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:

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- Interactive cellular automaton:
  - Configuration
  - Performance parameters

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- Implemented in Haskell using:
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Video:
`https://www.youtube.com/watch?v=v0HIkFR1EN4`

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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
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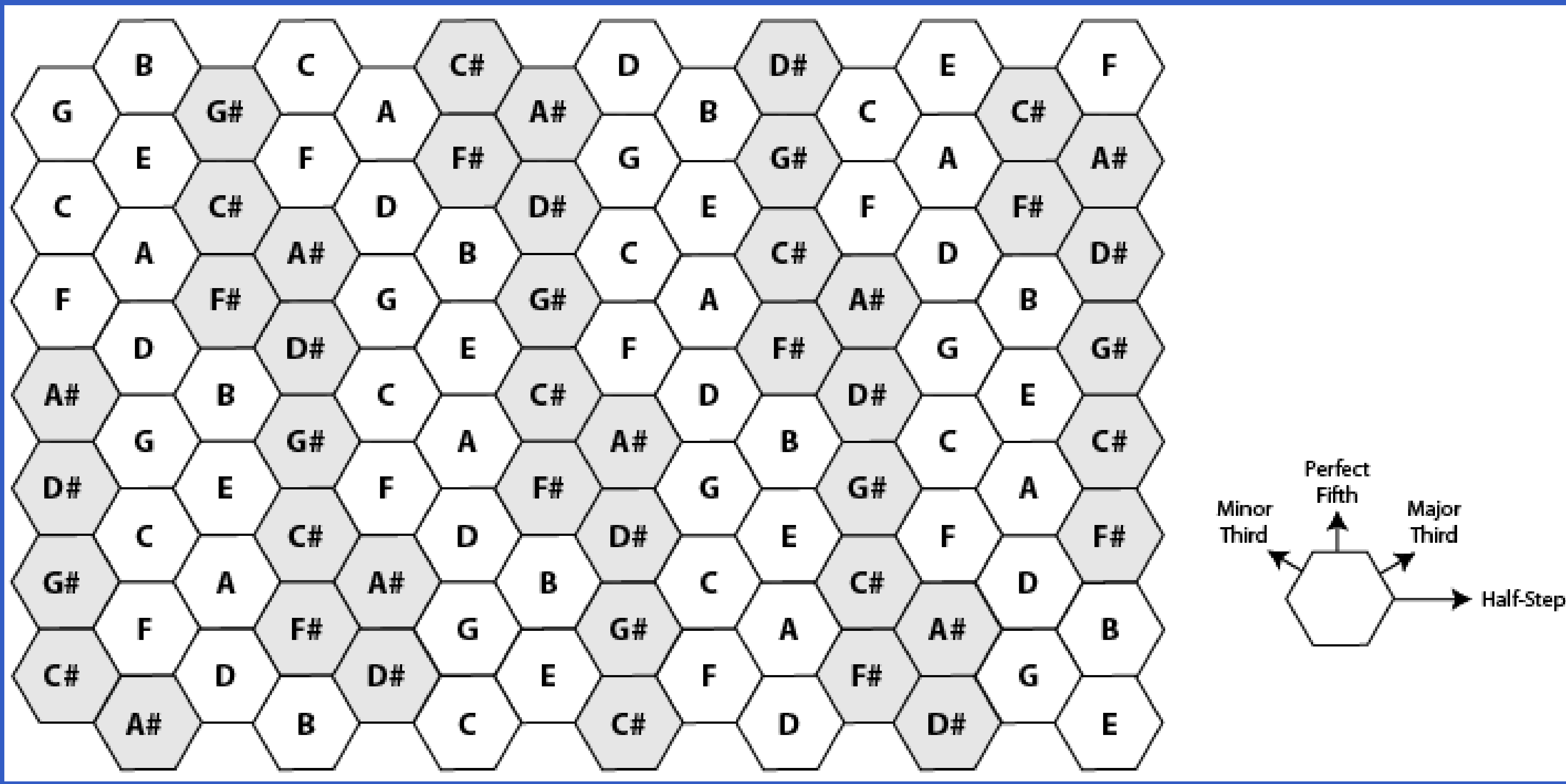
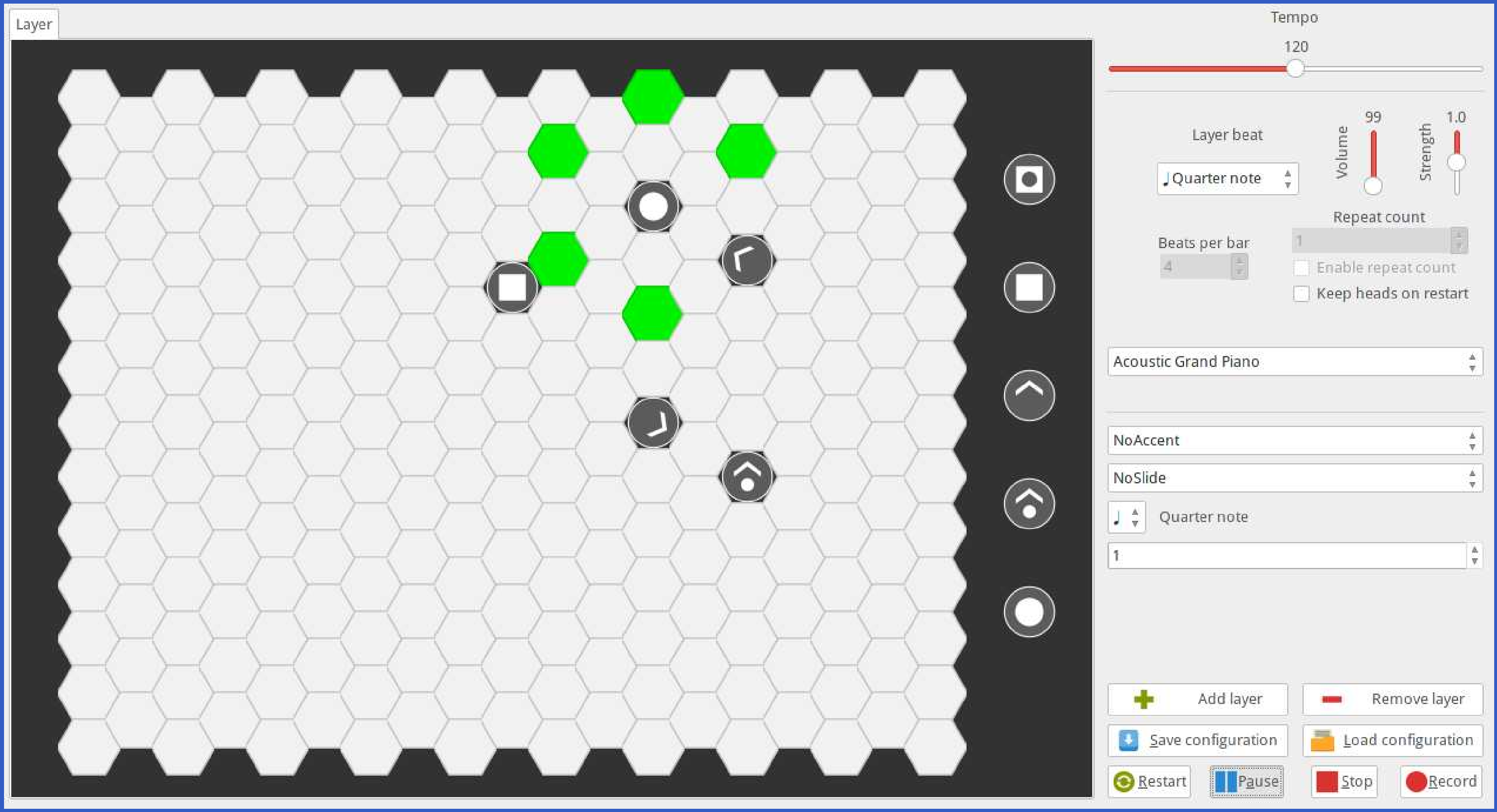
- RVR allows declarative-style interfacing with external components

