

A model for interactive media authoring

Jean-Michaël Celerier ^{1,†,‡} , Myriam Desainte-Catherine ^{1,‡} and Bernard Serpette ^{2,*}

¹ Affiliation 1; e-mail@e-mail.com

² Affiliation 2; e-mail@e-mail.com

* Correspondence: e-mail@e-mail.com; Tel.: +x-xxx-xxx-xxxx

† Current address: Affiliation 3

‡ These authors contributed equally to this work.

Academic Editor: name

Version October 4, 2017 submitted to Appl. Sci.

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Keywords: interactive scores; intermedia; dataflow; patcher; i-score

1. Introduction

Many music software fit in one of three categories: sequencers, patchers, and textual programming environments. Sequencers are used to describe temporal behaviours: an audio clip plays after another, while an automation curve changes an audio filter. Patchers are more commonly used to describe invariants: for instance specific audio filters, or compositional patterns.

We propose in this paper a method that combines the sequencer and the patcher paradigm in a live system.

The general approach is as follows: we first introduce a minimal model of the data we are operating on: namely, remote software or hardware such as OSC peripherals and sound cards. Then, two structures are presented: the first is a temporal structure, which allows to position events and processes relatively to each other, hierarchically, and in a timely fashion. The second is a graph structure akin to dataflows. This graph uses special connection types to take into account the fact that nodes of the graph might not always be active at the same time. Both structures are then combined: the state of the temporal processes is bound to the dataflow nodes. This combination is then expanded with specific implicit cases that are relevant in computer music workflows. These cases are described using structures wrapping the temporal and dataflow graphs.

We compare the various models in the context of music creation: what entails using only the temporal structure, only the graph structure, and the combination of both.

The latter model is shown to have enough expressive power to allow for recreation of common audio software logic within it: for instance traditional or looping audio sequencers. Additionally, its

use is presented in sample compositions: the first one is an example of audio editing, the second an interactive musical installation.

1.1. State of the art

base: max, pd, séquenceurs: cubase/protools, live/bitwig...
openmusic
antescofo
inscore

1.2. Relationship with i-score

-> formalisation du papier icmc
-> refonte suite à tentative avec LibAudioStream

2. Orchestrated data

We first define the data we operate on. External devices are modeled as a tree of optional parameters.

Value parameters can have values of common data types such as integer, float, etc. Audio parameters are arrays that contain either the current input audio buffers of the sound card or the buffers that will be written to the sound card's output.

The tree of nodes is akin to the methods and containers described in the OSC specification.

$$\mathbf{Value} = \text{Float} \mid \text{Int} \mid \text{Bool} \mid \text{String} \mid \dots$$

$$\mathbf{ValueParameter} = \text{Value} \times \text{Protocol}$$

$$\mathbf{AudioParameter} = \text{Float}[] \times \text{Protocol}$$

$$\mathbf{Parameter} = \text{ValueParameter} \mid \text{AudioParameter}$$

$$\mathbf{Node} = \text{String} \times \text{Maybe Parameter} \times \text{Node}[]$$

Parameters and nodes bear additional metadata which is not relevant to describe here: textual description, tags, etc.

The parameters's associated values match the state of an external device: synthesizer, etc. Multiple protocols are implemented to allow this: for instance OSC, MIDI, etc.

We define two core operations on parameters:

$$\mathbf{pull} : \text{Parameter} \rightarrow \text{Parameter}$$

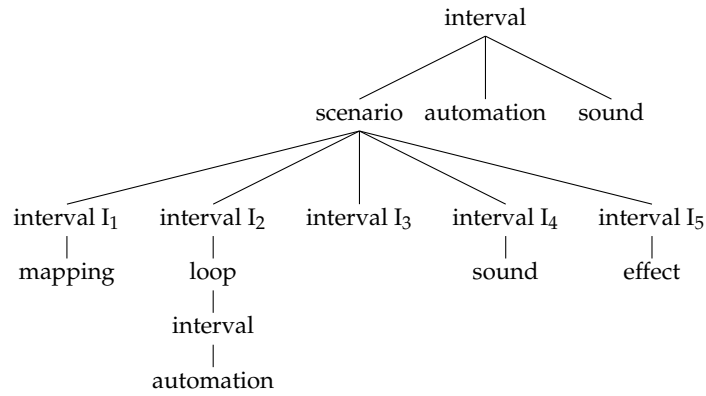
$$(v, p) \mapsto (v', p) \text{ where } v' \text{ is the current value of the remote device}$$

$$\mathbf{push} : \text{Parameter} \times \text{Value} \rightarrow \text{Parameter}$$

