A Rationale for Faust Design Decisions

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DSLDI, October 20, 2014

1-Music DSLs Quick Overview

Some Music DSLs

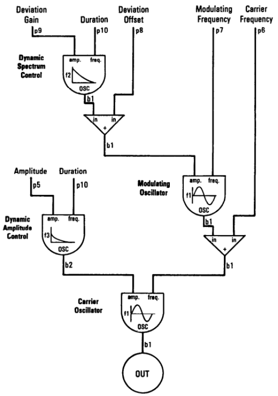
- 4CED
- Adagio
- AML
- AMPLE
- Arctic
- Autoklang
- Bang
- Canon
- CHANT
- Chuck
- CLCE
- CMIX
- Cmusic
- CMUSIC
- Common Lisp Music
- Common Music
- Common Music Notation
- Csound
- CyberBand
- DARMS
- DCMP
- DMIX
- Elody
- EsAC
- Euterpea
- Extempore
- Faust
- Flavors Band
- Fluxus
- FOIL
- FORMES
- FORMULA
- Fugue
- Gibber
- GROOVE
- GUIDO
- HARP
- Haskore
- HMSL
- INV
- invokator
- KERN
- Keynote
- LPC
- Mars
- MASC
- Max
- MidiLisp
- MidiLogo
- MODE
- MOM
- Moxc
- MSX
- MUS10
- MUS8
- MUSCMP
- MuseData
- MusES
- MUSIC 10
- MUSIC 11
- MUSIC 360
- MUSIC 4B
- MUSIC 4BF
- MUSIC 4F
- MUSIC 6
- MCL
- MUSIC III/IV/V
- MusicLogo
- Music1000
- MUSIC7
- Musictex
- MUSIGOL
- MusicXML
- Musixtex
- NIFF
- NOTELIST
- Nyquist
- OPAL
- OpenMusic
- Organum1
- Outperform
- Overtone
- PE
- Patchwork
- PILE
- Pla
- PLACOMP
- PLAY1
- PLAY2
- PMX
- POCO
- POD6
- POD7
- PROD
- Puredata
- PWGL
- Ravel
- SALIERI
- SCORE
- ScoreFile
- SCRIPT
- SIREN
- SMDL
- SMOKE
- SSP
- SSSP
- ST
- Supercollider
- Symbolic Composer

First Music DSLs, Music III/IV/V (Max Mathews)

- 1960: Music III introduces the concept of Unit Generators
- 1963: Music IV, a port of Music III using a macro assembler
- 1968: Music V written in Fortran (inner loops of UG in assembler)

```
ins 0 FM;
osc b1 p9 p10 f2 d;
adn b1 b1 p8;
osc b1 b1 p7 f1 d;
adn b1 b1 p6;
osc b2 p5 p10 f3 d;
osc b1 b2 b1 f1 d;
out b1;
```

FM synthesis coded in CMusic



Csound

Originally developed by Barry Vercoe in 1985, Csound is today "a sound design, music synthesis and signal processing system, providing facilities for composition and performance over a wide range of platforms." (see `http://www.csounds.com`)

```
        instr  2
a1      oscil       p4, p5, 1   ; p4=amp
        out         a1          ; p5=freq
        endin
```

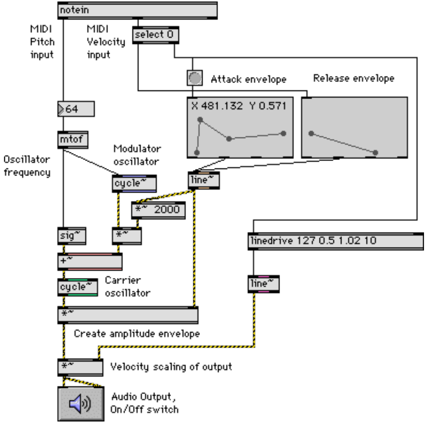
Example of Csound instrument

```
f1    0     4096  10  1        ; sine  wave

;ins  strt  dur   amp(p4)      freq(p5)
i2    0     1     2000         880
i2    1.5   1     4000         440
i2    3     1     8000         220
i2    4.5   1     16000        110
i2    6     1     32000        55

e
```

