# Signal Processing in Faust and Pd

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**Abstract**

The Faust programming language is a high-level language for digital signal processing with special support for real-time plugin environments such as Pure Data (Pd), LADSPA, and many others. This tutorial describes how to make Pd, LADSPA, and VST plugins, focusing on a simple example of white noise filtered by a variable resonator. Additionally, generation of an 8-voiced MIDI synthesizer from Faust source and the `faust2pd` script is illustrated.

## Contents

[*]Work supported by the Wallenberg Global Learning Network

## 1 Note

This document is somewhat out of date. A more up-to-date extended subset is `http://ccrma.stanford.edu/~jos/`

## 2 Introduction

This module describes use of the *Faust programming language*[1] by Yann Orlarey [2, 1] to generate real-time DSP applications and plugins from a high-level specification. In addition to generating efficient inner loops, Faust supports Graphical User Interface (GUI) specification in the source code, and can emit code for various application and plugin environments.[2] Moreover, Faust can generate easy-to-read block diagrams directly from the source, illustrating signal flow and processing graphically. This module focuses on generating `pd`, LADSPA, and VST plugins from a simple Faust program specifying a resonator driven by white noise.

### 2.1 Installing Faust

On a Fedora Linux system (and presumably many other Linux distributions), say

```
yum search faust
```

to find out about the Faust-related packages. On a Mac with MacPorts installed, say this:

```
port search faust
```

At the time of this writing (5/23/2010), the two packages available on the Mac are `faust` and `pure-faust`. Thus, to install the main Faust package, say `port install faust` (on your Mac). On Fedora 11 Linux, at the time of this writing, the available packages are `faust`, `faust-doc`, `faust-kate`, and `faust-tools`.

The versions in the Linux and MacPorts distributions tend to be significantly behind the latest. To check out the latest CVS version at `sourceforge`, say

```
cvs -z3 -d:pserver:anonymous@faudiostream.cvs.sourceforge.net:/cvsroot/faudiostream co .
```

I have always done this and find it to be generally quite reliable. From time to time, update and reinstall as follows:

```
cd Faust
cvs -q update
make
sudo make install
```

[1]The Faust home page is `http://faust.grame.fr/`. Faust is included in the Planet CCRMA distribution (`http://ccrma.stanford.edu/planetccrma/software/`). The examples in this module have been tested with Faust version 0.9.9.2a2.

[2]Faust "architecture files" and plugin-generators are currently available for Max/MSP, Pd [3, 1], VST, LADSPA, ALSA-GTK, JACK-GTK, and SuperCollider, as of this writing.

### 2.2 Installing Faust Examples

The software discussed in this module can be downloaded as a compressed tarball:

```
http://ccrma.stanford.edu/~jos/faust/faustpd.tar.gz
```

Additional software and more advanced examples can be found in [6].

## 3 A Simple Faust Program

Figure 1 lists a minimal Faust program specifying the constant-peak-gain resonator discussed in [5]. This module does not cover the Faust language itself, so the Faust Tutorial,[3] or equivalent, should be considered prerequisite reading. We will summarize briefly, however, the Faust operators relevant to this example: signal processing blocks are connected in series via a colon (`:`), and feedback is indicated by a tilde (`~`). The colon and tilde operators act on "block diagrams" to create a larger block diagram. There are also signal operators. For example, a unit-sample delay is indicated by appending a prime (`'`) after a signal variable; thus, `x'` expands to `x : MEM` and indicates a signal obtained by delaying the signal `x` by one sample.

Function application applies to operator symbols as well as names; thus, for example, `+(x)` expands to `_,x : +`, and `*(x)` expands to `_,x : *`, where `_` denotes a simple "wire". There is a special unary minus in Faust (as of release 0.9.9.4), so that `-x` is equivalent to `0 - x`. However, `-(x)` still expands to `_,x : -`, which is a blockdiagram that subtracts signal `x` from the input signal on `_` .

The `with` block provides local definitions in the context of the `process` definition.[4]

Other aspects of the language used in this example should be fairly readable to those having a typical programming background. [5]

Constants such as `RR` in Fig. 1 are better thought of as *constant signals*. As a result, operators such as `*` (multiplication) conceptually act only on signals. Thus, the expression `2*x` denotes the constant-signal $2, 2, 2, \ldots$ muliplied pointwise by the signal `x`. The Faust compiler does a good job of optimizing expressions so that operations are not repeated unnecessarily at run time. In summary, a Faust expression expands into a block diagram which processes causal signals,[6] some of which may be constant signals.

## 4 Generating Faust Block Diagrams

When learning the Faust language, it can be helpful to generate a block diagram using the `-svg` option. For example, the command

```
> faust -svg cpgr.dsp
```

[3]http://www.grame.fr/pub/faust_tutorial.pdf

[4]A "`with`" block is not required, but it minimizes "global name pollution." In other words, a definition and its associated `with` block are more analogous to a C function definition in which local variables may be used. Faust statements can be in any order, so multiple definitions of the same symbol are not allowed. A `with` block can thus be used also to override global definitions in a local context.

[5]Facility with basic C++ programming is also assumed for this module.

[6]A *causal signal* is any signal that is zero before time 0.

```
process = firpart : + ~ feedback
with {
  bw = 100; fr = 1000; g = 1; // parameters - see caption
  SR = fconstant(int fSamplingFreq, <math.h>); // Faust fn
  pi = 4*atan(1.0);    // circumference over diameter
  R = exp(0-pi*bw/SR); // pole radius [0 required]
  A = 2*pi*fr/SR;      // pole angle (radians)
  RR = R*R;
  firpart(x) = (x - x'') * g * ((1-RR)/2);
  // time-domain coefficients ASSUMING ONE PIPELINE DELAY:
  feedback(v) = 0 + 2*R*cos(A)*v - RR*v';
};
```

Figure 1: Faust program specifying a constant-peak-gain resonator. Input parameters are the resonance frequency `fr` (Hz), resonance bandwidth `bw` (Hz), and the desired peak-gain `g`.

creates a subdirectory of the current working directory named `cpgr-svg` which contains a "scalable vector graphics" (`.svg`) file for each block-diagram expression in `cpgr.dsp`.[7] For this example, there is a block diagram generated for the `process` line, and for each of the last five lines in the `with` clause (not counting the comment).

Figure 2 shows the block diagram generated for the main `process` block from Fig. 1:

```
process = firpart : + ~ feedback
```

The dot on each block indicates its standard orientation (analogous to a "pin 1" indicator on an integrated circuit chip). The small open square at the beginning of the feedback loop indicates a *unit sample delay* introduced by creating a signal loop. Needless to say, it is important to keep track of such added delays in a feedback loop.

Figure 3 shows the block diagram generated for the `firpart` abstraction:

```
firpart(x) = (x - x'') * g * ((1-RR)/2);
```

Similarly, Fig. 4 shows the block diagram generated for the feedback path:

```
feedback(v) = 0 + 2*R*cos(A)*v - RR*v';
```

If not for the added sample of delay in the feedback loop (indicated by the small open square in Fig. 2), the feedback-path processing would have been instead `0 + 2*R*cos(A)*v' - RR*v''`.

Note that the block diagrams are drawn as though all details of the expression are to be evaluated every sample. However, the Faust compiler instead computes constant expressions at `init` time and allocates memory locations for them. More generally, the Faust compiler separately optimizes full-rate signals at the sampling rate (calculated in the inner loop), slowly varying signals (updated at the "buffer rate" outside of the inner loop—currently every 64 samples), and constant signals (evaluated once at initialization time).

[7]The `faust2firefox` script can be used to generate SVG block diagrams and open them in the Firefox web browser.