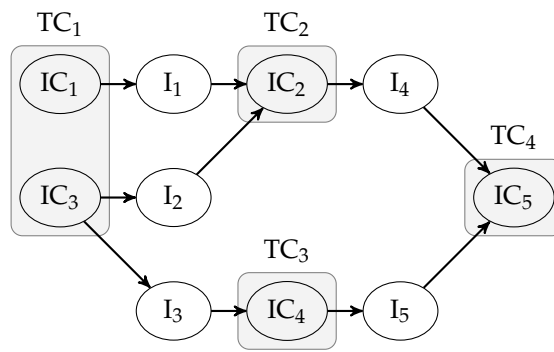
$$(v, p), v' \mapsto (v', p) \text{ and } v' \text{ is sent to the remote device}$$

3. Temporal model

The temporal model is two-fold: it is a hierarchical tree of processes, whose durations and execution times are directed by intervals. The beginning and end of the intervals is subjected to various conditions that will be presented ; these conditions allow for various interactive behaviours. Processes are any kind of relevant artistic process: automations, notes sequences, sound files. In particular, specific dispositions of intervals and conditions are implemented as processes themselves, scenario and loop, which allows for hierarchy.



(a) Hierarchical tree



(b) Temporal DAG

We note: TC for temporal conditions, IC for instantaneous conditions, I for intervals. First, these elements are defined, then the semantics imposed on them by the scenario and the loop are presented. These semantics allow both serial and parallel execution.

3.1. Data types

3.1.1. Conditions and expressions

We first define the conditional operations we want to be able to express. We restrain ourselves to simple propositional logic operands: **and**, **or**, **not**.

Expressions operate on addresses and values of the device tree presented in chap. ??, according to the grammar in ??.

Formally, expressions are defined as a tree: Let **Comparator** be an identifier for standard value comparison operations: $<$, \leq , $>$, \geq , $=$, \neq and **Operator** standard logical operators **and** & **or**.

Atom : (Parameter | Value) \times (Parameter | Value) \times Comparator

Negation : Expression

Composition : Expression \times Expression \times Operator

Impulse : Parameter \times Bool

Expression : Atom | Negation | Composition | Impulse

Two operations are defined on expressions and the data types that compose them:

- **update** : Expression \rightarrow Expression. Used to reset any internal state and query up-to-date values for the expressions. For instance, **update** on an **Atom** fetches if possible new values for the parameters, why may include network requests.

Precisely:

$$\left\{ \begin{array}{l} \text{update : Composition} \rightarrow \text{Composition} \\ \quad (e_1, e_2, o) \mapsto (\text{update } e_1, \text{update } e_2, o) \\ \text{update : Negation} \rightarrow \text{Negation} \\ \quad e_1 \mapsto \text{update } e_1 \\ \text{update : Atom} \rightarrow \text{Atom} \\ \quad \left\{ \begin{array}{l} (\text{parameter } p_1, \text{parameter } p_2, o) \mapsto (\text{pull } p_1, \text{pull } p_2, o) \\ (\text{parameter } p_1, \text{value } v_2, o) \mapsto (\text{pull } p_1, v_2, o) \\ \dots \end{array} \right. \\ \text{update : Impulse} \rightarrow \text{Impulse} \\ \quad (p, b) \mapsto (p, \text{false}) \end{array} \right.$$

- **evaluate** : Expression \rightarrow Bool. Performs the actual logical expression evaluation, according to the expected logical rules.

- An atom is a comparison between two parameters, a parameter and a value, or two values.
- Negations and compositions are the traditional predicate logic building blocks.
- We introduce a specific operator, “impulse”, which allows to decide whether a value was received.

3.1.2. Interval

We want to be able to express the passing of time, for a given duration. This duration may or may not be finite.

A duration is defined as a positive integer. An interval is at its core a set of durations: a min, an optional max, and the current position. The lack of max means infinity. An interval is said to be fixed when its min equals its max. It may be enabled or disabled.

$$\text{Status} = \text{Waiting} \mid \text{Pending} \mid \text{Happened} \mid \text{Disposed}$$

$$\text{Interval} = \text{Duration} \times \text{Maybe Duration} \times \text{Duration} \times \text{Status}$$

The time scale is not specified by the system: for instance, when working with audio data it may be better to use the audio sample as a base unit of time. But many applications don’t use the audio rate: when working purely with visuals it may be better to use the screen refresh rate as time base in order not to waste computer resources and energy.

