Musicdsp.org Documentation

Too many to list

May 23, 2020
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Welcome to musicdsp.org.

Musicdsp.org is a collection of algorithms, thoughts and snippets, gathered for the music dsp community. Most of this data was gathered by and for the people of the splendid Music-DSP mailing list at http://sites.music.columbia.edu/cmc/music-dsp/

**Important:** Please help us edit these pages at https://github.com/bdejong/musicdsp

- Special thanks: http://www.fxpansion.com for sponsoring a server to host the archive for many, many years
- Special thanks: http://www.dspdimension.com for pointing http://www.musicdsp.com to this site too
1.1 (Allmost) Ready-to-use oscillators

- **Author or source:** Ross Bencina, Olli Niemitalo, ...
- **Type:** waveform generation
- **Created:** 2002-01-17 01:01:39

Listing 1: notes

Ross Bencina: original source code poster
Olli Niemitalo: UpdateWithCubicInterpolation

Listing 2: code

```cpp
//this code is meant as an EXAMPLE
//uncomment if you need an FM oscillator
//define FM_OSCILLATOR

/*
members are:

float phase;
int TableSize;
float sampleRate;

float *table, dtable0, dtable1, dtable2, dtable3;

-->these should be filled as follows... (remember to wrap around!!!)
table[i] = the wave-shape
dtable0[i] = table[i+1] - table[i];
dtable1[i] = (3.f*(table[i]-table[i+1])-table[i-1]+table[i+2])/2.f
```

(continues on next page)
float Oscillator::UpdateWithoutInterpolation(float frequency) {
    int i = (int) phase;
    phase += (sampleRate/(float)TableSize)/frequency;
    if(phase >= (float)TableSize)
        phase -= (float)TableSize;

#ifdef FM_OSCILLATOR
    if(phase < 0.f)
        phase += (float)TableSize;
#endif

    return table[i] ;
}

float Oscillator::UpdateWithLinearInterpolation(float frequency) {
    int i = (int) phase;
    float alpha = phase - (float) i;
    phase += (sampleRate/(float)TableSize)/frequency;
    if(phase >= (float)TableSize)
        phase -= (float)TableSize;

#ifdef FM_OSCILLATOR
    if(phase < 0.f)
        phase += (float)TableSize;
#endif

    /*
     * dtable0[i] = table[i+1] - table[i]; //remember to wrap around!!!
     */
    return table[i] + dtable0[i]*alpha;
}

float Oscillator::UpdateWithCubicInterpolation(float frequency) {
    int i = (int) phase;
    float alpha = phase - (float) i;
    phase += (sampleRate/(float)TableSize)/frequency;
    if(phase >= (float)TableSize)
        phase -= (float)TableSize;

#ifdef FM_OSCILLATOR
    if(phase < 0.f)
        phase += (float)TableSize;
#endif
}
1.2 AM Formantic Synthesis

- **Author or source:** Paul Sernine
- **Created:** 2006-07-05 20:14:14

Listing 3: notes

Here is another tutorial from Doc Rochebois.
It performs formantic synthesis without filters and without grains. Instead, it uses
"double carrier amplitude modulation" to pitch shift formantic waveforms. Just beware
→ the
phase relationships to avoid interferences. Some patches of the DX7 used the same
→ trick
but phase interferences were a problem. Here, Thierry Rochebois avoids them by using
cosine-phased waveforms.

Various formantic waveforms are precalculated and put in tables, they correspond to
different formant widths.
The runtime uses many intances (here 4) of these and pitch shifts them with double
carriers (to preserve the harmonicity of the signal).

This is a tutorial code, it can be optimized in many ways.
Have Fun

Paul

Listing 4: code

// FormantsAM.cpp
// Thierry Rochebois' "Formantic Synthesis by Double Amplitude Modulation"
// Based on a tutorial by Thierry Rochebois.
// Comments by Paul Sernine.
// The spectral content of the signal is obtained by adding amplitude modulated
// formantic
// waveforms. The amplitude modulations spectrally shift the formantic waveforms.
// Continuous spectral shift, without losing the harmonic structure, is obtained
// by using crossfaded double carriers (multiple of the base frequency).
// To avoid unwanted interference artifacts, phase relationships must be of the
// "cosine type".
// The output is a 44100Hz 16bit stereo PCM file.

#include <math.h>
#include <stdio.h>
#include <stdlib.h>

//Approximates cos(pi*x) for x in [-1,1].
inline float fast_cos(const float x)
{
    float x2=x*x;
    return 1+x2*(-4+2*x2);
}

//Length of the table
#define L_TABLE (256+1) //The last entry of the table equals the first (to avoid a _modulo)

//Maximal formant width
#define I_MAX 64

//Table of formants
float TF[L_TABLE*I_MAX];

//Formantic function of width I (used to fill the table of formants)
float fonc_formant(float p, const float I)
{
    float a=0.5f;
    int hmax=int(10*I)>L_TABLE/2?L_TABLE/2:int(10*I);
    float phi=0.0f;
    for(int h=1;h<hmax;h++)
    {
        phi+=3.14159265359f*p;
        float hann=0.5f+0.5f*fast_cos(h*(1.0f/hmax));
        float gaussienne=0.85f*exp(-h*h/(I*I));
        float jupe=0.15f;
        float harmonique=cosf(phi);
        a+=hann*(gaussienne+jupe)*harmonique;
    }
    return a;
}

//Initialisation of the table TF with the fonction fonc_formant.
void init_formant(void)
{
    float coef=2.0f/(L_TABLE-1);
    for(int I=0;I<I_MAX;I++)
        for(int P=0;P<L_TABLE;P++)
            TF[P+I*L_TABLE]=fonc_formant(-1+P*coef,float(I));
}

//This function emulates the function fonc_formant
// thanks to the table TF. A bilinear interpolation is
// performed
float formant(float p,float i)
{
    i=i<0?0:i>I_MAX-2?I_MAX-2:i; // width limitation
    float P=(L_TABLE-1)*(p+1)*0.5f; // phase normalisation
    int P0=int(P); float fP=P-P0; // Integer and fractional
    int I0=int(i); float fI=i-I0; // parts of the phase (p) and width (i).
    int i00=P0+L_TABLE*I0; int i10=i00+L_TABLE;
    // (continues on next page)
71 //bilinear interpolation.
72     return (1-fI)*(TF[100] + fP*(TF[100+1]-TF[100]))
73       + fI*(TF[110] + fP*(TF[110+1]-TF[110]));
74 }
75
76 // Double carrier.
77 // h : position (float harmonic number)
78 // p : phase
79 float porteuse(const float h, const float p)
80 {
81     float h0=floor(h); //integer and
82     float hf=h-h0;   //decimal part of harmonic number.
83     // modulos pour ramener p*h0 et p*(h0+1) dans [-1,1]
84     float phi0=fmodf(p* h0 +1+1000,2.0f)-1.0f;
85     float phi1=fmodf(p*(h0+1)+1+1000,2.0f)-1.0f;
86     // two carriers.
87     float Porteuse0=fast_cos(phi0); float Porteuse1=fast_cos(phi1);
88     // crossfade between the two carriers.
89     return Porteuse0+hf*(Porteuse1-Porteuse0);
90 }
91
92 int main()
93 {
94     //Formant table for various french vowels (you can add your own)
95     float F1[]={ 730, 200, 400, 250, 190, 350, 550, 550, 450};
96     float A1[]={ 1.0f, 0.5f, 1.0f, 1.0f, 0.7f, 1.0f, 1.0f, 0.3f, 1.0f};
97     float F2[]={ 1090, 2100, 900, 1700, 800, 1900, 1600, 850, 1100};
98     float A2[]={ 2.0f, 0.5f, 0.7f, 0.7f, 0.35f, 0.3f, 0.5f, 1.0f, 0.7f};
99     float F3[]={ 2440, 3100, 2300, 2100, 2000, 2500, 2250, 1900, 1500};
100    float A3[]={ 0.3f,0.15f, 0.2f, 0.4f, 0.1f, 0.3f, 0.7f, 0.2f, 0.2f};
101    float F4[]={ 3400, 4700, 3000, 3300, 3400, 3700, 3200, 3000, 3000};
102    float A4[]={ 0.2f, 0.1f, 0.2f, 0.3f, 0.1f, 0.3f, 0.7f, 0.2f, 0.3f};
103
104    float f0,dp0,p0=0.0f;
105    int F=7; //number of the current formant preset
106    float f1,f2,f3,f4,a1,a2,a3,a4;
107    f1=f2=f3=f4=100.0f; a1=a2=a3=a4=0.0f;
108
109    init_formant();
110    FILE *f=fopen("sortie.pcm","wb");
111    for(int ns=0;ns<10*44100;ns+)
112    {
113        if(0==(ns%11025)){F++;F%=8;} //formant change
114        f0=12*powf(2.0f,4-4*ns/(10*44100.0f)); //sweep
115        f0*=(1.0f+0.01f*sinf(ns*0.0015f));    //vibrato
116        dp0=f0*(1/22050.0f);
117        float un_f0=1.0f/f0;
118        p0+=dp0; //phase increment
119        p0-=2*(p0>1);
120        { //smoothing of the commands.
121            float r=0.001f;
122            f1+=r*(F1[F]-f1);f2+=r*(F2[F]-f2);f3+=r*(F3[F]-f3);f4+=r*(F4[F]-f4);
123            a1+=r*(A1[F]-a1);a2+=r*(A2[F]-a2);a3+=r*(A3[F]-a3);a4+=r*(A4[F]-a4);
124        }
125
126        //The f0/fn coefficients stand for a -3dB/oct spectral enveloppe
127        float out=
128            a1*(f0/f1)*formant(p0,100+un_f0)+porteuse(f1+un_f0,p0)
129       (continues on next page)
+0.7f*a2*(f0/f2)*formant(p0,120*un_f0)*porteuse(f2*un_f0,p0) + a3*(f0/f3)*formant(p0,150*un_f0)*porteuse(f3*un_f0,p0) + a4*(f0/f4)*formant(p0,300*un_f0)*porteuse(f4*un_f0,p0);

short s=(short)(15000.0f*out);
fwrite(&s,2,1,f);fwrite(&s,2,1,f); //fichier raw pcm stereo
}
close(f);
return 0;

1.2.1 Comments

• Date: 2007-04-24 12:04:12
  • By: Baltazar
  Quite interesting and efficient for an algo that does not use any filter ;-)

• Date: 2007-08-14 11:30:14
  • By: phoenix-69
  Very funny sound !

• Date: 2008-08-19 20:51:30
  • By: Wait.
  What header files are you including?

1.3 Alias-free waveform generation with analog filtering

• Author or source: Magnus Jonsson
• Type: waveform generation
• Created: 2002-01-15 21:25:29
• Linked files: synthesis001.txt.

Listing 5: notes
(see linkfile)

1.4 Another LFO class

• Author or source: mdsp
• Created: 2003-08-26 14:56:14
• Linked files: LFO.zip.
This LFO uses an unsigned 32-bit phase and increment whose 8 Most Significant Bits adress a Look-up table while the 24 Least Significant Bits are used as the fractionnal part. Note: As the phase overflow automatically, the index is always in the range 0-255.

It performs linear interpolation, but it is easy to add other types of interpolation.

Don't know how good it could be as an oscillator, but I found it good enough for a LFO. BTW there is also different kind of waveforms.

Modifications:
We could use phase on 64-bit or change the proportion of bits used by the index and the fractionnal part.

1.4.1 Comments

• Date: 2004-09-07 13:52:17
• By: ku.oc.enydranos@aja

This type of oscillator is know as a numerically controlled oscillator(nco) or phase accumulator sythesiser. Integrated circuits that implement it in hardware are available such as the AD7008 from Analog Devices. The frequency resolution is very high and is = (SampleRate)/32^2. So if clocked at 44.1Khz the frequency resolution would be 0.00001026Hz! As you said the output waveform can be whatever shape you choose to put in the lookup table. The phase register is already in saw tooth form.

Regards,
Tony

• Date: 2004-12-22 08:40:40
• By: moc.yddaht@yddaht

It works great!
Here's a Delphi version I just knocked up. Both VCL and KOL supported.

code:
unit PALFO;
//
// purpose: LUT based LFO
// author: © 2004, Thaddy de Koning

interface
uses
{$IFDEF KOL}
  Windows, Kol,KolMath;
{$ELSE}
  Windows, math;
{$ENDIF}
const
  k1Div24lowerBits = 1/(1 shl 24);

WFStrings:array[0..4] of string =
  ('triangle', 'sinus', 'sawtooth', 'square', 'exponent');

type
  TWaveform = (triangle, sinus, sawtooth, square, exponent);

{$IFDEF KOL}
PPaLfo = ^TPaLfo;
TPaLfo = object(TObj)
{$ELSE}
TPaLfo = class
{$ENDIF}
private
  FTable:array[0..256] of Single;// 1 more for linear interpolation
  FPhase,
  FInc: Single;
  FRate: Single;
  FSampleRate: Single;
  FWaveForm: TWaveForm;
  procedure SetRate(const Value: Single);
  procedure SetSampleRate(const Value: Single);
  procedure SetWaveForm(const Value: TWaveForm);
public
{$IFNDEF KOL}
  constructor create(SampleRate: Single); virtual;
{$ENDIF}
// increments the phase and outputs the new LFO value.
// return the new LFO value between [-1;+1]
function WaveformName: String;
function Tick: Single;
// The rate in Hz
property Rate: Single read FRate write SetRate;
// The Samplerate
property SampleRate: Single read FSampleRate write SetSampleRate;
property WaveForm: TWaveForm read FWaveForm write SetWaveForm;
end;
{$IFDEF KOL}
function NewPaLfo(aSamplerate: Single): PPaLfo;
{$ENDIF}
implementation