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

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Good conceptual fit for games, musical applications . . .

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  - ***Signal Functions***: pure functions on signals
  - ***Switching***: temporal composition of signal functions

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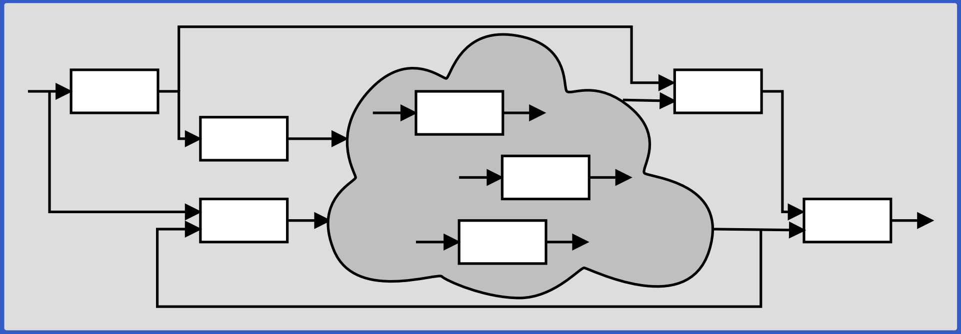

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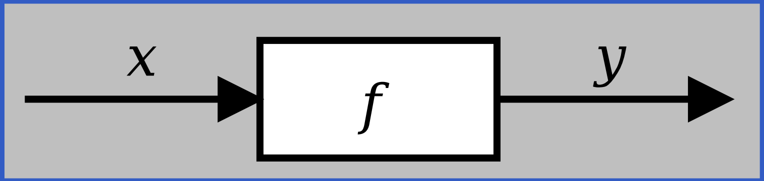

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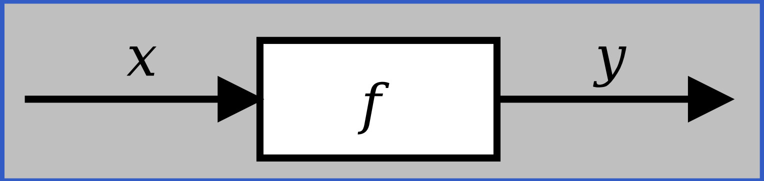

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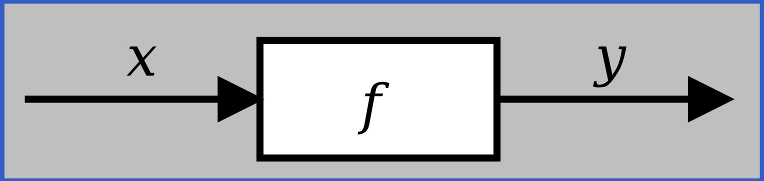

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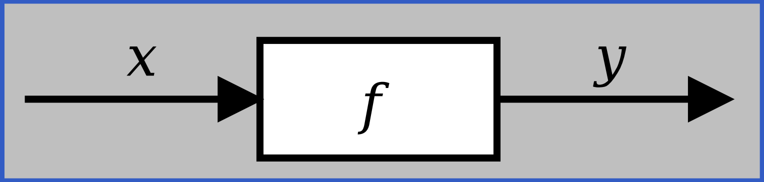

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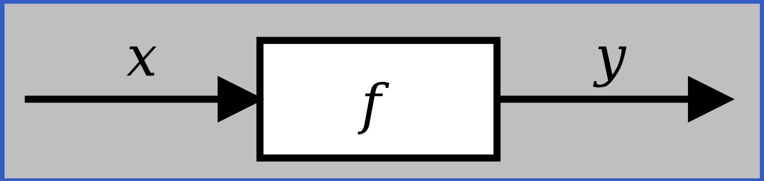

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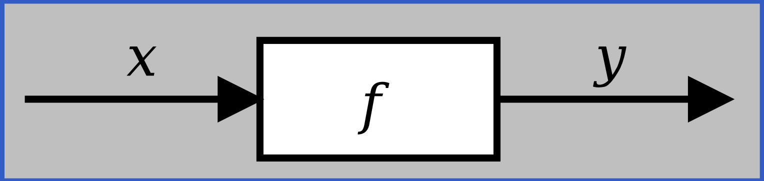

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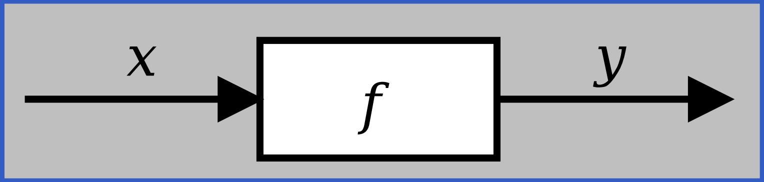
Additionally, ***causality*** required: output at time t must be determined by input on interval $[0, t]$.

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 $[0, t]$.

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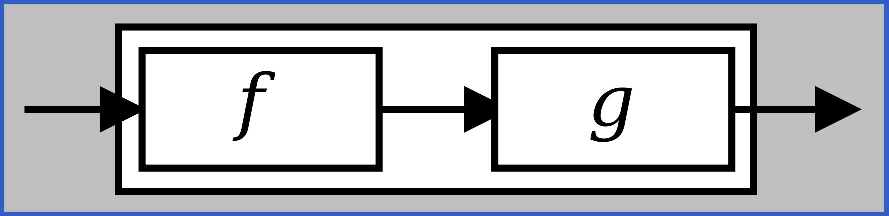

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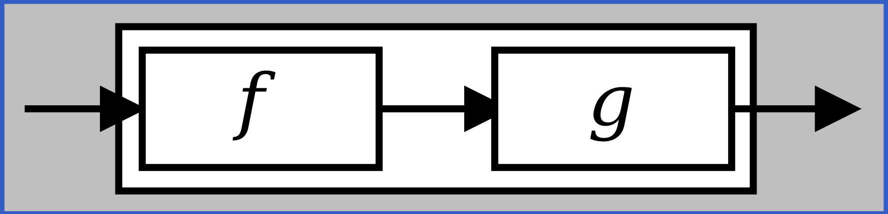

