

Rethinking the audio workstation : tree-based sequencing with i-score and the LibAudioStream

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ABSTRACT

Place your abstract at the top left column on the first page. Please write about 150–200 words that specifically highlight the purpose of your work, its context, and provide a brief synopsis of your results. Avoid equations in this part.

1. INTRODUCTION

Software audio sequencers are generally considered to be digital versions of the traditional tools that are used in a recording studio : tape recorders, mixing desks, effect racks. . .

Most of the existing software metaphors follow this very closely, with concepts of tracks, buses, linear time, which are a skeuomorphic reinterpretation of the multi-track tape recorder [1]. At the other side of the music creation spectrum, entirely interaction-oriented tools, like Max/MSP, Pure Data, Csound, or SuperCollider, allow to create musical works in programming-oriented environments. In-between, one can find tools with limited interaction capabilities but full-fledged audio sequencing support, like Ableton Live, or Bitwig Studio. The interaction lies in the triggering of loops and the ability to change the speed on the fly but is mostly separate from the "traditional" sequencer.

In this paper, we present a tree-based approach to interactive audio sequencing. By exposing the LibAudioStream audio engine to the interactive control sequencer i-score, we provide an audio sequencing software that allows to author music in a timeline with the possibility to arbitrarily nest sounds and effects, trigger sounds interactively while keeping the logical coherency wanted by the composer, and arrange audio effects in a temporal graph. For instance, instead of simply applying a chain of effects to an audio track, it is possible to apply temporal sequences of effects : an effect would be enabled for ten seconds, then, if a condition becomes true, another effect would be applied until the musician chooses to stop it.

We will first present the existing works in advanced audio sequencing and workstations, and give a brief presentation of both i-score and the LibAudioStream. Then, the new objects introduced in order to integrate these software together, allowing for rich audio routing capabilities, will be

explained. Finally, examples of usage in the graphical interface of i-score will be provided.

2. EXISTING WORKS

Outside of the traditional audio sequencer realm, we can find multiple occurrences of graphical environments aiming to provide some level of interactivity.

Möllenkamp presents in [2] the commons paradigms for creating music on a computer : Score-based with MUSIC and Csound, patch-based with Max/MSP or PureData, programming-based with SuperCollider and many of the other music creation languages, music trackers such as FastTracker which were used to make the music in old video game consoles, and multitrack-like such as Cubase, Pro Tools. Ableton Live and Bitwig Studio are given their own category thanks to the ability to compose clips of sound interactively.

Drile [3] is a virtual reality music software : loops are manipulated and bound together in a 3D environment. Hierarchy is achieved by representing the loops in a tree structure.

Mobile and web applications are also a way that is more and more used to create music, but their are often embedded in a bigger score or framework and act more as an instrument than other systems. An interesting example of web-based sequencer is JamOn [4] which allows multiple persons to author music interactively in collaboration by drawing in a web page.

Finally, modern video game music engines such as FMOD and Audiokinetic wWise allow some level of interactivity : when some event occurs in a video game, then a sound will be played. Automation of parameters is possible, and these environments are geared towards three-dimensional positioning of sound.

For audio engines, one of the predominant metaphors is the audiograph. Prime examples are Jamoma AudioGraph [5] and Integra Framework [6]. Audio processing is thought of as a graph of audio nodes, where the output of a node can go to the input of another node.

3. CONTEXT

In this section, we will present the two tools that are used to achieve rich audio sequencing : i-score and the LibAudioStream. i-score is an interactive sequencer for parameters, which allows to position events in time, and gives the possibility to introduce interaction points and conditions in the score. The detailed execution semantics are given in [?].

The LibAudioStream [7] provides the ability to write rich audio expression by creating and combining streams. The notion of symbolic date, introduced in an extension of the library, allows to start and stop the execution of streams at an arbitrary date.

The goal of this work is to bind the audio capabilities of the LibAudioStream with the i-score execution engine and graphical interface, in order to allow the creation of rich hierarchic and interactive musical pieces.

3.1 Presentation of i-score

The main use of i-score is to communicate and orchestrate other software in a timely manner, through the OSC protocol. The software can send automations, cue-like OSC messages at a given point in time, and call arbitrary JavaScript functions, in a sequenced environment. It supports arbitrary nesting : a score can be embedded in another recursively. This is similar to the notion of group tracks in many other sequencers, but there is no limit of depth. Besides, there is no notion of "track" per se; rather, the composer works with temporal intervals which contains arbitrary data that can be provided by plug-ins.

There are multiple possibilities of interactivity in i-score : trigger points, conditions, mappings, speed control.