{$IFDEF KOL}
function NewPaLfo(aSamplerate: Single): PPaLfo;
{$ENDIF}

implementation

{ TPaLfo }
{$IFDEF KOL}
function NewPaLfo(aSamplerate: Single): PPaLfo;
begin
  New(Result, Create);
  with Result^ do
  begin
    FPhase := 0;
```
Finc:=0;
FSamplerate:=aSamplerate;
SetWaveform(triangle);
FRate:=1;
end;
end;
{$ELSE}
constructor TPaLfo.create(SampleRate: Single);
begin
  inherited create;
  FPhase:=0;
  Finc:=0;
  FSamplerate:=aSamplerate;
  SetWaveform(triangle);
  FRate:=1;
end;
{$ENDIF}

procedure TPaLfo.SetRate(const Value: Single);
begin
  FRate := Value;
  // the rate in Hz is converted to a phase increment with the following formula
  // f[ inc = (256*rate/samplerate) * 2^24]
  Finc := (256 * Frate / Fsamplerate) * (1 shl 24);
end;

procedure TPaLfo.SetSampleRate(const Value: Single);
begin
  FSampleRate := Value;
end;

procedure TPaLfo.SetWaveForm(const Value: TWaveForm);
var
  i:integer;
begin
  FWaveForm := Value;
  Case FWaveform of
    sinus:
      for i:=0 to 256 do
        FTable[i] := sin(2*pi*(i/256));
    triangle:
      begin
        for i:=0 to 63 do
          begin
            FTable[i] := i / 64;
            FTable[i+64] := (64-i) / 64;
            FTable[i+128] := -i / 64;
            FTable[i+192] := -(64-i) / 64;
          end;
        FTable[256] := 0;
      end;
    sawtooth:
      begin
        for i:=0 to 255 do
          begin
            FTable[i] := 2*(i/255) - 1;
            FTable[256] := -1;
          end;
  end;
(continues on next page)
end;

square:
begin
for i:=0 to 127 do
begin
FTable[i] := 1;
FTable[i+128] := -1;
end;
FTable[256] := 1;
end;

exponent:
begin
// symmetric exponent similar to triangle
for i:=0 to 127 do
begin
FTable[i] := 2 * ((exp(i/128) - 1) / (exp(1) - 1)) - 1;
FTable[i+128] := 2 * ((exp((128-i)/128) - 1) / (exp(1) - 1)) - 1;
end;
FTable[256] := -1;
end;

function TPaLfo.WaveformName:String;
begin
result:=WFStrings[Ord(Fwaveform)];
end;

function TPaLfo.Tick: Single;
var
  i:integer;
  frac:Single;
begin
  // the 8 MSB are the index in the table in the range 0-255
  i := Pinteger(Fphase)^ shr 24;
  // and the 24 LSB are the fractional part
  frac := (PInteger(Fphase)^ and $00FFFFFF) * k1Div24lowerBits;
  // increment the phase for the next tick
  Fphase := FPhase + Finc; // the phase overflows itself
  Result:= Ftable[i]*(1-frac) + Ftable[i+1]* frac; // linear interpolation
end;
end.

• Date: 2004-12-22 12:43:17

• By: moc.yddaht@yddaht

Oops,

This one is correct:

code:
unit PALFO;
//
// purpose: LUT based LFO

(continues on next page)
interface
uses
{$IFDEF KOL}
  Windows, Kol,KolMath;
{$ELSE}
  Windows, math;
{$ENDIF}

const
  k1Div24lowerBits = 1/(1 shl 24);

WFStrings:array[0..4] of string =
  ('triangle','sinus', 'sawtooth', 'square', 'exponent');

type
  Twaveform = (triangle, sinus, sawtooth, square, exponent);

{$IFDEF KOL}
  PPaLfo = ^TPaLfo;
  TPaLfo = object(TObj)
{$ELSE}
  TPaLfo = class
{$ENDIF}
private
  FTable:array[0..256] of Single;// 1 more for linear interpolation
  FPhase,
  FInc:dword;
  FRate: Single;
  FSampleRate: Single;
  FWaveForm: TWaveForm;
  procedure SetRate(const Value: Single);
  procedure SetSampleRate(const Value: Single);
  procedure SetWaveForm(const Value: TWaveForm);
public
{$IFNDEF KOL}
  constructor create(SampleRate:Single);virtual;
{$ENDIF}
  // increments the phase and outputs the new LFO value.
  // return the new LFO value between [-1;+1]
  function WaveformName:String;
  function Tick:Single;
  // The rate in Hz
  property Rate:Single read FRate write SetRate;
  // The Samplerate
  property SampleRate:Single read FSampleRate write SetSampleRate;
  property WaveForm:TWaveForm read FWaveForm write SetWaveForm;
end;

{$IFDEF KOL}
function NewPaLfo(aSamplerate:Single):PPaLfo;
{$ENDIF}

1.4. Another LFO class
function NewPaLfo(aSamplerate:Single):PPaLfo;
begin
  New(Result,Create);
  with Result^ do
  begin
    FPhase:=0;
    FSamplerate:=aSamplerate;
    SetWaveform(sinus);
    Rate:=1;
  end;
end;
{$ENDIF}

constructor TPaLfo.create(SampleRate: Single);
begin
  inherited create;
  FPhase:=0;
  FSamplerate:=aSamplerate;
  SetWaveform(sinus);
  FRate:=1;
end;
{$ENDIF}

procedure TPaLfo.SetRate(const Value: Single);
begin
  FRate := Value;
  // the rate in Hz is converted to a phase increment with the following formula
  // f[increment] = (256 * rate / samplerate) * 2^24
  Finc := round((256 * FRate / FSamplerate) * (1 shl 24));
end;

procedure TPaLfo.SetSampleRate(const Value: Single);
begin
  FSampleRate := Value;
end;

procedure TPaLfo.SetWaveForm(const Value: TWaveForm);
var
  i:integer;
begin
  FWaveForm := Value;
  Case FWaveForm of
  sinus:
    for i:=0 to 256 do
      FTable[i] := sin(2*pi*(i/256));
  triangle:
    begin
      for i:=0 to 63 do
        begin
          FTable[i] := i / 64;
          FTable[i+64] := (64-i) / 64;
          FTable[i+128] := -i / 64;
          FTable[i+192] := -(64-i) / 64;
        end;
  esac;
end;
FTable[256] := 0;
end;
sawtooth:
begin
for i:=0 to 255 do
  FTable[i] := 2*(i/255) - 1;
FTable[256] := -1;
end;
square:
begin
  for i:=0 to 127 do
    begin
      FTable[i] := 1;
      FTable[i+128] := -1;
    end;
  FTable[256] := 1;
end;
exponent:
begin
  // symetric exponent similar to triangle
  for i:=0 to 127 do
    begin
      FTable[i] := 2 * ((exp(i/128) - 1) / (exp(1) - 1)) - 1 ;
      FTable[i+128] := 2 * ((exp((128-i)/128) - 1) / (exp(1) - 1)) - 1 ;
    end;
  FTable[256] := -1;
end;

function TPaLfo.WaveformName:String;
begin
  result:=WFStrings[Ord(Fwaveform)];
end;

function TPaLfo.Tick: Single;
var
  i:integer;
  frac:Single;
begin
  // the 8 MSB are the index in the table in the range 0-255
  i := Fphase shr 24;
  // and the 24 LSB are the fractionnal part
  frac := (Fphase and $00FFFFFF) * k1Div24lowerBits;
  // increment the phase for the next tick
  Fphase :=FPhase + Finc; // the phase overflows itself
  Result:= Ftable[i]*(1-frac) + Ftable[i+1]* frac; // linear interpolation
end;
end.
1.5 Another cheap sinusoidal LFO

- **Author or source:** moc.cinohp-e@ofni
- **Created:** 2004-05-14 18:32:57

### Listing 7: notes

Some pseudo code for a easy to calculate LFO.

You can even make a rough triangle wave out of this by substracting the output of 2 of these with different phases.

PJ

### Listing 8: code

```c
1 r = the rate 0..1
2
3 -------------
4 p += r
5 if (p > 1) p -= 2;
6 out = p*(1-abs(p));
7 -------------
```

#### 1.5.1 Comments

- **Date:** 2004-06-10 21:32:22
- **By:** moc.regnimmu@psd-cisum

Slick! I like it!

Sincerely,
Frederick Umninger

- **Date:** 2005-02-23 22:24:03
- **By:** es.tensse@idarozs.szalab

Great! just what I wanted a fast triangle lfo. :D

```c
float rate = 0..1;
float phase1 = 0;
float phase2 = 0.1f;

-------------
phase1 += rate;
if (phase1>1) phase1 -= 2;

phase2 += rate;
if (phase2>1) phase2 -= 2;

out = (phase1*(1-abs(phase1)) - phase2*(1-abs(phase2))) * 10;
-------------
```

- **Date:** 2006-08-02 22:10:54
Nice! If you want the output range to be between -1..1 then use:

```
--------------
p += r
if(p > 2) p -= 4;
out = p*(2-abs(p));
--------------
```

A better way of making a triangle LFO (out range is -1..1):

```
rate = 0..1;
p = -1;
{
  p += rate;
  if (p>1) p -= 4.0f;
  out = abs(-(abs(p)-2))-1;
}
```

/* this goes from -1 to +1 */
#include <iostream>
#include <math.h>
using namespace std;
int main(int argc, char *argv[]) {

    //r = the rate 0..1
    float r = 0.5f;
    float p = 0.f;
    float result=0.f;
    //------------------
    for(int i=1;i<=2048;i++){
        p += r;
        if(p > 1) p -= 2;
        result = 4*p*(1-fabs(p));
        cout << result;
        cout <<"\r";
    }
}
```

## 1.6 Antialiased square generator

- **Author or source:** Paul Sernine
- **Type:** 1st April edition
- **Created:** 2006-04-01 12:46:23
Listing 9: notes

It is based on a code by Thierry Rochebois, obfuscated by me. It generates a 16bit MONO raw pcm file. Have Fun.

Listing 10: code

```c
//sqrfish.cpp
#include <math.h>
#include <stdio.h>
//obfuscation P.Sernine
int main()
{ float ccc,cccc=0,cc=0,CCC,
  C,C,c; FILE *CCCCCCC=fopen("sqrfish.pcm",
  "wb" ); int cccc= 0; float CCCCC=6.89e-6f;
for(int CCCCCC=0;CCCCCCC<1764000;CCCCCCC++ ){
  if(!(CCCCCCC%7350))if(++ccccc>=30){ ccccc =0;
  CCCCC*=2; }CCC=1;)ccc=CCCCCCC*expf(0.057762265f*
  "aiakahiafahadfaiakahiahafahadf"[ccccc]);CCC
  =0.75f-1.5f*ccc;cccc+=ccc;CCC*=0.9999f;cccc=;
  2*(cccc>1);C=ccc+CCCC*X; c=ccc+CCCC+c; C
  -=2*(C>1);c-=2*(c>1);C+=2*(C<-1); c+=1+2
  *c(C<1);c+=2*(C>1);C=C*C*(2*C*C-4); c+=2*(c<-1); c
  -=2*(c>1);C=C*C*(2*C*C-4); c+=2*(c<-1); c
  -=2*(c>1);CC=0.5f*(1+C+CC);cc=0.5f*(1+
  c+cc); fwrite(&cccccc,2,1,CCCCCCC);}
//algo by Thierry Rochebois
fclose(CCCCCCCC);
return 0000000;}
```

1.7 Arbitrary shaped band-limited waveform generation (using over-sampling and low-pass filtering)

- Author or source: uh.doilop.cak@egamer
- Created: 2003-01-02 20:27:18

Listing 11: code

```c
Arbitrary shaped band-limited waveform generation
(using oversampling and low-pass filtering)

There are many articles about band-limited waveform synthesis techniques, that provide correct and fast methods for generating classic analogue waveforms, such as saw, pulse, and triangle wave. However, generating arbitrary shaped band-limited waveforms, such as the "sawsin" shape (found in this source-code archive), seems to be quite hard using these techniques.

My analogue waveforms are generated in a _very_ high sampling rate (actually it's 1.4112 GHz for 44.1 kHz waveforms, using 32x oversampling). Using this sample-rate, the amplitude of the aliasing harmonics are negligible (the base analogue waveforms has exponentially decreasing harmonics amplitudes).

Using a 511-tap windowed sync FIR filter (with Blackman-Harris window, and 12 kHz cutoff frequency) the harmonics above 20 kHz are killed, the higher harmonics (that cause the sharp overshoot at step response) are dampened. (continues on next page)
The filtered signal downsamped to 44.1 kHz contains the audible (non-aliased) harmonics only.

This waveform synthesis is performed for wavetables of 4096, 2048, 1024, ... 8, 4, 2 samples. The real-time signal is interpolated from these waveform-tables, using Hermite-(cubic-)interpolation for the waveforms, and linear interpolation between the two wavetables near the required note.

This procedure is quite time-consuming, but the whole waveform (or, in my implementation, the whole waveform-set) can be precalculated (or saved at first launch of the synth) and reloaded at synth initialization.

I don't know if this is a theoretically correct solution, but the waveforms sound good (no audible aliasing). Please let me know if I'm wrong...

1.7.1 Comments

- **Date**: 2003-01-23 13:26:38
  - **By**: moc.xinortceletrams@xelA

  Why can't you use fft/ifft to synthesis directly wavetables of 2048,1024,..? It'd be not so "time consuming" comparing to FIR filtering.
  Further cubic interpolation still might give you audible distortion in some cases.
  --Alex.

- **Date**: 2003-02-02 19:24:23
  - **By**: uh.doilop.cak@egamer

  What should I use instead of cubic interpolation? (I had already some aliasing problems with cubic interpolation, but that can be solved by oversampling 4x the realtime signal generation)
  Is this theory of generating waves from wavetables of 4096, 2084, ... 8, 4, 2 samples wrong?

- **Date**: 2003-02-19 17:12:42
  - **By**: moc.xinortceletrams@xelA

  I think tablesise should not vary depending on tone (4096,2048...) and you'd better stay with the same table size for all notes (for example 4096, 4096...).

  To avoid interpolation noise (it's NOT caused by aliasing) try to increase wavetable size and be sure that waveform spectrum has steep roll off (don't forget Gibbs phenomena as well).

- **Date**: 2004-08-24 08:04:28

1.7. Arbitrary shaped band-limited waveform generation (using oversampling and low-pass filtering)
By: es.tensse@idarozs.szalab

you say that the higher harmonics (that cause the sharp overshoot at step response) are dampened. How? Or is it a result of the filtering?

Date: 2005-04-03 07:10:58
By: uh.doilop.scakam@egamer

Yes. The FIR-filter cutoff is set to 12 kHz, so it dampens the audible frequencies too. This way the frequencies above 20 kHz are about -90 dB (don't remember exactly, but killing all harmonics above 20 kHz was the main reason to set the cutoff to 12 kHz).

Anyway, as Alex suggested, FFT/IFFT seems to be a better solution to this problem.

1.8 Audiable alias free waveform gen using width sine

Author or source: moc.emagno@mortshad.mikaoj
Type: Very simple
Created: 2004-04-07 09:37:32

Warning, my english abilities is terribly limited.

How ever, the other day when finally understanding what bandlimited wave creation is (i am a noobie, been doing DSP stuf on and off for a half/year) it hit me i can implement one little part in my synths. It's all about the freq (that i knew), very simple you can reduce alias (the alias that you can hear that is) extremely by keeping track of your frequency, the way i solved it is using a factor, afact = 1 - sin(f*2PI). This means you can do audiable alias free synthesis without very complex algorithms or very huge tables, even though the sound becomes kind of low-filtered.

Propably something like this is mentioned b4, but incase it hasn't this is worth looking up

The psuedo code describes it more.

// Druttis

Listing 13: code

```plaintext
f := freq factor, 0 - 0.5 (0 to half samplingrate)
afact(f) = 1 - sin(f*2PI)
t := time (0 to ...)
ph := phase shift (0 to 1)
```

(continues on next page)
\begin{verbatim}
fm := freq mod (0 to 1)
sine(t,f,ph,fm) = sin((t*f+ph)*2PI + 0.5PI*fm*afact(f))
fb := feedback (0 to 1) (1 max saw)
saw(t,f,ph,fm,fb) = sine(t,f,ph,fb*sine(t-1,f,ph,fm))

pm := pulse mod (0 to 1) (1 max pulse)
pw := pulse width (0 to 1) (1 square)
pulse(t,f,ph,fm,fb,pm,pw) = saw(t,f,ph,fm,fb) - saw(t,f,ph+0.5*pw,fm,fb) * pm

I am not completely sure about fm for saw & pulse since i cant test that atm. but it should work :) otherwise just make sure fm are 0 for saw & pulse.

As you can see the saw & pulse wave are very variable.

// Druttis
\end{verbatim}

1.8.1 Comments

- **Date:** 2003-02-05 03:10:00
  - **By:** es.pp.ecafkrad@sitturd
  
  Um, reading it I can see a big flaw...
  
  \[ \text{afact}(f) = 1 - \sin(f \times 2\pi) \text{ is not correct!} \]
  
  should be
  
  \[ \text{afact}(f) = 1 - \sqrt{f \times 2 / \text{sr}} \]
  
  where \text{sr} := \text{samplingrate}
  
  \[ f \text{ should be exceed half sr} \]

- **Date:** 2003-02-22 16:49:50
  - **By:** moc.ecrofmho@tmemual
  
  \[ f \text{ has already be divided by sr, right? So it should become :} \]
  
  \[ \text{afact} (f) = 1 - \sqrt{f \times 2} \]
  
  And i see a typo (saw forgotten in the second expression):
  
  \[ \text{pulse}(t,f,ph,fm,fb,pm,pw) = \text{saw}(t,f,ph,fm,fb) - \text{saw}(t,f,ph+0.5*pw,fm,fb) * pm \]
  
  However I haven't checked the formula.

- **Date:** 2003-06-25 08:54:21
  - **By:** ed.xmg@909

1.8. Audible alias free waveform gen using width sine
Hi Lauent,
I'm new to that DSP stuff and can't get the key to what'S the meaning of afact? - Can you explain please!? - Thanks in advice!

- **Date**: 2004-04-16 14:09:26
- **By**: es.ollehc@sitturd

I've been playing around with this for some time. Expect a major update in a while, as soon as I know how to describe it ;)

- **Date**: 2004-04-16 14:14:34
- **By**: es.ollehc@sitturd

afact is used as an amplitude factor for fm or fb depending on the carrier frequency. The higher frequency the lower afact. It's not completely resolving the problem with aliasing but it is a cheap way that dramatically reduces it.

1.9 Band Limited waveforms my way

- **Author or source**: Anton Savov (gb.liam@ottna)
- **Type**: classic Sawtooth example
- **Created**: 2009-06-22 18:09:08

Listing 14: notes

This is my <ugly> C++ code for generating a single cycle of a Sawtooth in a table
normaly i create my "fundamental" table big enough to hold on around 20-40Hz in the current Sampling rate
also, i create the table twice as big, i do "mip-maps" then
so the size should be a power of two, say 1024 for 44100Hz = 44100/1024 = ~43.066Hz
then the mip-maps are with decreasing sizes (twice) 512, 256, 128, 64, 32, 16, 8, 4,
and 2
if the "gibbs" effect is what i think it is - then i have a simple solution
here is my crappy code:

Listing 15: code

