Efficient audio signal processing using LLVM and Haskell

Henning Thielemann

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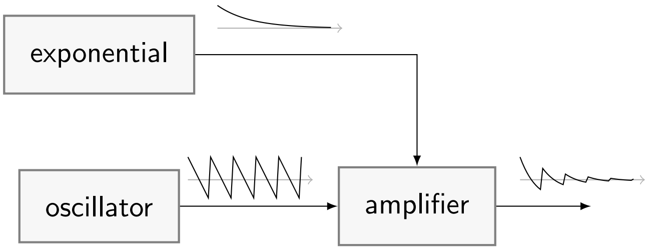
Haskell and Signal Processing

Thinking in terms of signal flow diagrams
means thinking functional.




```
amplify
   (exponential halfLife amp)
   (oscillator Wave.saw phase freq)
```

Haskell and LLVM

Haskell

- strong type system
- purely functional
- lazy = stream processing
- efficiency is not primary

LLVM

- produces efficient code, especially vector instructions
- weak type system
- Just-In-Time compilation
    - transparent usage in Haskell
    - adaption to available vector instructions

Embedded Domain Specific Language

```
amplify
   (exponential halfLife amp)
   (oscillator Wave.saw phase freq)
```

Direct interpretation:

- `exponential` and `oscillator` create infinite (lazy) lists of sample values
- `amplify` multiplies two lists element-wise

EDSL interpretation:

- `exponential` and `oscillator` provide LLVM IR code for generating values successively
- `amplify` appends the code provided by `exponential` and `oscillator` and multiplies their generated values

Embedded Domain Specific Language – Problems

Needed to solve more problems:

- sharing ($\rightarrow$ causal arrows)
- feedback ($\rightarrow$ causal arrows)
- cumbersome usage of arrows ($\rightarrow$ functional interface)
- passing parameters to LLVM code (complicated by bug 8281)
- vector computing
- expensive computation of frequency filter parameters ($\rightarrow$ opaque types)

Types of Vectorisation needed for Signal Processing

Given: Vectors of size 2^n

- ideal speedup:
  2^n scalar instructions $\rightarrow$ 1 vector instruction
- often speedup:
  2^n scalar instructions $\rightarrow$ $c \cdot n$ vector instructions

That is:

- Vectorisation not always optimization
- But: Assembling and disassembling vectors and conversion between different vector schemes also expensive
- Auto-vectorisation still possible?

Example: Cumulative Sum (`cumsum`)

Goal:

$$\overset{v_0}{[a, b, c, d]} \quad \rightarrow \quad \overset{v_2}{[a, a+b, a+b+c, a+b+c+d]}$$

Vectorisation:

$$\begin{array}{ll} & v_0 \gg 1 \\ + & v_0 \\ \hline = & v_1 \end{array} \qquad \begin{array}{rccccl} [& & a, & b, & c &] \\ +[& a, & b, & c, & d &] \\ \hline =[& a, & a+b, & b+c, & c+d &] \end{array}$$

$$\begin{array}{ll} & v_1 \gg 2 \\ + & v_1 \\ \hline = & v_2 \end{array} \qquad \begin{array}{rccccl} [& & & a, & a+b &] \\ +[& a, & a+b, & b+c, & c+d &] \\ \hline =[& a, & a+b, & a+b+c, & a+b+c+d &] \end{array}$$

4 vector instructions instead of 3 scalar instructions

Where to do vectorisation in LLVM?

Different approaches:

- Program with vectors in Haskell,
  expand `cumsum` in Haskell (my current approach)
- Program with vectors in Haskell,
  expand `cumsum` in a custom LLVM pass (I'd prefer that)
- Program with scalars in Haskell,
  standard LLVM vectoriser detects `cumsum`
  (seems to be favorite of some LLVM developers)

Optimizations and JIT

- JIT compiles to host machine by default
- Optimizer does not optimize to host machine by default
  Result: crashs
- I was told, I must set target data. Why?
  And how, using the C interface?