Example of Csound score

Max

Max (Miller Puckette, 1987) is visual programming language for real time audio synthesis and algorithmic composition with multimedia capabilities. It is named Max in honor of Max Mathews. It was initially developed at IRCAM. Since 1999 Max has been developed and commercialized by Cycling74. (see `http://cycling74.com/`)

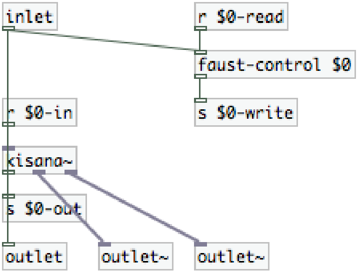


SuperCollider

SuperCollider (James McCartney, 1996) is an open source environment and programming language for real time audio synthesis and algorithmic composition. It provides an interpreted object-oriented language that functions as a network client to a state of the art, real-time sound synthesis server. (see `http://supercollider.sourceforge.net/`)

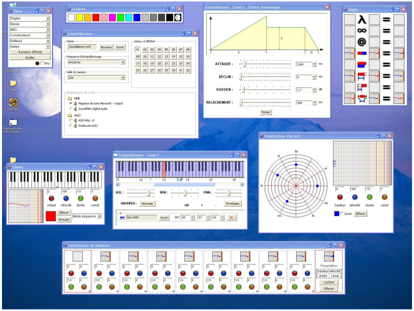
Pure Data

Pure Data (Miller Puckette, 1996) is an open source visual programming language of the Max family. "Pd enables musicians, visual artists, performers, researchers, and developers to create software graphically, without writing lines of code". (see `http://puredata.info/`)



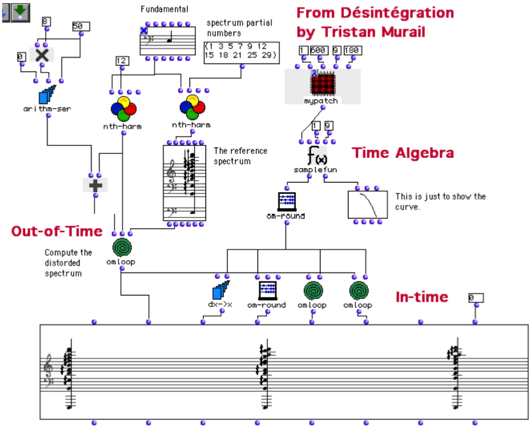
Elody

Elody (Fober, Letz, Orlarey, 1997) is a music composition environment developed in Java. The heart of Elody is a music language that embeds the lambda-calculus. The language expressions are handled through visual constructors and Drag and Drop actions allowing the user to play in real-time with the language.



OpenMusic

OpenMusic (Agon et al. 1998) is a music composition environment embedded in Common Lisp. It introduces a powerful visual syntax to Lisp and provides composers with a large number of composition tools and libraries.



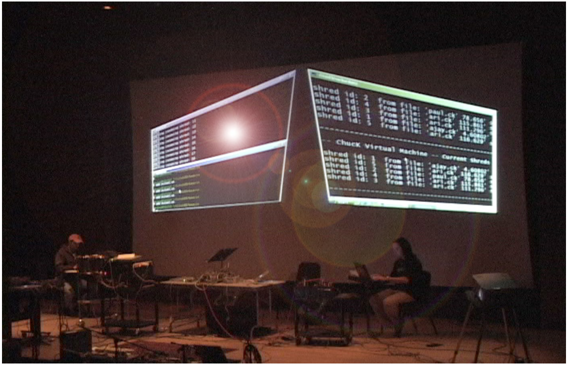
ChucK

ChucK (Ge Wang, Perry Cook 2003) is a concurrent, on-the-fly, audio programming language. It offers a powerful and flexible programming tool for building and experimenting with complex audio synthesis programs, and real-time interactive control. (see `http://chuck.cs.princeton.edu`)

```
// make our patch
SinOsc s => dac;

// time-loop, in which the osc's frequency
// is changed every 100 ms
while( true ) {
   100::ms => now;
   Std.rand2f(30.0, 1000.0) => s.freq;
}
```

Live Coding

Live Coding is programming live, on stage, as an artistic performance.