```c
int sz = 1024; // the size of the table
int i = 0;
float *table; // pointer to the table
double scale = 1.0;
double pd; // phase
double omega = 1.0 / (double)(sz);

while (i < sz)
{
    double amp = scale;
    double x = 0.0; // the sample
    double h = 1; // harmonic number (starts from 1)
    double dd; // fix high frequency "ring"
    pd = (double)(i) / (double)(sz); // calc phase
```
double hp = pd; // phase of the harmonic
while (true) // start looping for this sample
{
    if ((omega * h) < 0.5) // harmonic frequency is in range?
    {
        dd = cos(omega * h * 2 * pi);
        x = x + (amp * dd * sin(hpd * 2 * pi));
        h = h + 1;
        hpd = pd * h;
        amp = 1.0 / h;
    }
    else { break; }
}

    table[i] = x;
    ++i;
}

the peaks are around +/- 0.8
a square can be generated by just changing h = h+2; the peaks would be +/- 0.4
any bugs/improvements?

1.9.1 Comments

• Date: 2009-06-22 18:37:34
  • By: gh.liam@ottna
  excuse me, there is a typo
  amp = scale / h;
  
  • Date: 2009-09-20 10:34:18
  • By: antto mail bg
  for even smoother edges:
  dd = cos(sin(omega * h * pi) * 0.5 * pi);
  no visual ringing, smooth waveform
  
  • Date: 2009-09-25 04:15:31
  • By: antto mail bg
  to get +/- 1.0 amplitude: scale = 1.25

1.10 Bandlimited sawtooth synthesis

• Author or source: moc.ailet@mlohdnal.leuname
• Type: DSF BLIT
• Created: 2002-03-29 18:06:44
• Linked files: synthesis002.txt.
Listing 16: notes

This is working code for synthesizing a bandlimited sawtooth waveform. The algorithm is
DSF BLIT + leaky integrator. Includes driver code.

There are two parameters you may tweak:

1) Desired attenuation at nyquist. A low value yields a duller sawtooth but gets rid of
those annoying CLICKS when sweeping the frequency up real high. Must be strictly less than
1.0!

2) Integrator leakiness/cut off. Affects the shape of the waveform to some extent, esp. at
the low end. Ideally you would want to set this low, but too low a setting will give you
problems with DC.

Have fun!
/Emanuel Landeholm

(see linked file)

1.10.1 Comments

- Date: 2003-02-26 00:58:41
  - By: moc.liamtoh@hsats_wobniar

there is no need to use a butterworth design for a simple leaky integrator, in this case actually the
variable curcps can be used directly in a simple: leak += curcps * (blit - leak);
this produces a nearly perfect saw shape in almost all cases

- Date: 2011-05-31 05:25:01
  - By: pj.oc.liamtoh@evawtuah

The square wave type will be able to be generated from this source.
Please teach if it is possible.

1.11 Bandlimited waveform generation

- Author or source: Joe Wright
- Type: waveform generation
- Created: 2002-01-17 01:06:49
- Linked files: bandlimited.cpp.
1.11 Comments

- **Date**: 2012-02-10 16:26:11
- **By**: ed.redienhc@psdcisum

The code to reduce the gibbs effect causes aliasing if a transition is made from wavetable A with x partials to wavetable B with y partials.
The aliasing can clearly be seen in a spectral view.
The problem is, that the volume modification for partial N is different depending on the number of partials the wavetable row contains.

1.12 Bandlimited waveforms synopsis.

- **Author or source**: Joe Wright
- **Created**: 2002-02-11 17:37:20
- **Linked files**: waveforms.txt

1.12.1 Comments

- **Date**: 2005-11-15 20:07:11
- **By**: dflatcc@stanford.edu

The abs(sin) method from the Lane CMJ paper is not bandlimited! It's basically just a crappy method for BLIT.
You forgot to mention Eli Brandt's minBLEP method. It's the best! You just have to know how to properly generate a nice minblep table... (slightly dilated, see Stilson and Smith BLIT paper, at the end regarding table implementation issues)

1.13 Bandlimited waveforms...

- **Author or source**: Paul Kellet
- **Created**: 2002-01-17 00:56:04
Below is another waveform generation method based on a train of sinc functions, actually an alternating loop along a sinc between t=0 and t=period/2).

The code integrates the pulse train with a dc offset to get a sawtooth, but other shapes can be made in the usual ways... Note that 'dc' and 'leak' may need to be adjusted for very high or low frequencies.

I don't know how original it is (I ought to read more) but it is of usable quality, particularly at low frequencies. There's some scope for optimisation by using a table for sinc, or maybe a a truncated/windowed sinc?

I think it should be possible to minimise the aliasing by fine tuning 'dp' to slightly less than 1 so the sincs join together neatly, but I haven't found the best way to do it.

Any comments gratefully received.

```
float p=0.0f; //current position
float dp=1.0f; //change in position per sample
float pmax; //maximum position
float x; //position in sinc function
float leak=0.995f; //leaky integrator
float dc; //dc offset
float saw; //output

//set frequency...
float pmax = 0.5f * getSampleRate() / freqHz;
dc = -0.498f/pmax;

//for each sample...
p += dp;
if(p < 0.0f)
{
    p = -p;
    dp = -dp;
}
else if(p > pmax)
{
    p = pmax + pmax - p;
    dp = -dp;
}

x= pi * p;
if(x < 0.00001f)
x=0.00001f; //don't divide by 0
```

(continues on next page)
34 saw = leak*saw + dc + (float)sin(x)/(x);

### 1.13.1 Comments

- **Date:** 2004-09-23 00:07:02
- **By:** es.ollehc@evawenis

Hi,
Has anyone managed to implement this in a VST?
If anyone could mail me and talk me through it I'd be very grateful. Yes, I'm a total newbie and yes, I'm after a quick-fix solution...we all have to start somewhere, eh?

As it stands, where I should be getting a sawtooth I'm getting a full-on and inaudible signal...!

Even a small clue would be nice.
Cheers,
A

- **Date:** 2012-01-01 23:17:35
- **By:** ku.oc.oohay@ekolbiurd

this sounds quite nice, maybe going to use it an LV 2 plugin

- **Date:** 2016-01-17 13:24:11
- **By:** pvdmeer [atorsomething] gmail [point] com

this is really amazing, and easily hacked into a lut-based algo. i'll try windowing it too, but it already looks like aliasing is well within acceptable levels.

### 1.14 Butterworth

- **Author or source:** ed.luodosruoivas@naitsirhC
- **Type:** LPF 24dB/Oct
- **Created:** 2006-07-16 11:39:35

Listing 21: code

```
First calculate the prewarped digital frequency:
K = tan(Pi * Frequency / Samplerate);

Now calc some intermediate variables: (see 'Factors of Polynomials' at http://en.wikipedia.org/wiki/Butterworth_filter, especially if you want a higher order like 48dB/Oct)
a = 0.76536686473 * Q * K;
b = 1.84775906502 * Q * K;
```

(continues on next page)
K = K*K; (to optimize it a little bit)

Calculate the first biquad:

A0 = (K+a+1);
A1 = 2*(1-K);
A2 = (a-K-1);
B0 = K;
B1 = 2*B0;
B2 = B0;

Calculate the second biquad:

A3 = (K+b+1);
A4 = 2*(1-K);
A5 = (b-K-1);
B3 = K;
B4 = 2*B3;
B5 = B3;

Then calculate the output as follows:

Stage1 = B0*Input + State0;
State0 = B1*Input + A1/A0*Stage1 + State1;
Stage1 = B2*Input + A2/A0*Stage1;
Output = B3*Stage1 + State2;
State2 = B4*Stage1 + A4/A3*Output + State2;
State3 = B5*Stage1 + A5/A3*Output;

1.14.1 Comments

- **Date:** 2006-07-18 18:44:09
- **By:** uh.etle.fnj@yfoocs

If you have a Q factor different than 1, then filter won’t be a Butterworth filter (in terms of maximally flat passband). So, your filter is a kind of a tweaked Butterworth filter with added resonance.

Highpass version should be:

A0 = (K+a+1);
A1 = 2*(1-K);
A2 = (a-K-1);
B0 = 1;
B1 = -2;
B2 = 1;

Calculate the second biquad:

A3 = (K+b+1);
A4 = 2*(1-K);
A5 = (b-K-1);
B3 = 1;
B4 = -2;
B5 = 1;
The rest is the same. You might want to leave out B0, B2, B3 and B5 completely, because they all equal to 1, and optimize the highpass loop as:

\[
\begin{align*}
\text{Stage1} &= \text{Input} + \text{State0}; \\
\text{State0} &= B1 \times \text{Input} + A1/A0 \times \text{Stage1} + \text{State1}; \\
\text{State1} &= \text{Input} + A2/A0 \times \text{Stage1}; \\
\text{Output} &= \text{Stage1} + \text{State2}; \\
\text{State2} &= B4 \times \text{Stage1} + A4/A3 \times \text{Output} + \text{State2}; \\
\text{State3} &= \text{Stage1} + A5/A3 \times \text{Output};
\end{align*}
\]

Anyone confirms this code works? (Being too lazy to throw this into a compiler...)

Cheers,
Peter

And of course it is not a good idea to do divisions in the process loop, because they are very heavy, so the best is to precalculate A1/A0, A2/A0, A4/A3 and A5/A3 after the calculation of coefficients:

\[
\begin{align*}
\text{inv}_A0 &= 1.0/A0; \\
A1A0 &= A1 \times \text{inv}_A0; \\
A2A0 &= A2 \times \text{inv}_A0; \\
\text{inv}_A3 &= 1.0/A3; \\
A4A3 &= A4 \times \text{inv}_A3; \\
A5A3 &= A5 \times \text{inv}_A3;
\end{align*}
\]

(The above should be faster than writing

A1A0 = A1/A0;
A2A0 = A2/A0;
A4A3 = A4/A3;
A5A3 = A5/A3;

but I think some compilers do this optimization automatically.)

Then the lowpass process loop becomes

\[
\begin{align*}
\text{Stage1} &= B0 \times \text{Input} + \text{State0}; \\
\text{State0} &= B1 \times \text{Input} + A1A0 \times \text{Stage1} + \text{State1}; \\
\text{State1} &= B2 \times \text{Input} + A2A0 \times \text{Stage1}; \\
\text{Output} &= B3 \times \text{Stage1} + \text{State2}; \\
\text{State2} &= B4 \times \text{Stage1} + A4A3 \times \text{Output} + \text{State2}; \\
\text{State3} &= B5 \times \text{Stage1} + A5A3 \times \text{Output};
\end{align*}
\]

Much faster, isn't it?

Cheers,
Peter

---

**Date:** 2006-07-21 11:15:06

**By:** uh.etle.fnj@yfoocs

---

**Date:** 2006-07-31 22:48:39
Once you figured it out, it's even possible to do higher order butterworth shelving → filters. Here's an example of an 8th order lowshelf.

First we start as usual prewarping the cutoff frequency:

\[ K = \tan(fW0 \times 0.5); \]

Then we settle up the Coefficient V:

\[ V = \text{Power}(\text{GainFactor},-1/4)-1; \]

Finally here's the loop to calculate the filter coefficients:

```plaintext
for i = 0 to 3
{
    cm = \cos(\pi \times (i \times 2+1) / (2 \times 8));
    B[3*i+0] = 1/ ( 1 + 2*K*cm + K*K + 2*V*K*K + 2*V*K*cm + V*V*K*K);
    B[3*i+1] = 2 * ( 1 - K*K - 2*V*K*K - V*V*K*K);
    B[3*i+2] = (-1 + 2*K*cm - K*K - 2*V*K*K + 2*V*K*cm - V*V*K*K);
    A[3*i+0] = ( 1-2*K*cm+K*K);
    A[3*i+1] = 2*(-1 +K*K);
    A[3*i+2] = ( 1+2*K*cm+K*K);
}
```

Hmm... interesting. I guess the phase response/group delay gets quite funky, which is → generally unwanted for an equalizer.

I think the 1/ is not necessary for the first B coefficient! (of course you divide → all the other coeffs with the inverse of that coeff at the end...)

I guess the next will be Chebyshev shelving filters ;)

BTW did you check whether my 4 pole highpass Butterworth code is correct?

Peter

The 1/ is of course an error here. It's left of my own implementation, where I divide → directly. Also I think A and B is exchanged.

I've already nearly done all the different filter types (except elliptic filters), → but I won't post too much here.

The highpass maybe a highpass, but not the exact complementary. At least my (working) → implementation looks different.

The lowpass<->highpass transform is to replace s with 1/s and by doing this, more → than one sign is changing.
Different authors tend to mix up A and B coeffs.

If I take this lowpass derived by bilinear transform and change B0 and B2 to 1, and B1 to -2 then I get a perfect highpass. At least that's what I see in FilterExplorer. Probably you could get the same by replacing s with 1/s and deriving it by bilinear transform.

Well, there are many ways to get a filter working, for example if I replace \( \tan(\pi w) \) with \( 1.0 / \tan(\pi w) \), inverse the sign of B1, and replace \( A1 = 2 \times (1-K) \) with \( A1 = 2 \times (K-1) \), I also get the same highpass.

Well, the reason for the sign inversion is that the coeffs you named B1 and B2 here are responsible for the locations of the zeroes. B1 is responsible for the angle, and B2 is for the radius, so if you invert B1 then the zeroes get on the opposite side of the unit circle, so you get a highpass filter. You then need to adjust the gain coefficient (B0) so that the passband gain is 1. Well, this is not a very precise explanation, but this is the reason why this works.

Ok, you're right. I've been doing too much stuff these days that I missed that simple thing. Your version is even numerical better, because there is less potential of annihilation. Thanks for that.

Btw. the group delay really get a little bit 'funky', i've also noticed that, but for not too high orders it doesn't hurt that much.

Well, it isn't a big problem unless you start modulating the filter very fast... then you get this strange pitch-shifting effect ;)

Well, I read sometimes that when you do EQing, phase is a very important factor. I guess that's why ppl sell a lot of linear phase EQ plugins. Or just the marketing? Don't know, haven't compared linear and non-linear phase stuff very much..

State2 = B4*Stage1 + A4/A3*Output + State2;
should read
State2 = B4*Stage1 + A4/A3*Output + State3;

1.15 C# Oscilator class

Author or source: neotec
Type: Sine, Saw, Variable Pulse, Triangle, C64 Noise
Created: 2007-01-08 10:49:36
Listing 22: notes

Parameters:

Pitch: The Osc's pitch in Cents [0 - 14399] starting at A -> 6.875Hz
Pulsewidth: [0 - 65535] -> 0% to 99.99%
Value: The last Output value, a set to this property 'syncs' the Oscillator

Listing 23: code

```java
public class SynthOscilator {
    public enum OscWaveformType {
        SAW, PULSE, TRI, NOISE, SINE
    }

    public int Pitch {
        get {
            return this._Pitch;
        }
        set {
            this._Pitch = thisMinMax(0, value, 14399);
            this.OscStep = WaveSteps[this._Pitch];
        }
    }

    public int PulseWidth {
        get {
            return this._PulseWidth;
        }
        set {
            this._PulseWidth = thisMinMax(0, value, 65535);
        }
    }

    public OscWaveformType Waveform {
        get {
            return this._WaveForm;
        }
        set {
            this._WaveForm = value;
        }
    }

    public int Value {
        get {
            ...
        }
    }

    (continues on next page)
```
    { return this._Value; }
    set
    {
        this._Value = 0;
        this.OscNow = 0;
    }
}

private int _Pitch;
private int _PulseWidth;
private int _Value;
private OscWaveformType _WaveForm;

private int OscNow;
private int OscStep;
private int ShiftRegister;

public const double BaseFrequency = 6.875;
public const int SampleRate = 44100;
public static int[] WaveSteps = new int[0];
public static int[] SineTable = new int[0];

public SynthOscilator()
{
    if (WaveSteps.Length == 0)
        this.CalcSteps();
    if (SineTable.Length == 0)
        this.CalcSine();

    this._Pitch = 7200;
    this._PulseWidth = 32768;
    this._WaveForm = OscWaveformType.SAW;
    this.ShiftRegister = 0x7fff8;

    this.OscNow = 0;
    this.OscStep = WaveSteps[this._Pitch];
    this._Value = 0;
}

private void CalcSteps()
{
    WaveSteps = new int[14400];
    for (int i = 0; i < 14400; i++)
    {
        double t0, t1, t2;
        t0 = Math.Pow(2.0, (double)i / 1200.0);
        t1 = BaseFrequency * t0;
        t2 = (t1 * 65536.0) / (double)SampleRate;
        WaveSteps[i] = (int)Math.Round(t2 * 4096.0);
    }
}
private void CalcSine()
{
    SineTable = new int[65536];
    double s = Math.PI / 32768.0;
    for (int i = 0; i < 65536; i++)
    {
        double v = Math.Sin((double)i * s) * 32768.0;
        int t = (int)Math.Round(v) + 32768;
        if (t < 0)
            t = 0;
        else if (t > 65535)
            t = 65535;
        SineTable[i] = t;
    }
}

public override int Run()
{
    int ret = 32768;
    int osc = this.OscNow >> 12;
    switch (this._WaveForm)
    {
        case OscWaveformType.SAW:
            ret = osc;
            break;
        case OscWaveformType.PULSE:
            if (osc < this.PulseWidth)
                ret = 65535;
            else
                ret = 0;
            break;
        case OscWaveformType.TRI:
            if (osc < 32768)
                ret = osc << 1;
            else
                ret = 131071 - (osc << 1);
            break;
        case OscWaveformType.NOISE:
            ret = ((this.ShiftRegister & 0x400000) >> 11) |
                ((this.ShiftRegister & 0x100000) >> 10) |
                ((this.ShiftRegister & 0x010000) >> 7) |
                ((this.ShiftRegister & 0x002000) >> 5) |
                ((this.ShiftRegister & 0x000800) >> 4) |
                ((this.ShiftRegister & 0x000080) >> 1) |
                ((this.ShiftRegister & 0x000004) << 2);
            ret <<= 4;
            break;
        case OscWaveformType.SINE:


```
ret = SynthTools.SineTable[osc];
break;
default:
break;
}

this.OscNow += this.OscStep;

if (this.OscNow > 0xffffffff)
{
    int bit0 = {this.ShiftRegister >> 22} ^ {this.ShiftRegister >> 17}) & 0x1;
    this.ShiftRegister <<= 1;
    this.ShiftRegister &= 0x7fffff;
    this.ShiftRegister |= bit0;
}

this.OscNow &= 0xffffffff;
this._Value = ret - 32768;
return this._Value;
}
```

public int MinMax(int a, int b, int c)
{
    if (b < a)
        return a;
    else if (b > c)
        return c;
    else
        return b;
}
```

1.16 C++ gaussian noise generation

- **Author or source:** ku.oc.latigidpxe@luap
- **Type:** gaussian noise generation
- **Created:** 2004-05-20 09:12:55

Listing 24: notes

References:
Tobybears delphi noise generator was the basis. Simply converted it to C++.
Link for original is:
http://www.musicdsp.org/archive.php?classid=0#129
The output is in noise.
/* Include requisits */
#include <cstdlib>
#include <ctime>

/* Generate a new random seed from system time - do this once in your constructor */
srand(time(0));

/* Setup constants */
const static int q = 15;
const static float c1 = (1 << q) - 1;
const static float c2 = ((int)(c1 / 3)) + 1;
const static float c3 = 1.f / c1;

/* random number in range 0 - 1 not including 1 */
float random = 0.f;

/* the white noise */
float noise = 0.f;

for (int i = 0; i < numSamples; i++)
{
    random = ((float)rand() / (float)(RAND_MAX + 1));
    noise = (2.f * ((random * c2) + (random * c2) + (random * c2)) - 3.f * (c2 - 1.f)) * c3;
}

1.16.1 Comments

• Date: 2009-07-10 17:39:39
  By: moc.enon@enon
What's the difference between the much simpler noise generator:

```
randSeed = (randSeed * 196314165) + 907633515; out=((int)randSeed)*0.0000000004656612873077392578125f;
```
and this one? they both sound the same to my ears...

