FAUST
Programming language for audio and signal processing

Yann Orlarey

GRAME – Centre National de Création Musicale

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1-Introduction

Introduction

What is FAUST ?

FAUST stands for *Functional AUdio STream*:

- It is a *Domain-Specific Language* for real-time audio signal processing and synthesis.
- It can be used to develop:
  - *audio effects,*
  - *sound synthesizers*
  - real-time applications processing signals.
- Who uses FAUST ?
  - Developers of audio applications and plugins
  - Sound engineers and musical assistants
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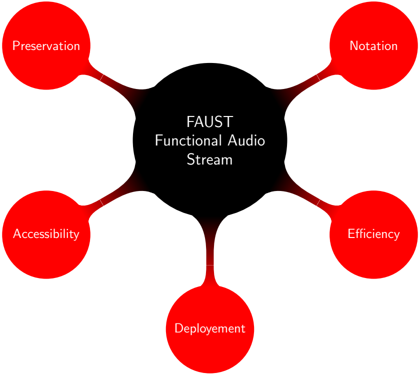
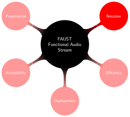
Main goals of the FAUST project



Main Goals

Notation



- **How to easily describe dsp algorithms with a high level, expressive and modular notation ?**
- By using a purely functional approach based on a block diagram algebra
- *White noise formula*
  - **Mathematical notation** :
    ```
    x(n) = x(n-1) * 1103515245 + 12345
    y(n) = x(n) / 2147483647.0
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  - **Faust notation** :
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    +(12345) ~ *(1103515245) : /(2147483647.0)
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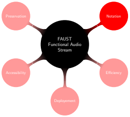

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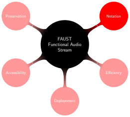

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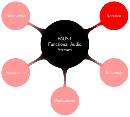

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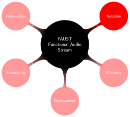

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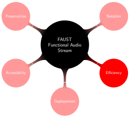

- **How to implement these algorithms with an efficiency comparable to low level languages like C ?**
- By automatically translating FAUST programs to highly optimized imperative programs. Several backends are available :
  - C++
  - C
  - Java
  - Javascript
  - LLVM
- By automatic parallelization :
  - OpenMP
  - Work Stealing

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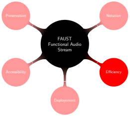

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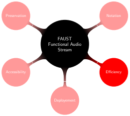

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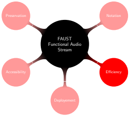

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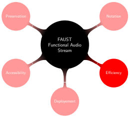

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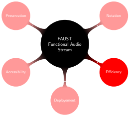

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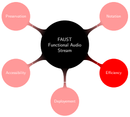

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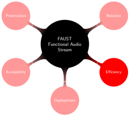

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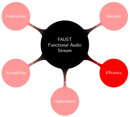

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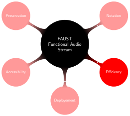

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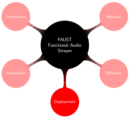

- **How to transparently deploy these programs on a large variety of software and hardware plateforms, from desktop to mobile devices ?**
- By a separation of concerns between the audio computation itself (described by the FAUST code), and its relations to the external world (described by an architecture file). Recent additions :
  - Web Audio API
  - iOS
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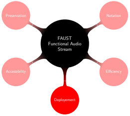

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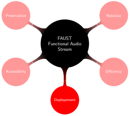

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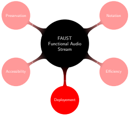

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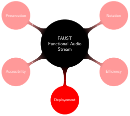

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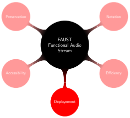

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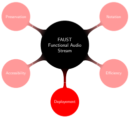

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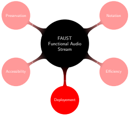

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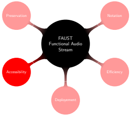

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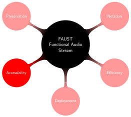

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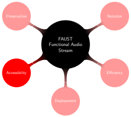

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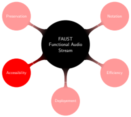

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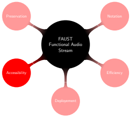

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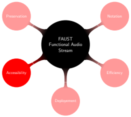

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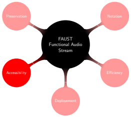

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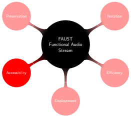

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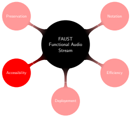

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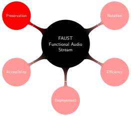

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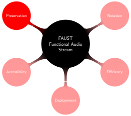

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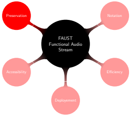

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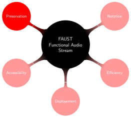

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Introduction

What is a FAUST program ?