- Interactive triggers allow to block and synchronize the score until a specific event happens. For instance, when an OSC parameter fulfills a condition, such as $/a/b \geq 3.14$, then a part of the score can continue.
- Conditions allow to execute or disable part of the score according to a boolean condition. It makes if-then-else or switch-case programming construct easy to implement in a temporal way.
- Mappings allow to map an input parameter to an output parameter, with a transfer function applied to the input.
- The execution speed of hierarchical elements can be controlled during the execution.

A span of time in i-score might have a fixed or indefinite duration; we refer to this span as a Time Constraint since it imposes both a logical and temporal order to the elements before and after it.

This span of time may contain data by the form of processes : automations, mappings, but also loops and scenarios; a scenario is the process that allows nesting.

Time Constraints are linked together with Time Nodes, which allows for synchronization and branching of multiple streams of time. An example of the temporal syntax of i-score is presented in fig. 1.

3.2 Presentation of the LibAudioStream

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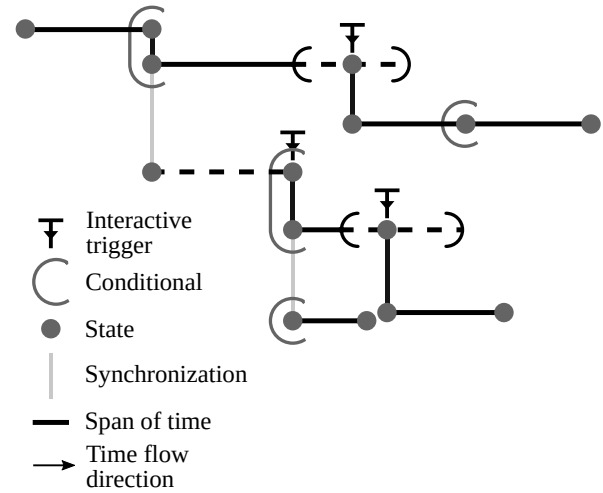


Figure 1. Part of an i-score scenario, showcasing the temporal syntax used. A full horizontal line means that the time must not be interrupted, while a dashed horizontal line means that the time of this Constraint can be interrupted to proceed to the following parts of the score according to an external event.

4. PROPOSED AUDIO SYSTEM

In this section, we will explain the audio routing features offered by the software.

First, we introduce new audio streams that allow a LibAudioStream expression to encapsulate the execution of a virtual audio player, in order to allow for hierarchy.

We make the choice to allow for hierarchy by mixing the played streams together. This is done in accordance with the principle of least astonishment [8] for the composer : in most audio software, the notion of grouping implies that the grouped sounds will be mixed together and routed to a single audio bus.

Then, we present the concept of audio buses integrated to the LibAudioStream, with two special Send and Return streams.

4.1 Group audio stream

In order to be able to apply hierarchical effects on the streams, we have to introduce a way to use hierarchy in the LibAudioStream.

Our method employs two elements :

- A particular audio player that will be able to sequence the starting and stopping of interactive sounds. Such players already exist in the LibAudioStream but are tailored for direct output to the soundcard.
- A way to introduce the Renderer into the stream system, so that it is able to be pulled like it would be by a real soundcard.

We introduce two matching objects in the LibAudioStream :

- A Group player. This is a player whose processing function has to be called manually. Timekeeping supposes that it will be pulled in accordance at the clock rate and samplerate of the soundcard.

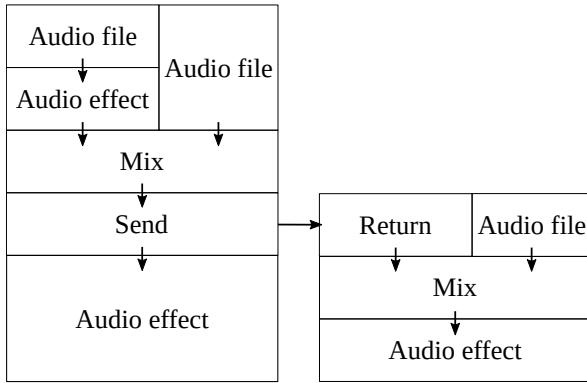


Figure 2. An example of audio stream composition with the Send and Return objects. An arrow from A to B means that B pulls the audio data from A.

- A Group audiostream. This particular audiostream, of infinite length, allows to introduce a Group player in a series of chained streams. For instance, in LISP-like notation :
(mix (fx playerA fxA) (fx playerB fxB))

The execution time of the hierarchized objects will be relative to the start time of the Group audiostream. The sound of the objects will be mixed together.

4.2 Send and return audio streams

In order to be able to create rich effect graphs, we introduce another couple of objects.