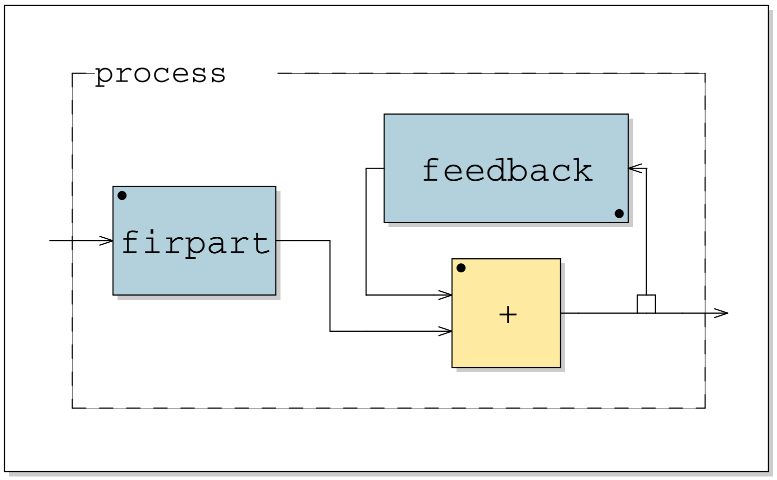


Figure 2: Main *process* block for the constant-peak-gain resonator.

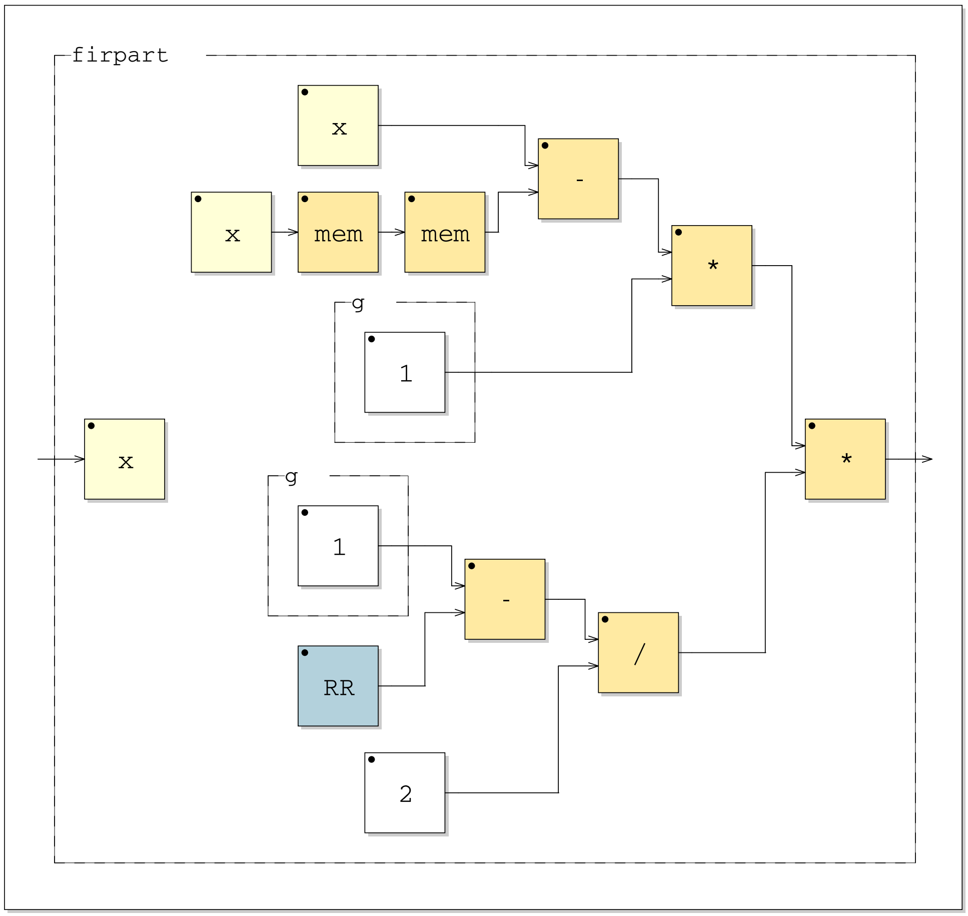


Figure 3: FIR-part `((x - x'') * g * ((1-RR)/2))` in Faust.

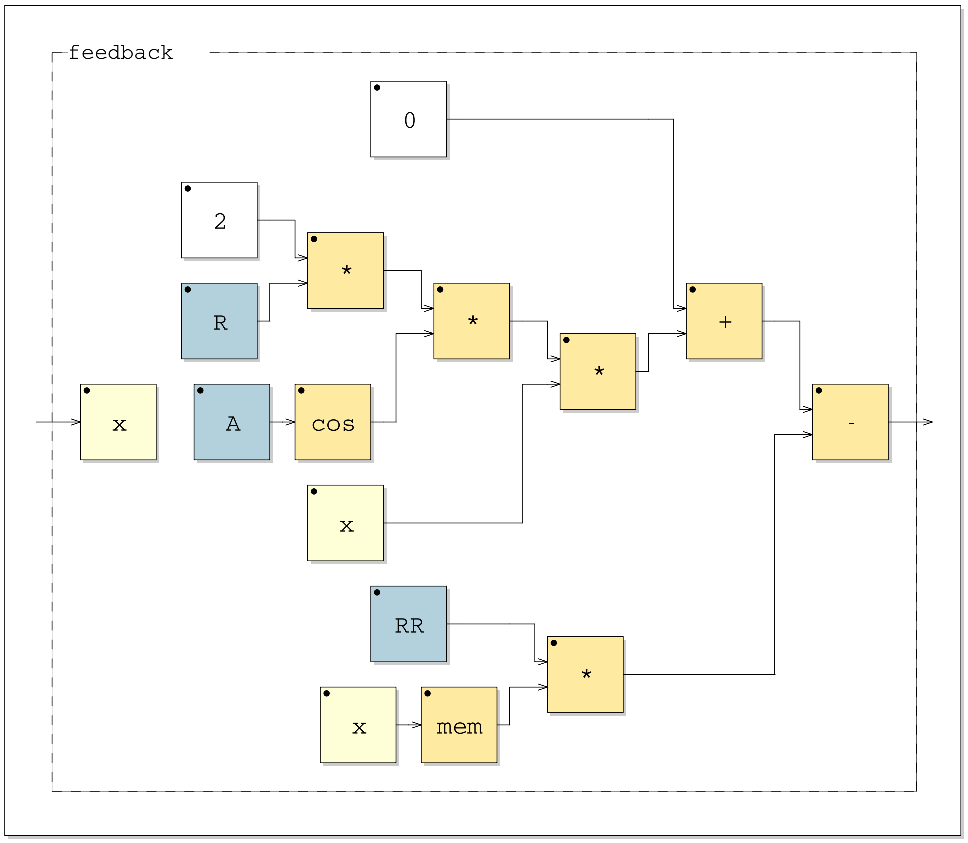


Figure 4: Feedback block `(0 + 2*R*cos(A)*x - RR*x')` in Faust.

## 5 Testing a Faust Filter Section

It takes a bit of experience to write a correct program on the first try. Therefore, we often have to *debug* our programs by some technique. Typically, inspecting the automatically generated block diagrams and listening to the results are tools enough for debugging Faust source code. However, sometimes it is useful to verify the output signal(s) in more detail. For this purpose, Faust has a useful "architecture file" named `plot.cpp` which results in generation of a main C++ program that simply prints the output signal(s) to the standard output. This printout can be used to plot the output (using, *e.g.*, `gnuplot`) or compare it to the output of some other program. This section gives an example of comparing the impulse response of the filter in Fig. 1 to the output of a matlab version. Specifically, we will compare the printed output from the Faust-generated program to the output of the matlab test program shown in Fig. 5.

```
SR = 44100; % Sampling rate

fr = 1000;  % Resonant frequency
bw = 100;   % Bandwidth
g  = 1;     % Peak gain
N = 10;     % Samples to generate in test

R = exp(-pi*bw/SR); % pole radius
A = 2*pi*fr/SR;     % pole angle (radians)
firpart = g * [1 0 -1] * (1-R^2)/2;
feedback = [1 -2*R*cos(A) R^2]; % freq-domain coeffs
freqz(firpart,feedback);        % freq-response display
format long;
h = impz(firpart,feedback,N)    % print impulse response
```

Figure 5: Constant Peak-Gain Resonator—matlab version

In our Faust program, we need a test impulse, *e.g.*,

```
process = 1-1' : firpart : + ~ feedback
with { ... <same as before> ... };
```

The signal `1` $= [1, 1, 1, \ldots]$ is the unit-step signal consisting of all ones, and `1'` $= [0, 1, 1, \ldots]$ is the unit step delayed by one sample. Therefore, `1-1'` is the impulse signal $\delta = [1, 0, 0, \ldots]$.