Reactable

The Reactable is a tangible programmable synthesizer. It was conceived in 2003 by Sergi Jordà, Martin Kaltenbrunner, Günter Geiger and Marcos Alonso at the Pompeu Fabra University in Barcelona.

2-Faust Overview

Brief Overview to Faust

http://faust.grame.fr

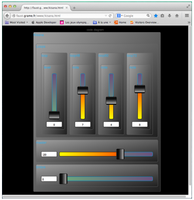
- Faust (Orlarey, Letz, Fober 2002) is a *Domain-Specific Language* for real-time signal processing and synthesis (like *Csound*, *Max/MSP*, *Supercollider*, *Puredata*,...).
- A Faust program denotes a *signal processor*: a *(continuous) function* that maps input *signals* to output *signals*.
- Programming in Faust is essentially combining *signal processors* using an algebra of 5 composition operations:

```
process = noise*hslider("level",0,0,1,0.01);
noise = +(12345)~*(1103515245):/(2147483647.0);
```

Brief overview to Faust

http://faust.grame.fr

- Faust offers end-users a high-level alternative to C to develop audio applications for a large variety of platforms, from desktop to web applications, from audio plug-ins to embedded systems.
- The role of the Faust compiler is to synthesize the most efficient implementations for the target language (C, C++, LLVM, Javascript, etc.).
- Faust is used on stage for concerts and artistic productions, for education and research, for open sources projects and commercial applications:



3-Composing Signal Processors

Faust programs are *signal processors*

- A Faust program denotes a *signal processor* $p : \mathbb{S}^n \rightarrow \mathbb{S}^m$, a (continuous) function that maps a group of n input *signals* to a group of m output *signals*.
- Two kinds of signals:
  - Integer signals: $\mathbb{S}_{\mathbb{Z}} = \mathbb{Z} \rightarrow \mathbb{Z}$
  - Floating-point signals: $\mathbb{S}_{\mathbb{R}} = \mathbb{Z} \rightarrow \mathbb{R}$
  - $\mathbb{S} = \mathbb{S}_{\mathbb{Z}} \cup \mathbb{S}_{\mathbb{R}}$
- The value of a Faust signal is always 0 before time 0:
  - $\forall s \in \mathbb{S}, s(t < 0) = 0$
- Programming in Faust is essentially composing signal processors together using an algebra of five composition operations: `<:` `:>` `:` `,` `~`

Some Primitive Signal Processors

- `!`: $\left| \begin{array}{l} \mathbb{S}^1 \rightarrow \mathbb{S}^0 \\ \lambda\langle x\rangle.\langle\rangle \end{array} \right.$ (cut)
- `_`: $\left| \begin{array}{l} \mathbb{S}^1 \rightarrow \mathbb{S}^1 \\ \lambda\langle x\rangle.\langle x\rangle \end{array} \right.$ (wire)
- `3`: $\left| \begin{array}{l} \mathbb{S}^0 \rightarrow \mathbb{S}^1 \\ \lambda\langle\rangle.\langle\lambda t. \begin{cases} 0 & t < 0 \\ 3 & t \geq 0 \end{cases} \rangle \end{array} \right.$ (number)
- `+`: $\left| \begin{array}{l} \mathbb{S}^2 \rightarrow \mathbb{S}^1 \\ \lambda\langle x, y\rangle.\langle\lambda t.x(t) + y(t)\rangle \end{array} \right.$ (addition)
- `@`: $\left| \begin{array}{l} \mathbb{S}^2 \rightarrow \mathbb{S}^1 \\ \lambda\langle x, y\rangle.\langle\lambda t.x(t - y(t))\rangle \end{array} \right.$ (delay)

Composition Operations

- `(A,B)` parallel composition
- `(A:B)` sequential composition
- `(A<:B)` split composition
- `(A:>B)` merge composition
- `(A~B)` recursive composition

The *parallel composition* `(A,B)` is probably the simplest one. It places the two block-diagrams one on top of the other, without connections.