3.1.3. Instantaneous condition

Then, we want to be able to enable or disable events and intervals according to a condition, given in the expression language seen in ???. An instantaneous condition is defined as follows:

$$\text{Condition} = \text{Expression} \times \text{Interval}[] \times \text{Interval}[] \times \text{Status}$$

It is preceded and followed by a set of intervals.

Expressions are disabled either when they are false or when they are preceded by a non-null number of intervals, all of them already disabled through other conditions. This propagates recursively to the following intervals and conditions.

95 3.1.4. Temporal condition

96 A temporal condition is used to synchronize starts and ends of intervals, while allowing to
97 implement behaviours such as : “start part *B* when the fader is at 0”.

98 Asynchronicity: because if in a given tick we receive the successive messages: false, true, false,
99 we want to be able to trigger even if the "last seen" message is "false". Thus the condition evaluation
100 operates asynchronously; however, the actual triggering is synchronous.

101 3.1.5. Process

102 3.1.6. Operations

103 `add_process interval proc: interval * proc -> interval`
104 `(t1, t2, p, t3) -> (t1, t2, proc::p, t3)`

105 `add_event tc ic: TemporalCond * InstCond -> TemporalCond`
106 `(..., ics, ...) -> (... , ic::ics , ...)`

107 `exécution :`

108 `interval:`

109 `get_node graph node_id -> node`

110 `update_node graph node_id node -> graph`

111

112 `graph_fun: graph -> graph ; va transformer un noeud du graphe d'une maniere donnee`

113

114 `tuple_first tpls: retourne les premiers elements d'une liste de paires`

115 `tuple_second tpls: retourne les premiers elements d'une liste de paires`

116

117 `tick: itv, count, offset : interval * duration * duration -> interval * graph_fun[]`

118 `((..., nom, t, pos, procs), new_date) -> (`

119 `let procs = map procs (state _ t offset) in`

120 `(..., t + count, t + count / nom, tuple_first procs),`

121 `fun (node_date, node_offset) -> (t+count, offset) :: tuple_second procs)`

122 `processes:`

123 `state: process * t -> process * graph_fun`

124

125 `described for each process (polymorphic)`

126 3.2. Temporal graph: scenario

127 3.2.1. Creational operations

128 `add_interval sc itv sev eev`

129 `add_sync sc`

130 3.2.2. Execution operations

131 `state :`

132 `process_event:`

133 make_happen :

134 make_dispose :

135 3.3. *Loop*

136 Pbq: not introducing cycles in the temporal graph

137 **4. Data model**

138 => set date => set offset pour offset audio (p-ê pas nécessaire si on fait comme LAStream)

139 4.1. *Data types*

140 add_node graph

141 connect graph node node edge

142 4.2. *Operations*

143 4.3. *Data graph*

144 4.4. *Data nodes*

145 4.4.1. Passthrough

146 -> used for scenario and interval

147 4.4.2. Automation

148 4.4.3. Mapping

149 4.4.4. JavaScript

150 4.4.5. Piano Roll

151 4.4.6. Sound file

152 4.4.7. Sound input

153 4.4.8. Mix

154 **5. Combined model**

155 5.1.

156 **6. Proposed sequencer behaviour**

157 Conditions et cie: The most common case for an expression is to be true.

158 UI: création automatique de liens implicites des enfants vers les parents => "cable créé par défaut"
159 quand on rajoute un processus dont on marque l'entrée

160 => pour toute contrainte, pour tout scénario, créer noeud qui fait le mixage => création d'objets
161 récursivement, etc

- Problème des states dans scénario ? => states du scénario: comment interviennent-ils ? faire un scénario fantôme *

- Mettre l'accent sur la recreation de la sémantique de i-score à partir du graphe: => messages: actuellement "peu" typés ; rajouter type de l'unité ?

=> pbq du multicanal: pour l'instant non traitée, on ne gère que les cas mono / stereo pour le upmix / downmix Choix pour multicanal: faire comme jamoma avec objets tilde => sliders et dispatching de canaux ? => cables: rubberband ? il faut mettre un rubberband dès qu'on a une entrée et une sortie qui n'ont pas la même vitesse relative. Dire que pour les automatisations ça interpole de manière naturelle avec le ralentissement et l'accélération (on sépare vitesse et granularité)

Exécution complète d'un tick:

- Copie des buffers audio - Exécution du tick temporel - Récupération des states

- Dire qu'on pourrait affiner en combinant plus précisément les "sous-ticks" temporels et de données pour que par exemple la production d'un état dans un scénario entraîne une condition dans un autre scénario

7. Applications

- Exemple article Myriam: micro-montage et sélection d'effets - Carrousel -> Réutilisation et filtrage des données d'entrées -> Gammes

8. Evaluation

8.1. *Reconstructing existing paradigms*

In this part we give example of reconstruction of standard audio software behaviours with the given model.