Suppose the file `cpgrir.dsp` ("Constant-Peak-Gain Resonator Impulse-Response") contains our test Faust program. Then we can generate the impulse-response printout as follows at the command line:

```
> faust -a plot.cpp -o cpgrir-print.cpp cpgrir.dsp
> g++ -Wall -g -lm -lpthread cpgrir-print.cpp -o cpgrir-print
> cpgrir-print -n 10
```

(The first two lines above are done by the `faust2plot` utility distributed with Faust.) The first line generates the C++ program `cpgrir.cpp` from the Faust source file `cpgrir.dsp` using the architecture file `plot.cpp`. The second line compiles the C++ file to produce the executable program `cpgrir-print`. Finally, the third line generates and prints the first 10 samples of the output signal (anything more than the number of filter coefficients is usually enough), which is our desired impulse response:[8]

```
h = [    0.00707331  0.0139039   0.013284
         0.012405    0.0112882   0.00995947
         0.00844865  0.00678877  0.00501544
         0.00316602      ... ]
```

The matlab version produces the following impulse response:

```
h =
 [ 0.00707328459864603 0.01390382707778288 0.01328399389241600
   0.01240496991806334 0.01128815312793390 0.00995943544693653
   0.00844861689634155 0.00678874919376101 0.00501542304704597
   0.00316601431505539 ... ]
```

Since matlab uses double-precision floating-point while Faust only supports single-precision `float`s, we will normally see differences after six or so decimal digits.

## 6 A Look at the Generated C++ code

Running Faust with no architecture file, *e.g.*,

```
 > faust cpgrir.dsp
```

causes the C++ signal-processing code to be printed on the standard output, as shown for this example in Fig. 6. Notice how the constant subexpressions are computed only once per instance in the `instanceInit` member function. Also, even in `instanceInit`, which is only called once, repeated computation of $R^2$ is avoided by use of the temporary variable `fConst1`, and division by 2 is converted to multiplication by 0.5.

## 7 Generating a Pure Data (Pd) Plugin

This section illustrates making a `pd` plugin using the Faust architecture file `puredata.cpp`, and Albert Gräf's `faust2pd` script (version 0.9.8.6—also included in the Planet CCRMA distribution). Familiarity with Pure Data (the `pd` program by Miller Puckette [3, 4]) is assumed in this section. Also, the original `faust2pd` paper [1] contains the most complete description of `faust2pd` at the time of this writing.

Even if one prefers writing real-time signal-processing programs in C++, C, or assembly language,[9] the ability to generate user interfaces and plugins with Faust is compellingly useful.

[8]This specific output was obtained by editing `cpgrir-print.cpp` to replace `%8f` by `%g` in the print statements, in order to print more significant digits.

[9]In many cases the signal processing in Faust can occur within a "foreign function" written in C or C++ and used as a "black box" within Faust, like the `cos()` function in Fig. 5 on page 8. However, this approach is presently limited because foreign functions can have only `float` and `int` argument types, and they can only return a `float` each sample. It is possible to set up persistent state in a foreign function by means of static variables, but this does not generalize easily to multiple instances. Therefore, more general extensions may require direct modification of the generated C++, which usually obsoletes the Faust source code.

```
class mydsp : public dsp {
private:
  float fConst0;    float fConst1;
  int   iVec0[2];   float fConst2;
  int   iVec1[3];   float fConst3;   float fRec0[3];
public:
  virtual int getNumInputs()    { return 0; }
  virtual int getNumOutputs()   { return 1; }
  static void classInit(int samplingFreq) { }
  virtual void instanceInit(int samplingFreq) {
    fSamplingFreq = samplingFreq;
    fConst0 = expf((0 - (314.159271f / fSamplingFreq)));
    fConst1 = (fConst0 * fConst0);
    for (int i=0; i<2; i++) iVec0[i] = 0;
    fConst2 = ((2 * fConst0) * cosf((2764.601562f
                           / fSamplingFreq)));
    for (int i=0; i<3; i++) iVec1[i] = 0;
    fConst3 = (0.500000f * (1 - fConst1));
    for (int i=0; i<3; i++) fRec0[i] = 0; }
  virtual void init(int samplingFreq) {
    classInit(samplingFreq);
    instanceInit(samplingFreq); }
  virtual void buildUserInterface(UI* interface) {
    interface->openVerticalBox("faust");
    interface->closeBox(); }
  virtual void compute (int count, float** input,
                                   float** output) {
    float* output0 = output[0];
    for (int i=0; i<count; i++) {
      iVec0[0] = 1;
      int iTemp0 = iVec0[1];
      iVec1[0] = (1 - iTemp0);
      fRec0[0] = (((fConst3 * (1 - (iTemp0 + iVec1[2])))
                               + (fConst2 * fRec0[1]))
                               - (fConst1 * fRec0[2]));
      output0[i] = fRec0[0];
      // post processing
      fRec0[2] = fRec0[1]; fRec0[1] = fRec0[0];
      iVec1[2] = iVec1[1]; iVec1[1] = iVec1[0];
      iVec0[1] = iVec0[0];
    }
  }
};
```

Figure 6: C++ code emitted by the shell command
`faust cpgrir.dsp` (and reformatted slightly).

To illustrate automatic generation of user-interface controls, we will add two "numeric entry" fields and one "horizontal slider" to our example of Fig. 1. These controls will allow the plugin user to vary the center-frequency, bandwidth, and peak gain of the constant-peak-gain resonator in real time. A complete listing of `cpgrui.dsp` ("Constant-Peak-Gain Resonator with User Interface") appears in Fig. 7.

```
declare name "Constant-Peak-Gain Resonator";
declare author "Julius Smith";
declare version "1.0";
declare license "GPL";

/* Controls */
fr = nentry("frequency (Hz)", 1000, 20, 20000, 1);
bw = nentry("bandwidth (Hz)", 100, 20, 20000, 10);
g  = hslider("peak gain", 1, 0, 10, 0.01);

/* Constants (Faust provides these in math.lib) */
SR = fconstant(int fSamplingFreq, <math.h>);
PI = 3.1415926535897932385;

/* The resonator */
process = firpart : + ~ feedback
with {
  R = exp(0-PI*bw/SR); // pole radius [0 required]
  A = 2*PI*fr/SR;      // pole angle (radians)
  RR = R*R;
  firpart(x) = (x - x'') * (g) * ((1-RR)/2);
  // time-domain coeffs ASSUMING ONE PIPELINE DELAY:
  feedback(v) = 0 + 2*R*cos(A)*v - RR*v';
};
```

Figure 7: Listing of `cpgrui.dsp`—a Faust program specifying a constant-peak-gain resonator with three user controls. Also shown are typical header declarations.

## 7.1 Generating the Pd Plugin

The plugin may be compiled on a Linux system as follows:

```
> faust -a puredata.cpp -o cpgrui-pd.cpp cpgrui.dsp
> g++ -DPD -Wall -g -shared -Dmydsp=cpgrui \
      -o cpgrui~.pd_linux  cpgrui-pd.cpp
```

The first line uses `faust` to generate a compilable `.cpp` file, this time using the architecture file `puredata.cpp` which encapsulates the `pd` plugin API. The second line (which wraps) compiles `cpgrui-pd.cpp` to produce the dynamically loadable (binary) object file `cpgrui~.pd_linux`, which is our signal-processing plugin for `pd`. Such `pd` plugins are also called *externals* (externally compiled loadable modules). The filename extension "`.pd_linux`" indicates that the plugin was compiled on a Linux system.

Figure 8 shows an example test patch,[10] named `cpgrui~-help.pd`,[11] written (manually) for the generated plugin. By convention, the left inlet and outlet of a Faust-generated plugin correspond to control info and general-purpose messages. Any remaining inlets and outlets are signals.