A FAUST program describes a *signal processor* :

- A *signal processor* is a mathematical function that maps input *signals* to output *signals* :
  - $\mathbb{P} = \mathbb{S}^n \rightarrow \mathbb{S}^m$
- A (periodically sampled) *signal* is a *time* to *samples* function:
  - $\mathbb{S} = \mathbb{N} \rightarrow \mathbb{R}$
- Everything in FAUST is a *signal processor* :
  - $+ : \mathbb{S}^2 \rightarrow \mathbb{S}^1 \in \mathbb{P}$,
  - $3.14 : \mathbb{S}^0 \rightarrow \mathbb{S}^1 \in \mathbb{P}, \ldots,$
- Programming in FAUST is essentially combining signal processors :
  - $\{:\ \ ,\ \ <:\ \ :>\ \ \sim\} \subset \mathbb{P} \times \mathbb{P} \rightarrow \mathbb{P}$

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Example of signal processor

- A digital signal processor, here a Lexicon 300, can be modeled as a *mathematical function* transforming *input signals* into *output signals*.
- FAUST allows to describe both the *mathematical computation* and the *user interface*.

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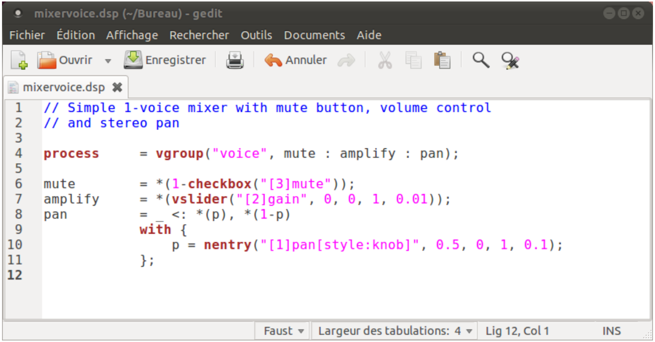
A simple FAUST program




```
// Simple 1-voice mixer with mute button, volume control
// and stereo pan

process     = vgroup("voice", mute : amplify : pan);

mute        = *(1-checkbox("[3]mute"));
amplify     = *(vslider("[2]gain", 0, 0, 1, 0.01));
pan         = _ <: *(p), *(1-p)
            with {
                p = nentry("[1]pan[style:knob]", 0.5, 0, 1, 0.1);
            };
```

Figure: Source code of a simple 1-voice mixer

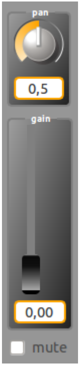


Figure: Resulting application

FAUST is based on several design principles:

- High-level Specification language
- Purely functional approach
- Textual, block-diagram oriented, syntax
- Efficient sample level processing
- Fully compiled code (sequential or parallel)
- Embeddable code (no runtime dependences, constant memory and CPU footprint)
- Easy deployment : single code multiple targets (from VST plugins to iPhone or standalone applications)

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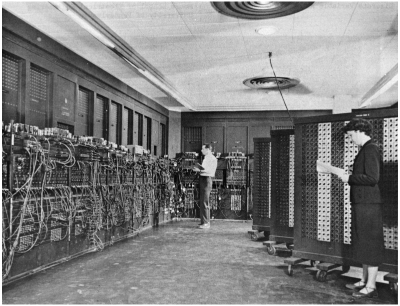
2-Block Diagram Algebra

Block-Diagram Algebra

Programming by patching is familiar to musicians :



Block-Diagram Algebra

Today programming by patching is widely used in Visual Programming Languages like Max/MSP:

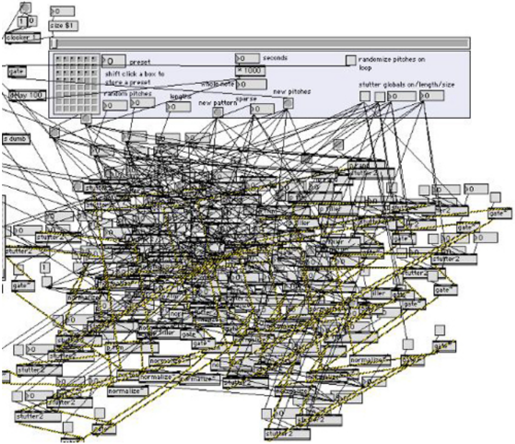


Figure: Block-diagrams can be a mess

Block-Diagram Algebra

Faust allows structured block-diagrams

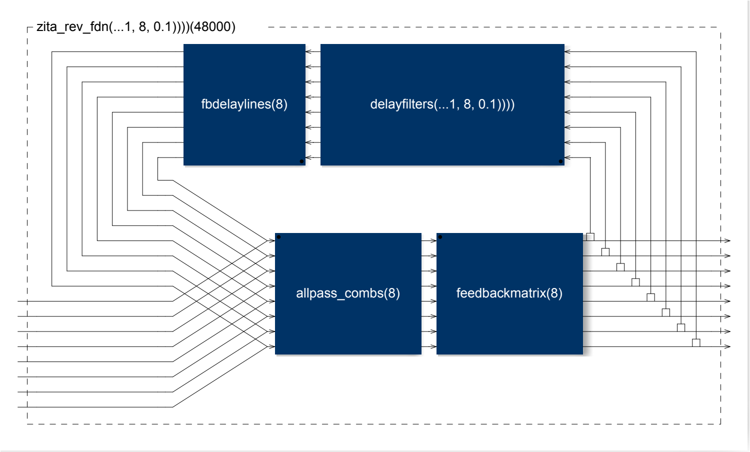


Figure: A complex but structured block-diagram

Block-Diagram Algebra

Faust syntax is based on a *block diagram algebra*

5 Composition Operators

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

2 Constants

- `!` cut
- `_` wire

Block-Diagram Algebra

Parallel 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.

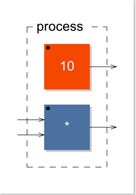


Figure: Example of parallel composition `(10,*)` The *sequential composition* $(A : B)$ connects the outputs of A to the inputs of B. $A[0]$ is connected to $[0]B$, $A[1]$ is connected to $[1]B$, and so on.

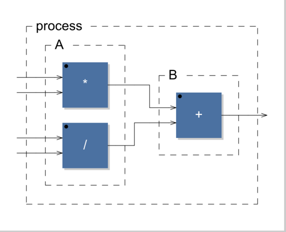


Figure: Example of sequential composition `((*,/):+)`

Block-Diagram Algebra

Split Composition

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

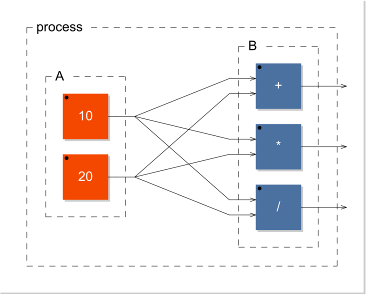


Figure: example of split composition `((10,20) <: (+,*,/))`

Block-Diagram Algebra

Merge Composition

The *merge composition* $(A :> B)$ is used to connect several outputs of A to the same inputs of B.

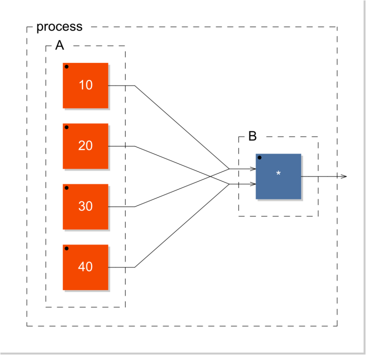


Figure: example of merge composition `((10,20,30,40) :> *)`

Block-Diagram Algebra

Recursive Composition

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

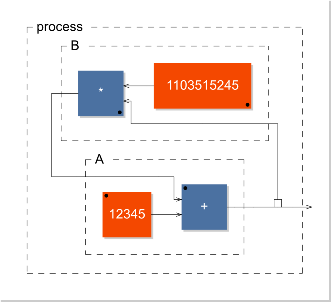


Figure: example of recursive composition `+(12345) ~ *(1103515245)`

3-Primitive operations

Faust Primitives

Arithmetic operations

Syntax	Type	Description
`+`	$\mathbb{S}^2 \to \mathbb{S}^1$	addition: $y(t) = x_1(t) + x_2(t)$
`-`	$\mathbb{S}^2 \to \mathbb{S}^1$	subtraction: $y(t) = x_1(t) - x_2(t)$
`*`	$\mathbb{S}^2 \to \mathbb{S}^1$	multiplication: $y(t) = x_1(t) * x_2(t)$
`∧`	$\mathbb{S}^2 \to \mathbb{S}^1$	power: $y(t) = x_1(t)^{x_2(t)}$
`/`	$\mathbb{S}^2 \to \mathbb{S}^1$	division: $y(t) = x_1(t)/x_2(t)$
`%`	$\mathbb{S}^2 \to \mathbb{S}^1$	modulo: $y(t) = x_1(t)\%x_2(t)$
`int`	$\mathbb{S}^1 \to \mathbb{S}^1$	cast into an int signal: $y(t) = (int)x(t)$
`float`	$\mathbb{S}^1 \to \mathbb{S}^1$	cast into an float signal: $y(t) = (float)x(t)$