`(A,B)`: $(\mathbb{S}^n \to \mathbb{S}^m) \to (\mathbb{S}^{n'} \to \mathbb{S}^{m'}) \to (\mathbb{S}^{n+n'} \to \mathbb{S}^{m+m'})$

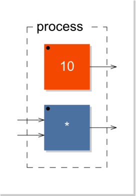


Figure 1 : Example of parallel composition `(10,*)`

Composition Operations

Sequential Composition

The *sequential composition* `(A:B)` connects the outputs of `A` to the corresponding inputs of `B`.

`(A:B)`: $(\mathbb{S}^n \rightarrow \mathbb{S}^m) \rightarrow (\mathbb{S}^m \rightarrow \mathbb{S}^p) \rightarrow (\mathbb{S}^n \rightarrow \mathbb{S}^p)$

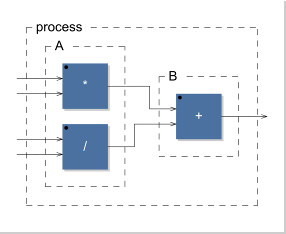


Figure 2 : Example of sequential composition `((*,/):+)`

Composition Operations

Split Composition

The *split composition* `(A<:B)` operator is used to distribute the outputs of `A` to the inputs of `B`.

$$(A<:B): (\mathbb{S}^n \rightarrow \mathbb{S}^m) \rightarrow (\mathbb{S}^{k.m} \rightarrow \mathbb{S}^p) \rightarrow (\mathbb{S}^n \rightarrow \mathbb{S}^p)$$

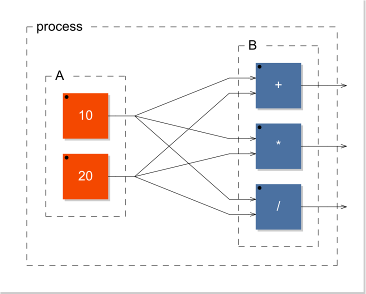


Figure 3 : Example of split composition `((10,20) <: (+,*,/))`

Composition Operations

Merge Composition

The *merge composition* `(A:>B)` is used to connect several outputs of `A` to the same inputs of `B`. Signals connected to the same input are added.

$$\texttt{(A:>B)}: (\mathbb{S}^n \to \mathbb{S}^{k.m}) \to (\mathbb{S}^m \to \mathbb{S}^p) \to (\mathbb{S}^n \to \mathbb{S}^p)$$

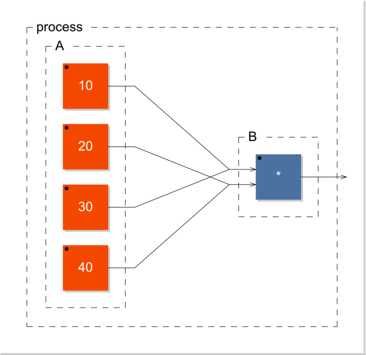


Figure 4 : Example of merge composition `((10,20,30,40) :> *)`

Composition Operations

Recursive Composition

The *recursive composition* (A~B) is used to create cycles in the block-diagram in order to express recursive computations.

$$(A\sim B) : (\mathbb{S}^{n+n'} \rightarrow \mathbb{S}^{m+m'}) \rightarrow (\mathbb{S}^{m'} \rightarrow \mathbb{S}^{n'}) \rightarrow (\mathbb{S}^{n} \rightarrow \mathbb{S}^{m+m'})$$

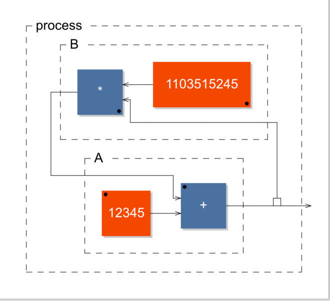
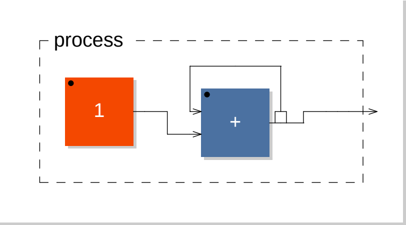