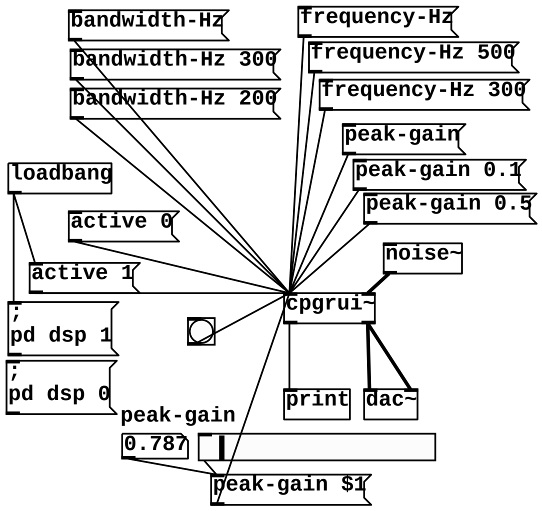


Figure 8: Pure Data test patch `cpgrui~-help.pd` exercising features of the external `pd` plugin `cpgrui~` generated by Faust using the `puredata.cpp` architecture file.

A simple "bang" message to the control-inlet of the plugin (sent by clicking on the "button" drawn as a circle-within-square in Fig. 8), results in a list being sent to the control (left) outlet describing all plugin controls and their current state. The `print` object in Fig. 8 prints the received list in the main `pd` console window. For our example, we obtain the following bang-response in the `pd` console:

```
print: nentry /faust/bandwidth-Hz 100 100 20 20000 10
print: nentry /faust/frequency-Hz 1000 1000 20 20000 1
print: hslider /faust/peak-gain 1 1 0 10 0.01
```

These are the three controls we expected corresponding to the frequency, bandwidth, and gain of the resonator. However, note that the message-names generated for the controls have changed. In particular, spaces have been replaced by hyphens, and parentheses have been removed, to observe `pd` naming rules for messages [1].

Controls may be queried or set to new values in the plugin by sending the following `pd` *messages*:

- `frequency-Hz [newval]`
- `bandwidth-Hz [newval]`
- `peak-gain [newval]`

[10]All manually generated `.dsp` files and `pd` patches in this module are available at `http://ccrma.stanford.edu/realsimple/faust/faustpd.tar.gz`.

[11]In `pd`, a dynamically loadable module (`pd` plugin) is called an *abstraction*. (This is distinct from the *one-off subpatch* which is encapsulated code within the parent patch, and which resides in the same file as the parent patch [4].) It is customary to document each abstraction with its own "help patch". The convention is to name the help patch "name-help.pd", where "name" is the name of the abstraction. Right-clicking on an object in `pd` and selecting "Help" loads the help patch in a new `pd` window.

The longer form of the control name printed in the `pd` console, *e.g.*,
`/faust/peak-gain`, is the complete "fully qualified path" that can be used to address controls within a hierarchy of nested controls and abstractions. For example, if we were to add the instance argument "foo" to the plugin (by changing the contents of the plugin box to "`cpgrui~ foo`" in Fig. 8), then the path to the `peak-gain` control, for example, would become `/foo/faust/peak-gain` (see [1] and the Faust documentation for more details and examples).

In the test-patch of Fig. 8, the various controls are exercised using `pd` *message boxes*. For example, the message "`peak-gain`" with no argument causes the plugin to print the current value of the peak-gain parameter on its control outlet. Messages with arguments, such as "`peak-gain 0.01`", set the parameter to the argument value without generating an output message. The slider and number-box output raw numbers, so they must be routed through a message-box in order to prepend the controller name ("peak-gain" in this case).

The plugin input signal (second inlet) comes from a `noise~` object in Fig. 8, and the output signal (second outlet) is routed to both channels of the D/A converter (for center panning).

In addition to the requested controls, all plugins generated using the `puredata.cpp` architecture file respond to the boolean "`active`" message, which, when given a "false" argument such as 0, tells the plugin to bypass itself. This too is illustrated in Fig. 8. Note that setting active to "true" at load time using a `loadbang`[12] message is not necessary; the plugin defaults to the active state when loaded and initialized—no `active` message is needed. The `loadbang` in this patch also turns on `pd` audio computation for convenience.

## 7.2 Generating a Pd Plugin-Wrapper Abstraction

The test patch of Fig. 8 was constructed in `pd` by manually attaching user-interface elements to the left (control) inlet of the plugin. As is well described in [1], one can alternatively use the `faust2pd` script to generate a `pd` abstraction containing the plugin and its `pd` controllers. When this abstraction is loaded into `pd`, its controllers are brought out to the top level using the "graph on parent" mechanism in `pd`, as shown in Fig. 10 on page 15.

The `faust2pd` script works from the XML file generated by Faust using the `-xml` option:

```
> faust -xml -a puredata.cpp -o cpgrui-pd.cpp cpgrui.dsp
> faust2pd cpgrui.dsp.xml
```

Adding the `-xml` option results in generation of the file `cpgrui.dsp.xml` which is then used by `faust2pd` to generate `cpgrui.pd`. Type `faust2pd -h` (and read [1]) to learn more of the features and options of the `faust2pd` script.

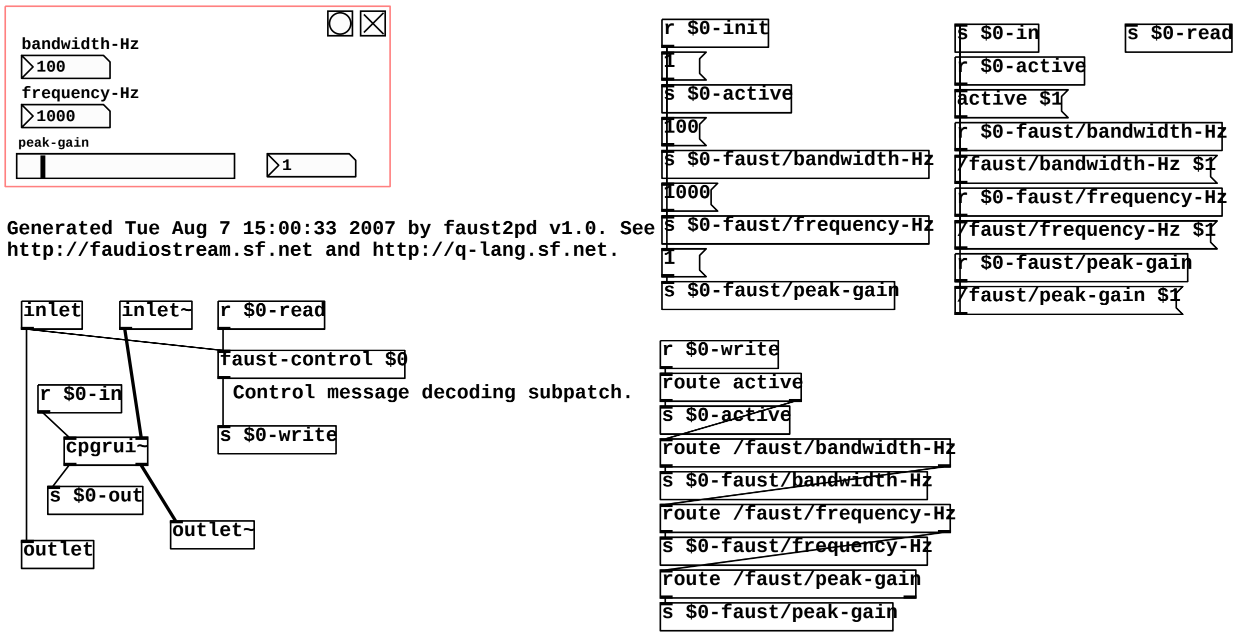
The generated abstraction can be opened in `pd` as follows:

```
> pd cpgrui.pd
```

Figure 9 shows the result. As indicated by the `inlet~` and `outlet~` objects, the abstraction is designed to be used in place of the plugin. For this reason, we will refer to it henceforth as a *plugin wrapper*.