• Date: 2011-07-22 11:07:12
  By: moc.nwonknu@nwonknu
How can you change the variance (sigma)?

• Date: 2013-06-12 12:30:33
  By: moc.enon@lubeb
This is NOT a good code to generate Gaussian Noise. Look into:
```
(random * c2) + (random * c2) + (random * c2)
```
It is all nonsense! The reason of adding three numbers it the Central Limit Theorem to aproximate Gaussian distribution. But the random numbers inside must differ, which is not the case. The code on original link http://www.musicdsp.org/archive.php?classid=0#129 is correct.
1.17 Chebyshev waveshaper (using their recursive definition)

- **Author or source:** mdsp
- **Type:** chebyshev
- **Created:** 2005-01-10 18:03:29

Listing 26: notes

someone asked for it on kvr-audio.

I use it in an unreleased additive synth. There's no oversampling needed in my case since I feed it with a pure sinusoid and I control the order to not have frequencies above Fs/2. Otherwise you should oversample by the order you'll use in the function or bandlimit the signal before the waveshaper unless you really want that aliasing effect... :)

I hope the code is self-explaining, otherwise there's plenty of sites explaining chebyshev polynoms and their applications.

Listing 27: code

```c
float chebyshev(float x, float A[], int order)
{
    // T0 = 1
    // T1 = x
    // Tn = 2.x.Tn-1 - Tn-2
    // out = sum(Ai*Ti(x)) , i C {1,..,order}
    float Tn_2 = 1.0f;
    float Tn_1 = x;
    float Tn;
    float out = A[0]*Tn_1;
    for(int n=2;n<=order;n++)
    {
        Tn = 2.0f*x*Tn_1 - Tn_2;
        out += A[n-1]*Tn;
        Tn_2 = Tn_1;
        Tn_1 = Tn;
    }
    return out;
}
```

1.17.1 Comments

- **Date:** 2005-01-10 18:10:12
- **By:** mdsp

BTW you can achieve an interesting effect by feeding back the output in the input. It adds a kind of interesting pitched noise to the signal.

I think VirSyn is using something similar in microTERA.
Hi, it was me that asked about this on KvR. It seems that it is possible to use such a waveshaper on a non-sinusoidal input without oversampling; split the input signal into bands, and use the highest frequency in each band to determine which order polynomials to send each band to. The idea about feeding back the output to the input occurred to me as well, good to know that such an effect might be interesting. If I come across any other points of interest while coding this plugin, I'll be glad to mention them on here.

Dan

Of course you can use it on non sinusoidal input, but you won't achieve the same result.

If you express your input as a sum of sinusoids of frequencies \([f_0 f_1 f_2 \ldots]\) and use the chebyshev polynomial of order 2 you won't have \(2[f_0 f_1 f_2 \ldots]\) as the resulting frequencies. As it's a nonlinear function you can't use the superposition theorem anymore.

Beware that chebyshev polynomials are sensitive to the range of your input. Your sinusoid has to have a gain exactly equal to 1 in order to work as expected.

That's a nice trick but it has it's limits.

### 1.18 Cubic polynomial envelopes

- **Author or source:** Andy Mucho
- **Type:** envelope generation
- **Created:** 2002-01-17 00:59:16

#### Listing 28: notes

This function runs from:
startlevel at Time=0
midlevel at Time/2
endlevel at Time

At moments of extreme change over small time, the function can generate out of range (of the 3 input level) numbers, but isn't really a problem in actual use with real numbers, and sensible/real times.

#### Listing 29: code

```
1 time = 32
2 startlevel = 0
3 midlevel = 100
4 endlevel = 120
```
\[ k = \text{startlevel} + \text{endlevel} - (\text{midlevel} \times 2) \]
\[ r = \text{startlevel} \]
\[ s = (\text{endlevel} - \text{startlevel} - (2 \times k)) / \text{time} \]
\[ t = (2 \times k) / (\text{time} \times \text{time}) \]
\[ \text{bigr} = r \]
\[ \text{bigs} = s + t \]
\[ \text{bigt} = 2 \times t \]

\[ \text{for(int i=0;i<\text{time};i++)} \]
\[ \{ \]
\[ \text{bigr} = \text{bigr} + \text{bigs} \]
\[ \text{bigs} = \text{bigs} + \text{bigt} \]
\[ \} \]

1.18.1 Comments

- **Date:** 2004-01-13 12:31:55
- **By:** ti.otinifni@reiruoceht

I have try this and it works fine, but what hell is bigs?????

bye bye

\[ \text{float time} = (\text{float})\text{pRect.Width();} \quad //\text{time in sampleframes} \]
\[ \text{float startlevel} = (\text{float})\text{pRect.Height();} \quad //\text{max h vedi ma 1.0} \]
\[ \text{float midlevel} = 500.f; \]
\[ \text{float endlevel} = 0.f; \]

\[ \text{float k} = \text{startlevel} + \text{endlevel} - (\text{midlevel} \times 2); \]
\[ \text{float r} = \text{startlevel}; \]
\[ \text{float s} = (\text{endlevel} - \text{startlevel} - (2 \times k)) / \text{time}; \]
\[ \text{float t} = (2 \times k) / (\text{time} \times \text{time}); \]

\[ \text{float bigr} = r; \]
\[ \text{float bigs} = s + t; \]
\[ \text{float bigt} = 2 \times t; \]

\[ \text{for(int i=0;i<\text{time};i++)} \]
\[ \{ \]
\[ \text{bigr} = \text{bigr} + \text{bigs}; \]
\[ \text{bigs} = \text{bigs} + \text{bigt}; \quad // \text{bigs? co'è} \]
\[ \text{pDC->SetPixel(i,(int)bigr,RGB (0, 0, 0));} \]
\]

- **Date:** 2006-10-08 17:50:48
- **By:** if.iki@xemxet

The method uses a technique called forward differencing, which is based on the fact that a successive values of an polynomial function can be calculated using only additions instead of evaluating the whole polynomial which would require huge amount of multiplications.
Actually the method presented here uses only a quadratic curve, not cubic. The number of the variables in the adder is \( N+1 \), where \( N \) is the order of the polynomial to be generated. In this example we have only three, thus second order function. For linear we would have two variables: the current value and the constant adder.

The trickiest part is to set up the adder variables...

Check out forward difference in mathworld for more info.

1.19 DSF (super-set of BLIT)

- **Author or source:** David Lowenfels
- **Type:** matlab code
- **Created:** 2003-04-02 23:59:24

Listing 30: notes

Discrete Summation Formula ala Moorer

```
computes equivalent to \( \sum_{k=0}^{N-1} (a^k \times \sin(\beta + k\theta)) \)
modified from Emanuel Landeholm's C code
output should never clip past \([-1,1]\]

If using for BLIT synthesis for virtual analog:
\( N = \text{max}N; \)
\( a = \text{attn} \_\text{at}_\text{Nyquist} ^ {1/\text{max}N}; \) %hide top harmonic popping in and out when sweeping frequency
\( \beta = \pi/2; \)
\( \text{num} = 1 - a^N \times \cos(N\theta) - a \times (\cos(\theta) - a^N \times \cos(N\theta - \theta)); \) %don't waste time on \( \beta \)

You can also get growing harmonics if \( a > 1 \), but the min statement in the code must be removed, and the scaling will be weird.
```

Listing 31: code

```matlab
function output = dsf( freq, a, H, samples, beta)

% a = rolloff coefficient
% H = number of harmonic overtones (fundamental not included)
% beta = harmonic phase shift

samplerate = 44.1e3;
freq = freq/samplerate; % normalize frequency

bandlimit = samplerate / 2; % Nyquist
maxN = 1 + floor( bandlimit / freq ); % prevent aliasing
N = min(H+2,maxN);
theta = 2*pi * phasor(freq, samples);
```

(continues on next page)
15 \( \epsilon = 10^{-6}; \)
16 \( a = \min(a, 1-\epsilon); \) %prevent divide by zero
17 
18 \( \text{num} = \sin(\beta) - a \cdot \sin(\beta - \theta) - a^N \cdot \sin(\beta + N \cdot \theta) + a^{N+1} \cdot \sin(\beta + (N-1) \cdot \theta); \)
19 \( \text{den} = (1 + a \cdot (a - 2 \cdot \cos(\theta))); \)
20 
21 \( \text{output} = 2 \cdot (\text{num} ./ \text{den} - 1) \cdot \text{freq}; \) %subtract by one to remove DC, scale by freq to normalize
22 \( \text{output} = \text{output} \cdot \maxN / N; \) %OPTIONAL: rescale to give louder output as rolloff increases
23 
24 function out = phasor(normfreq, samples);
25 out = mod( (0:samples-1) * normfreq , 1);
26 out = out * 2 - 1; %make bipolar

1.19.1 Comments

- Date: 2003-04-03 15:05:42
- By: David Lowenfels

oops, there's an error in this version. frequency should not be normalized until after the maxN calculation is done.

1.20 Direct pink noise synthesis with auto-correlated generator

- Author or source: RidgeRat \(<ten.knilhtrae@6741emmartl>\>
- Type: 16-bit fixed-point
- Created: 2007-02-11 20:15:42

Listing 32: notes

Canonical C++ class with minimum system dependencies, BUT you must provide your own uniform random number generator. Accurate range is a little over 9 octaves, degrading gracefully beyond this. Estimated deviations \( \pm 0.25 \) dB from ideal 1/f curve in range. Scaled to fit signed 16-bit range.

Listing 33: code

// Pink noise class using the autocorrelated generator method.
// Method proposed and described by Larry Trammell "the RidgeRat" --
// see http://home.earthlink.net/~ltrammell/tech/newpink.htm
// There are no restrictions.
//
// This is a canonical, 16-bit fixed-point implementation of the
generator in 32-bit arithmetic. There are only a few system
dependencies.
//
// -- access to an allocator 'malloc' for operator new
// -- access to definition of 'size_t'
// -- assumes 32-bit two's complement arithmetic
// -- assumes long int is 32 bits, short int is 16 bits
// -- assumes that signed right shift propagates the sign bit
//
// It needs a separate URand class to provide uniform 16-bit random
// numbers on interval [1,65535]. The assumed class must provide
// methods to query and set the current seed value, establish a
// scrambled initial seed value, and evaluate uniform random values.
//
//
// ----------- header -----------------------------------------------
// pinkgen.h

#ifndef _pinkgen_h_
#define _pinkgen_h_ 1

#include <stddef.h>
#include <alloc.h>

// You must provide the uniform random generator class.
#ifndef _URand_h_
#include "URand.h"
#endif

class PinkNoise
{
private:
  // Coefficients (fixed)
  static long int const pA[5];
  static short int const pPSUM[5];

  // Internal pink generator state
  long int contrib[5];  // stage contributions
  long int accum;       // combined generators
  void internal_clear();

  // Include a UNoise component
  URand ugen;

public:
  PinkNoise( );
  PinkNoise( PinkNoise & );
~PinkNoise( );
  void * operator new( size_t );
  void pinkclear( );
  short int pinkrand( );
};
#endif

// ----------- implementation ---------------------------------------
// pinkgen.cpp
#include "pinkgen.h"

// Static class data
long int const PinkNoise::pA[5] = (continues on next page)
69 \{ 14055, 12759, 10733, 12273, 15716 \};
70
short int const PinkNoise::pPSUM[5] =
71 \{ 22347, 27917, 29523, 29942, 30007 \};
72
73 // Clear generator to a zero state.
74 void PinkNoise::pinkclear( )
75 {
76    int i;
77    for (i=0; i<5; ++i) { contrib[i]=0L; }
78    accum = 0L;
79 }
80
81 // PRIVATE, clear generator and also scramble the internal
82 // uniform generator seed.
83 void PinkNoise::internal_clear( )
84 {
85    pinkclear();
86    ugen.seed(0); // Randomizes the seed!
87 }
88
89 // Constructor. Guarantee that initial state is cleared
90 // and uniform generator scrambled.
91 PinkNoise::PinkNoise( )
92 {
93    internal_clear();
94 }
95
96 // Copy constructor. Preserve generator state from the source
97 // object, including the uniform generator seed.
98 PinkNoise::PinkNoise( PinkNoise & Source )
99 {
100    int i;
101    for (i=0; i<5; ++i) contrib[i]=Source.contrib[i];
102    accum = Source.accum;
103    ugen.seed( Source.ugen.seed( ) );
104 }
105
107 void * PinkNoise::operator new( size_t size )
108 {
109    return malloc(size);
110 }
111
112 // Destructor. No special action required.
113 PinkNoise::~PinkNoise( ) { /* NIL */ }
114
115 // Coding artifact for convenience
116 #define UPDATE_CONTRIB(n) \
117 \{ \
118     accum -= contrib[n]; \
119     contrib[n] = (long)randv * pA[n]; \
120     accum += contrib[n]; \
121     break; \
122 \}
123
124 // Evaluate next randomized 'pink' number with uniform CPU loading.
125 short int PinkNoise::pinkrand( )
1.20. Direct pink noise synthesis with auto-correlated generator


1.21 Discrete Summation Formula (DSF)

- **Author or source:** Stylson, Smith and others... (Alexander Kritov)
- **Created:** 2002-02-10 12:43:30

Listing 34: notes

Buzz uses this type of synth.
For cool sounds try to use variable,
for example a=exp(-x/12000)*0.8 // x- num.samples

Listing 35: code

double DSF (double x, // input
do ble a, // a<1.0
do ble N, // N<SmplFQ/2,
do ble fi) // phase
{
    double s1 = pow(a,N-1.0)*sin((N-1.0)*x+fi);
    double s2 = pow(a,N)*sin(N*x+fi);
    double s3 = a*sin(x+fi);
    double s4 =1.0 - (2*a*cos(x)) +(a*a);
    if (s4==0)
        return 0;
    else

(continues on next page)
return (sin(fi) - s3 - s2 +s1)/s4;
}

1.21.1 Comments

• Date: 2002-11-08 11:21:19
  By: dfl AT ccrma.stanford.edu

According to Stilson + Smith, this should be

double s1 = pow(a,N+1.0)*sin((N-1.0)*x+fi);
  ^

Could be a typo though?

• Date: 2003-03-14 17:01:46
  By: Alex

yepp..

• Date: 2003-03-20 04:20:51
  By: TT

So what is wrong about "double" up there?
For DSF, do we have to update the phase (fi input) at every sample?
Another question is what's the input x supposed to represent? Thanks!

• Date: 2003-04-01 01:45:47
  By: David Lowenfels

input x should be the phase, and fi is the initial phase I guess? Seems redundant to me.
There is nothing wrong with the double, there is a sign typo in the original posting.

• Date: 2007-02-14 18:04:44
  By: moc.erchwon@ydobon

I'm not so sure that there is a sign typo. (I know--I'm five years late to this party.)

The author of this code just seems to have an off-by-one definition of N. If you expand it all out, it looks like Stilson & Smith's paper, except you have N here, where S&S had N+1, and you have N-1 where S&S had N.

I think the code is equivalent. You just have to understand how to choose N to avoid aliasing.

I don't have it working yet, but that's how it looks to me as I prepare a DSF oscillator. More later.

• Date: 2008-11-02 11:47:07
Musicdsp.org Documentation

• By: mysterious T

Got it working nicely, but it took a few minutes to pluck it apart. Had to correct it for my pitch scheme, too. But it's quite amazing! Funny concept, though, it's like a generator with a built-in filter. It holds up into very high pitches, too, in terms of aliasing, as far as I can tell... ehm... and without any further oversampling (so far).

