ITU FRP 2010

Lecture 6:
Switched-on Yampa:
Programming Modular Synthesizers in Haskell

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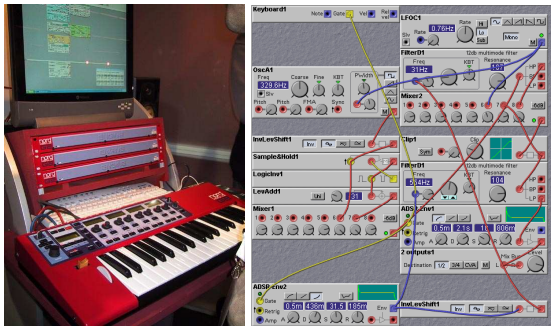
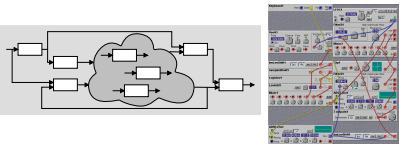
Modular synthesizers?

Modern Modular Synthesizers



Where does Yampa enter the picture?

- Music can be seen as a hybrid phenomenon. Thus interesting to explore a hybrid approach to programming music and musical applications.
- Yampa's programming model is very reminiscent of programming modular synthesizers:



- Fun application! Useful for teaching?

What have we done?

Framework for programming modular synthesizers in Yampa:

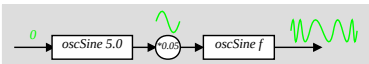
- Sound-generating and sound-shaping modules
- Additional supporting infrastructure:
  - Input: MIDI files (musical scores), keyboard
  - Output: audio files (.wav), sound card
  - Reading SoundFont files (instrument definitions)
- Status: proof-of-concept, but decent performance.

Example 1: Sine oscillator

$$
\begin{aligned}
&\mathit{oscSine} :: \mathit{Frequency} \rightarrow \mathit{SF}\ \mathit{CV}\ \mathit{Sample}\\
&\mathit{oscSine}\ \mathit{f0} = \mathbf{proc}\ \mathit{cv} \rightarrow \mathbf{do}\\
&\quad \mathbf{let}\ f = \mathit{f0} * (2 ** \mathit{cv})\\
&\quad \mathit{phi} \leftarrow \mathit{integral} \rightarrowtail 2 * \mathit{pi} * f\\
&\quad \mathit{returnA} \rightarrowtail \mathit{sin}\ \mathit{phi}
\end{aligned}
$$

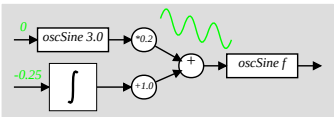
$$\mathit{constant}\ 0 \ggg \mathit{oscSine}\ 440$$

Example 2: Vibrato



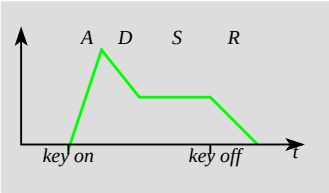
$$
\begin{aligned}
&\mathit{constant}\ 0\\
&\ggg \mathit{oscSine}\ 5.0\\
&\ggg \mathit{arr}\ (*0.05)\\
&\ggg \mathit{oscSine}\ 440
\end{aligned}
$$

Example 3: 50's Sci Fi



$$
\begin{aligned}
&\mathit{sciFi} :: \mathit{SF}\ ()\ \mathit{Sample}\\
&\mathit{sciFi} = \mathbf{proc}\ () \rightarrow \mathbf{do}\\
&\quad \mathit{und} \leftarrow \mathit{arr}\ (*0.2) \lll \mathit{oscSine}\ 3.0 \rightarrowtail 0\\
&\quad \mathit{swp} \leftarrow \mathit{arr}\ (+1.0) \lll \mathit{integral} \rightarrowtail -0.25\\
&\quad \mathit{audio} \leftarrow \mathit{oscSine}\ 440 \rightarrowtail \mathit{und} + \mathit{swp}\\
&\quad \mathit{returnA} \rightarrowtail \mathit{audio}
\end{aligned}
$$

Envelope Generators (1)

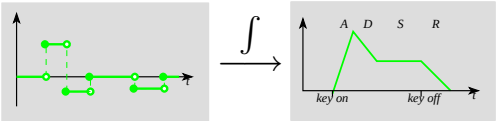


$$
\begin{aligned}
&\mathit{envGen} :: \mathit{CV} \rightarrow [(\mathit{Time}, \mathit{CV})] \rightarrow (\mathit{Maybe}\ \mathit{Int})\\
&\qquad \rightarrow \mathit{SF}\ (\mathit{Event}\ ())\ (\mathit{CV}, \mathit{Event}\ ())\\
&\mathit{envEx} = \mathit{envGen}\ 0\ [(0.5, 1), (0.5, 0.5), (1.0, 0.5), (0.7, 0)]\\
&\qquad (\mathit{Just}\ 3)
\end{aligned}
$$

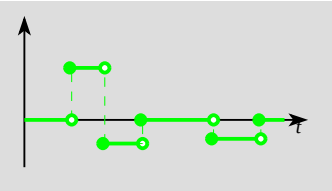
Envelope Generators (2)

How to implement?