Notice in Fig. 9 that a plugin wrapper forwards its control messages (left-inlet messages) to the encapsulated plugin, as we would expect. However, it also forwards a copy of each control message

[12] The `loadbang` object sends a "bang" message when the patch finishes loading.



```
Generated Tue Aug 7 15:00:33 2007 by faust2pd v1.0. See
http://faudiostream.sf.net and http://q-lang.sf.net.
```

Figure 9: Pure Data abstraction generated by `faust2pd` from the XML file emitted by Faust for the constant-peak-gain resonator (`cpgrui.dsp`).

to its control outlet. This convention facilitates making *cascade chains* of plugin-wrappers, as illustrated in `faust2pd` examples such as `synth.pd`.[13]

## 7.3 A Pd Test Patch for the Plugin Wrapper

Figure 10 shows `pd` patch developed (manually) to test the plugin wrapper generated by `faust2pd`. Compare this with Fig. 8 on page 12. Notice how the three controls are brought out to the plugin-wrapper object automatically using the "graph on parent" convention for `pd` abstractions with controllers. The bang button on the plugin resets all controls to their default values, and the toggle switch in the upper-right corner functions as a "bypass" switch (by sending the `active` message with appropriate argument). The previous mechanism of setting controls via message boxes to the control inlet still works, as illustrated. However, as shown in Fig. 9 (or by opening the plugin-wrapper in `pd`), the control outlet simply receives a copy of everything sent to the control inlet. In particular, "bang" no longer prints a list of all controls and their settings, and controls cannot be queried.

## 8 Generating a LADSPA Plugin via Faust

LADSPA stands for "Linux Audio Developer Simple Plugin API", and it is the most common audio plugin API for Linux applications. It can be considered the Linux counterpart of the widely used

[13]On a Linux system with Planet CCRMA installed, the command "`locate synth.pd`" should find it, *e.g.*, at `/usr/share/doc/faust-pd-0.9.8.6/examples/synth/synth.pd` .

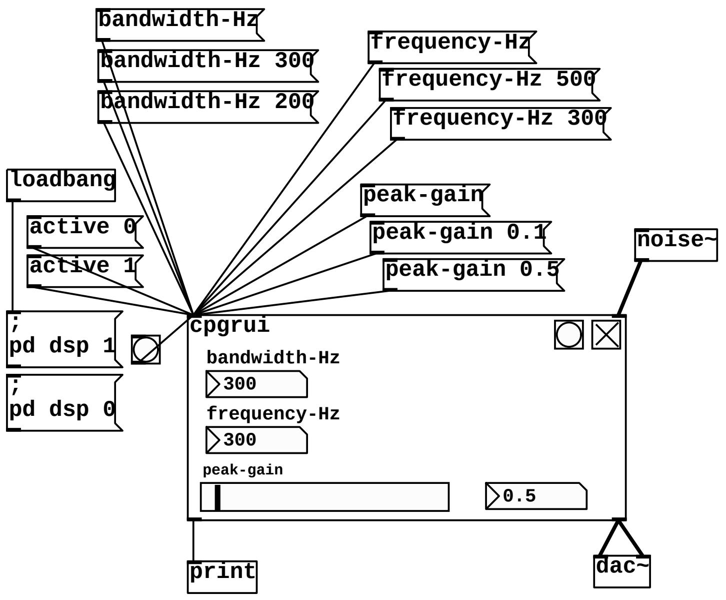


Figure 10: Pure Data test patch (`cpgrui-help.pd`) for exercising the plugin-wrapper (`cpgrui.pd`) generated by `faust2pd` to control the `faust`-generated `pd` plugin (`cpgrui~.pd_linux`).

VST plugin standard for Windows applications. In the Planet CCRMA distribution, most of the LADSPA plugins are found in the directory `/usr/lib/ladspa/`. At the time of this writing, there are 161 audio plugins (`.so` files) in or under that directory.

To generate a LADSPA plugin from Faust source, it is merely necessary to use the `ladspa.cpp` architecture file, as in the following example:

```
> faust -a ladspa.cpp cpgrui.dsp -o cpgruilp.cpp
> g++ -fPIC -shared -O3 \
      -Dmydsp='Constant_Peak_Gain_Resonator' \
      cpgruilp.cpp -o cpgruilp.so
> cp cpgruilp.so /usr/local/lib/ladspa/
```

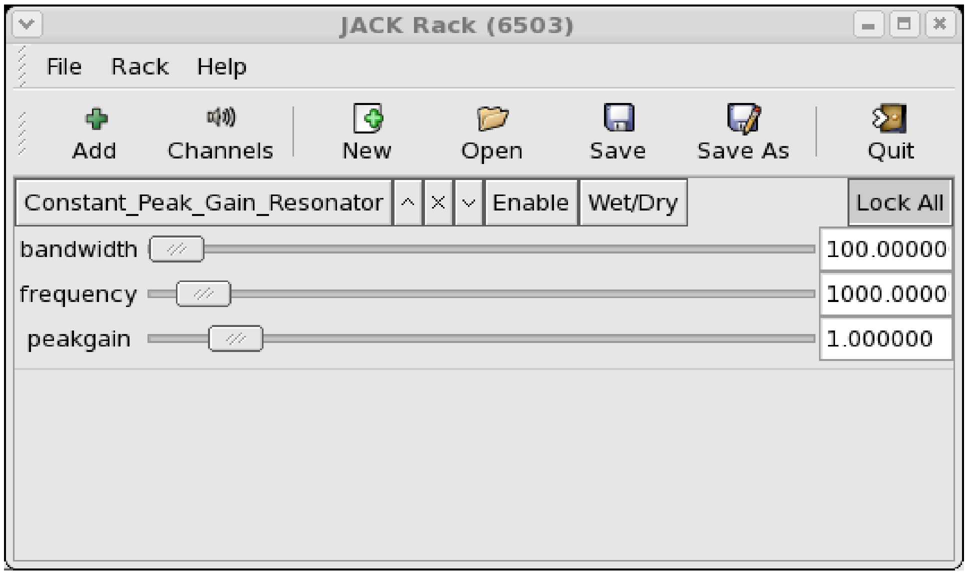
(Recall that `cpgrui.dsp` was listed in Fig. 7 on page 11.) We see that the C++ compilation step calls for "position-independent code" (option `-fPIC`) and a "shared object" format (option `-shared`) in order that the file be dynamically loadable by a running program. (Recall that `pd` similarly required its externals to be compiled `-shared`.) The Faust distribution provides the make file `/usr/lib/faust/Makefile.ladspacompile` (among others) which documents such details.

Many Linux programs support LADSPA programs, such as the sound editor Audacity, the multitrack audio recorder/mixer Ardour, and the sequencer Rosegarden. However, for our example, we'll use a simple application-independent LADSPA effects rack called JACK Rack (select "Applications / Planet CCRMA / Jack / JACK Rack").

Figure 11 shows the appearance of the `jack-rack` main window after adding[14] the plugin named

[14]After running `jack-rack`, the LADSPA plugin was added by clicking on the menu items "Add / Uncategorised /

`Constant_Peak_Gain_Resonator`. Note that the two numeric entry fields have been converted to horizontal sliders. (Vertical sliders are also converted to horizontal.) Also, the controller names have been simplified. A bug is that the default values for the controls are not set correctly when the plugin loads. (They were set manually to obtain Fig. 11 as shown.)



bandwidth 100.00000
frequency 1000.0000
peakgain 1.000000

Figure 11: JACK Rack screenshot after adding the LADSPA plugin `Constant_Peak_Gain_Resonator`. Additional LADSPA plugins can be loaded in the space below (and connected in series).

To test the LADSPA plugin, any program's audio output can be routed through `jack-rack` to the sound-out driver (typically "ALSA PCM" these days). For example, `pd`'s audio output can be routed through `jack-rack` to `alsa_pcm` as shown in Fig. 12.[15]

## 9 Generating a VST Plugin via Faust

This section describes generation of a Windows VST plugin starting from Faust code, again using the constant-peak-gain resonator example.

The *VST* (Virtual Studio Technology) plugin standard was developed by Steinberg Media Technologies (makers of Cubase). It enjoys wide usage on Windows and Macintosh platforms. The Faust distribution contains the make-file `/usr/lib/faust/Makefile.vstcompile` for compiling and installing VST plugins using Xcode on a Mac OS-X machine. For our example, however, we'll create a Windows-format VST plugin (`.dll` file) using Microsoft Visual C++. The example was

C / Constant_Peak_Gain_Resonator". If `jack-rack` does not find this or other plugins, make sure your `LADSPA_PATH` environment variable is set. A typical setting would be `/usr/local/lib/ladspa/:/usr/lib/ladspa/`.