The Send audiostream by itself is a passthrough : it just pulls the stream it owns. It possesses the same definition : same length, same number of channels. The Return audiostream, constructed with a Send stream, will make a copy of the data in the send stream and allow it to be used by the processing chain it is part of. This means that a sound source can be sent to sound effects in parallel, for instance.

The Return stream is infinite in length : to allow for long-lasting audio effects like reverb queues or delays, we suppose that we can pull the data from the Send stream at any point in time. If a Return stream tries to fetch the data of a Send stream that has not started yet, or that has already finished, a buffer of silence is provided instead.

A byproduct of the imposed acyclicity of the graph, some level of parallel processing may be achieved, as long as causality is respected between nodes. For instance, if two Returns with each their own effect chain are connected to a Send, it is possible to compute these returns on different threads after the current buffer of the Send has been processed.

An important point is that the Send stream must itself be pulled regularly by being played as a sound, either directly or by a stream that would encapsulate it.

4.3 Audio processes

We provide multiple audio processes in i-score, that map to lower-level audio streams.

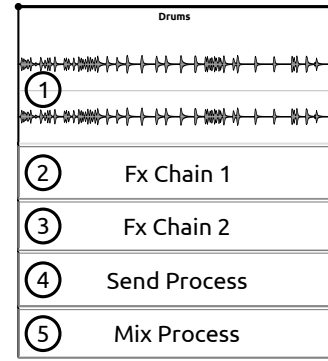


Figure 3. An example of a Time Constraint loaded with audio processes in i-score. Selecting a particular process shows a complete widget for editing the relevant parameters. On a single Time Constraint, there can be only a single Mixing process, but there is no limit to the amount of other processes.

- Effect chain process : register multiple audio effects one after the other. For instance :
Equalizer → *Distortion* → *Reverb*.
Currently only Faust effects are supported.
- Generator process : a sound generator, like a synthesizer. Currently only Faust instruments are supported.
- Sound file : reads a sound file from the filesystem.
- Explicit send and return processes.
- Mixing process : it exposes a matrix which allows to adjust the percentage of each sound-generating process going to each input process.

An important feature of audio workstations is the support for automation, that is, controlling the value of a parameter over time, generally with piecewise continuous functions. In i-score, automation is achieved by sending OSC messages to a remote software. Hence, the OSC message tree is modeled as an object tree. We present the loaded effect plug-ins to this object tree, so that automations and mappings are able to control audio effects and audio routing volume.

An example is given in fig. 3.

4.4 Stream graph

One problem caused by the presence of routing is that it is possible to create a data loop : if a Send is directly or indirectly fed its own data through a Return, the output would be garbage data : the Return would be asked to read the currently requested output from the Send which has not been written yet.

To prevent this, we create a graph where :

- Vertices are the sound generating elements : audio file reader, etc.
- Edges are the connections going from a send to a return.

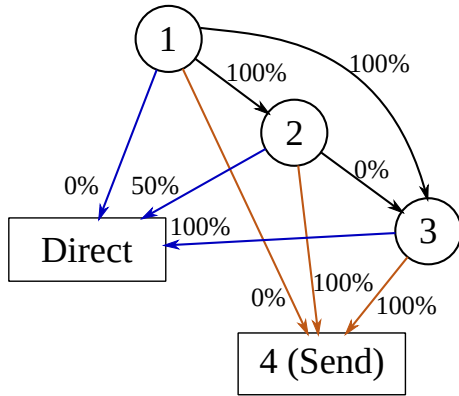


Figure 4. Translation of the Time Constraint of fig. 3 in a dependency graph. The edges in black represent the intra-Constraint connections. The edges in blue (resp. orange) represent a connection to a visible output of the Constraint. The percentages represent the level of mixing of the stream. *Direct* corresponds to the signal that will be sent at the upper level of hierarchy.

The graph, implemented with the Boost Graph Library [9] can then be used to guarantee the acyclicity, and return an user error if that is not the case.

We provide here the method to build the graph :

Vertices are created recursively from the Time Constraints in i-score : an i-score document is entirely contained in a top-level Time Constraint. First, we iterate through all the processes of the given constraint. If the process is hierarchical (Scenario, Loop), then we call the algorithm recursively on the process. In the case of the Scenario, it means that we call recursively on all its Constraints; in the case of the Loop, we call recursively on its loop pattern Constraint. In both case, we create a Group vertice to model the process. If the process is a send or a return, we create a corresponding vertice. Then, we create inner Sends for all the streams and a vertice for the Constraint itself. Once all the vertices are created, the edges are added as mentioned before.