A ***combinator*** that captures this idea:

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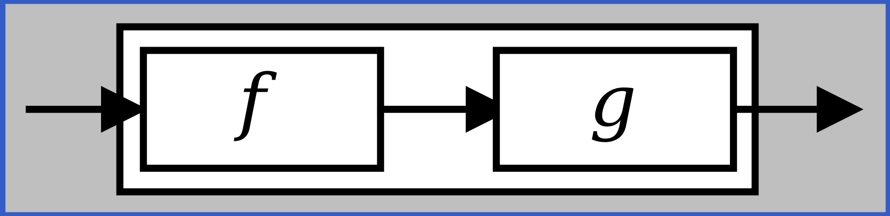

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Signal functions are the primary notion; signals a secondary one, only existing indirectly.

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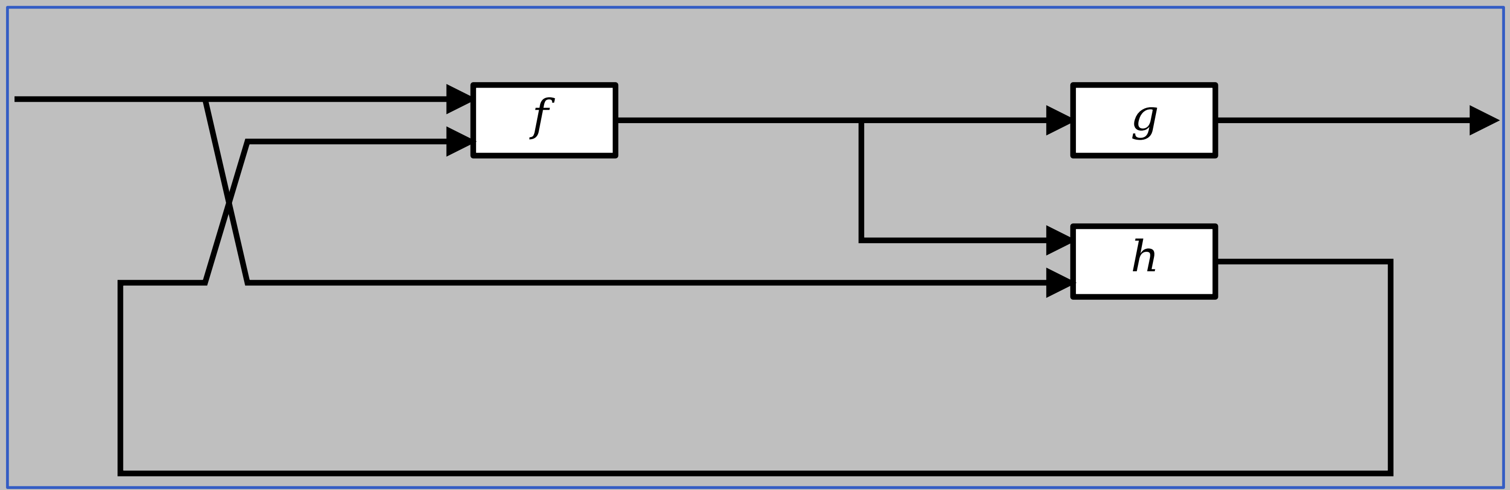