Faust Primitives

Bitwise operations

Syntax	Type	Description
`&`	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	logical AND: $y(t) = x_1(t) \& x_2(t)$
`|`	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	logical OR: $y(t) = x_1(t) \vert x_2(t)$
`xor`	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	logical XOR: $y(t) = x_1(t) \wedge x_2(t)$
`<<`	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	arith. shift left: $y(t) = x_1(t) << x_2(t)$
`>>`	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	arith. shift right: $y(t) = x_1(t) >> x_2(t)$

Faust Primitives

Comparison operations

Syntax	Type	Description
<	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	less than: $y(t) = x_1(t) < x_2(t)$
<=	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	less or equal: $y(t) = x_1(t) \Leftarrow x_2(t)$
>	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	greater than: $y(t) = x_1(t) > x_2(t)$
>=	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	greater or equal: $y(t) = x_1(t) >= x_2(t)$
==	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	equal: $y(t) = x_1(t) == x_2(t)$
!=	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	different: $y(t) = x_1(t)! = x_2(t)$

Faust Primitives

Trigonometric functions

Syntax	Type	Description
`acos`	$\mathbb{S}^1 \to \mathbb{S}^1$	arc cosine: $y(t) = \mathrm{acosf}(x(t))$
`asin`	$\mathbb{S}^1 \to \mathbb{S}^1$	arc sine: $y(t) = \mathrm{asinf}(x(t))$
`atan`	$\mathbb{S}^1 \to \mathbb{S}^1$	arc tangent: $y(t) = \mathrm{atanf}(x(t))$
`atan2`	$\mathbb{S}^2 \to \mathbb{S}^1$	arc tangent of 2 signals: $y(t) = \mathrm{atan2f}(x_1(t), x_2(t))$
`cos`	$\mathbb{S}^1 \to \mathbb{S}^1$	cosine: $y(t) = \mathrm{cosf}(x(t))$
`sin`	$\mathbb{S}^1 \to \mathbb{S}^1$	sine: $y(t) = \mathrm{sinf}(x(t))$
`tan`	$\mathbb{S}^1 \to \mathbb{S}^1$	tangent: $y(t) = \mathrm{tanf}(x(t))$

Faust Primitives

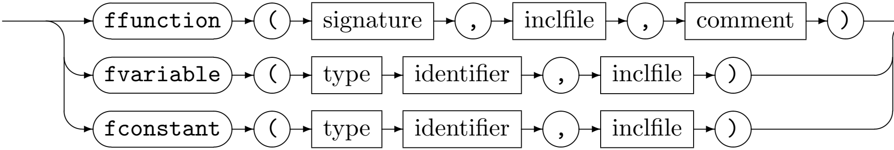
Other Math operations

Syntax	Type	Description
`exp`	$\mathbb{S}^1 \rightarrow \mathbb{S}^1$	base-e exponential: $y(t) = \mathrm{expf}(x(t))$
`log`	$\mathbb{S}^1 \rightarrow \mathbb{S}^1$	base-e logarithm: $y(t) = \mathrm{logf}(x(t))$
`log10`	$\mathbb{S}^1 \rightarrow \mathbb{S}^1$	base-10 logarithm: $y(t) = \mathrm{log10f}(x(t))$
`pow`	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	power: $y(t) = \mathrm{powf}(x_1(t), x_2(t))$
`sqrt`	$\mathbb{S}^1 \rightarrow \mathbb{S}^1$	square root: $y(t) = \mathrm{sqrtf}(x(t))$
`abs`	$\mathbb{S}^1 \rightarrow \mathbb{S}^1$	absolute value (int): $y(t) = \mathrm{abs}(x(t))$
		absolute value (float): $y(t) = \mathrm{fabsf}(x(t))$
`min`	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	minimum: $y(t) = \min(x_1(t), x_2(t))$
`max`	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	maximum: $y(t) = \max(x_1(t), x_2(t))$
`fmod`	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	float modulo: $y(t) = \mathrm{fmodf}(x_1(t), x_2(t))$
`remainder`	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	float remainder: $y(t) = \mathrm{remainderf}(x_1(t), x_2(t))$
`floor`	$\mathbb{S}^1 \rightarrow \mathbb{S}^1$	largest int $\leq$: $y(t) = \mathrm{floorf}(x(t))$
`ceil`	$\mathbb{S}^1 \rightarrow \mathbb{S}^1$	smallest int $\geq$: $y(t) = \mathrm{ceilf}(x(t))$
`rint`	$\mathbb{S}^1 \rightarrow \mathbb{S}^1$	closest int: $y(t) = \mathrm{rintf}(x(t))$