Really, really nice! I was looking for a way to give my sinus an edge! ;)

1.22 Drift generator

• Author or source: ti.oohay@odrasotniuq
• Type: Random
• Created: 2004-09-23 16:07:34

Listing 36: notes

I use this drift to modulate any sound parameter of my synth. It is very effective if it slightly modulates amplitude or frequency of an FM modulator. It is based on an incremental random variable, sine-warped. I like it because it is "continuous" (as opposite to "sample and hold"), and I can set variation rate and max variation. It can go to upper or lower constraint (+/- max drift) but it gradually decreases rate of variation when approaching to the limit. I use it exactly as an LFO (-1.f .. +1.f) I use a table for sin instead of sin() function because this way I can change random distribution, by selecting a different curve (different table) from sine...

I hope that it is clear ... (sigh... :-)
Bye!!!
P.S. Thank you for help in previous submission ;-)
1.22.1 Comments

• Date: 2004-09-24 17:37:38
• By: ti.oohay@odrasotniuq

...sorry...
random() must be in [-1..+1] !!!

1.23 Easy noise generation

• Author or source: moc.psd-nashi@liam
• Type: White Noise
• Created: 2006-02-23 22:40:20

Listing 38: notes

Easy noise generation,
in .hpp,
b_noise = 19.1919191919191919191919191919191919191919;

alternatively, the number 19 below can be replaced with a number of your choice, to get
that particular flavour of noise.

Regards,
Ove Karlsen.

Listing 39: code

1 b_noise = b_noise * b_noise;
2 int i_noise = b_noise;
3 b_noise = b_noise - i_noise;
4
5 double b_noiseout;
6 b_noiseout = b_noise - 0.5;
7
8 b_noise = b_noise + 19;

1.23.1 Comments

• Date: 2006-07-16 18:24:22
• By: moc.liamg@saoxyz

This is quite a good PRNG! The numbers it generates exhibit a slight a pattern (obviously, since it's not very sophisticated) but they seem quite usable! The real FFT spectrum is very flat and "white" with just one or two aberrant spikes while the imaginary spectrum is almost perfect (as is the case with most PRNGs). Very nice! Either that or I need more practice with MuPad...

• Date: 2007-01-16 12:16:24
• By: moc.liamtoh@neslakevofira
Alternatively you can do:

```c
double b_noiselast = b_noise;
b_noise = b_noise + 19;
b_noise = b_noise * b_noise;
b_noise = b_noise + ((-b_noise + b_noiselast) * 0.5);
int i_noise = b_noise;
b_noise = b_noise - i_noise;
```

This will remove the patterning.

- **Date:** 2007-01-16 16:56:19
- **By:** moc.erehwon@ydobon

```c
>>b_noise = b_noise + ((-b_noise + b_noiselast) * 0.5);
```

That seems to reduce to just:

```c
b_noise=(b_noise+b_noiselast) * 0.5;
```

- **Date:** 2007-01-18 22:04:19
- **By:** mymail@com

Hi, is this integer? Please do not disturb the forum, rather send me an email.

B.i.T

- **Date:** 2007-02-01 16:21:12
- **By:** moc.liamtoh@neslrakevofira

The line is written like that, so you can change 0.5, to for instance 0.19.

- **Date:** 2007-02-01 16:52:21
- **By:** moc.erehwon@ydobon

```c
>>The line is written like that, so you can change 0.5, to for instance 0.19.
```

OK. Why would I do that? What’s that number control?

- **Date:** 2007-02-03 15:51:46
- **By:** moc.liamtoh@neslrakevofira

It controls the patterning. I usually write my algorithms tweakable.

You could try even lower aswell, maybe 1e-19.

### 1.24 Fast Exponential Envelope Generator

- **Author or source:** Christian Schoenebeck
- **Created:** 2005-03-03 14:44:11
Listing 40: notes

The naive way to implement this would be to use a `exp()` call for each point of the envelope. Unfortunately `exp()` is quite a heavy function for most CPUs, so here is a numerical, much faster way to compute an exponential envelope (performance gain measured in benchmark: about factor 100 with an Intel P4, gcc -O3 --fast-math -march=i686 -mcpu=i686).

Note: you can't use a value of 0.0 for `levelEnd`. Instead you have to use an appropriate, very small value (e.g. 0.001 should be sufficiently small enough).

Listing 41: code

```c
const float sampleRate = 44100;
float coeff;
float currentLevel;

void init(float levelBegin, float levelEnd, float releaseTime) {
    currentLevel = levelBegin;
    coeff = (log(levelEnd) - log(levelBegin)) / (releaseTime * sampleRate);
}

inline void calculateEnvelope(int samplePoints) {
    for (int i = 0; i < samplePoints; i++) {
        currentLevel += coeff * currentLevel;
        // do something with 'currentLevel' here
        ...
    }
}
```

1.24.1 Comments

- Date: 2005-03-03 21:16:41
  - By: moc.erawknuhc@knuhcnezitic

  is there a typo in the runtime equation? or am i missing something in the implementation?

- Date: 2005-03-04 15:13:56
  - By: schoenebeck (@) software ( minus ) engineering.org

  Why should there be a typo?

  Here is my benchmark code btw:
  http://stud.fh-heilbronn.de/~cschoene/studienarbeit/benchmarks/exp.cpp

- Date: 2005-03-04 16:20:41
  - By: moc.erawknuhc@knuhcnezitic
ok, i think i get it. this can only work on blocks of samples, right? not per-sample calc?

i was confused because i could not find the input sample(s) in the runtime code. but now i see that the equation does not take an input; it merely generates a defined envelope across the number of samples. my bad.

Well, the code above is only meant to show the principle. Of course you would adjust it for your application. The question if you are calculating on a per-sample basis or applying the envelope to a block of samples within a tight loop doesn't really matter; it would just mean an adjustment of the interface of the execution code, which is trivial.

This is not working for long envelopes because of numerical accuracy problems. Try calculating is over 10 seconds @ 192KHz to see what I mean: it drifts.

I have an equivalent system that permits to have linear to log and to exp curves with a simple parameter. I may submit it one of these days...

Sebastien Metrot
--
http://www.usbsounds.com

No, here is a test app which shows the introduced drift:
http://stud.fh-heilbronn.de/~cschoene/studienarbeit/benchmarks/expaccuracy.cpp

Even with an envelope duration of 30s, which is really quite long, a sample rate of 192kHz and single-precision floating point calculation I get this result:

Calculated sample points: 5764846
Demanded duration: 30.000000 s
Actual duration: 30.025240 s

So the envelope just drifts about 25ms for that long envelope!

I believe you are seeing unrealistic results with this test because on x86 the fpu's internal format is 80bits and your compiler probably optimises this cases quite easily. Try doing the same test, calculating the same envelope, but by breaking the calculation in blocks of 256 or 512 samples at a time and then storing in memory the temp values for the next block. In this case you may see different results and a much bigger drift (that's my experience with the same algo).
Anyway my algo is a bit different as it permits to change the current type with a parameter, this makes the formula looks like
value = value * coef + constant;
May be this leads to more calculation errors :).
Also, assuming that your startLevel is 1.0, to calculate an appropriate endLevel, you can use something like:

```
endLevel = 10 ^ dB/20;
```

where dB is your endLevel in decibels (and must be a negative value of course) - for amplitude envelopes, -90 dB should be a suitable level for "near inaudible"...

---

**Date**: 2005-03-31 14:45:51  
**By**: schoenebeck (@) software ( minus ) engineering.org

```
Sorry, you are right of course; that simplification of the execution equation works here because we are calculating all points with linear discretization. But you will agree that your init() function is not good, because exp(log(x)) == x and it's not generalized at all. Usually you might have more than one exp segment in your EG and maybe even have an exp attack segment. So we arrive at the following solution:

```
const float sampleRate = 44100;
float coeff;
float currentLevel;

void init(float levelBegin, float levelEnd, float releaseTime) {
    currentLevel = levelBegin;
    coeff = 1.0f + (log(levelEnd) - log(levelBegin)) / (releaseTime * sampleRate);
}

inline void calculateEnvelope(int samplePoints) {
    for (int i = 0; i < samplePoints; i++) {
        currentLevel *= coeff;
        // do something with 'currentLevel' here ...
    }
}
```

You can use a dB conversion for both startLevel and endLevel of course.
```
---

**Date**: 2006-03-10 01:53:44  
**By**: na

```
i would say that calculation of coeff is still wrong. It should be:  
coeff = pow( levelEnd / levelBegin, 1 / N );
```

---

**Date**: 2006-03-10 02:23:29  
**By**: na[ eldur # starman # ee]
or coeff = exp(log(levelEnd/levelBegin) / (releaseTime * sampleRate) );
not sure but it looks computationally more expensive

• Date: 2006-11-26 15:44:04
• By: hc.xmg@i.l.e

what's about?
coeff = 1.0f + (log(levelEnd) - log(levelBegin)) /
(releaseTime * sampleRate - 1);

• Date: 2006-11-26 15:55:12
• By: hc.xmg@i.l.e

sorry for the double post. and i'm now almost sure, that it should be:
coeff = 1.0f + (log(levelEnd) - log(levelBegin)) /
(releaseTime * sampleRate + 1);

1.25 Fast LFO in Delphi...

• Author or source: Dambrin Didier ( moc.tcerideciffo-e@log )
• Created: 2003-07-15 09:01:18
• Linked files: LFOGenerator.zip

Listing 42: notes

[from Didier's mail...
[see attached zip file too!]
I was working on a flanger, & needed an LFO for it. I first used a Sin(), but it was
→too
slow, then tried a big wavetable, but it wasn't accurate enough.
I then checked the alternate sine generators from your web site, & while they're good,
they all can drift, so you're also wasting too much CPU in branching for the drift
→checks.
So I made a quick & easy linear LFO, then a sine-like version of it. Can be useful for
LFO's, not to output as sound.
If has no branching & is rather simple. 2 Abs() but apparently they're fast. In all
→cases
faster than a Sin()
It's in delphi, but if you understand it you can translate it if you want.
It uses a 32bit integer counter that overflows, & a power for the sine output.
If you don't know delphi, $ is for hex (h at the end in c++?), Single is 32bit float,
icenter integer is 32bit integer (signed, normally).

Listing 43: code

unit Unit1;
interface
uses
(continues on next page)
Windows, Messages, SysUtils, Classes, Graphics, Controls, Forms, Dialogs,
StdCtrls, ExtCtrls, ComCtrls;

type
TFrm1 = class(TForm)
  PaintBox1: TPaintBox;
  Bevel1: TBevel;
  procedure PaintBox1Paint(Sender: TObject);
private
  { Private declarations }
public
  { Public declarations }
end;

var
  Form1: TForm1;

implementation

{$R *.DFM}

procedure TForm1.PaintBox1Paint(Sender: TObject);
var n,Pos,Speed:Integer;
  Output,Scale,HalfScale,PosMul:Single;
  OurSpeed,OurScale:Single;
begin
  OurSpeed:=100; // 100 samples per cycle
  OurScale:=100; // output in -100..100
  Pos:=0; // position in our linear LFO
  Speed:=Round($100000000/OurSpeed);

  // --- triangle LFO ---
  Scale:=OurScale*2;
  PosMul:=Scale/$80000000;
  // loop
  for n:=0 to 299 do
    Begin
      // inc our 32bit integer LFO pos & let it overflow. It will be seen as signed when
      // read by the math unit
      Pos:=Pos+Speed;
      Output:=Abs(Pos*PosMul)-OurScale;
      // visual
      PaintBox1.Canvas.Pixels[n,Round(100+Output)]:=clRed;
    End;

  // --- sine-like LFO ---
  Scale:=Sqrt(OurScale*4);
  PosMul:=Scale/$80000000;
  HalfScale:=Scale/2;  
  // loop

for n:=0 to 299 do
  Begin
    // inc our 32bit integer LFO pos & let it overflow. It will be seen as signed when read by the math unit
    Pos:=Pos+Speed;
    Output:=Abs(Pos*PosMul)-HalfScale;
    Output:=Output*(Scale-Abs(Output));
    // visual
    Paintbox1.Canvas.Pixels[n,Round(100+Output)]:=clBlue;
  End;
end;
end.

1.25.1 Comments

- **Date**: 2004-04-29 09:18:58
- **By**: ed.luosfosruoivas@naitsirhC

LFO Class...

unit Unit1;

interface

uses
  Windows, Messages, SysUtils, Classes, Graphics, Controls, Forms, Dialogs,
  StdCtrls, ExtCtrls, ComCtrls;

type
  TLFOType = (lfoTriangle,lfoSine);
  TLFO = class(TObject)
  private
    iSpeed : Integer;
    fSpeed : Single;
    fMax, fMin : Single;
    fValue : Single;
    fPos : Integer;
    fType : TLFOType;
    fScale : Single;
    fPosMul : Single;
    fHalfScale : Single;
  function GetValue:Single;
  procedure SetType(tt: TLFOType);
  procedure SetMin(v:Single);
  procedure SetMax(v:Single);
  public
    { Public declarations }
    constructor Create;
  published
    property Value:Single read GetValue;
    property Speed:Single read FSpeed Write FSpeed;
property Min:Single read FMin write SetMin;
property Max:Single read FMax write SetMax;
property LFO:TLFOType read fType write SetType;
end;

TForm1 = class(TForm)
  Bevel1: TBevel;
  PaintBox1: TPaintBox;
  procedure PaintBox1Paint(Sender: TObject);
private
  { Private declarations }
public
  { Public declarations }
end;

var
  Form1: TForm1;

implementation

{$R *.DFM}

constructor TLFO.Create;
begin
  fSpeed:=100;
  fMax:=1;
  fMin:=0;
  fValue:=0;
  fPos:=0;
  iSpeed:=Round($100000000/fSpeed);
  fType:=lfoTriangle;
  fScale:=fMax-((fMin+fMax)/2);
end;

procedure TLFO.SetType(tt: TLFOType);
begin
  fType:=tt;
  if fType = lfoSine then
    begin
      fPosMul:=(Sqrt(fScale*2))/80000000;
      fHalfScale:=(Sqrt(fScale*2))/2;
    end
  else
    begin
      fPosMul:=fScale/80000000;
    end;
end;

procedure TLFO.SetMin(v: Single);
begin
  fMin:=v;
  fScale:=fMax-((fMin+fMax)/2);
end;

procedure TLFO.SetMax(v: Single);
begin
  fMax:=v;
end;

(continues on next page)
fScale:=fMax-((fMin+fMax)/2);
end;

function TLFO.GetValue:Single;
begin
  if fType = lfoSine then
    begin
      Result:=Abs(fPos*fPosMul)-fHalfScale;
      Result:=Result*(fHalfScale*2-Abs(Result))*2;
      Result:=Result+((fMin+fMax)/2);
    end
  else
    begin
      Result:=Abs(fPos*(2*fPosMul))+fMin;
    end;
  fPos:=fPos+iSpeed;
end;

procedure TForm1.PaintBox1Paint(Sender: TObject);
var n : Integer;
  LFO1 : TLFO;
begin
  LFO1:=TLFO.Create;
  LFO1.Min:=-100;
  LFO1.Max:=100;
  LFO1.Speed:=100;
  LFO1.LFO:=lfoTriangle;
  // --- triangle LFO ---
  for n:=0 to 299 do Paintbox1.Canvas.Pixels[n,Round(100+LFO1.Value)]:=clRed;
  
  LFO1.LFO:=lfoSine;
  // --- sine-like LFO ---
  for n:=0 to 299 do Paintbox1.Canvas.Pixels[n,Round(100+LFO1.Value)]:=clBlue;
end;
end.

• Date: 2005-06-01 23:36:15
• By: ed.luofosruoivas@naiturhC

Ups, i forgot something:

TLFO = class(TObject)
private
  ... procedure SetSpeed(v:Single);
public
  ... published
  ... property Speed:Single read FSpeed Write SetSpeed;
  ... end;

(continues on next page)
1.26 Fast SIN approximation for usage in e.g. additive synthesizers

- Author or source: neotec
- Created: 2008-12-09 11:56:33

Listing 44: notes

This code presents 2 'fastsin' functions. fastsin2 is less accurate than fastsin. In fact, it's a simple taylor series, but optimized for integer phase.

Phase is in 0 -> (2^32)-1 range and maps to 0 -> ~2PI

I get about 55000000 fastsin's per second on my P4,3.2GHz which would give a nice Kawai K5 emulation using 64 harmonics and 8->16 voices.