8.1.1. Audio sequencer

Notable software in this category includes Steinberg Cubase, Avid Pro Tools, ...

The common metaphor for audio sequencers is the track, inspired from mixing desks and tape recorders. We will take the example of audio and midi tracks. Such an audio sequencer can be modeled by :

- A root: an infinite interval.
- This interval contains two processes: a scenario and an effect bus. The sound output of the scenario goes to the input of the effect bus.
- The scenario contains the actual tracks.
- These tracks are also modeled by infinite constraints.

We divide the tracks in two categories. Audio tracks are built with :

- A scenario with a single sequence of intervals, some of which may bear sound file processes and others being empty.
- An effect bus process. The output of the scenario goes to the input of the effect bus. Generally, this effect bus would end by channel operations such as panning and volume adjustment, in a similar fashion to mixing desks.

Midi tracks are built with :

- A scenario with a single sequence of intervals, some of which may bear MIDI notes processes and others being empty.
- An instrument process, which takes MIDI data and outputs sound.
- Like before, an effect bus applied to the instrument's output.

This can easily be extended with further features: sends, automatisations, etc.

8.1.2. Looping audio sequencer

More recently, a different kind of sequencer has emerged: the looping, non-linear sequencer. The prime exemple of this is Ableton Live. We give the example for a simplified model of live-looping without quantization.

These sequencers are also organized in tracks ; however, within a track, the musician can choose a single loop that is currently playing, and regularly switch the current loop.

Hence, the general organization stays the same than for the audio sequencer: most importantly, the way effect buses are applied does not change.

- Each clip of a track is given an index.
- Each track also has a parameter which is the next clip to play, `next_clip`. These parameters can be introduced as variables in the device tree.
- We replace the scenarios containing the actual sound files or midi notes by loop processes.
- The loops processes are defined with an ending temporal condition.
- Inside the loop pattern, there is a single scenario process. This scenario process has a set of parallel intervals, each with one sound file. Every interval begins with an instantaneous condition that compares the `next_clip` parameter to the current clip's index. Hence, at most one clip is playing at the same time in each track. If the `next_clip` does not change the track keeps looping on the sound file.

Extension: par ex. dans une boucle on peut mettre un autre scénario. Pb : tic qui manque. On peut y remédier en exécutant le trigger "en avance".

8.1.3. Patcher

8.2. Notes on implementation

=> "third gen" audio sequencer. first gen: cubase, etc second gen: non-linear: ableton, bitwig third gen: entirely interactive: i-score, iannix. what else ?
reproductibilité: code source dispo

9. Discussion

Enforcing graph constraints: mostly done through UI. For instance: ic are created on tc, etc. No "going back" which would break DAG-ness.

Faire parenthèse sur domain driven design sur logiciels de musique qui fournit de meilleurs résultats que application directe de modèles existants (petri, etc). Peut-être donner un méta-modèle qui correspond à nos structures ?

Dire pourquoi un tic est introduit lors d'une interaction (notamment, permet de ne pas avoir de "boucle infinie" si on a une boucle de durée 0 avec deux triggers vrais) ; est aussi plus cohérent pour les utilisateurs pour qui une interaction doit être manifeste.

Avantage: manipulation uniforme des processus, que ce soit des automatisations, des groupes, des fichiers sons, etc.

10. Conclusion

missing: quantification

Supplementary Materials: The following are available online at www.mdpi.com/link, Figure S1: title, Table S1: title, Video S1: title.

Acknowledgments: Blue Yeti, ANRT, SCRIME All sources of funding of the study should be disclosed. Please clearly indicate grants that you have received in support of your research work. Clearly state if you received funds for covering the costs to publish in open access.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "X.X. and Y.Y. conceived and

designed the experiments; X.X. performed the experiments; X.X. and Y.Y. analyzed the data; W.W. contributed reagents/materials/analysis tools; Y.Y. wrote the paper." Authorship must be limited to those who have contributed substantially to the work reported.

Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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