Faust Primitives

Add new ones using Foreign Functions

foreignexp



- Reference to external C *functions*, *variables* and *constants* can be introduced using the *foreign function* mechanism.
- example :

```
asinh = ffunction(float asinhf (float), <math.h>, "");
```

Faust Primitives

Delays and Tables

Syntax	Type	Description
`mem`	$\mathbb{S}^1 \rightarrow \mathbb{S}^1$	1-sample delay: $y(t+1) = x(t), y(0) = 0$
`prefix`	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	1-sample delay: $y(t+1) = x_2(t), y(0) = x_1(0)$
`@`	$\mathbb{S}^2 \rightarrow \mathbb{S}^1$	fixed delay: $y(t + x_2(t)) = x_1(t), y(t < x_2(t)) = 0$
`rdtable`	$\mathbb{S}^3 \rightarrow \mathbb{S}^1$	read-only table: $y(t) = T[r(t)]$
`rwtable`	$\mathbb{S}^5 \rightarrow \mathbb{S}^1$	read-write table: $T[w(t)] = c(t); y(t) = T[r(t)]$
`select2`	$\mathbb{S}^3 \rightarrow \mathbb{S}^1$	select between 2 signals: $T[] = \{x_0(t), x_1(t)\}; y(t) = T[s(t)]$
`select3`	$\mathbb{S}^4 \rightarrow \mathbb{S}^1$	select between 3 signals: $T[] = \{x_0(t), x_1(t), x_2(t)\}; y(t) = T$

Faust Primitives

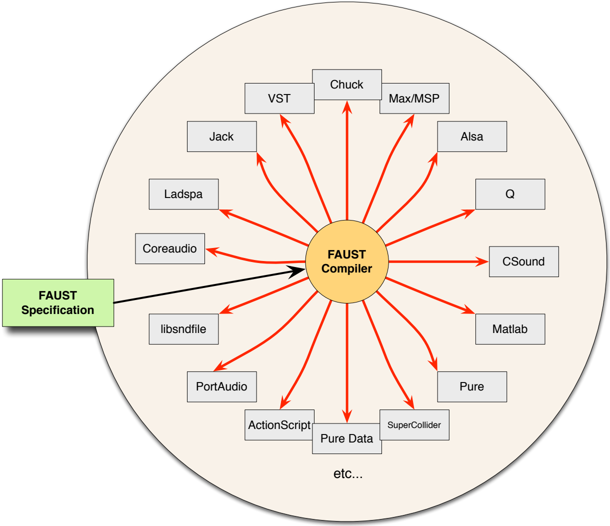
User Interface Primitives

Syntax	Example
button(*str*)	button("play")
checkbox(*str*)	checkbox("mute")
vslider(*str*,*cur*,*min*,*max*,*inc*)	vslider("vol",50,0,100,1)
hslider(*str*,*cur*,*min*,*max*,*inc*)	hslider("vol",0.5,0,1,0.01)
nentry(*str*,*cur*,*min*,*max*,*inc*)	nentry("freq",440,0,8000,1)
vgroup(*str*,*block-diagram*)	vgroup("reverb", ...)
hgroup(*str*,*block-diagram*)	hgroup("mixer", ...)
tgroup(*str*,*block-diagram*)	vgroup("parametric", ...)
vbargraph(*str*,*min*,*max*)	vbargraph("input",0,100)
hbargraph(*str*,*min*,*max*)	hbargraph("signal",0,1.0)

4-Architectures

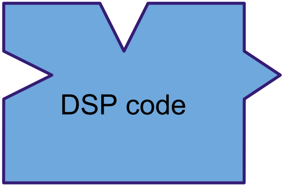
Faust Architecture System

Motivations : Easy deployment (one Faust code, multiple targets)



Faust Architecture System

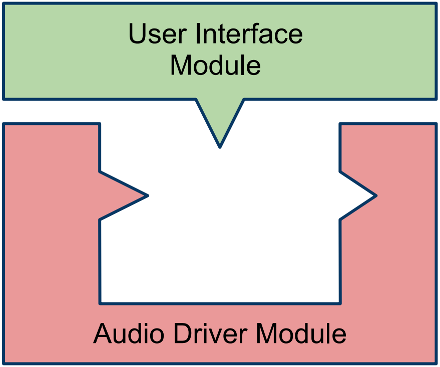
Principle : separation of concerns between the audio computation and its usage



To provide easy deployment, the DSP code generated by compiling a Faust program should be pure audio computation, abstracted from any audio drivers or GUI toolkit.