Listing 45: code

```c
float fastsin(UINT32 phase)
{
    const float frf3 = -1.0f / 6.0f;
    const float frf5 = 1.0f / 120.0f;
    const float frf7 = -1.0f / 5040.0f;
    const float frf9 = 1.0f / 362880.0f;
    const float f0pi5 = 1.570796327f;
    float x, x2, asin;
    UINT32 tmp = 0x3f800000 | (phase >> 7);
    if (phase & 0x80000000)
        tmp ^= 0x007fffff;
    x = (((float)*tmp) - 1.0f) * f0pi5;
    x2 = x * x;
    asin = (((frf9 * x2 + frf7) * x2 + frf5) * x2 + frf3) * x2 + 1.0f) * x;
    return (phase & 0x80000000) ? -asin : asin;
}
```
17 float fastsin2(UINT32 phase)
18 {
19     const float frf3 = -1.0f / 6.0f;
20     const float frf5 = 1.0f / 120.0f;
21     const float frf7 = -1.0f / 5040.0f;
22     const float f0pi5 = 1.570796327f;
23     float x, x2, asin;
24     UINT32 tmp = 0x3f800000 | (phase >> 7);
25     if (phase & 0x40000000)
26         tmp ^= 0x007fffff;
27     x = (*(float*)&tmp) - 1.0f) * f0pi5;
28     x2 = x * x;
29     asin = (((frf7 * x2 + frf5) * x2 + frf3) * x2 + 1.0f) * x;
30     return (phase & 0x80000000) ? -asin : asin;
31 }

1.26.1 Comments

- Date: 2008-12-09 12:11:11
- By: neotec

PS: To use this as an OSC you'll need the following vars/equ's:

UINT32 phase = 0;
UINT32 step = frequency * powf(2.0f, 32.0f) / samplerate;

Then it's just:
...
out = fastsin(phase);
phase += step;
...

- Date: 2008-12-14 20:04:10
- By: moc.toohay@bob

Woah! Seven multiplies, on top of those adds and memory lookup. Is this really all →that fast?

1.27 Fast Whitenoise Generator

- Author or source: ed.bew@hcridldef.dreg
- Type: Whitenoise
- Created: 2006-02-23 22:39:56

Listing 46: notes

This is Whitenoise... :o)
Listing 47: code

```c
float g_fScale = 2.0f / 0xffffffff;
int g_x1 = 0x67452301;
int g_x2 = 0xefcdab89;

void whitenoise(
    float* _fpDstBuffer, // Pointer to buffer
    unsigned int _uiBufferSize, // Size of buffer
    float _fLevel ) // Noiselevel (0.0 ... 1.0)
{
    _fLevel *= g_fScale;
    while( _uiBufferSize-- )
    {
        g_x1 ^= g_x2;
        *_fpDstBuffer++ = g_x2 * _fLevel;
        g_x2 += g_x1;
    }
}
```

1.27.1 Comments

- **Date:** 2006-07-18 17:34:00  
  **By:** uh.etle.fni@yfoocs  
  Works well! Kinda fast! The spectrum looks completely flat in an FFT analyzer.

- **Date:** 2006-11-29 20:50:44  
  **By:** ed.bew@hcrikdlef.dreg  
  As I said! :-)
  Take care

- **Date:** 2006-11-30 00:57:31  
  **By:** moc.erehwon@ydobon  
  I'm now waiting for pink and brown. :-)

- **Date:** 2006-11-30 15:02:54  
  **By:** uh.etle.fni@yfoocs  
  To get pink noise, you can apply a 3dB/Oct filter, for example the pink noise filter → in the Filters section.
  To get brown noise, apply an one pole LP filter to get a 6dB/oct slope.
  Peter

- **Date:** 2006-11-30 17:55:02  
  **By:** moc.erehwon@ydobon
Yeah, I know how to do it with a filter. I was just looking to see if this guy had anything else clever up his sleeve.

I'm currently using this great stuff:
vellocet.com/dsp/noise/VRand.html

- **Date**: 2006-12-15 17:12:19
  - **By**: moc.liang@palbmer

I compiled it, but I get some grainyness that a unisgned long LC algorithm does not give me... am I the only one?

- **Date**: 2006-12-17 18:12:42
  - **By**: uh.etle.fn@yfoocs

Did you do everything right? It works here.

- **Date**: 2006-12-19 21:24:04
  - **By**: ed.bew@hcrikdlef.dreg

I've noticed that my code is similar to a so called "feedback shift register" as used in the Commodore C64 Soundchip 6581 called SID for noise generation.

Links:
en.wikipedia.org/wiki/Linear_feedback_shift_register
en.wikipedia.org/wiki/MOS_Technology_SID
www.cc65.org/mailarchive/2003-06/3156.html

- **Date**: 2007-03-13 00:39:39
  - **By**: —.liam@firA

SID noise! cool.

### 1.28 Fast sine and cosine calculation

- **Author or source**: Lot’s or references… Check Julius O. SMith mainly
- **Type**: waveform generation
- **Created**: 2002-01-17 00:54:32

Listing 48: code

```c
init:
float a = 2.f*(float)sin(Pi*frequency/samplerate);
float s[2];
s[0] = 0.5f;
s[1] = 0.f;
```

(continues on next page)
Loop:

\[
\begin{align*}
    s[0] &= s[0] - a \cdot s[1]; \\
    s[1] &= s[1] + a \cdot s[0]; \\
    \text{output_sine} &= s[0]; \\
    \text{output_cosine} &= s[1]
\end{align*}
\]

1.28.1 Comments

- **Date**: 2003-04-05 10:52:49  
  **By**: DFL

Yeah, this is a cool trick! :)  
FYI you can set \( s[0] \) to whatever amplitude of sinewave you desire. With 0.5, you will get +/- 0.5

- **Date**: 2003-04-05 17:02:22  
  **By**: gro.tucetontsap@kcitgib

After a while it may drift, so you should resync it as follows:

```cpp
const float tmp=1.5f-0.5f*(s[1]*s[1]+s[0]*s[0]);
\text{s[0]}*=\text{tmp}; \text{s[1]}*=\text{tmp};
```

This assumes you set \( s[0] \) to 1.0 initially.

'Tick

- **Date**: 2003-04-08 09:19:40  
  **By**: DFL

Just to expalin the above "resync" equation  
\((3-x)/2\) is an approximation of \(1/\sqrt{x}\)  
So the above is actually renormalizing the complex magnitude.  
\[ \sin^2 (x) + \cos^2(x) = 1 \]

- **Date**: 2003-05-15 08:26:22  
  **By**: nigel

This is the Chamberlin state variable filter specialized for infinite Q oscillation.  
A few things to note:

Like the state variable filter, the upper frequency limit for stability is around one-sixth the sample rate.

The waveform symmetry is very pure at low frequencies, but gets skewed as you get near the upper limit.

For low frequencies, \( \sin(n) \) is very close to \( n \), so the calculation for "a" can be reduced to \( a = 2\pi\text{frequency/samplerate}.\)

You shouldn't need to resync the oscillator--for fixed point and IEEE floating point, errors cancel exactly, so the oscillator runs forever without drifting in amplitude or frequency.
I made a nice little console 'game' using your cordic sinewave approximation. Download it at http://users.pandora.be/antipro/Other/Ascillator.zip (includes source code). Just for oldschool fun :).

Note that the peaks of the waveforms will actually be between samples, and the functions will be phase offset by one half sample's worth. If you need exact phase, you can compensate by interpolating using cubic hermite interpolation.

... can be found in Jon Datorro, Effect Design, Part 3, a paper that can be easily found in the web.

Funny, this is just a complex multiply that is optimized for small angles (low frequencies)
When the CPU rounding mode is set to nearest, it should be stable, at least for small frequencies.

More on that can be found in Jon Datorro, Effect Design, Part 3, a paper that can be easily found in the web.

Funny, this is just a complex multiply that is optimized for small angles (low frequencies)
When the CPU rounding mode is set to nearest, it should be stable, at least for small frequencies.

How do I set a particular phase for this? I've tried setting s[0] = cos(phase) and s[1] = sin(phase), but that didn't seem to be accurate enough.
Thanks

1.29 Fast sine wave calculation

• Author or source: James McCartney in Computer Music Journal, also the Julius O. Smith paper
• **Type:** waveform generation  
• **Created:** 2002-01-17 00:52:33

### Listing 49: notes

(posted by Niels Gorisse)

If you change the frequency, the amplitude rises (pitch lower) or lowers (pitch rise). I fixed the first problem by thinking about what actually goes wrong. The answer was to recalculate the phase for that frequency and the last value, and then continue normally.

### Listing 50: code

```plaintext
1 Variables:
2 ip = phase of the first output sample in radians
3 w = freq*pi / samplerate
4 bl = 2.0 * cos(w)

5 Init:
6 y1=sin(ip-w)
7 y2=sin(ip-2*w)

8 Loop:
9 y0 = bl*y1 - y2
10 y2 = y1
11 y1 = y0

output is in y0 (y0 = sin(ip + n*freq*pi / samplerate), n= 0, 1, 2, ... I *think*)

Later note by James McCartney:  
if you unroll such a loop by 3 you can even eliminate the assigns!!

12 y0 = bl*y1 - y2
13 y2 = bl*y0 - y1
14 y1 = bl*y2 - y0
```

### 1.29.1 Comments

• **Date:** 2003-04-22 15:05:21
  • **By:** moc.liamtoh@trahniak
  
  try using this to make sine waves with frequency less than 1. I did and it gives very rough half triangle-like waves. Is there any way to fix this? I want to use a sine generated for LFO so I need one that works for low frequencies.

• **Date:** 2006-10-24 22:34:59
  • **By:** moc.oi@htnysa
  
  looks like the formula has gotten munged.  
  \[ w = \text{freq} \times \text{twopi} / \text{samplerate} \]
1.30 Fast square wave generator

- **Author or source:** Wolfgang (ed.tfoxen@redienhcsw)
- **Type:** NON-bandlimited osc...
- **Created:** 2002-02-10 12:46:22

### Listing 51: notes

Produces a square wave \(-1.0f .. +1.0f\). The resulting waveform is NOT band-limited, so it's probably of not much use for synthesis.
It's rather useful for LFOs and the like, though.

### Listing 52: code

```c
Idea: use integer overflow to avoid conditional jumps.

// init:
typedef unsigned long ui32;

// whatever
float sampleRate = 44100.0f; // whatever
float freq = 440.0f; // 440 Hz
float one = 1.0f;
ui32 intOver = 0L;
ui32 intIncr = (ui32)(4294967296.0 / hostSampleRate / freq));

// loop:
((ui32 *)&one) &= 0x7FFFFFFF; // mask out sign bit
((ui32 *)&one) |= (intOver & 0x80000000);
t
intOver += intIncr;
```

1.30.1 Comments

- **Date:** 2003-08-03 01:35:08
  - **By:** moc.jecnal@psdcisum

So, how would I get the output into a float variable like square_out, for instance?

- **Date:** 2009-04-12 15:33:37
  - **By:** moc.liamtoh@18_ogag_leafar

In response to lancej, yo can declare a union with a float and a int and operate the float as here using the int part of the union.

If I remember correctly the value for \(-1.f = 0xBF800000\) and the value for \(1.f = 0x3F800000\), note the \(0x80000000\) difference between them that is the sign.

1.31 Gaussian White Noise

- **Author or source:** uh.atsopten@egamer
1.31.1 Comments

- Date: 2002-08-28 02:05:50
- By: gro.sdikgninnips@nap

The previous one seems better for me, since it requires only a rand, half log and half sqrt per sample. Actually, I used that one, but I can't remember where I found it, too. Maybe on Knuth's book.

1.32 Gaussian White noise

- Author or source: Alexey Menshikov
- Created: 2002-08-01 01:13:47

Code I use sometimes, but don't remember where I ripped it from.

- Alexey Menshikov
11  \( y_1 = y_2; \)
12  \}
13  \} else {
14     do {
15         \( x_1 = 2.0f \times \text{ranf}() - 1.0f; \)
16         \( x_2 = 2.0f \times \text{ranf}() - 1.0f; \)
17         \( w = x_1 \times x_1 + x_2 \times x_2; \)
18     } while (w >= 1.0f);
19
20     \( w = (\text{float})\text{sqrt}(-2.0 \times \text{log}(w) / w); \)
21     \( y_1 = x_1 \times w; \)
22     \( y_2 = x_2 \times w; \)
23     \}
24
25  return ( (y_1 \times s + (\text{float}) m));
26

### 1.32.1 Comments

- **Date:** 2004-01-29 15:41:35  
  **By:** davidchristenATgmxDOTnet

White Noise does not consist of uniformly distributed values. Because in white noise, the power of the frequencies are uniformly distributed. The values must be normal (or gaussian) distributed. This is achieved by the Box-Muller Transformation. This function is the polar form of the Box-Muller Transformation. It is faster and numerically more stable than the basic form. The basic form is coded in the other (second) post.

Detailed information on this topic:  
http://www.taygeta.com/random/gaussian.html  
http://www.eece.unm.edu/faculty/bsantha/EECE-541/white2.pdf

Cheers David

- **Date:** 2007-09-06 04:09:52  
  **By:** moc.dlrownepotb@wahs.a.kcin

I'm trying to implement this in C#, but \( y_2 \) isn't initialized. Is this a typo?

- **Date:** 2010-07-17 20:35:18  
  **By:** ed.rab@oof

@nick: Way to late, but \( y_2 \) will always be initialized as in the first run "pass" is 0 (i.e. false). The C# compiler just can't prove it.

- **Date:** 2011-09-03 20:43:59  
  **By:** moc.liamg@htnysa

David is wrong. The distribution of the sample values is irrelevant. 'white' simply describes the spectrum. Any series of sequentially independent random values whatever their distribution -- will have a white spectrum.

### 1.32. Gaussian White noise
### 1.33 Generator

- **Author or source:** Paul Sernine
- **Type:** antialiased sawtooth
- **Created:** 2006-02-23 22:38:56

Listing 57: notes

This code generates a swept antialiasing sawtooth in a raw 16bit pcm file. It is based on the quad differentiation of a 5th order polynomial. The polynomial harmonics (and aliased harmonics) decay at 56 dB per oct. The differentiators correct the spectrum and waveform, while aliased harmonics are still attenuated.

Listing 58: code

```c
/* clair.c Examen Partiel 2b
T.Rochebois
02/03/98 */

#include <stdio.h>
#include <math.h>

main()
{
    double phase=0,dphase,freq,compensation;
    double aw0=0,aw1=0,ax0=0,ax1=0,ay0=0,ay1=0,az0=0,az1=0,sortie;
    short aout;
    int sr=44100;    //sample rate (Hz)
    double f_debut=55.0; //start freq (Hz)
    double f_fin=sr/6.0; //end freq (Hz)
    double octaves=log(f_fin/f_debut)/log(2.0);
    double duree=50.0; //duration (s)
    int i;

    FILE* f;
    f=fopen("saw.pcm","wb");
    for(i=0;i<duree*sr;i++)
    {
        //exponential frequency sweep
        //Can be replaced by anything you like.
        freq=f_debut*pow(2.0,octaves*i/(duree*sr));
        dphase=freq*(2.0/sr); //normalised phase increment
        phase+=dphase; //phase incrementation
        if(phase>1.0) phase-=2.0; //phase wrapping (-1,+1)

        //polynomial calculation (extensive continuity at -1 +1)
        // P(x) = --- x - -- x + --- x
        // 360 36 120
        aw0=phase*(7.0/360.0 + phase*phase*(-1/36.0 + phase*phase*(1/120.0)));
        ax0=aw1-aw0; ay0=ax1-ax0; az0=ay1-ay0; sortie=az1-az0;
        //compensation of the attenuation of the quad differentiator
        //this can be calculated at "control rate" and linearly
        //interpolated at sample rate.
        compensation=1.0/(dphase*dphase*dphase*dphase);
    }
    fclose(f);
}
```

(continues on next page)
40  // compensation and output
41  aout=(short)(15000.0*compensation*sortie);
42  fwrite(&aout,1,2,f);
43  //old memories of differentiators
44  aw1=aw0; ax1=ax0; ay1=ay0; az1=az0;
45  }
46  fclose(f);

1.33.1 Comments

- **Date**: 2006-03-14 09:02:47
- **By**: rf.liamtoh@57eninreS_luaP


- **Date**: 2006-05-05 17:09:03
- **By**: moc.asile@nobnob

nice but i prefer the fishy algo, it generates less alias.
bonaveture rosignol

1.34 Inverted parabolic envelope

- **Author or source**: James McCartney
- **Type**: envelope generation
- **Created**: 2002-01-17 00:57:43

Listing 59: code

```
dur = duration in samples
midlevel = amplitude at midpoint
beglevel = beginning and ending level (typically zero)
amp = midlevel - beglevel;
rdur = 1.0 / dur;
rdur2 = rdur * rdur;
level = beglevel;
slope = 4.0 * amp * (rdur - rdur2);
curve = -8.0 * amp * rdur2;
...
for (i=0; i<dur; ++i) {
    level += slope;
    slope += curve;
}
```
1.34.1 Comments

- **Date:** 2002-04-11 17:20:10
  - **By:** ti.orebil@erognekark
  
  This parabola approximation seems more like a linear than a parab/expo envelope... or i'm mistaking something but i tried everything and is only linear.

- **Date:** 2002-04-13 23:51:49
  - **By:** moc.liamtoh@r0x0r0xe
  
  slope is linear, but 'slope' is a function of 'curve'. If you imagine you threw a ball upwards, think of 'curve' as the gravity, 'slope' as the vertical velocity, and 'level' as the vertical displacement.