As can be seen, there can be an ordering between nodes of the graph : the parentmost vertice has to be pulled before the others to reflect the causality.

Inside a Time Constraint, causality also has to be enforced. Since a mixing matrix is provided, we have to ensure that an effect bus cannot be routed in itself in a loop. To prevent this at the user interface level, the vertical order of effect chains is used : if Effect Chain 1 comes before Effect Chain 2, then Effect Chain 1 can be routed into Effect Chain 2, but not the contrary.

4.5 Stream creation

The stream creation is achieved by first walking the graph created earlier from its root in a breadth-first way, and create all the required Sends : the Return audiostreams need to be created with knowledge of the corresponding Send audiostream. Then, the hierarchical tree of i-score is traversed and the other streams are created.

We detail in this section the stream creation for particular

elements.

4.5.1 Scenario

An i-score scenario is an arrangement of temporal structures, as shown in fig. 1. Since the duration of these structures can change at run-time, it is not meaningful to use the tools provided by the LibAudioStream : sequence stream, parallel stream, mix stream.

The creation of the Scenario stream is done as follows :

1. A Group player is created.
2. For each Time Node in the scenario, a symbolic date is generated.
3. For each Time Constraint in the scenario, a stream is built; it is started and stopped at the symbolic date matching its start and end Time Nodes in the group player.

The Audio stream of this process is the group player.

4.5.2 Loop

Due to their interactive nature, loops in i-score can be entirely different from one iteration to another. They are more similar to traditional programming language `do-while` constructs, than audio sequencer loops. This prevents us from using the LibAudioStream's loop stream, since it expects a looping sound whose duration will not change from an iteration to another. Instead, we wrap the loop pattern Time Constraint's audiostream in a Group player, reset the stream and start it again upon looping.

4.5.3 Time Constraint

As explained earlier, a Time Constraint is a process container. Such processes can be the sound processes presented in section 4.3, and the control processes such as automation, etc.

The creation of the Constraint audio stream is done as follows :

1. For each sound-generating process, a stream and a send are created.
2. For each effect chain, the effects are instantiated and an effect stream is created with a mix of the returns of the elements to which this effect applies. A send is also created.
3. The mixing matrix is used to create mix audio streams from the sends and returns, which are routed either in the user-created sends, or in the stream corresponding to the Time Constraint. A time-stretching audio stream is inserted before the send : it is linked to the execution speed of the time constraint in i-score which can vary interactively.

5. EXAMPLES

We present in this part three examples of usage of the presented system.

5.1 Recreation of a multi-track sequencer

The first example, in fig.5, is a recreation of the multitrack audio sequencer metaphor, with the primitives presented in this paper.

This score has three tracks, **Guitar**, **Bass**, and **Drums**, which are implemented with three Time Constraints. Each Time Constraint has an audio track and an effect track; the mix track is hidden for clarity. The bass track is a looping one-note sound. Automations are applied either at the track level, as for the drums, or at the clip level, as for the guitar **outro** clip.

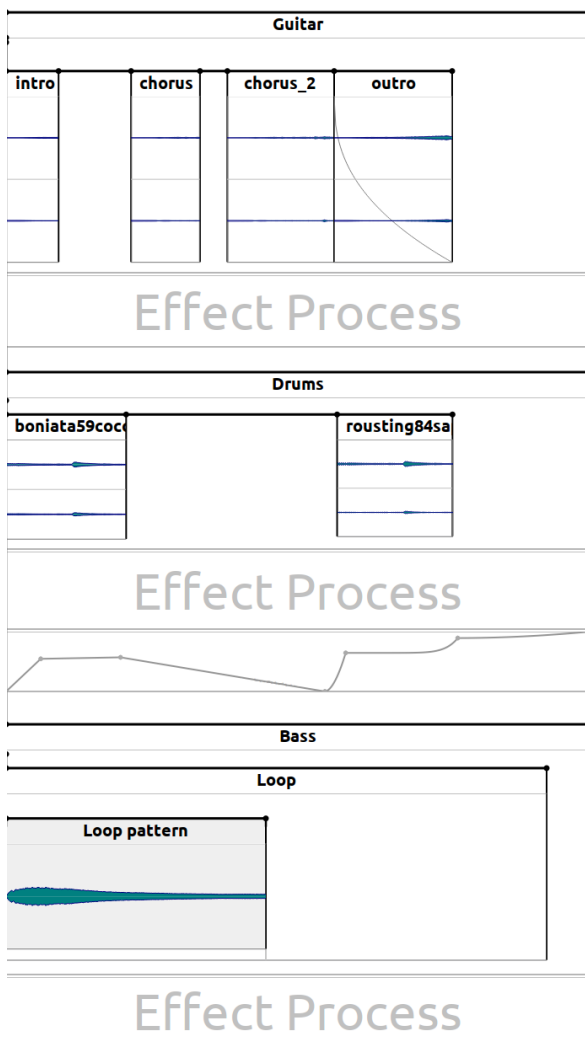


Figure 5. Multi-track sequencing.

