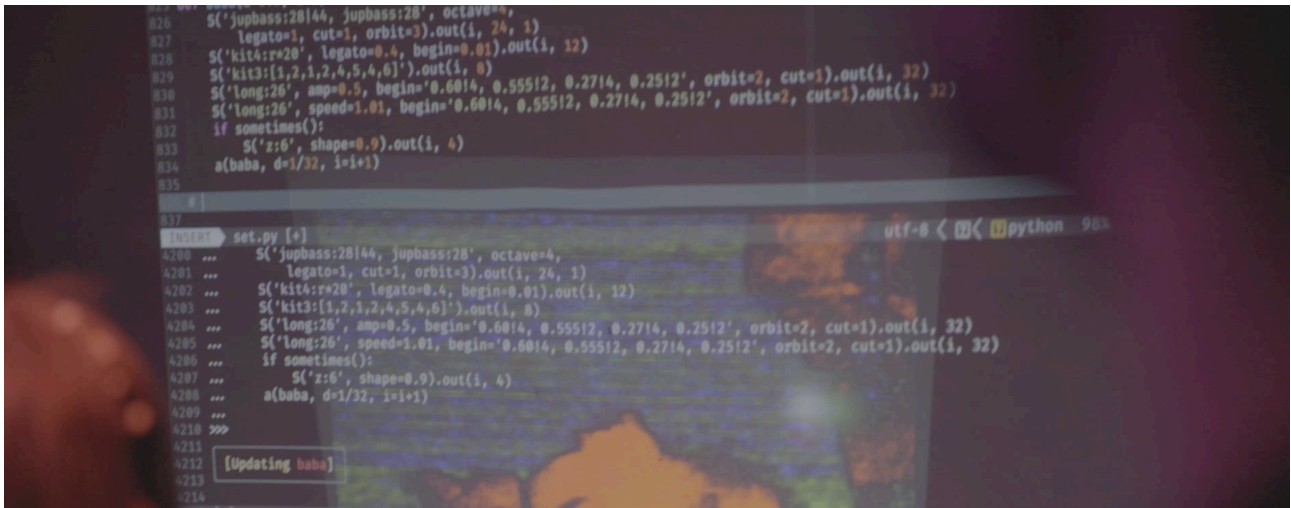
The iterator-based pattern system appears to be well suited to a system based on temporal recursion, partly as recursive operations are often used as iteration tools in functional approaches to programming. Multiple iterators can be used in the same pattern by playing around with the *P()* mechanism previously described. This allows for the creation of arbitrarily complex patterns composed of multiple values assigned to any parameter accessible through a given sender. Even though the list of features provided by the pattern language is dense, its architecture is not complex and allows for quick customisation and feature addition. As a downside, the Sardine Pattern Language syntax and mode of operation can prove particularly difficult to learn for new users as it requires a good understanding of both recursion and iteration, the two concepts being used extensively in the overall design of the basic components. Being modal and modular in nature, understanding how to apply patterns to both *swimming functions* and *Players* (shorthand notation) can also prove difficult for new users.

3.3.3 Planned extensions of the parser mechanism

The basic Sardine parser, in spite of its experimental status, is already useful for increasing the general playability of the system and for generating complex musical algorithmic patterns. Multiple extensions and refinements will come in future versions, specifically aimed at making the pattern language more easy to write and less error prone for the end-user. New additions will come in two categories, the first focusing on additions and improvements to this pattern language, and the second on adding new or different pattern languages. Support for the *Ziffers* numerical notation created by Miika Alonen, re-implemented in Python, is in progress and can already be used thanks to the addition of an [additional package](#), *ziffers-python*. To be supported, *Ziffers* requires new types of *Players*, relying on Sardine's low-level scheduling mechanisms. Supporting *Ziffers* is helpful to test the ease of integrating new writing and patterning paradigms into Sardine, while – in the process – gaining access to new ways to write melodic and harmonic patterns. The addition of the *CLCE* (*Common Lisp Compositional Environment*) *Time Generators*, a non documented library for algorithmic composition written by Stéphane Letz and Yann Orlarey (GRAME CNCM⁷, France) is being considered as a way to preserve the legacy and compositional ideas explored by this project. This would make use of Sardine as a tool for the study of algorithmic composition while allowing the exploration of more functional approaches to pattern generation.

⁷CLCE: <https://github.com/sletz/CLCE>. GRAME National center for Music Creation based in Lyon, France (<https://www.grame.fr/>).