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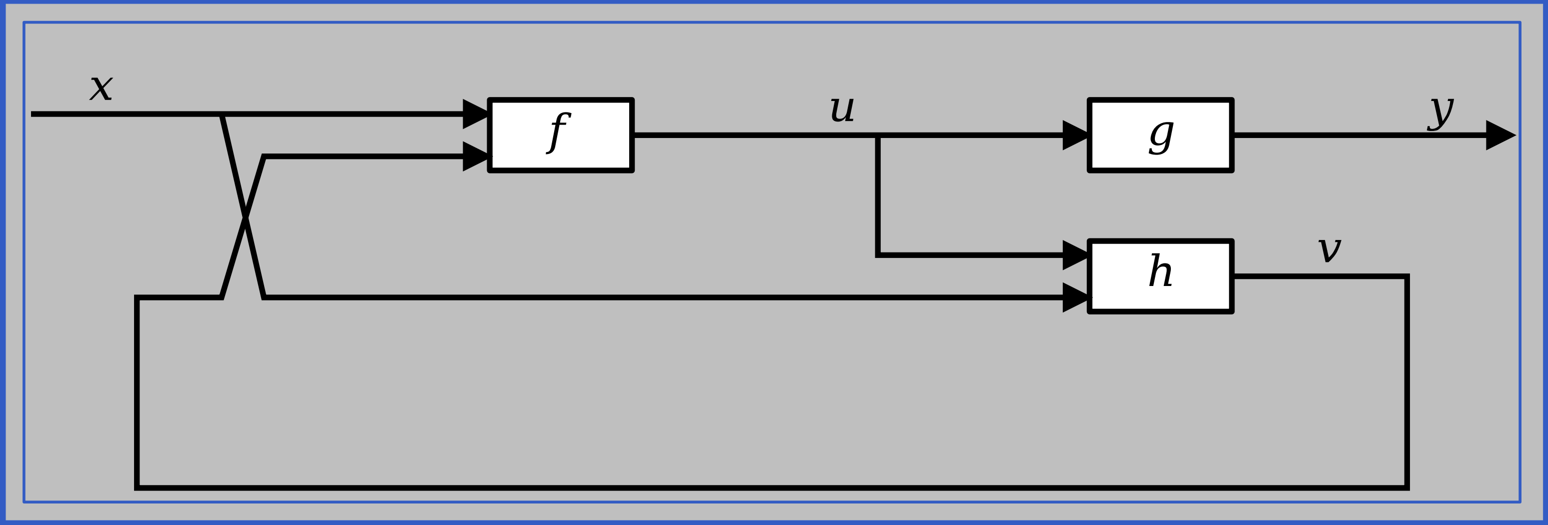

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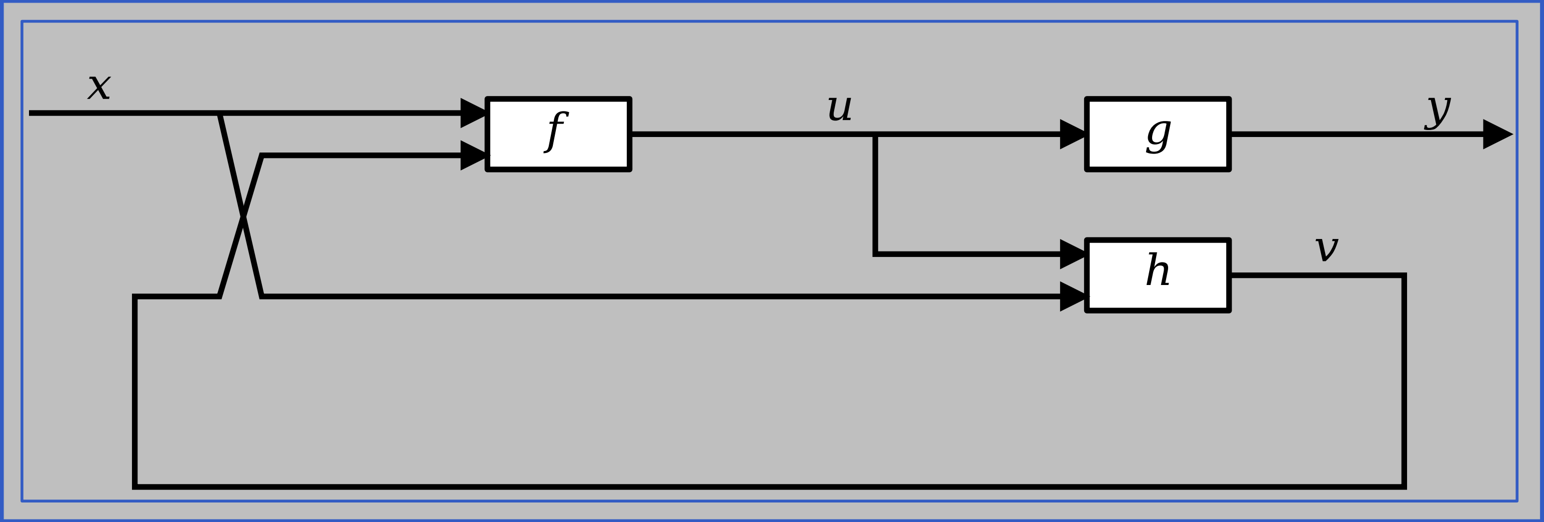

