The Arpeggigon: A Functional Reactive Musical Automaton

Haskell in Leipzig 2017, 26–27 Oct., Leipzig

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The Arpeggigon (1)

- Software realisation of the reacTogon:

- Interactive cellular automaton:
  - Configuration
  - Performance parameters

The Arpeggigon (2)

- Implemented in Haskell using:
  - The Functional Reactive Programming (FRP) system Yampa
  - Reactive Values and Relations (RVR)
- Based on the *Harmonic Table*

Code: `https://gitlab.com/chupin/arpeggigon`
Video:
`https://www.youtube.com/watch?v=v0HIkFR1EN4`

Before you get too excited: ***Work in progress!***

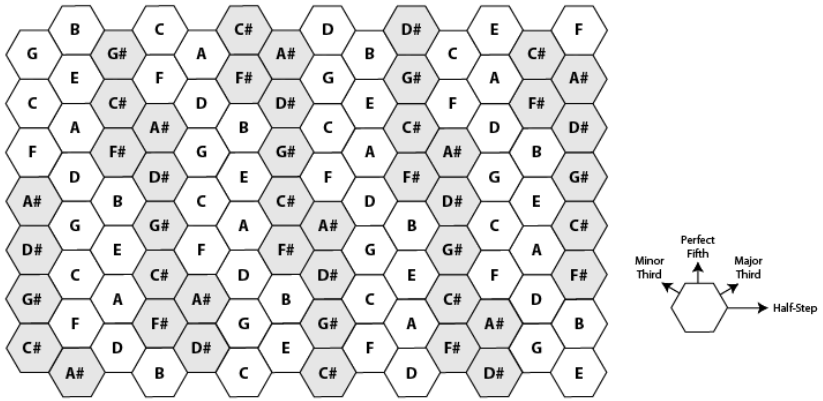
Motivation

Exploring FRP and RVR as an (essentially) declarative way for developing full-fledged musical applications:

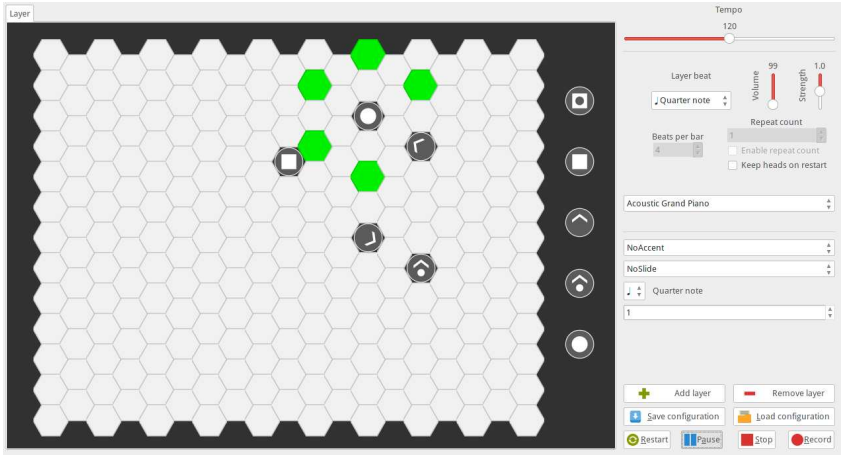
- FRP aligns with declarative and temporal (discrete and continuous) nature of music
- RVR allows declarative-style interfacing with external components

The ***structure*** of the application should be such that it in principle is usable in a MIDI-studio setting.

The Harmonic Table



Running a Sample Configuration



The Rest of this Talk

- Brief introduction to FRP and Yampa
- The Arpeggigon core
- Brief introduction to Reactive Values and Relations
- The Arpeggigon shell

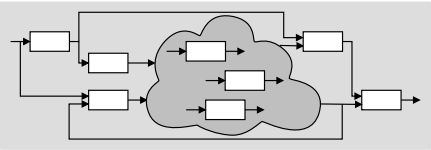
Functional Reactive Programming

- Key idea: Don't program one-time-step-at-a-time, but describe an evolving entity as a ***whole***.
- Combines conceptual simplicity of ***synchronous data flow*** with the flexibility of ***higher-order functional programming***:
  - First class temporal abstractions
  - Dynamic system structure
- Traditionally ***hybrid***: mixed continuous and discrete time

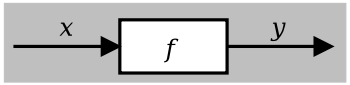
Good conceptual fit for games, musical applications . . .