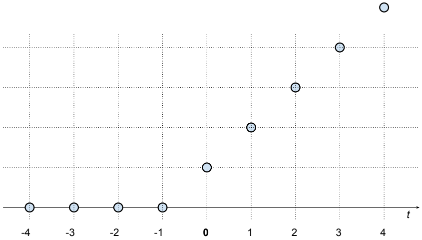
Figure 5 : Example of recursive composition +(12345)~*(1103515245)

A Very Simple Example

```
process = 1 : +~_;
```

$$y(t) = \begin{cases} 0 & t < 0 \\ 1 + y(t-1) = 1 + t & t \geq 0 \end{cases}$$





A Mixer Channel

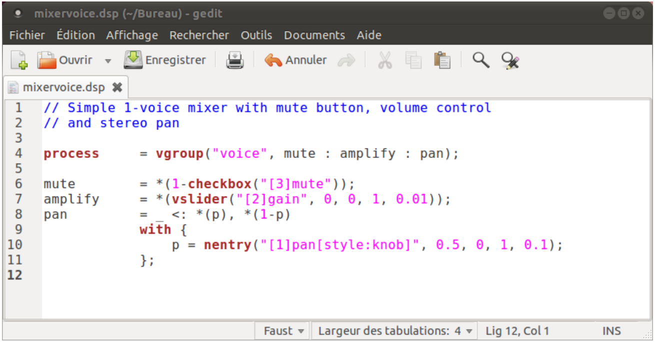


Figure 6 : Source code of a simple mixer channel

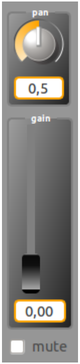
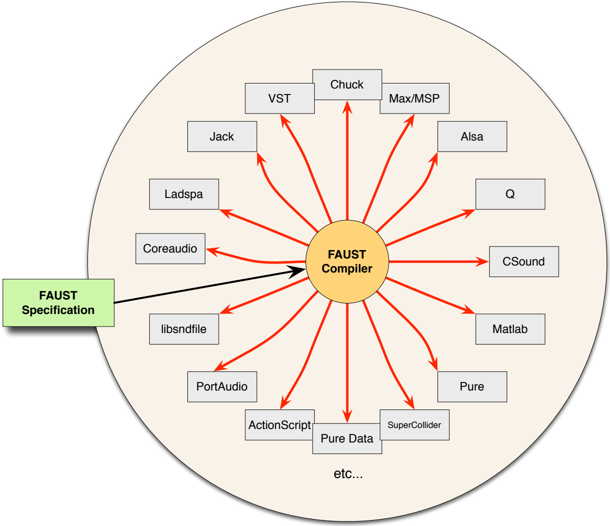


Figure 7 : Resulting application

4-Easy Deployment

Faust Architecture System

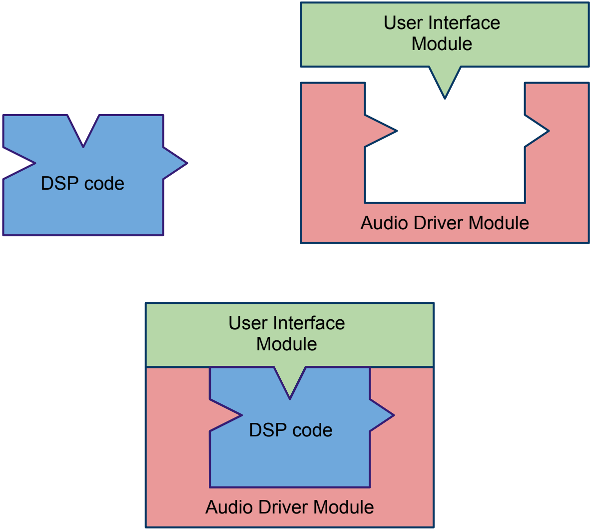
Easy deployment: one Faust code, multiple targets



Faust Architecture System

Separation of concern

The *architecture file* describes how to connect the audio computation to the external world.