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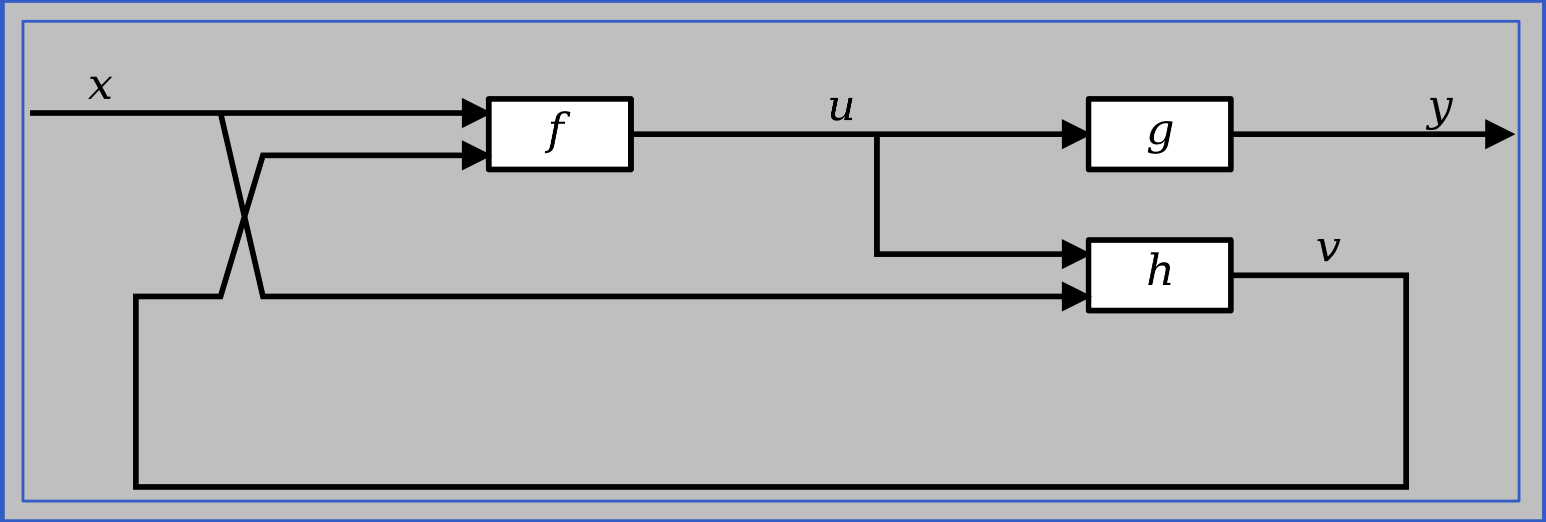

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Only syntactic sugar: everything translated into a combinator expression.

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 $= \texttt{Signal}\ (\texttt{Event}\ \alpha)$.

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

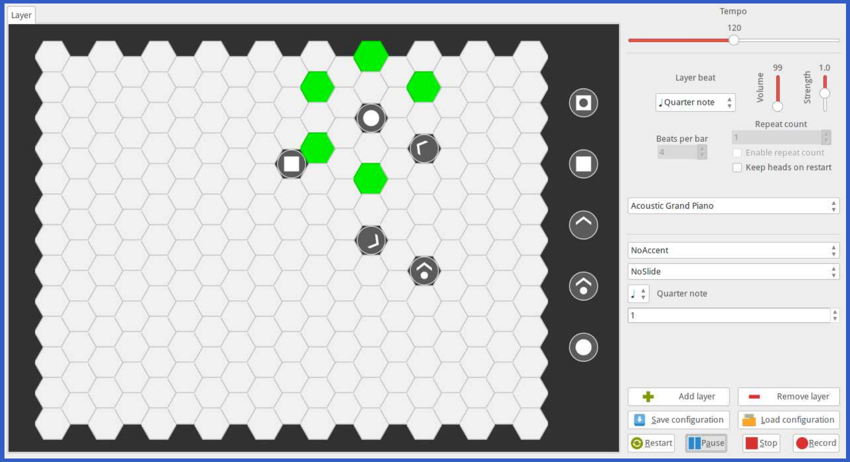
Some functions and event sources:

$$tag :: Event\ a \to b \to Event\ b$$

$$after :: Time \to b \to SF\ a\ (Event\ b)$$

$$edge :: SF\ Bool\ (Event\ ())$$

Aspects of the Arpeggigon



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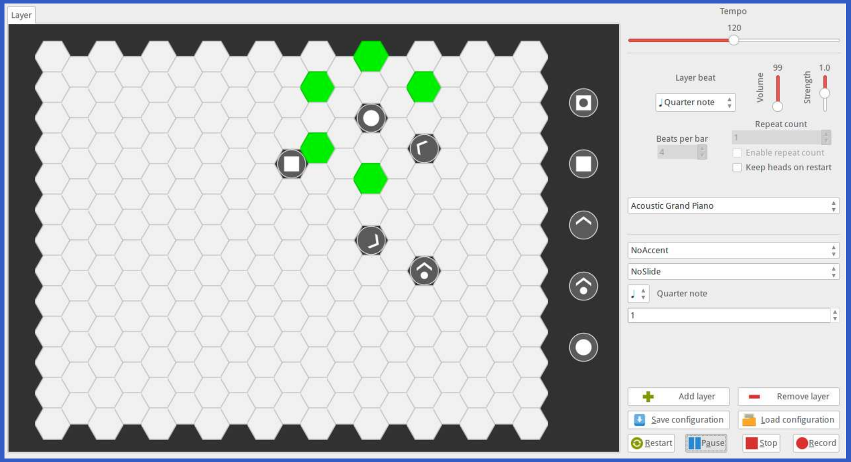