- **Date:** 2005-01-17 07:39:28
  - **By:** asynth(at)io(dot)com
  
  This is not an approximation of a parabola, it IS a parabola. This entry has become corrupted since it was first posted. Should be:
  
  ```
  for (i=0; i<dur; ++i) {
      out = level;
      level += slope;
      slope += curve;
  }
  ```

1.35 Matlab/octave code for minblep table generation

- **Author or source:** ude.drofnats.amrcc@lfd
  
  - **Created:** 2005-11-15 22:27:53

  **Listing 60: notes**
  
  When I tested this code, it was running with each function in a separate file... so it might need some tweaking (endfunction statements?) if you try and run it all as one file.

  Enjoy!

  PS There's a C++ version by Daniel Werner here. http://www.experimentalscene.com/?type=2&id=1
  Not sure if it the output is any different than my version. (eg no thresholding in minphase calculation)

  **Listing 61: code**
  
  ```
  % Octave/Matlab code to generate a minblep table for bandlimited synthesis
  % original minblep technique described by Eli Brandt:
  % http://www.cs.cmu.edu/~eli/L/icmc01/hardsync.html
  % (c) David Lowenfels 2004
  ```

(continues on next page)
%% you may use this code freely to generate your tables,
%% but please send me a free copy of the software that you
%% make with it, or at least send me an email to say hello
%% and put my name in the software credits :) 
%% (IIRC: mps and clipdb functions are from Julius Smith)

%% usage:
%% fc = dilation factor
%% Nzc = number of zero crossings
%% omega = oversampling factor
%% thresh = dB threshold for minimum phase calc

mbtable = minblep( fc, Nzc, omega, thresh );
mblen = length( mbtable );
save -binary mbtable.mat mbtable ktable nzc mblen;

*******************************************************************************
function [out] = minblep( fc, Nzc, omega, thresh )
out = filter( 1, [1 -1], minblip( fc, Nzc, omega, thresh ) );
len = length( out );
normal = mean( out( floor(len*0.7):len ) )
out = out / normal; % normalize

%% now truncate so it ends at proper phase cycle for minimum discontinuity
thresh = 1e-6;
for i = len:-1:len-1000
  % pause
  a = out(i) - thresh - 1;
  b = out(i-1) - thresh - 1;
  if( (abs(a) < thresh) & (a > b) )
    break;
  endif
endfor
out = out(1:i);

******************************************************************************
function [out] = minblip( fc, Nzc, omega, thresh )
if (nargin < 4 )
  thresh = -100;
end
if (nargin < 3 )
  omega = 64;
end
if (nargin < 2 )
  Nzc = 16;
end
if (nargin < 1 )
  fc = 0.9;
end

(continues on next page)
blip = sinctable(omega, Nzc, fc);
% length(blip) must be nextpow2! (if fc < 1);

mag = fft(blip);
out = real(ifft(mps(mag, thresh)));

***********************************************************************/
function [sm] = mps(s, thresh)
% [sm] = mps(s)
% create minimum-phase spectrum sm from complex spectrum s

if nargin < 2
    thresh = -100;
endif

s = clipdb(s, thresh);
sm = exp(fft(fold(ifft(log(s)))));

***********************************************************************/
function [clipped] = clipdb(s, cutoff)
% [clipped] = clipdb(s, cutoff)
% Clip magnitude of s at its maximum + cutoff in dB.
% Example: clip(s,-100) makes sure the minimum magnitude
% of s is not more than 100dB below its maximum magnitude.
% If s is zero, nothing is done.

as = abs(s);
mas = max(as(:));
if mas==0, return; end
if cutoff >= 0, return; end
thresh = mas*10^(cutoff/20); % db to linear
toomall = find(as < thresh);
clipped = s;
clipped(toomall) = thresh;

***********************************************************************
function [out, phase] = sinctable(omega, Nzc, fc)

if nargin < 3
    fc = 1.0 %% cutoff frequency
endif
if nargin < 2
    Nzc = 16 %% number of zero crossings
endif
if nargin < 1
    omega = 64 %% oversampling factor
endif

Nzc = Nzc / fc %% This ensures more flatness at the ends.

phase = linspace(-Nzc, Nzc, Nzc*omega*2);

% sinc = sin(pi * fc * phase) ./ (pi * fc * phase);
num = sin(pi*fc*phase);
den = pi*fc*phase;
len = length( phase );
sinc = zeros( len, 1 );
%sinc = num ./ den;
for i=1:len
    if ( den(i) ~= 0 )
        sinc(i) = num(i) / den(i);
    else
        sinc(i) = 1;
    end
end
out = sinc;
window = blackman( len );
out = out .* window;

1.36 PADsynth synthesys method

- Author or source: moc.oohay@xfbusddanyz
- Type: wavetable generation

Listing 62: notes

Please see the full description of the algorithm with public domain c++ code here:
http://zynaddsubfx.sourceforge.net/doc/PADsynth/PADsynth.htm

Listing 63: code

It's here:
http://zynaddsubfx.sourceforge.net/doc/PADsynth/PADsynth.htm
You may copy it (everything is public domain).
Paul

1.36.1 Comments

- Date: 2005-11-23 15:49:26
  - By: moc.yddaht@yddaht
  Impressed at first hearing! Well documented.

- Date: 2005-11-25 08:18:58
  - By: moc.yticliam@qe.n
  1. Isn't this plain additive synthesis
  2. Isn't this the algorithm used by the waldorf microwave synths?
1. Nope. This is not a plain additive synthesis. It's a special kind :-P Read the doc → again :)  
2. No way.. this is NOT even close to waldord microwave synths. Google for this :)

1.37 PRNG for non-uniformly distributed values from trigonometric identity

- **Author or source:** moc.liamg@321tiloen  
- **Type:** pseudo-random number generator  
- **Created:** 2009-09-02 07:16:14

Listing 64: notes

```plaintext
a method, which generates random numbers in the [-1, +1] range, while having a  
probability density function with less concentration of values near zero for sin().  
you can use an approximation of sin() and/or experiment with such an equation for  
different distributions. using tan() will accordingly invert the pdf graph i.e. more  
concentration near zero, but the output range will be also affected.  
extended read on similar methods:  
http://www.stat.wisc.edu/~larget/math496/random2.html  
regards  
lubomir
```

Listing 65: code

```plaintext
1 //init  
2 x=y=1;  
3  
4 //sampleloop  
5 y=sin((x+=1)*y);  
```

1.38 Parabolic shaper

- **Author or source:** rf.eerf@aipotreza  
- **Created:** 2008-03-13 10:41:18

Listing 66: notes

```plaintext
This function can be used for oscillators or shaper.  
it can be driven by a phase accumulator or an audio input.
```
Function Parashape(inp: single): single;
var fgh, tgh: single;
begin
  fgh := inp;
  fgh := 0.25 - f_abs(fgh);
  tgh := fgh;
  tgh := 1 - 2 * f_abs(tgh);
  fgh := fgh * 8;
  result := fgh * tgh;
end;

// f_abs is the function of ddsputils unit.

1.39 Phase modulation Vs. Frequency modulation

- **Author or source:** Bram
- **Created:** 2002-08-05 15:31:25
- **Linked files:** SimpleOscillator.h

The difference between FM & PM in a digital oscillator is that FM is added to the
frequency before the phase integration, while PM is added to the phase after the phase
integration. Phase integration is when the old phase for the oscillator is added to
the current frequency (in radians per sample) to get the new phase for the oscillator. The
equivalent PM modulator to obtain the same waveform as FM is the integral of the FM
modulator. Since the integral of sine waves are inverted cosine waves this is no
problem.

In modulators with multiple partials, the equivalent PM modulator will have different
relative partial amplitudes. For example, the integral of a square wave is a triangle
wave; they have the same harmonic content, but the relative partial amplitudes are
different. These differences make no difference since we are not trying to exactly
recreate FM, but real (or nonreal) instruments.

The reason PM is better is because in PM and FM there can be non-zero energy produced
at 0
Hz, which in FM will produce a shift in pitch if the FM wave is used again as a
modulator, however in PM the DC component will only produce a phase shift. Another reason PM is better is that the modulation index (which determines the number of sidebands produced and which in normal FM is calculated as the modulator amplitude divided by frequency of modulator) is not dependant on the frequency of the modulator, it is always equal to the amplitude of the modulator in radians. The benefit of solving the DC frequency shift problem, is that cascaded carrier-modulator pairs and feedback modulation are possible. The simpler calculation of modulation index makes it easier to have voices keep the same harmonic structure throughout all pitches.

The basic mathematics of phase modulation are available in any text on electronic communication theory.

Below is some C code for a digital oscillator that implements FM, PM, and AM. It illustrates the difference in implementation of FM & PM. It is only meant as an example, and not as an efficient implementation.

```c
/* Example implementation of digital oscillator with FM, PM, & AM */

#define PI 3.14159265358979
#define RADIANS_TO_INDEX (512.0 / (2.0 * PI))

typedef struct
{ /* oscillator data */
  double freq; /* oscillator frequency in radians per sample */
  double phase; /* accumulated oscillator phase in radians */
  double wavetable[512]; /* waveform lookup table */
} OscilRec;

/* oscil - compute 1 sample of oscillator output whose freq, phase and wavetable are in the OscilRec structure pointed to by orec. */

double oscil(orec, fm, pm, am)
{
  OscilRec *orec; /* pointer to the oscil's data */
  double fm; /* frequency modulation input in radians per sample */
  double pm; /* phase modulation input in radians */
  double am; /* amplitude modulation input in any units you want */

  long tableindex; /* index into wavetable */
  double instantaneous_freq; /* oscillator freq + freq modulation */
  double instantaneous_phase; /* oscillator phase + phase modulation */
  double output; /* oscillator output */

  instantaneous_freq = orec->freq + fm; /* get instantaneous freq */
  orec->phase += instantaneous_freq; /* accumulate phase */
  instantaneous_phase = orec->phase + pm; /* get instantaneous phase */
```

(continues on next page)
/* convert to lookup table index */
#define RADIUS_TO_INDEX instant_phase;
tableindex &= 511; /* make it mod 512 === eliminate multiples of 2\pi */
output = orec->wavetable[tableindex] * am; /* lookup and mult by am input */
return (output); /* return oscillator output */

1.40.1 Comments

- **Date**: 2011-03-08 11:29:32
- **By**: ed.redienhcsslin@mapsvulipsdcisum

As the PM/FM is "iterative", won't this code produce different results at different sampling rates? How can this be prevented?

Any advice is highly appreciated!

1.41 Pseudo-Random generator

- **Author or source**: Hal Chamberlain, “Musical Applications of Microprocessors” (Phil Burk)
- **Type**: Linear Congruential, 32bit
- **Created**: 2002-01-17 03:11:50

Listing 71: notes

This can be used to generate random numeric sequences or to synthesise a white noise audio signal. If you only use some of the bits, use the most significant bits by shifting right. Do not just mask off the low bits.

Listing 72: code

/* Calculate pseudo-random 32 bit number based on linear congruential method. */
unsigned long GenerateRandomNumber(void)
{
    /* Change this for different random sequences. */
    static unsigned long randSeed = 22222;
    randSeed = (randSeed * 196314165) + 907633515;
    return randSeed;
}

1.42 PulseQuad

- **Author or source**: moc.ellehcim-erdna@ma
- **Type**: Waveform
This is written in Actionscript 3.0 (Flash9). You can listen to the example at
http://lab.andre-michelle.com/playing-with-pulse-harmonics
It allows to morph between a sinus like quadratic function and an ordinary pulse width
with adjustable pulse width. Note that the slope while morphing is always zero at the
→ edge
points of the waveform. It is not just distortion.

1.43 Pulsewidth modulation

• Author or source: Steffan Diedrichsen
• Type: waveform generation
• Created: 2002-01-15 21:29:52

Take an upramping sawtooth and its inverse, a downramping sawtooth. Adding these two
→ waves
with a well defined delay between 0 and period (1/f)
results in a square wave with a duty cycle ranging from 0 to 100%.

1.44 Quick & Dirty Sine

• Author or source: MisterToast
• Type: Sine Wave Synthesis
• Created: 2007-01-08 10:50:10

This is proof of concept only (but code works--I have it in my synth now).

Note that x must come in as 0<x<=4096. If you want to scale it to something else (like
0<x<=2*M_PI), do it in the call. Or do the math to scale the constants properly.

There's not much noise in here. A few little peaks here and there. When the signal is
→ at
-20dB, the worst noise is at around -90dB.

For speed, you can go all floats without much difference. You can get rid of that
→ unitary
negate pretty easily, as well. A couple other tricks can speed it up further--I went
→ for
clarity in the code.
The result comes out a bit shy of the range -1<x<1. That is, the peak is something like 0.999.

Where did this come from? I'm experimenting with getting rid of my waveform tables, which require huge amounts of memory. Once I had the Hamming anti-ringing code in, it looked like all my waveforms were smooth enough to approximate with curves. So I started with sine. Pulled my table data into Excel and then threw the data into a curve-fitting application.

This would be fine for a synth. The noise is low enough that you could easily get away with it. Ideal for a low-memory situation. My final code will be a bit harder to understand, as I'll break the curve up and curve-fit smaller sections.

```
1.44.1 Comments

• Date: 2007-01-08 18:39:26
• By: moc.dniftnacuoyerehwemos@tsaot

Improved version:
float xSin(double x)
{
    //x is scaled 0<=x<4096
    const double A=-0.40319426317E-08;
    const double B=217.68468676;
    const double C=0.00002871632164;
    const double D=-0.0030591066066;
    const double E=-7.3316892871734489e-005;
    double y;

    bool negate=false;
    if (x>2048)
    {
        negate=true;
        x-=2048;
    }
    if (x>1024)
        x=2048-x;
    if (negate)
        y=-(A+x)/(B+C*x*x)+D*x-E);
    else
        y=(A+x)/(B+C*x*x)+D*x-E;
    return (float)y;
}
```

1.44. Quick & Dirty Sine
const double B=0.21683205691E+03;
const double C=0.28463350538E-04;
const double D=-0.30774648337E-02;
double y;

bool negate=false;
if (x>2048)
{
    negate=true;
    x-=2048;
}
if (x>1024)
    x=2048-x;
y=(A+x)/(B+C*x*x)+D*x;
if (negate)
    return (float)(-y);
else
    return (float)y;

• Date: 2007-04-15 23:54:56
• By: ten.zo@1otniped

%This is Matlab code. you can convert it to C
%All it take to make a high quality sine
%wave is 1 multiply and one subtract.
%You first have to initialize the 2 unit delays
%and the coefficient

Fs = 48000; %Sample rate
oscfreq = 1000.0; %Oscillator frequency in Hz
c1 = 2 * cos(2 * pi * oscfreq / Fs);
%Initialize the unit delays
d1 = sin(2 * pi * oscfreq / Fs);
d2 = 0;
%Initialization done here is the oscillator loop
% which generates a sinewave
for j=1:100
    output = d1; %This is the sine value
    fprintf(1, '%f
', output);
    %one multiply and one subtract is all it takes
    d0 = d1 * c1 - d2;
    d2 = d1; %Shift the unit delays
    d1 = d0;
end

• Date: 2008-02-09 20:54:10
• By: moc.liamg@iratuusal.osuuj

Hi,

Can I use this code in a GPL2 or GPL3 licensed program (a soft synth project called Snarl)? In other words, will you grant permission for me to re-license your code?
And what name should I write down as copyright holder in the headers?
• Date: 2009-06-23 03:12:13
• By: by moc.dniftnacuoyerehwemos@tsaot

Juuso,
Absolutely!
Toast

1.45 Quick and dirty sine generator

• Author or source: moc.liamtoh@tsvreiruoc
• Type: sine generator
• Created: 2004-01-06 19:57:44

Listing 78: notes
this is part of my library, although I've seen a lot of sine generators, I've never seen the simplest one, so I try to do it, tell me something, I've try it and work so tell me something about it

Listing 79: code
PSPsample PSPsin1::doOsc(int numCh)
{
    double x=0;
    double t=0;
    if (m_time[numCh]>m_sampleRate) //re-init cycle
        m_time[numCh]=0;
    if (m_time[numCh]>0)
    {
        t=(double)((double)m_time[numCh])/(double)m_sampleRate;
        x=(m_2PI *(double)(t)*m_freq);
    }
    else
        x=0;
    PSPsample r=(PSPsample) sin(x+m_phase)*m_amp;
    m_time[numCh]++;
    return r;
}
1.45.1 Comments

- Date: 2004-01-08 13:51:26
- By: moc.sulp.52retsinnab@etep

isn't the sin() function a little bit heavyweight? Since this is based upon slices of time, would it not be much more processor efficient to use a state variable filter that is self oscillating?