Faust Architecture System

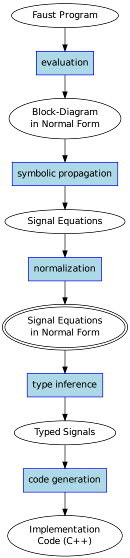
Examples of supported architectures

- Audio plugins :
  - AudioUnit
  - LADSPA
  - DSSI
  - LV2
  - Max/MSP
  - VST
  - Pure Data
  - Csound
  - SuperCollider
  - Pure
  - Chuck
  - Octave
  - Flash
- Audio drivers :
  - Jack
  - Alsa
  - CoreAudio
  - Web Audio API
- Graphic User Interfaces :
  - QT
  - GTK
  - Android
  - iOS
  - HTML5/SVG
- Other User Interfaces :
  - OSC
  - HTTPD

5-Compiler/Code Generation

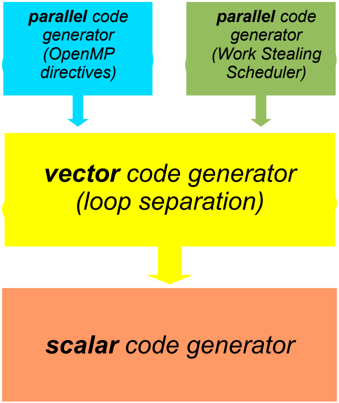
Faust Compiler

Main phases of the compiler



Faust Compiler

Four code generation modes



6-Performance

Performance of the Generated Code

How the C++ code generated by FAUST compares with hand written C++ code ?

STK vs FAUST (CPU load)

File name	STK	FAUST	Difference
blowBottle.dsp	3,23	2,49	-22%
blowHole.dsp	2,70	1,75	-35%
bowed.dsp	2,78	2,28	-17%
brass.dsp	10,15	2,01	-80%
clarinet.dsp	2,26	1,19	-47%
flutestk.dsp	2,16	1,13	-47%
saxophony.dsp	2,38	1,47	-38%
sitar.dsp	1,59	1,11	-30%
tibetanBowl.dsp	5,74	2,87	-50%

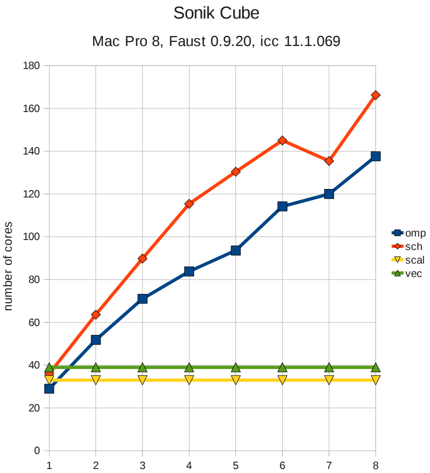
Overall improvement of about 41 % in favor of FAUST.

Performance of the Generated Code

What improvements to expect from parallelized code ?

Sonik Cube

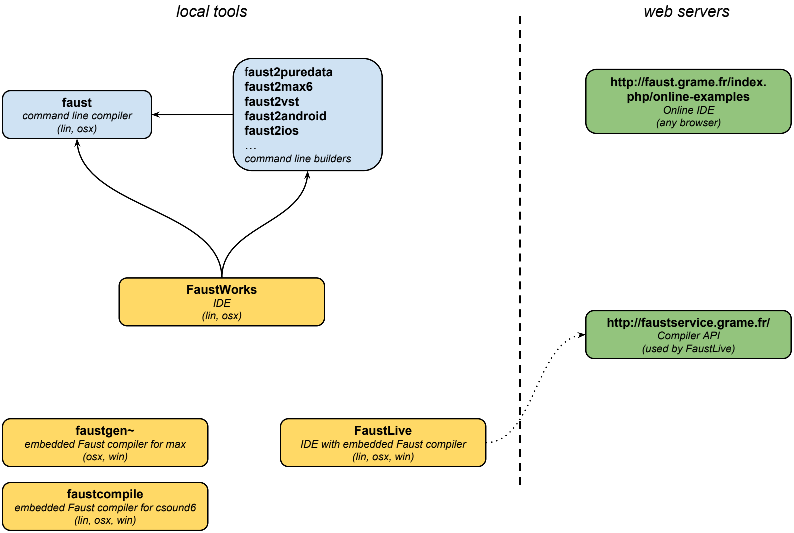
Compared performances of the various C++ code generation strategies according to the number of cores:



7-Tools

Tools

Faust ecosystem



Tools

Available compilers

- Command line tools
  - `faust` command line
  - `faust2xxx` command line
- Web based tools
  - Online Compiler (http://faust.grame.fr)
  - Faustweb API (http://faustservice.grame.fr)
- Embedded compiler (libfaust)
  - Faustgen for Max/MSP
  - Faustcompile, etc. for Csound (V. Lazzarini)
  - Faustnode for the Web Audio API
  - Antescofo (IRCAM's score follower)
  - LibAudioStream (Audio renderer)
  - iScore (LaBRI)
- IDE
  - FaustWorks (requires Faust)
  - FaustLive (self contained)

Some useful libraries

- math.lib
- music.lib, imports math.lib
- hoa.lib, imports math.lib
- filter.lib, imports music.lib
- effect.lib, imports filter.lib
- oscillator.lib, imports filter.lib

Tools

Some useful links

- Website and online compiler :
  - `http://faust.grame.fr`
- Faust distribution:
  - `http://sourceforge.net/projects/faudiostream/`
  - git clone git://faudiostream.git.sourceforge.net/gitroot/faudiostream/faudiostream
  - cd faudiostream; make; sudo make install
- FaustWorks:
  - `http://sourceforge.net/projects/faudiostream/`
  - git clone git://faudiostream.git.sourceforge.net/gitroot/faudiostream/FaustWorks
- FaustLive:
  - `http://sourceforge.net/projects/faudiostream/`
  - git clone git://faudiostream.git.sourceforge.net/gitroot/faudiostream/faustlive

8-To Summarize

To Summarize

FAUST is a DSL for real-time signal processing and synthesis. Its design is based on several principles:

- High-level specification language
- End-Users oriented
- Simple well-defined formal semantics
- Purely synchronous functional approach
- Textual, "block-diagram oriented", syntax
- Favors reuse and composition of existing programs,
- Efficient sample level processing
- Fully compiled code (sequential or parallel)
- Embeddable code
- Easy deployment: single code multiple targets
- Preservable via automatic documentation

9-Bibliography

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10-Acknowledgments

Acknowledgments

This research was funded in part by the Agence nationale pour la recherche (ANR) via the following projects:

- ASTREE [2008-CORD-003]
- INEDIT [ANR 2012 CORD 009]
- FEEVER [ANR-13-BS02-0008]

Many persons have been contributing to the FAUST project by providing code for the compiler, architecture files, libraries, examples, documentation, scripts, bug reports, ideas, etc. We would like to thank them and especially (in alphabetic order): *Fons Adriaensen, Karim Barkati, Jerome Barthelemy, Tim Blechmann, Tiziano Bole, Alain Bonardi, Myles Borins, Baktery Chanka, Thomas Charbonnel, Raffaele Ciavarella, Julien Colafrancesco, Damien Cramet, Sarah Denoux, Robin Gareus, Etienne Gaudrin, Olivier Guillerminet, Albert Graef, Pierre Guillot, Olivier Guillerminet, Pierre Jouvelot, Stefan Kersten, Victor Lazzarini, Matthieu Leberre, Christophe Lebreton, Mathieu Leroi, Fernando Lopez-Lezcano, Kjetil Matheussen, Hermann Meyer, Romain Michon, Remy Muller, Eliott Paris, Reza Payami, Laurent Pottier, Sampo Savolainen, Nicolas Scaringella, Anne Sedes, Priyanka Shekar, Stephen Sinclair, Travis Skare, Julius Smith, Mike Solomon, Michael Wilson*