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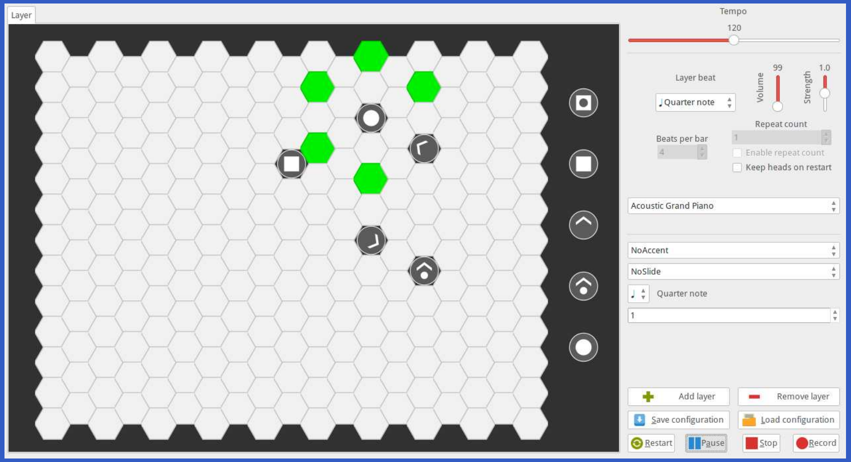

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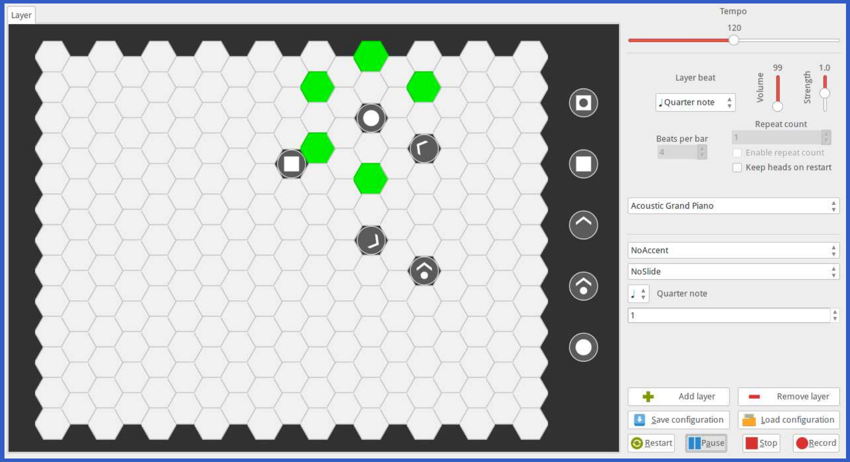