5.2 Interactive scenario

The second example, in fig.6, gives an overview of the interactive possibilities when creating a song.

The score can behave as follows : For a few seconds, **intro** will play. Then, if an external event happens, like a footswitch being pressed, multiple things may happen :

- In all cases, the **eqcontrol** part will play, and automate a value of a global effect.

- If a first condition is true (**case1**), then **case1.B** will start playing immediately, and **case1.A** will start playing after a slight delay. If another external event happens, **case1.A** will stop playing immediately.
- If a second condition is true, at the same time, **case2** will start playing.
- After **eqcontrol** finishes, a hierarchical scenario **outro** is played, which contains two sounds and a parameter mapping.

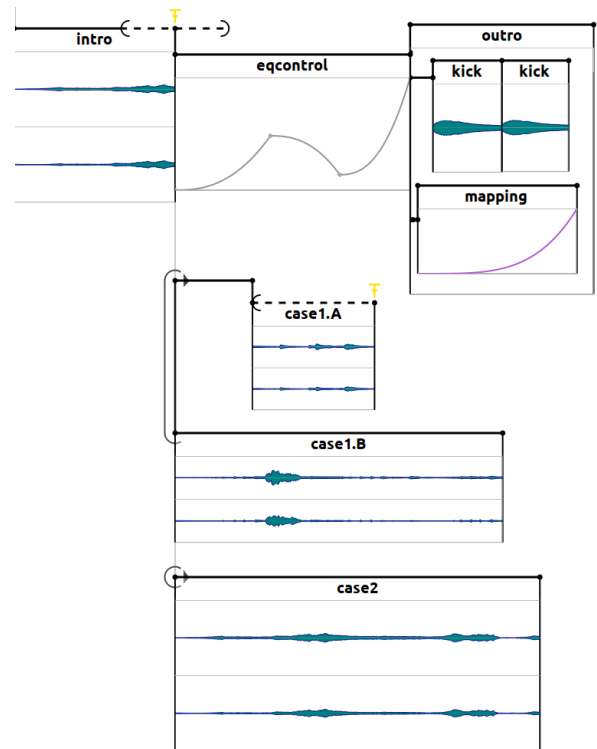


Figure 6. An interactive musical score.

5.3 Temporal effect graph

This last example shows how to arrange not sound, but sound processing temporally.

6. CONCLUSION

- lackluster areas : - MIDI support (but OSC) - no musical time information : first aimed for artists, but improvements could be the waiting of triggering on some measure of time. - "play from anywhere" - audio input ? - correction de latence ? - pour l'instant pas d'optimisations dans des cas simples (e.g. pas besoin de mixage) si on n'a qu'une seule piste

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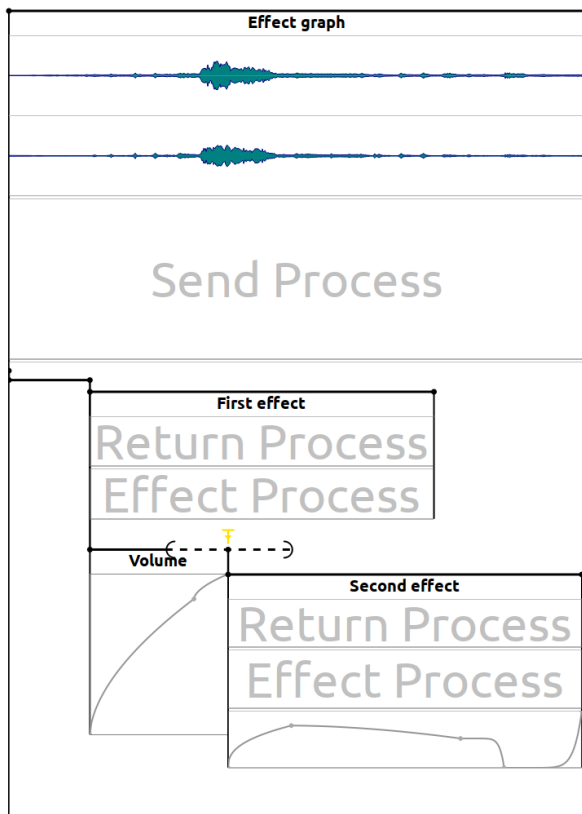


Figure 7. An interactive musical score.

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