4 Sardine usage



```
826 S('jupbass:20|44, jupbass:20', octave=4,
827   legato=1, cut=1, orbit=3).out(i, 24, 1)
828 S('kit4:r=20', legato=0.4, begin=0.01).out(i, 12)
829 S('kit3:[1,2,1,2,4,5,4,6]'.out(i, 8)
830 S('long:20', amp=0.5, begin='0.60|4, 0.555|2, 0.27|4, 0.25|2', orbit=2, cut=1).out(i, 32)
831 S('long:20', speed=1.01, begin='0.60|4, 0.555|2, 0.27|4, 0.25|2', orbit=2, cut=1).out(i, 32)
832 if sometimes():
833   S('z:6', shape=0.9).out(i, 4)
834 a(baba, d=1/32, i=i+1)
835
837
838 set.py [*]
839 ... S('jupbass:20|44, jupbass:20', octave=4,
840 ...   legato=1, cut=1, orbit=3).out(i, 24, 1)
841 ... S('kit4:r=20', legato=0.4, begin=0.01).out(i, 12)
842 ... S('kit3:[1,2,1,2,4,5,4,6]'.out(i, 8)
843 ... S('long:20', amp=0.5, begin='0.60|4, 0.555|2, 0.27|4, 0.25|2', orbit=2, cut=1).out(i, 32)
844 ... S('long:20', speed=1.01, begin='0.60|4, 0.555|2, 0.27|4, 0.25|2', orbit=2, cut=1).out(i, 32)
845 ... if sometimes():
846 ...   S('z:6', shape=0.9).out(i, 4)
847 ... a(baba, d=1/32, i=i+1)
848 ...
849 ...
850 ...
851 ... [Updating baba]
852 ...
853 ...
854 ...
```

Figure 11: *Sardine* v0.1.0 code during an *algorave* (Zorba, Paris), November 3rd, 2022

Over its relatively short timespan, from September 2022 to March 2023, *Sardine* has already been used multiple times for public music performances. The thrill and danger arising from using an unstable and unpolished software has constituted an obstacle as well as an appealing perspective for most users (Roberts and Wakefield 2018). Jams, informal meetings and dialogue with the wider live coding community were also of the utmost importance to study the integration of *Sardine* in various musical and technical environments. Here we mention a few specific examples of *Sardine* usage, and show how being able to live code in Python provides unique advantages (and also potential disadvantages). Numerous specialised devices or handlers have been created to facilitate *Sardine* interacting with other systems. Hybridations between multiple live coding environments, such as *Sardine/TidalCycles* and *Sardine/Sonic Pi* have been tried successfully. Initial failures mostly arised from improper or careless implementations of the synchronisation mechanism. Documentation pertaining to the implementation of live-coding oriented musical clocks and synchronisation mechanism is scarce and most of it had to be inferred from the inner workings of similar open-source libraries. In order to help with the collective effort of documenting live coding practices, we hope to upload a very thorough explanation of the system on the *Sardine* website to help future developers.

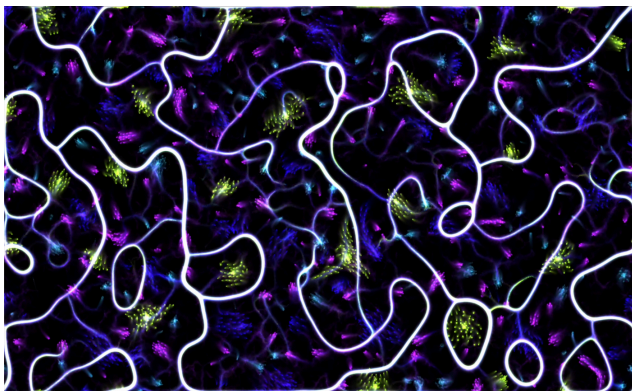


Figure 12: *Tölvera* artificial life simulation run inside a *Sardine* '@swim' function.

A proto-sender specialised in SysEx communication with a Yamaha TX7 synthesizer unit has been designed by Raphaël in order to enhance melodic and timbral capabilities of *Ralt144MI* (Rémi Georges) current live coding setup, previously mostly based on *TidalCycles*, MIDI controllers and audio-video hardware. Using a simple dictionary of lambda functions, this mechanism uses the previously described $P()$ function to provide a general patterning interface for each individual parameter defined in the MIDI specification of the unit. Subsequent performances led to the inclusion of more bespoke mechanisms that ultimately made their way into the main codebase, having been proved useful in the context of live performances (span, snap, support for polyphony, etc...). This experience also proved the usefulness of adding better support for the definition of custom-fit *senders* and output/patterning interfaces.