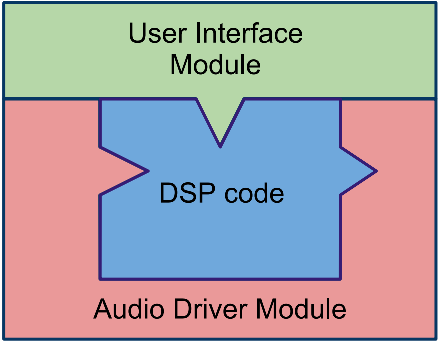
Faust Architecture System

Audio driver and User Interface modules



The role of the architecture file is to provide the missing information: the audio drivers and the user interface. The new modular architecture file combines an Audio driver module and one or more User Interface modules.

Faust Architecture System



The Faust compiler wraps the DSP code into the selected architecture file. For examples `faust -a jack-gtk.cpp noise.dsp` will wrap the DSP code of a noise generator into the architecture of jack-gtk standalone application.

Faust Architecture System

Examples of supported architectures

- Audio plugins :
  - AudioUnit
  - LADSPA
  - DSSI
  - LV2
  - Max/MSP
  - VST
  - PD
  - 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

6-Performances

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.

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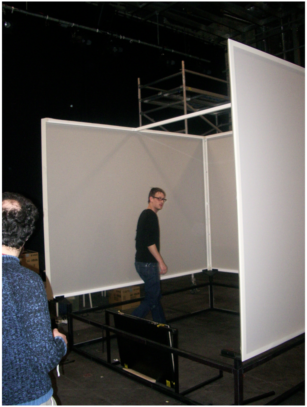
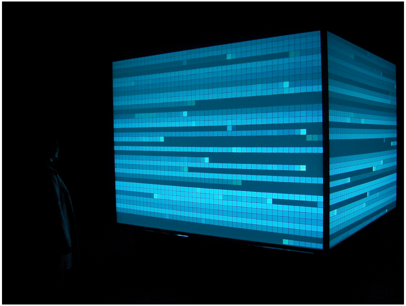
Performance of the generated code

What improvements to expect from parallelized code ?

Sonik Cube

Audio-visual installation involving a cube of light, reacting to sounds, immersed in an audio feedback room (Trafik/Orlarey 2006).



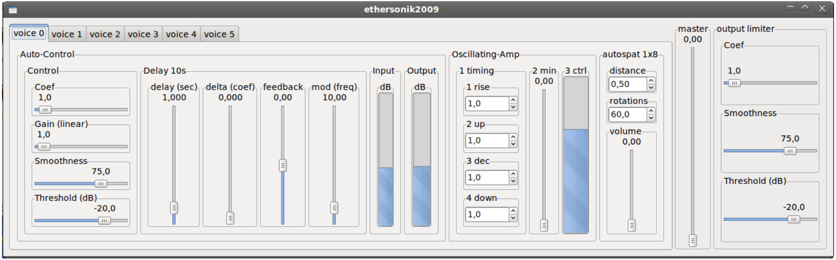


Performance of the generated code

What improvements to expect from parallelized code ?

Sonik Cube

- 8 loudspeakers
- 6 microphones
- audio software, written in FAUST, controlling the audio feedbacks and the sound spatialization.

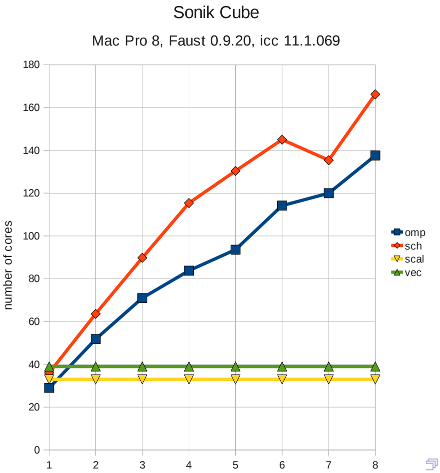


Performance of the generated code

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-DocumentationPreservation

- Binary and source code preservation of programs is not enough : quick obsolescence of languages, systems and hardware.
- We need to preserve the mathematical meaning of these programs independently of any programming language.
- The solution is to generate automatically the mathematical description of any FAUST program

Automatic Mathematical Documentation

Motivations et Principles

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Automatic Mathematical Documentation

Tools provided

- The easiest way to generate the complete mathematical documentation is to call the `faust2mathdoc` script on a FAUST file.
- This script relies on a new option of the FAUST compile : `-mdoc`
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Automatic Mathematical Documentation

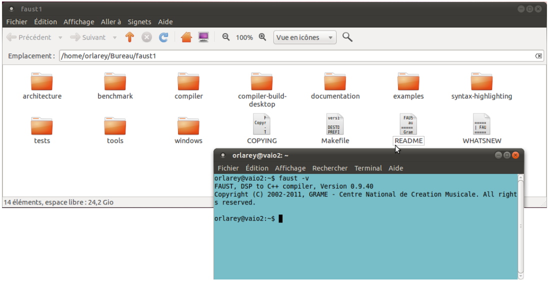
Files generated by `Faust2mathdoc noise.dsp`