[15]Sound routings such as this may be accomplished using the "Connect" window in `qjackctl`. In that window, there is an Audio tab and a MIDI tab, and the Audio tab is selected by default. Just click twice to select the desired source and destination and then click "Connect". Such connections can be made automatic by clicking "Patchbay" in the `qjackctl` control panel, specifying your connections, saving, then clicking "Activate". Connections can also be established at the command line using `aconnect` from the `alsa-utils` package (included with Planet CCRMA).

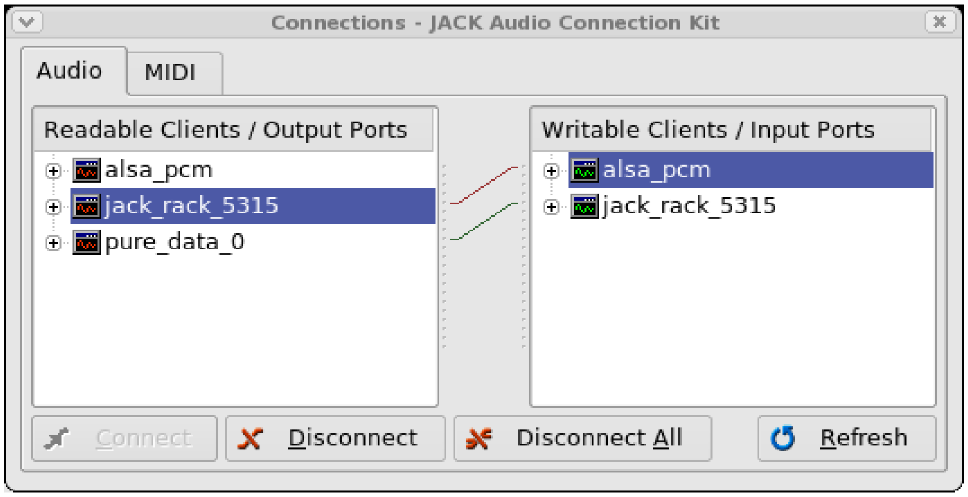


Figure 12: JACK audio connections routing `pd` through `jack-rack` to the ALSA sound-out driver `alsa_pcm`.

tested on a *Muse Receptor*.[16]

Because the Receptor does not support mono plugins, the `process` line in the Faust source in Fig. 7 on page 11 was modified as follows to make it stereo-compatible:

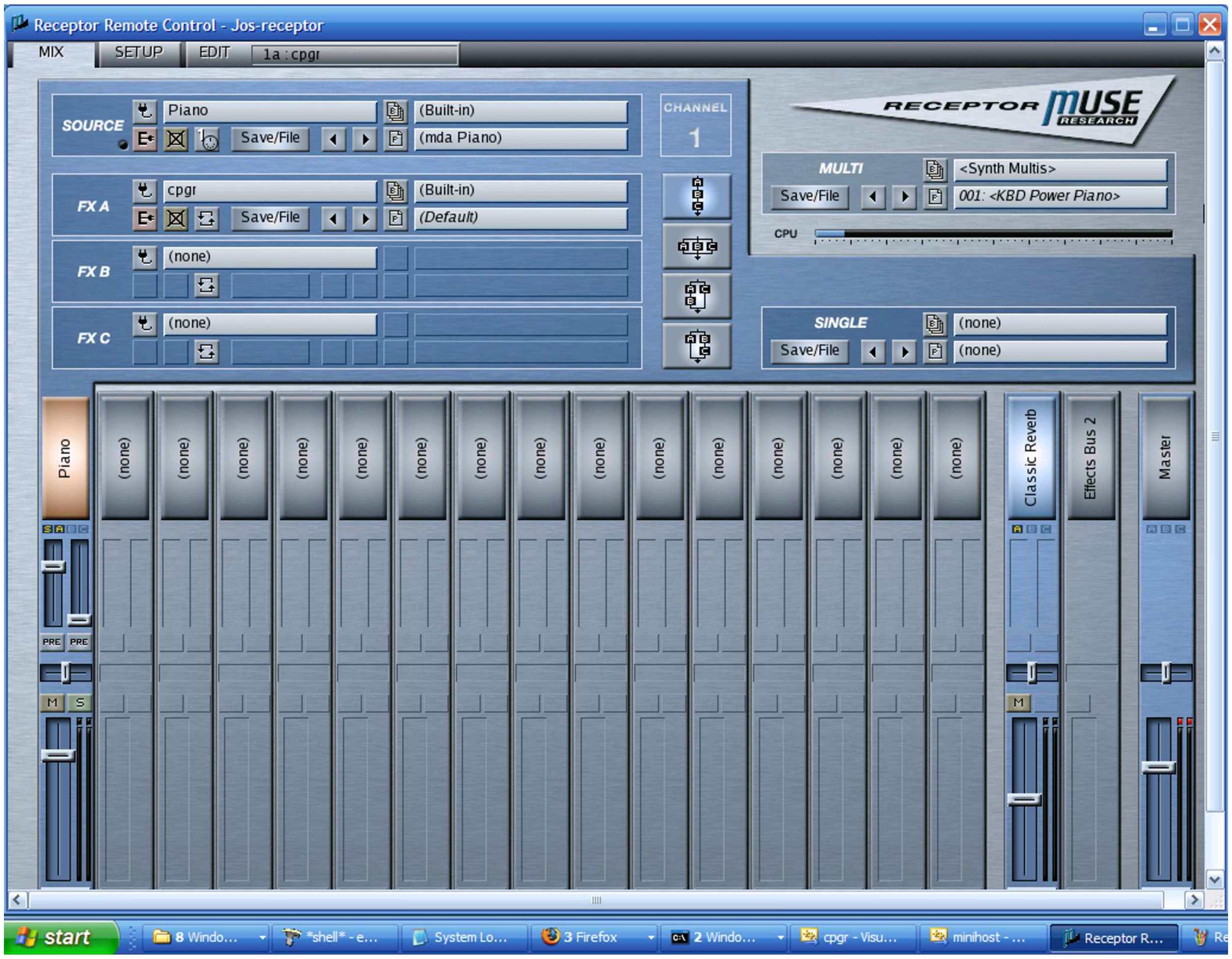
```
process = + : firpart : + ~ feedback <: (_,_)
```

This version was named `cpgrui_vst.dsp`. To generate a VST plugin, we simply use a VST architecture file:

```
faust -a vst2p4.cpp cpgrui_vst.dsp -o cpgrui_vst.cpp
```

Next, the file `cpgrui_vst.cpp` was copied over to a Windows-XP machine with Microsoft Visual Studio Express installed (including Visual C++ 2008). The programming sample "`again`" from the Steinberg VST-2.4 SDK was copied to an adjacent directory `cpgr` and trivially modified to create a compilable C++ project. (Specifically, replace `again.cpp` by `cpgrui_vst.cpp`, rename `again.vcproj` to `cpgr.vcproj`, and change all occurrences of "again" to "cpgrui_vst" in `cpgr.vcproj`, and change "Gain" to "CPGR" to rename the plugin. Finally, double-click on `cpgr.vcproj` to launch Visual C++ on the `cpgr` project.) Selecting the menu item "Build / Build cpgr" creates `cpgr/win/Debug/cpgr.dll` (the VST plugin itself). To test the plugin, it was copied into the "Unsupported Plugins" folder on the Receptor, and installed by clicking the "1 installs" button on the Receptor's Setup page. After that, the plugin could be instantiated on a Receptor "Mix" channel, as shown in Fig. 13, and Fig. 14 shows the automatically generated edit window of the plugin.

[16]The Receptor is a hardware VST plugin host designed for studio work and live musical performance. While it only supports Windows VST plugins, it is based on a Red Hat Linux operating system using `wine` for Windows compatibility. The VST plugin described in this section was tested on system version 1.6.20070717 running on Receptor hardware version 1.0. This system expects VST-2.3 plugins, and so VST-2.4 plugins cause a warning message to be printed in the Receptor's system log. However, v2.4 plugins seem to work fine in the 2.3 framework. There was a competitor to the Receptor called Plugzilla that supported both VST and LADSPA plugins, but Plugzilla no longer appears to be available.