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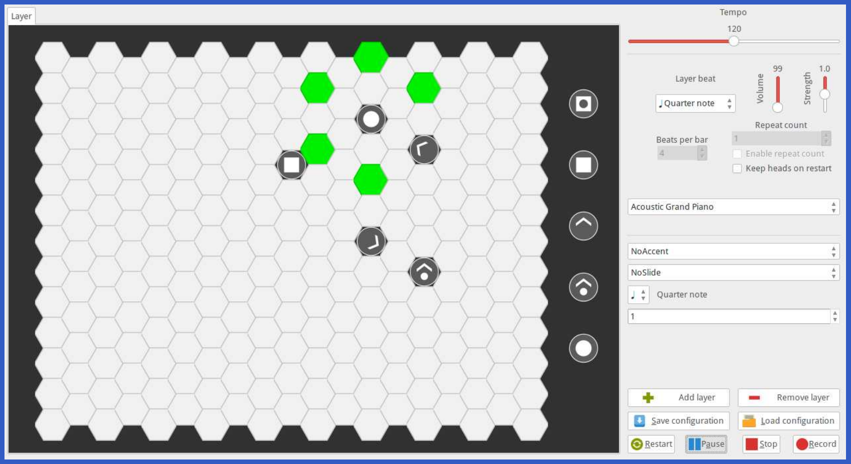
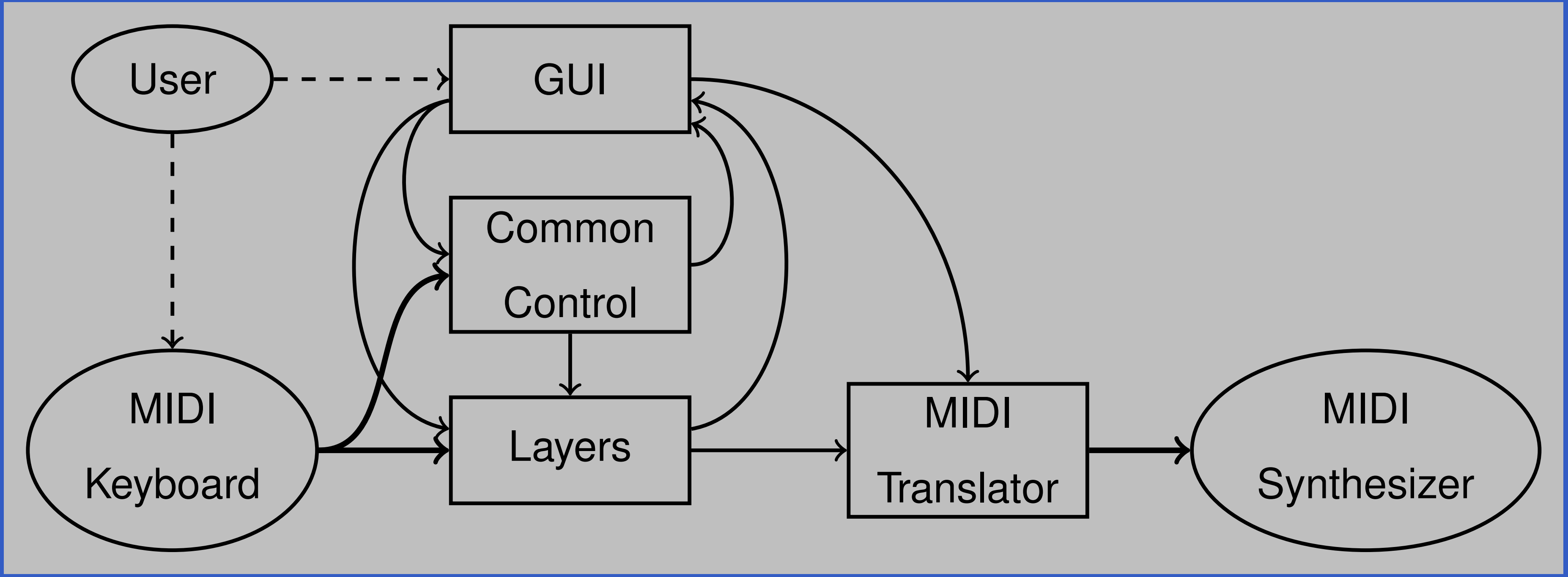


- ***Interactive***
- Layers can be added/removed: ***dynamic structure***
- Notes generated at ***discrete*** points in time
- Configuration and performance parameters can be changed at ***any*** time

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 $accumBy$:

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

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

Automated Smooth Tempo Change

Smooth transition between two preset tempos:

$$smoothTempo :: Tempo \rightarrow SF\ (Bool, Tempo, Tempo, Rate)\ Temp$$

$$\begin{array}{l}
smoothTempo\ tpo0 = \mathbf{proc}\ (sel1, tpo1, tpo2, rate) \rightarrow \mathbf{do} \\
\quad \mathbf{rec} \\
\quad\quad \mathbf{let}\ desTpo = \mathbf{if}\ sel1\ \mathbf{then}\ tpo1\ \mathbf{else}\ tpo2 \\
\quad\quad\quad\quad diff \quad = desTpo - curTpo \\
\quad\quad\quad\quad rate' \quad = \mathbf{if}\ \quad diff > 0.1\ \mathbf{then}\ rate \\
\quad\quad\quad\quad\quad\quad \mathbf{else\ if}\ diff < -0.1\ \mathbf{then}\ -rate \\
\quad\quad\quad\quad\quad\quad \mathbf{else}\ \quad 0 \\
\quad\quad curTpo \leftarrow arr\ (+tpo0) \lll integral \prec rate' \\
\quad returnA \prec curTpo
\end{array}$$

Reactive Values and Relations (1)

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- The Arpeggigon interacts with the outside world using two imperative toolkits:
  - GUI: GTK+
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- 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.

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- 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)
```

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- 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:

$$
\begin{aligned}
&\mathit{yampaReactiveDual} :: \\
&\quad a \\
&\quad \rightarrow \mathit{SF}\ a\ b \\
&\quad \rightarrow \mathit{IO}\ (\mathit{ReactiveFieldWrite}\ \mathit{IO}\ a, \mathit{ReactiveFieldRead}\ \mathit{IO}\ b)
\end{aligned}
$$

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

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- 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.