- `noise-mdoc/`
  - `cpp/`
    - `noise.cpp`
  - `pdf/`
    - `noise.pdf`
  - `src/`
    - `math.lib`
    - `music.lib`
    - `noise.dsp`
  - `svg/`
    - `process.pdf`
    - `process.svg`
  - `tex/`
    - `noise.pdf`
    - `noise.tex`

8-Resources

Resources

FAUST Distribution on Sourceforge



- http://sourceforge.net/projects/faudiostream/
- git clone git://faudiostream.git.sourceforge.net/gitroot/faudiostream/faudiostream faust
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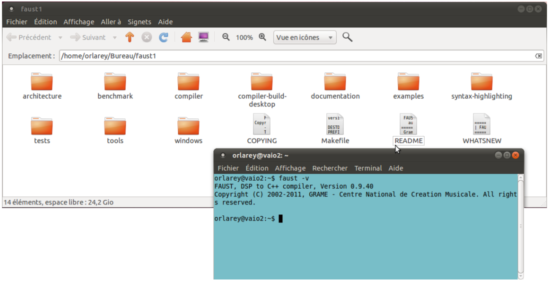

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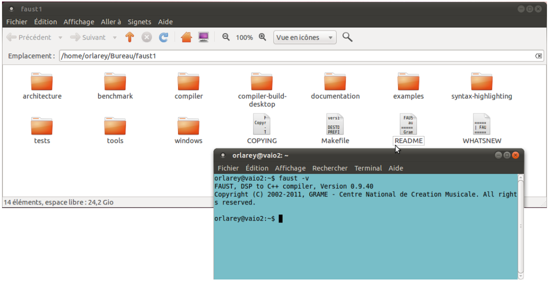

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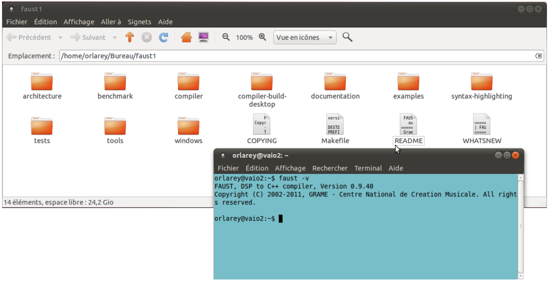

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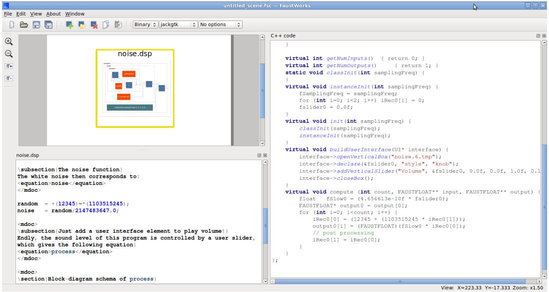
FaustWorks IDE on Sourceforge



- http://sourceforge.net/projects/faudiostream/files/FaustWorks-0.3.2.tgz/download
- git clone git://faudiostream.git.sourceforge.net/gitroot/faudiostream/FaustWorks
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Resources

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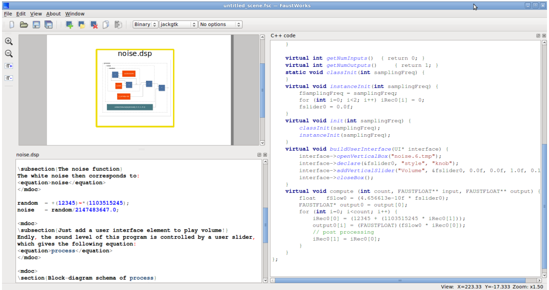

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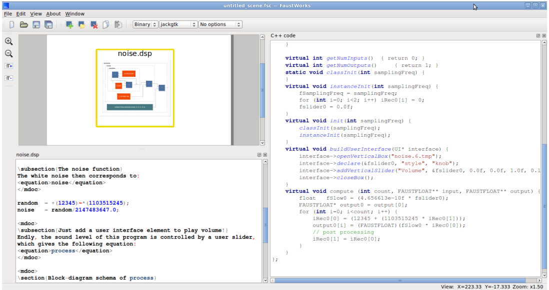