SOURCE: Piano — (Built-in) — (mda Piano)

FX A: cpgr — (Built-in) — (Default)

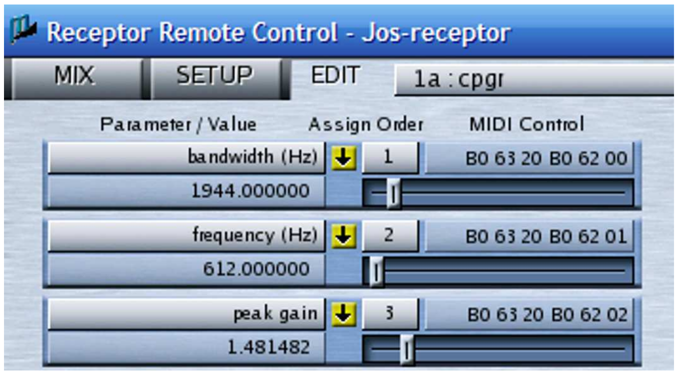
FX B: (none)

FX C: (none)

MULTI: <Synth Multis> — 001: <KBD Power Piano>

SINGLE: (none) — (none)

Figure 13: Screenshot of the Receptor Remote Control program, showing the “Mix” view. The constant-peak-gain resonator (named `cpgr`) is instantiated as a plugin processing the “Piano” source signal.



| Parameter / Value | Assign Order | MIDI Control |
|---|---|---|
| bandwidth (Hz) | 1 | B0 63 20 B0 62 00 |
| 1944.000000 | | |
| frequency (Hz) | 2 | B0 63 20 B0 62 01 |
| 612.000000 | | |
| peak gain | 3 | B0 63 20 B0 62 02 |
| 1.481482 | | |

Figure 14: Screenshot of the upper-left corner of the parameter-editing window of the Receptor’s remote-control program showing the constant-peak-gain resonator parameters.

## 9.1 Bypassing Windows

Beginning with Faust version `0.9.9.4j-par`, a new makefile called `Makefile.w32vstcompile` is distributed in the examples directory. This makefile can be adapted to work on Fedora F8 Linux as follows.

1. Download and install the following RPMs from SourceForge:

   ```
   mingw-binutils-2.18.50-6.fc8.i386.rpm
   mingw-gcc-core-4.2.1-6.fc8.i386.rpm
   mingw-gcc-g++-4.2.1-6.fc8.i386.rpm
   mingw-runtime-3.14-3.fc8.i386.rpm
   mingw-w32api-3.11-3.fc8.i386.rpm
   ```

   (Unfortunately, mingw is not in the standard yum repos yet.)

2. In `Makefile.w32vstcompile`, edit the `VST` line to say where your `vstsdk2.4` directory is located, and change all occurrences of `i586-mingw32msvc` to `i386-mingw32`.

3. The plugin name defaults to “FaustFx”. You can change this by declaring the `name` in your Faust source. For the example of the previous section, we could say

   ```
   declare name "CPGR";
   ```

   in place of the longer name used in Fig. 7 on page 11. (The longer name results in a plugin called “ConstantPeakGainResonator”.)

4. After the make, simply copy the dll file to the Receptor and tell the Receptor to install it on the Setup page of the Receptor Remote Control program as before (which requires Windows or a Mac). While one can press the Setup button on the Receptor front panel and rotate the Top Display Knob to “Install/Upgrade” (the next-to-last entry), there you will find “0 files” even when there is a file to install. The manual documents that it is not allowed to install plugins from the Receptor front panel, because some installs require a user interface (such as to receive an authorization code). This is an unfortunate and unnecessary restriction in our case that prevents working entirely directly with the Receptor from a Linux environment.

The Receptor’s “Unsupported Plugins” directory can be mounted as follows:

```
> mkdir /mnt/receptor
> mount -t cifs <ReceptorIPA>:hard\ drive/Program\ Files/VST\ Plugins/Unsupported\ Plugins \
       /mnt/receptor
```

(Remember to say `umount /mnt/receptor` when you are done.) The Receptor’s IP Address (typically assigned by DHCP) can also be viewed by pressing the Setup button and rotating the Top Display Knob to that field.

## 10 Generating a MIDI Synthesizer for Pd

The `faust2pd` script (introduced in §7 above) also has a mode for generating *MIDI synthesizer plugins* for `pd`. This mode is triggered by use of the `-n` option (“number of voices”). For this mode, the Faust program should be written to synthesize one voice using the following three parameters (which are driven from MIDI data in the `pd` plugin):

- `freq` - frequency of the played note (Hz)
- `gain` - amplitude of the played note (0 to 1)
- `gate` - 1 while “key is down”, 0 after “key up”

The parameters `freq` and `gain` are set according to MIDI note-number and velocity, respectively, while the `gate` parameter is set to 1 on a MIDI “note-on” and back to zero upon “note-off”. The `faust2pd` script handles instantiation of up to 8 instances of the synth patch, and provides the abstraction `midi-in.pd` for receiving and decoding MIDI data in `pd`.

Let’s make a simple 8-voiced MIDI synthesizer based on the example Faust program `cpgrs.dsp` (“Constant-Peak-Gain Resonator Synth”) listed in Fig. 15. In addition to converting the frequency and gain parameters to the standard names, we have added a classic ADSR envelope generator (defined in Faust’s `music.lib` file) which uses the new `gate` parameter, and which adds the four new envelope parameters `attack`, `decay`, `sustain`, and `release`.

Compiling the example is the same as for a `pd` plugin, except that the `-n` option is used (8 voices is the maximum):

```
> faust -xml -a puredata.cpp -o cpgrs-pd.cpp cpgrs.dsp
> g++ -DPD -Wall -g -shared -Dmydsp=cpgrs \
      -o cpgrs~.pd_linux cpgrs-pd.cpp
> faust2pd -n 8 -s -o cpgrs.pd cpgrs.dsp.xml
```

## 11 MIDI Synthesizer Test Patch

The example synth is loaded into `pd` like any plugin-wrapper. A manually written test patch (`cpgrs-help.pd`) is shown in Fig. 16. Note that the standard MIDI-synth control parameters (`freq, gain, gate`) are handled behind the scenes and do not appear among the plugin GUI controls.

To drive our MIDI synth, we need a source of MIDI data. Perhaps the simplest resource for this purpose is the Virtual Keyboard (`vkeybd`), which is standard in Red Hat Fedora 6, and in the `planetccrma-menus` at “Applications / Planet CCRMA / MIDI / Vkeybd”). Figure 17 shows a screen shot of the Virtual Keyboard with its key-range and velocity controllers displayed (menu item “View / Key/Velocity”). The velocity controller sets the `gain` parameter, mapping MIDI velocity (0-127) to the unit interval (0-1). The key-range controller transposes the keyboard by octaves. Pressing a key determines, together with the key-range, the `freq` parameter in our synth. Pressing a key also sets the `gate` parameter to 1, and releasing it sets `gate` to 0. The ADSR envelope is triggered when `gate` transitions to 1, and it begins its “release” phase when `gate` transitions to 0, as is standard for ADSR envelopes triggered by a keyboard. Note that the bottom two rows of ASCII keyboard keys are mapped to virtual-keyboard keys, enabling the playing of chords in real time on the regular computer keyboard.

Figure 18 illustrates the MIDI tab of `qjackctl`’s Connect window after connecting the Virtual Keyboard MIDI output to `pd`’s MIDI input.[17]

[17] Pd must have at least one MIDI-input port defined at startup for this to work. For example, a typical `~/.pdrc` file might contain the following startup options for `pd`:

```
-jack -r 48000 -alsamidi -midiindev 1 -midioutdev 1 -audiooutdev 1 -outchannels 2 -path
/usr/lib/pd/...
```

```
declare name "Constant-Peak-Gain Resonator Synth";
declare author "Julius Smith";
declare version "1.0";
declare license "GPL";

/* Standard synth controls supported by faust2pd */
freq = nentry("freq", 440, 20, 20000, 1); // Hz
gain = nentry("gain", 0.1, 0, 1, 0.01); // frac
gate = button("gate"); // 0/1

/* User Controls */
bw = hslider("bandwidth (Hz)", 100, 20, 20000, 10);

import("music.lib"); // define noise, adsr, PI, SR, et al.

/* ADSR envelope parameters */
attack  = hslider("attack", 0.01,0, 1, 0.001); // sec
decay   = hslider("decay",  0.3, 0, 1, 0.001); // sec
sustain = hslider("sustain",0.5, 0, 1, 0.01);  // frac
release = hslider("release",0.2, 0, 1, 0.001); // sec

/* Synth */
process = noise * env * gain : filter
with {
  env = gate :
        vgroup("1-adsr",
               adsr(attack, decay, sustain, release));
  filter = vgroup("2-filter", (firpart : + ~ feedback));
  R = exp(0-PI*bw/SR); // pole radius [0 required]
  A = 2*PI*freq/SR;      // pole angle (radians)
  RR = R*R;
  firpart(x) = (x - x'') * ((1-RR)/2);
  // time-domain coeffs ASSUMING ONE PIPELINE DELAY:
  feedback(v) = 0 + 2*R*cos(A)*v - RR*v';
};
```

Figure 15: Listing of `cpgrs.dsp`—a Faust program specifying a simple synth patch consisting of white noise through a constant-peak-gain resonator.