Yampa

- FRP implementation embedded in Haskell
- Key notions:
  - ***Signals***: time-varying values
  - ***Signal Functions***: pure functions on signals
  - ***Switching***: temporal composition of signal functions
- Programming model:



Signal Functions (1)

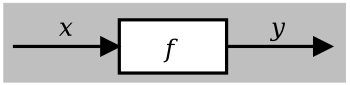


Intuition:

$$Time \approx \mathbb{R}$$
$$Signal\ a \approx Time \to a$$
$$x :: Signal\ T1$$
$$y :: Signal\ T2$$
$$SF\ a\ b \approx Signal\ a \to Signal\ b$$
$$f :: SF\ T1\ T2$$

Additionally, ***causality*** required: output at time t must be determined by input on interval $[0, t]$.

Signal Functions (2)



Example:

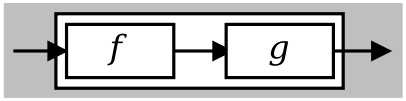
$$integral :: VectorSpace\ a\ s \Rightarrow SF\ a\ a$$
$$y(t) = \int_0^t x(\tau)\,\mathrm{d}\tau$$

Clearly causal: output at time t determined by input on interval $[0, t]$.

Composition

In Yampa, systems are described by combining signal functions (forming new signal functions).

For example, serial composition:

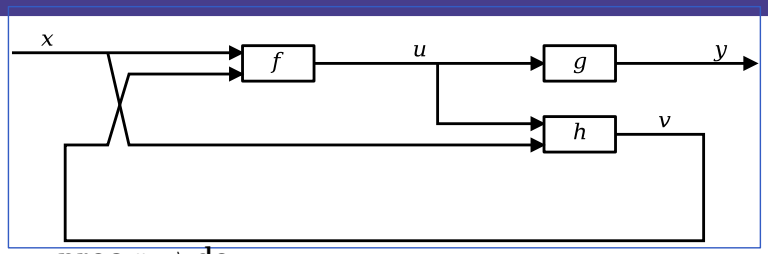


A ***combinator*** that captures this idea:

$$(\ggg) :: SF\ a\ b \to SF\ b\ c \to SF\ a\ c$$

Signal functions are the primary notion; signals a secondary one, only existing indirectly.

Arrow Notation



$\mathbf{proc}\ x \rightarrow \mathbf{do}$

$\mathbf{rec}$

$u \leftarrow f \prec (x, v)$

$y \leftarrow g \prec u$

$v \leftarrow h \prec (u, x)$

$returnA \prec y$

Only syntactic sugar: everything translated into a combinator expression.

Events

Yampa models discrete-time signals by lifting the ***co-domain*** of signals using an option-type:

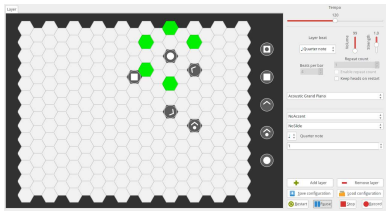
$$\mathbf{data}\ Event\ a = NoEvent \mid Event\ a$$

Discrete-time signal $=$ `Signal` (`Event` α).

Some functions and event sources:

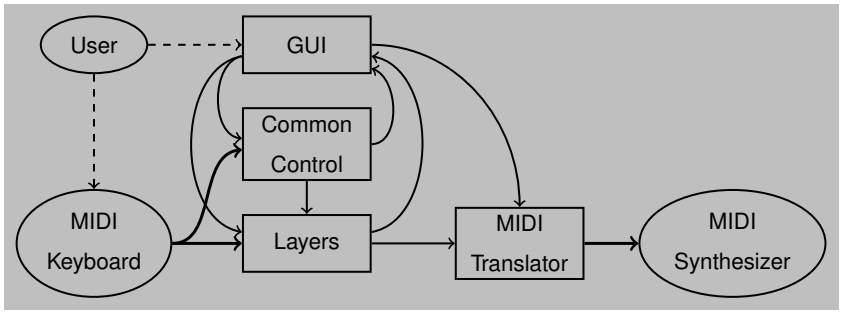
$$tag :: Event\ a \rightarrow b \rightarrow Event\ b$$
$$after :: Time \rightarrow b \rightarrow SF\ a\ (Event\ b)$$
$$edge :: SF\ Bool\ (Event\ ())$$

Aspects of the Arpeggigon



- ***Interactive***
- Layers can be added/removed: ***dynamic structure***
- Notes generated at ***discrete*** points in time
- Configuration and performance parameters can be changed at ***any*** time

Arpeggigon Architecture



Cellular Automaton

State transition function for the cellular automaton:

$$\begin{aligned} advanceHeads &:: Board \to BeatNo \to RelPitch \to Strength \\ &\to [PlayHead] \to ([PlayHead], [Note]) \end{aligned}$$

Lifted into a signal function primarily using $accumBy$:

$$accumBy :: (b \to a \to b) \to b \to SF\ (Event\ a)\ (Event\ b)$$

$$\begin{aligned} automaton &:: [PlayHead] \\ &\to SF\ (Board, DynamicLayerCtrl, Event\ BeatNo) \\ &\quad (Event\ [Note], [PlayHead]) \end{aligned}$$