Integration of a step function yields suitable shapes:



Envelope Generators (3)



$$
\begin{aligned}
&afterEach :: [(Time, b)] \to SF\ a\ (Event\ b)\\
&hold \quad :: a \to SF\ (Event\ a)\ a\\
&steps = afterEach\ [(0.7, 2), (0.5, -1), (0.5, 0), (1, -0.7), (0.7, 0)]\\
&\qquad \ggg hold\ 0
\end{aligned}
$$

Envelope Generators (4)

Envelope generator with predetermined shape:

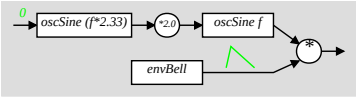
$$
\begin{aligned}
&envGenAux :: CV \to [(Time, CV)] \to SF\ a\ CV\\
&envGenAux\ l0\ tls = afterEach\ trs \ggg hold\ r0\\
&\qquad \ggg integral \ggg arr\ (+l0)\\
&\quad \textbf{where}\\
&\qquad (r0, trs) = toRates\ l0\ tls
\end{aligned}
$$

Envelope Generators (5)

Envelope generator responding to key off:

$$
\begin{aligned}
&envGen :: CV \to [(Time, CV)] \to (Maybe\ Int)\\
&\qquad \to SF\ (Event\ ())\ (CV, Event\ ())\\
&envGen\ l0\ tls\ (Just\ n) =\\
&\quad switch\ (\textbf{proc}\ noteoff \to \textbf{do}\\
&\qquad l \leftarrow envGenAux\ l0\ tls1 \prec ()\\
&\qquad returnA \prec ((l, noEvent), noteoff\ `tag`\ l))\\
&\qquad (\lambda l \to envGenAux\ l\ tls2\\
&\qquad \&\&\&\ after\ (sum\ (map\ fst\ tls2))\ ())\\
&\quad \textbf{where}\\
&\qquad (tls1, tls2) = splitAt\ n\ tls
\end{aligned}
$$

Example 4: Bell



$$
\begin{aligned}
&bell :: Frequency \to SF\ ()\ (Sample, Event)\\
&bell\ f = \textbf{proc}\ () \to \textbf{do}\\
&\quad m \leftarrow oscSine\ (2.33 * f) \prec 0\\
&\quad audio \leftarrow oscSine\ f \prec 2.0 * m\\
&\quad (ampl, end) \leftarrow envBell \prec noEvent\\
&\quad returnA \prec (audio * ampl, end)
\end{aligned}
$$

Example 5: Tinkling Bell

$$
\begin{aligned}
&tinkle :: SF\ ()\ Sample\\
&tinkle = (repeatedly\ 0.25\ 84\\
&\qquad \ggg constant\ ()\\
&\qquad \quad \&\&\&\ arr\ (fmap\ (bell \circ midiNoteToFreq))\\
&\qquad \ggg rSwitch\ (constant\ 0))
\end{aligned}
$$

Example 6: Playing a C-major scale

$$
\begin{aligned}
&scale :: SF\ ()\ Sample\\
&scale = (afterEach\ [(0.0, 60), (2.0, 62), (2.0, 64),\\
&\qquad\qquad (2.0, 65), (2.0, 67), (2.0, 69),\\
&\qquad\qquad (2.0, 71), (2.0, 72)]\\
&\qquad \ggg constant\ ()\\
&\qquad \quad \&\&\&\ arr\ (fmap\ (bell \circ midiNoteToFreq))\\
&\qquad \ggg rSwitch\ (constant\ 0))\\
&\quad \&\&\&\ after\ 16\ ()
\end{aligned}
$$

Example 7: Playing simultaneous notes

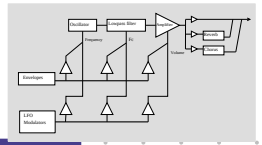
$$
\begin{aligned}
&mysterySong :: SF\ ()\ (Sample, Event\ ())\\
&mysterySong = \textbf{proc}\ \_ \to \textbf{do}\\
&\quad t \leftarrow tinkle \prec ()\\
&\quad m \leftarrow mystery \prec ()\\
&\quad returnA \prec (0.4 * t + 0.6 * m)
\end{aligned}
$$

A polyphonic synthesizer (1)

Sample-playing monophnic synthesizer:

- Read samples (instrument recordings) from SoundFont file into internal table.
- Oscillator similar to sine oscillator, except table lookup and interpolation instead of computing the sine.

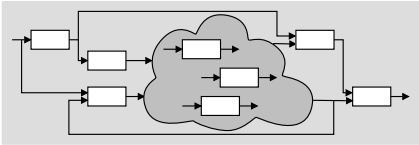
SoundFont synthesizer structure:



A polyphonic synthesizer (2)

Exploit Yampa's switching capabilities to:

- create and switch in a mono synth instance is response to each note on event;
- switch out the instance in response to a corresponding note off event.



Switched-on Yampa?

Software and paper: `www.cs.nott.ac.uk/~ggg`