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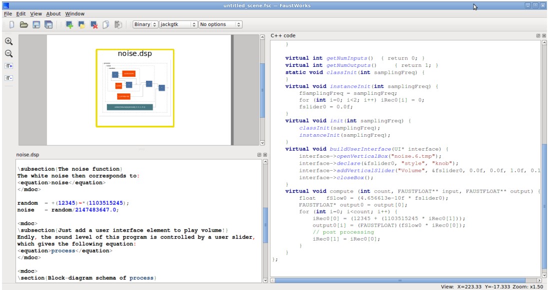

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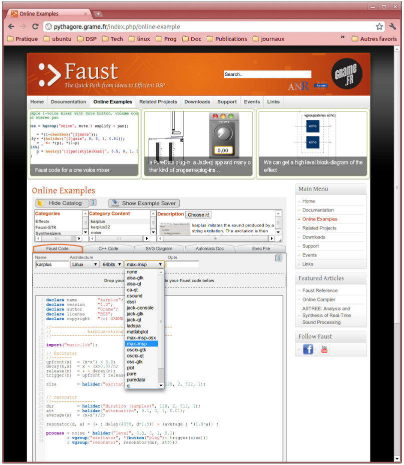
Using FAUST Online Compiler



- http://faust.grame.fr
- No installation required
- Compile to C++ as well as binary (Linux, MacOSX and Windows)

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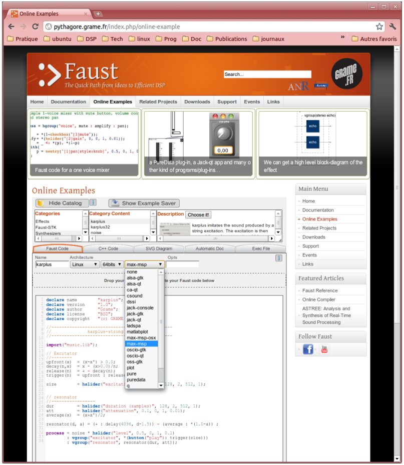

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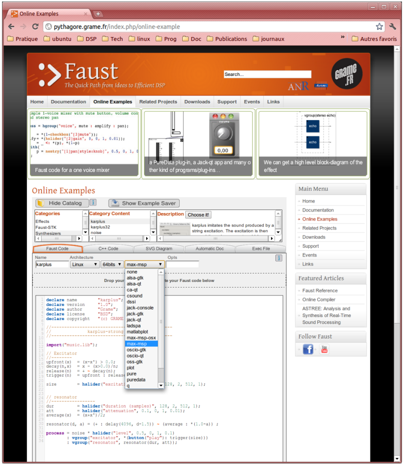

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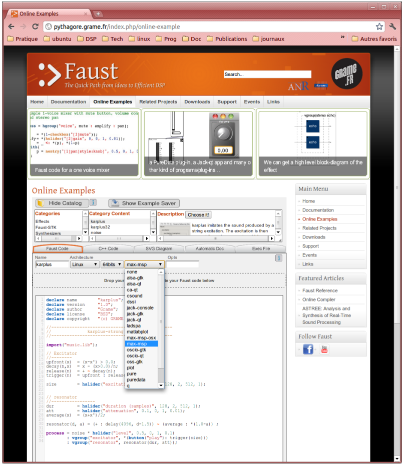

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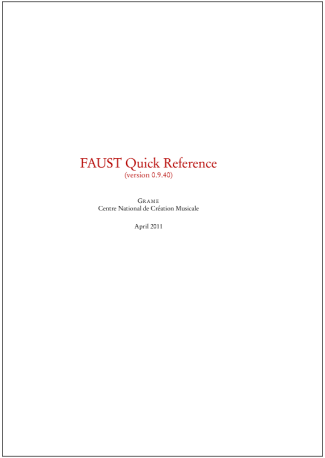
FAUST Quick Reference



FAUST Quick Reference
(version 0.9.40)

GRAME
Centre National de Création Musicale

April 2011

Figure: *Faust Quick Reference*, Grame

Resources

Some research papers

- 2004 : **Syntactical and semantical aspects of Faust**, Orlarey, Y. and Fober, D. and Letz, S., in *Soft Computing*, vol 8(9), p623-632, Springer.
- 2009 : **Parallelization of Audio Applications with Faust**, Orlarey, Y. and Fober, D. and Letz, S., in *Proceedings of the SMC 2009-6th Sound and Music Computing Conference*,
- 2011 : **Dependent vector types for data structuring in multirate Faust**, Jouvelot, P. and Orlarey, Y., in *Computer Languages, Systems & Structures*, Elsevier

9-Acknowledgments

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OS Community

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Sponsors

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Former Students

Tiziano Bole, Damien Cramet, Sarah Denoux, Étienne Gaudrin, Matthieu Leberre, Mathieu Leroi, Nicolas Scaringella