Automated Smooth Tempo Change

Smooth transition between two preset tempos:

$$\begin{aligned} &smoothTempo :: Tempo \to SF\ (Bool, Tempo, Tempo, Rate)\ Tempo \\ &smoothTempo\ tpo0 = \mathbf{proc}\ (sel1, tpo1, tpo2, rate) \to \mathbf{do} \\ &\quad \mathbf{rec} \\ &\qquad \mathbf{let}\ desTpo = \mathbf{if}\ sel1\ \mathbf{then}\ tpo1\ \mathbf{else}\ tpo2 \\ &\qquad\quad diff\ \ = desTpo - curTpo \\ &\qquad\quad rate'\ = \mathbf{if}\ \ diff > 0.1\ \ \mathbf{then}\ rate \\ &\qquad\qquad\quad \mathbf{else\ if}\ diff < -0.1\ \mathbf{then}\ -rate \\ &\qquad\qquad\quad \mathbf{else}\ \ 0 \\ &\qquad curTpo \leftarrow arr\ (+tpo0) \lll integral \prec rate' \\ &\quad returnA \prec curTpo \end{aligned}$$

Reactive Values and Relations (1)

- The Arpeggigon interacts with the outside world using two imperative toolkits:
  - GUI: GTK+
  - MIDI I/O: Jack
- Very imperative APIs: Hard or impossible to provide FRP wrappers.
- Instead, we use Ivan Perez's ***Reactive Values and Relations*** (RVR) to wrap the FRP core in a "shell" that acts as a bridge between the outside world and the pure FRP core.

Reactive Values and Relations (2)

- A Reactive Value (RV) is a typed mutable value with access rights and subscribable change notification.
- RVs provide a uniform interface to GUI widgets, files, network devices, ...
- A Reactive Relation (RR) is a relation between RVs that is maintained automatically.
- RVR programming takes place in the IO monad, allowing arbitrary interfacing with imperative APIs.
- Yet, the high-level view is quite declarative/FRP-like.

System Tempo Slider

```
globalSettings :: IO (VBox, ReactiveFieldReadWrite IO Int)
globalSettings = do
  globalSettingsBox ← vBoxNew False 10
  tempoAdj          ← adjustmentNew 120 40 200 1 1 1
  tempoLabel        ← labelNew (Just "Tempo")
  boxPackStart globalSettingsBox tempoLabel PackNatural 0
  tempoScale        ← hScaleNew tempoAdj
  boxPackStart globalSettingsBox tempoScale PackNatural 0
  scaleSetDigits tempoScale 0
  let tempoRV =
    bijection (floor, fromIntegral)
    `liftRW` scaleValueReactive tempoScale
  return (globalSettingsBox, tempoRV)
```


Pause

- Pausing is achieved by setting the tempo to 0 when the pause button is engaged.
- Easy to implement by combining two RVs:

```
tempoRV' =
  liftR2 (λtempo paused → if paused then 0 else tempo)
         tempoRV
         pauseButtonRV
```

- This is an equation defining $tempoRV'$ once and for all.

Connecting the Core to the Shell

The following function makes a signal function available as RVs:

```
yampaReactiveDual ::
  a
  → SF a b
  → IO (ReactiveFieldWrite IO a, ReactiveFieldRead IO b)
```

This creates two reactive values: one for the input and one for the output of the signal function.

Summary

- Yampa (FRP) good fit for writing interactive musical applications in a declarative way.
- Reactive Values and Relations proved very helpful for bridging the gap between the outside world and the FRP core in a fairly declarative way.
- Performance in terms of overall execution time and space perfectly fine.
- ***Timing*** is not yet as tight as it should be due to naive MIDI generation.

Reading (1)

- Henrik Nilsson and Guerric Chupin. Funky Grooves: Declarative Programming of Full-Fledged Musical Applications. In *9th International Symposium on Practical Aspects of Declarative Languages (PADL 2017)*, pp. 163–172, January 2017.
- Ivan Perez and Henrik Nilsson. Bridging the GUI Gap with Reactive Values and Relations. In *Proceedings of the 8th ACM SIGPLAN Symposium on Haskell (Haskell'15)*, pp. 47–58, September 2015.

Reading (2)

- Henrik Nilsson, Antony Courtney, and John Peterson. Functional reactive programming, continued. In *Proceedings of the 2002 Haskell Workshop*, pp. 51–64, October 2002.
- Antony Courtney and Henrik Nilsson and John Peterson. The Yampa Arcade. In *Proceedings of the 2003 Haskell Workshop*, pp. 7–18, August 2003.