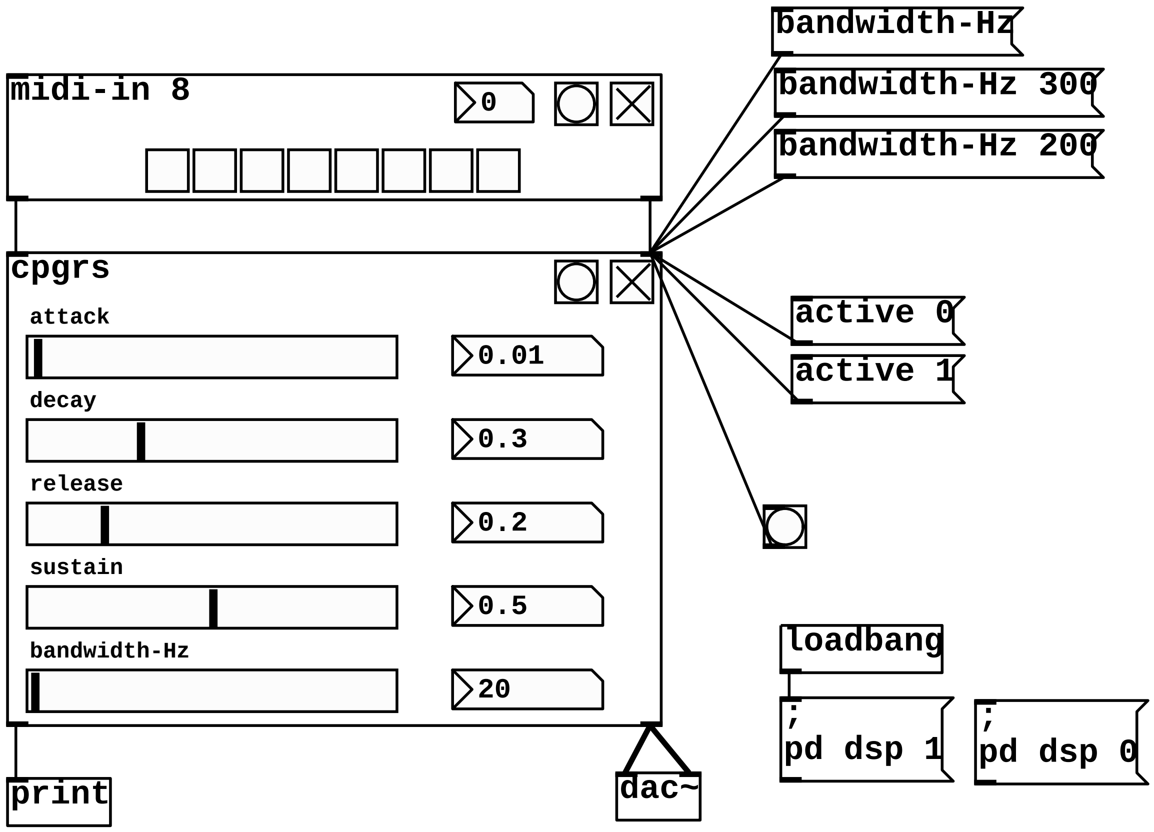


Figure 16: Test patch for the `pd` synth plugin `cpgrs.pd` generated by `faust2pd` based on `cpgrs.dsp` in Fig. 15.

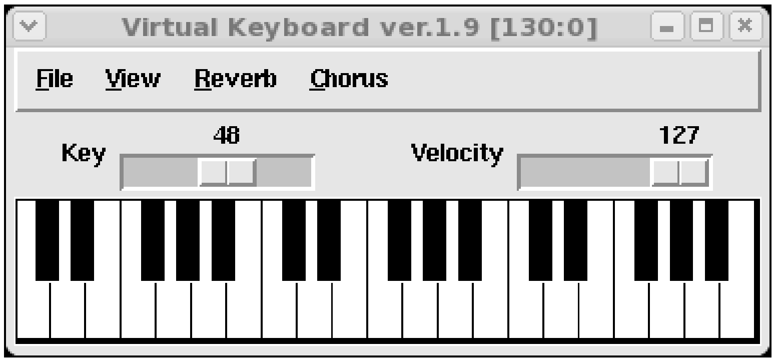


Figure 17: The Virtual Keyboard (MIDI source).

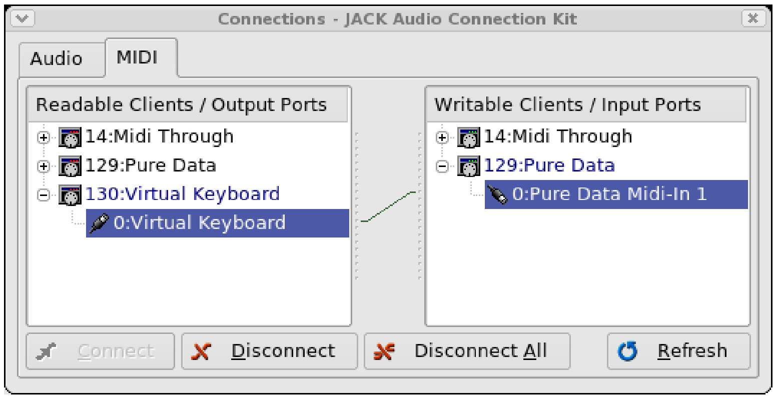


Figure 18: JACK MIDI connections routing MIDI from the Virtual Keyboard (`vkeybd`) to `pd`'s first MIDI input port.

To play back a MIDI file (extension `.mid`), a nice way is to open it in Rosegarden ("Applications / Planet CCRMA / Sequencers / Rosegarden") and connect Rosegarden's MIDI output to `pd`'s MIDI input as above. (You can still play along on the Virtual Keyboard.)

## References

[1] A. Gräf, "Interfacing Pure Data with Faust," in *Proceedings of the 5th International Linux Audio Conference (LAC2007)*, *http://www.kgw.tu-berlin.de/~lac2007/proceedings.shtml*.

[2] Y. Orlarley, A. Gräf, and S. Kersten, "DSP programming with Faust, Q and SuperCollider," in *Proceedings of the 4th International Linux Audio Conference (LAC2006)*, *http://lac.zkm.de/2006/proceedings.shtml*, 2006, `http://www.grame.fr/pub/lac06.pdf`.

[3] M. Puckette, *Pure Data (PD)*, `http://www.puredata.org`, July 2004.

[4] M. Puckette, *Theory and Techniques of Electronic Music*, http://www.worldscibooks.com/compsci/6277.html: World Scientific Press, May 2007, `http://www-crca.ucsd.edu/ msp/techniques.htm`.

[5] J. O. Smith, *Introduction to Digital Filters with Audio Applications*, `http://w3k.org/books/`: W3K Publishing, 2007, `http://ccrma.stanford.edu/~jos/filters/`.

[6] J. O. Smith, "Virtual electric guitars and effects using Faust and Octave," in *Proceedings of the 6th International Linux Audio Conference (LAC2008)*, *http://lac.linuxaudio.org/*, 2008, paper: `http://ccrma.stanford.edu/realsimple/faust_strings/faust_strings.pdf`, overheads: `http://ccrma-ftp.stanford.edu/~jos/pdf/LAC2008-jos.pdf`, supporting website: `http://ccrma.stanford.edu/realsimple/faust_strings/`.