At the Intelligent Instruments Lab in Reykjavík, Jack Armitage has been using *Sardine* to live code the Magnetic Resonator Piano (MRP) (McPherson and Kim 2010). In this case, *Sardine* enabled developing a Python API client for the MRP much more interactively, due to being able to redefine @swim functions on the fly. Another attractive feature of *Sardine* being written in Python in this case, is that the entire Python ecosystem can be explored for machine learning

based approaches to instrumental control and interaction⁸. This also positions Sardine as a bridging platform for researchers and practitioners interested in hybrid live coding interfaces, as in this case where live coding and instrumental practices are blurred. Jack Armitage has also been live coding artificial life simulations using Sardine, in the *Tölvera* library as part of the *Agential Scores* project (Armitage 2022). This is one of the first examples of Sardine being used for visual output. In this case, the Taichi numerical simulation library was able to run its animation frame loop as a `@swim` function, with Sardine’s recursion occurring fast enough to give 60fps graphics⁹ (see Figure 12). These early examples showed the diversity of approaches that are possible in the Python ecosystem, and they also usefully highlighted usability pain points and performance bottlenecks with Sardine. As a result, substantial rewriting efforts have been taking place to accommodate these needs. Motivation for the rewrite process was found in the perspective to support more of these creative endeavours that would be hard to undertake in more closed or less configurable live coding systems.

5 Conclusion

5.1 Current issues and shortcomings

Sardine is both a new software/environment and an architecture model for a Python based live coding library. Developed only by a small dedicated team of developers with a few enthusiastic users, some features are already hard to keep a track of, for they are not often used. Much needed updates are currently delayed to address more urgent concerns. Though tests have recently been introduced, only time-critical parts of the system are currently extensively covered. The `v.0.2.0` rewrite focused on improvements to the temporal model and component handling, and although it’s promising, it remains fragile and requires careful, time-consuming testing to identify regressions and new issues brought by additions to the model. As such, regular updates are being released to increase the robustness and playability of the system.

Now at version `v.0.3.0` – at the time of last revision of this paper –, Sardine has started to stabilise around its core features. Sardine is in need of documentation focused on new and inexperienced users. The installation process still requires the installation of a Python runtime and some knowledge of handling Python packages, a task which might not be easy for non programmers. Existing text-based documentation provides a thorough tour and exploration of the system, but lacks friendly videos, tutorials and content that could boost Sardine’s adoption curve. As a temporary solution to this, we show code used by performers in a special Showcase section of the website. The internal editor, already fully functional, has yet to become a gate of entry as an easy playground for new users. As a result of its design and multi-paradigm nature, Sardine is also a system that can prove to be hard to learn (and teach) depending on previous user experience with live coding interfaces and programming proficiency.

The source code is extensively documented for contributors but most of the internal documentation is currently invisible to end-users. Sardine’s modularity can be considered as both its major strength and weakness. Initial configuration of Sardine can be quite intimidating for newcomers that may not know what they wish to accomplish with it, especially regarding external IO (MIDI, OSC, SuperDirt, etc.). Most options are disabled by default and must be added manually to configure a session. The reliance of loosely coupled software components (*Web editor*, *Fishery*, *Sardine*, *SuperCollider*, etc) can prove helpful for veteran live coders that are familiar with such architectures but confusing for new users.

5.2 Learning, contributing, testing

The Sardine project is freely usable and modifiable by its users. It is currently hosted on GitHub under the GNU General Public License v.3.0 (“GNU General Public License, Version 3” 2007). We warmly encourage anyone interested to try this experimental system and help report and triage bugs, and collectively build this new live coding system. Sardine is currently by no means as complete or stable as other existing propositions used by the community. We are still in the process of catching up with the quality and featurefulness of known alternatives, thinking as Sardine as a way to extend or collaborate with other musicians and visualists using different live coding environments.

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⁸Python codebase for the Magnetic Resonator Piano: <https://github.com/Intelligent-Instruments-Lab/iil-mrp-tools/>

⁹Code from this experiment can be found on the *Tölvera* GitHub repository: <https://github.com/Intelligent-Instruments-Lab/iil-python-tools>

it to a wider audience these few last months, in particular the Cookie Collective, Rémi Georges, Yassin Siouda and many more from the online Sardine chat channels.

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