The operation:
\[
t = \frac{(double)(((double)m_time[numCh])/(double)m_sampleRate)}{ }
\]
also seems a little bit much, since t could be calculated by adding an interval value, which would eliminate the divide (needs more clocks). The divide would then only need to be done once.
An FDIV may take 39 clock cycles minimum (depending on the operands), whilst an FADD is far faster (3 clocks). An FMUL is comparable to an add, which would be a predominant instruction if using the SVF method.
FSIN may take between 16-126 clock cycles.
(cycle cycle info nabbed from: http://www.singlix.com/trdos/pentium.txt)

- Date: 2004-01-09 21:19:37
- By: moc.hclumoidua@bssor

See also the fun with sinusoids page:
http://www.audiomulch.com/~rossb/code/sinusoids/

- Date: 2014-11-18 07:37:27
- By: moc.oohay@trawets.tna

For audio generation, sines are expensive i think, they are so perfect and take up more processing. it's rare to find a synth that sounds nicer with a sine compared to a parabol wave. My favourite parabolic wave is simply triangle wave with x*x with one of the half periods flipped. x*x is a very fast!!!

- Date: 2014-12-06 12:06:58
- By: ed.xmg@retsneum.ellak

hmm... x*x second half flipped...
very cool! i'll give it a try!!

1.46 RBJ Wavetable 101

- Author or source: Robert Bristow-Johnson
1.47 Randja compressor

- **Author or source:** randja
- **Type:** compressor
- **Created:** 2009-09-29 07:37:05

I had found this code on the internet then made some improvements (speed) and now I post it here for others to see.

```cpp
#include <cmath>
define max(a,b) (a>b?a:b)

class compressor
{

private:
    float threshold;
    float attack, release, envelope_decay;
    float output;
    float transfer_A, transfer_B;
    float env, gain;

public:
    compressor()
    {
        threshold = 1.f;
        attack = release = envelope_decay = 0.f;
        output = 1.f;

        transfer_A = 0.f;
        transfer_B = 1.f;

        env = 0.f;
        gain = 1.f;
    }

    void set_threshold(float value)
    {
        threshold = value;
        transfer_B = output * pow(threshold, -transfer_A);
    }
}
```

(continues on next page)
```
void set_ratio(float value)
{
    transfer_A = value-1.f;
    transfer_B = output * pow(threshold,-transfer_A);
}

void set_attack(float value)
{
    attack = exp(-1.f/value);
}

void set_release(float value)
{
    release = exp(-1.f/value);
    envelope_decay = exp(-4.f/value); /* = exp(-1/(0.25*value)) */
}

void set_output(float value)
{
    output = value;
    transfer_B = output * pow(threshold,-transfer_A);
}

void reset()
{
    env = 0.f; gain = 1.f;
}

__forceinline void process(float *input_left, float *input_right, float *output_left, float *output_right, int frames)
{
    float det, transfer_gain;
    for(int i=0; i<frames; i++)
    {
        det = max(fabs(input_left[i]),fabs(input_right[i]));
        det += 10e-30f; /* add tiny DC offset (~600dB) to prevent denormals */
        env = det >= env ? det : det+envelope_decay*(env-det);
        transfer_gain = env > threshold ? pow(env,transfer_A)*transfer_B : output;
        gain = transfer_gain < gain ? transfer_gain+attack *(gain-transfer_gain) : transfer_gain+release*(gain-transfer_gain);
        output_left[i] = input_left[i] * gain;
    }
```

__forceinline void process(double *input_left, double *input_right, double *output_left, double *output_right, int frames)
{
    double det, transfer_gain;
    for(int i=0; i<frames; i++)
    {
        det = max(fabs(input_left[i]),fabs(input_right[i]));
        det += 10e-30f; /* add tiny DC offset (-600dB) to prevent denormals */
        env = det >= env ? det : det+envelope_decay*(env-det);
        transfer_gain = env > threshold ? pow(env,transfer_A)*transfer_B:
                          output;
        gain = transfer_gain < gain ? transfer_gain+attack *(gain-
                                      transfer_gain):
                              transfer_gain+release*(gain-
                                      transfer_gain);
        output_left[i] = input_left[i] * gain;
        output_right[i] = input_right[i] * gain;
    }
};

1.47.1 Comments

• Date: 2010-08-30 21:04:37
• By: moc.oohay@xofrgomsnart

I have found it is good to add either a timed peak hold-before-release or something like a "peak magnetism" with an attack/release time that is within a cycle of the lowest expected frequency in the side chain...often ~80Hz is a good reference point. For example here is a snippet to illustrate the idea...please keep in mind this will not work as show because of some obvious things needing to be added...

```c
class compressor {
    float patk; //"seek" slope
    float ipatk;
    float peakdet;
    float target;
    float envelope; //the final value used for gain control
    int hold; //time to hold peak
    int holdcnt;
};
```

(continues on next page)
float compressor::envelope_tracker(float input)
{
    float rect = fabs(input);
    holdcnt++;
    if(rect>peakdet) {
        peakdet = rect;
        if(holdcnt>hold) //the hold is really optional
            { //for the seek function this is really nothing more than a feedback control system,
                target = rect;
                holdcnt = 0;
            }
    }
    peakdet*=ipatk; //sort of like capacitor+diode discharge.
    if(envelope<target) envelope+=patk;
    else envelope -= patk; //sort of like a heat seeking missile ;)
    //the linear interpolation is good to use because
    ///it is simple while the main attack & release
    //functions filter off the corners.
    ///In either case it is an improvement to a leaky
    //peak detector.
}

Another thing I saw in the form of an analog circuit was a "round robin" peak
detector which had 4 peak detectors being reset by a JFET to ground and was clocked
by simple binary counter IC. The full cycle from 0 to 15 on the binary counter was
set at about 80Hz, then the JFET gates were reset every /4 of that period. That
way the envelope tracker pretty much grabbed every peak during the 1/80 period.
then the "release" time was 1/80th second. This could be implemented digitally.

• Date: 2012-12-14 15:24:30
  • By: moc.liamg@etteresemv

Hi randja,

I am trying to use your compressor.
Could you explain in what unity shall be given the values of threshold, ratio,
release, attack and output ?
Have you a good set of values for these parameters to make it work ?

Thanks in advance

• Date: 2013-07-17 21:22:21
  • By: moc.elpmaxe@ylper-on
To quote the original code that randja "found" on the Internet and then "made some __-improvements" (he only added __forceinline):

"How to use it:
--------------
free_comp.cpp and free_comp.hpp implement a simple C++ class called free_comp. (People are expected to know what to do with it! If not seek help on a beginner programming forum!)
The free_comp class implements the following methods:

void set_threshold(float value);
Sets the threshold level; 'value' must be a _positive_ value representing the amplitude as a floating point figure which should be 1.0 at 0dBFS

void set_ratio(float value);
Sets the ratio; 'value' must be in range [0.0; 1.0] with 0.0 representing a oo:1 ratio, 0.5 a 2:1 ratio; 1.0 a 1:1 ratio and so on

void set_attack(float value);
Sets the attack time; 'value' gives the attack time in _samples_

void set_release(float value);
Sets the release time; 'value' gives the release time in _samples_

void set_output(float value);
Sets the output gain; 'value' represents the gain, where 0dBFS is 1.0 (see set_threshold())

void reset();
Resets the internal state of the compressor (gain reduction)

void process(float *input_left, float *input_right,
            float *output_left, float *output_right,
            int frames, int skip);
void process(double *input_left, double *input_right,
            double *output_left, double *output_right,
            int frames, int skip);
Processes a stereo stream of length 'frames' from either two arrays of floats or arrays of doubles 'input_left' and 'input_right' then puts the processed data in 'output_left' and 'output_right'.
'input_{left,right}' and 'output_{left,right}' may be the same location in which case the algorithm will work in place. '{input,output}_left' and '{input,output}_right' can also point to the same data, in which case the algorithm works in mono (although if you process a lot of mono data it will yield more performance if you modify the source to make the algorithm mono in the first place).
The 'skip' parameter allows for processing of interleaved as well as two separate contiguous streams. For two separate streams this value should be 1, for interleaved stereo it should be 2 (but it can also have other values than that to process specific channels in an interleaved audio stream, though if you do that it is highly recommended to study the source first to check whether it yields the expected behaviour or not).
" - Source: http://outsim.co.uk/forum/download/file.php?id=7296

1.47. Randja compressor
1.48 Rossler and Lorenz Oscillators

- **Author or source:** moc.noicratse@ajelak
- **Type:** Chaotic LFO
- **Created:** 2004-10-10 00:13:58

### Listing 83: notes

The Rossler and Lorenz functions are iterated chaotic systems - they trace smooth curves that never repeat the same way twice. Lorenz is "unpitched", having no distinct peaks in its spectrum - similar to pink noise. Rossler exhibits definite spectral peaks against a noisy broadband background.

Time-domain and frequency spectrum of these two functions, as well as other info, can be found at:

http://www.physics.emory.edu/~weeks/research/tseries1.html

These functions might be useful in simulating "analog drift."

### Listing 84: code

```
1 Available on the web at:
2 http://www.tinygod.com/code/BLorenzOsc.zip
```

1.48.1 Comments

- **Date:** 2005-01-10 09:11:12
- **By:** moc.yddaht@yddaht

A Delphi/pascal version for VCL, KOL, Kylix and Freepascal on my website:
http://members.chello.nl/t.koning8/loro_sc.pas

Nice work!

1.49 SawSin

- **Author or source:** Alexander Kritov
- **Type:** Oscillator shape
- **Created:** 2002-02-10 12:40:59

### Listing 85: code

```
1 double sawsin(double x)
2 {
(continues on next page)
```
double t = fmod(x/(2*M_PI), (double)1.0);
if (t>0.5)
  return -sin(x);
if (t<=0.5)
  return (double)2.0*t-1.0;

1.50 Simple Time Stretching-Granular Synthesizer

- **Author or source:** Harry-Chris
- **Created:** 2008-12-18 07:08:20

---

**Listing 86: notes**

Matlab function that implements crude time stretching - granulizing function, by overlap add in time domain.

---

**Listing 87: code**

```matlab
function y = gran_func(x, w, H,H2, Fs, tr_amount)

% x -> input signal
% w -> Envelope - Window Vector
% H1 -> Original Hop Size
% H2 -> Synthesis Hop Size
% Fs -> Sample Rate
% str_amount -> time stretching factor

M = length(w);

pin = 1;
pend = length(x) - M;

y = zeros(1, floor(str_amount * length(x)) +M);

count = 1;
idx = 1;

while pin < pend
  input = x(pin : pin+M-1) .* w';
  y(idx : idx + M - 1) = y(idx : idx + M - 1) + input;
  pin = pin + H;
  count = count + 1;
  idx = idx + H2;
```

(continues on next page)
1.51 Sine calculation

• **Author or source:** Phil Burk

• **Type:** waveform generation, Taylor approximation of \( \sin() \)

• **Created:** 2002-01-17 00:57:01

---

**Listing 88: notes**

Code from JSyn for a sine wave generator based on a Taylor Expansion. It is not as efficient as the filter methods, but it has linear frequency control and is, therefore, suitable for FM or other time varying applications where accurate frequency is needed. The sine generated is accurate to at least 16 bits.

---

**Listing 89: code**

```c
for(i=0; i < nSamples ; i++)
{
    //Generate sawtooth phasor to provide phase for sine generation
    IncrementWrapPhase(phase, freqPtr[i]);
    //Wrap phase back into region where results are more accurate

    if(phase > 0.5)
        yp = 1.0 - phase;
    else
    {
        if(phase < -0.5)
            yp = -1.0 - phase;
        else
            yp = phase;
    }

    x = yp * PI;
    x2 = x*x;

    //Taylor expansion out to x**9/9! factored into multiply-adds
    fastsin = x*(x2*(x2*(x2*(x2*(1.0/362880.0)
                    - (1.0/5040.0))
                    + (1.0/120.0))
                    - (1.0/6.0))
                    + 1.0);

    outPtr[i] = fastsin * amplPtr[i];
}
```
1.52 Smooth random LFO Generator

- Author or source: Rob Belcham
- Created: 2009-06-30 08:31:24

Listing 90: notes

I've been after a random LFO that's suitable for modulating a delay line for ages (e.g. for chorus / reverb modulation), so after I rolled my own, I thought I'd better make it my first contribution to the music-dsp community.

My aim was to achieve a sinusoidal based random but smooth waveform with a frequency control that has no discontinuities and stays within a -1:1 range. If you listen to it, it sounds quite like brown noise, or wind through a microphone (at rate = 100Hz for example)

It's written as a matlab m function, so shouldn't be too hard to port to C.

The oscillator generates a random level stepped waveform with random time spent at each step (within bounds). These levels are linearly interpolated between and used to drive the frequency of a sinewave. To achieve amplitude variation, at each zero crossing a new random amplitude scale factor is generated. The amplitude coefficient is ramped to this value with a simple exponential.

An example call would be,

t = 4; Fs = 44100;
y = random_lfo(100, t*Fs, Fs);
axis([0, t*Fs, -1, 1]);
plot(y)

Enjoy!

Listing 91: code

```matlab
% Random LFO Generator
% creates a random sinusoidal waveform with no discontinuities
% rate = average rate in Hz
% N = run length in samples
% Fs = sample frequency in Hz
function y = random_lfo(rate, N, Fs)

step_freq_scale = Fs / (1*rate);
min_Cn = 0.1 * step_freq_scale;

An = 0;
lastA = 0;
Astep = 0;
y = zeros(1,N); % output
x = 0; % sine phase
lastSign = 0;
amp_scale = 0.6;
```

(continues on next page)
new_amp_scale = 0.6;
amp_scale_ramp = exp(1000/Fs)-1;
for (n=1:N)
    if (An == 0) || (An>=Cn)
        % generate a new random freq scale factor
        Cn = floor(step_freq_scale * rand());
        % limit to prevent rapid transitions
        Cn = max(Cn, min_Cn);
        % generate new value & step coefficient
        newA = 0.1 + 0.9*rand();
        Astep = (newA - lastA) / Cn;
        A = lastA;
        lastA = newA;
    % reset counter
    An = 0;
end
An = An + 1;
% generate output
y(n) = sin(x) * amp_scale;
% ramp amplitude
amp_scale = amp_scale + ( new_amp_scale - amp_scale ) * amp_scale_ramp;
sin_inc = 2*pi*rate*A/Fs;
A = A + Astep;
% increment phase
x = x + sin_inc;
if (x >= 2*pi)
    x = x - 2*pi;
end
% scale at each zero crossing
if (sign(y(n)) ~= 0) && (sign(y(n)) ~= lastSign)
    lastSign = sign(y(n));
    new_amp_scale = 0.25 + 0.75*rand();
end
end;

1.53 Square Waves

- Author or source: Sean Costello
- Type: waveform generation
- Created: 2002-01-15 21:26:38

Listing 92: notes

One way to do a square wave:

You need two buzz generators (see Dodge & Jerse, or the Csound source code, for implementation details). One of the buzz generators runs at the desired square wave frequency, while the second buzz generator is exactly one octave above this pitch. Subtract the higher octave buzz generator’s output from the lower buzz generator’s output - the result should be a signal with all odd harmonics, all at equal amplitude. Filter the resultant signal (maybe integrate it). Voila, a bandlimited square wave! Well, I think it...
should work...

The one question I have with the above technique is whether it produces a waveform that truly resembles a square wave in the time domain. Even if the number of harmonics, and the relative ratio of the harmonics, is identical to an "ideal" bandwidth-limited square wave, it may have an entirely different waveshape. No big deal, unless the signal is processed by a nonlinearity, in which case the results of the nonlinear processing will be far different than the processing of a waveform that has a similar shape to a square wave.

1.53.1 Comments

- **Date:** 2003-04-01 01:28:28
- **By:** dfl@stanford.edu

Actually, I don't think this would work... The proper way to do it is subtract a phase-shifted buzz (aka BLIT) at the same frequency. This is equivalent to comb filtering, which will notch out the even harmonics.

- **Date:** 2008-11-08 16:24:18
- **By:** moc.psdallahlav@naes

The above comment is correct, and my concept is inaccurate. My technique may have produced a signal with the proper harmonic structure, but it has been nearly 10 years since I wrote the post, so I can't remember what I was working with.

DFL's technique can be implemented with two buzz generators, or with a single buzz generator in conjunction with a fractional delay, where the delay controls the amount of phase shift.

1.54 Trammell Pink Noise (C++ class)

- **Author or source:** ude.drofnats.amrcc@lfd
- **Type:** pink noise generator
- **Created:** 2006-05-06 08:40:38

Listing 93: code

```c++
#ifndef _PinkNoise_H
#define _PinkNoise_H

// Technique by Larry "RidgeRat" Trammell 3/2006
// http://home.earthlink.net/~ltrammell/tech/pinkalg.htm
// implementation and optimization by David Lowenfels

#include <cstdlib>
```
```cpp
#include <ctime>

#define PINK_NOISE_NUM_STAGES 3

class PinkNoise {
    public:
        PinkNoise()
            : srand( time(NULL) ) // initialize random generator
            , clear()
        {
        }
        void clear()
            for( size_t i=0; i<PINK_NOISE_NUM_STAGES; i++ )
            state[ i ] = 0.0;
        }
        float tick()
            static const float RMI2 = 2.0 / float( RAND_MAX ); // + 1.0; // change for range [0, 1)
            // unrolled loop
            float temp = float( rand() );
            state[0] = P[0] * (state[0] - temp) + temp;
            temp = float( rand() );
            temp = float( rand() );
    }
    protected:
        float state[ PINK_NOISE_NUM_STAGES ];
        static const float A[ PINK_NOISE_NUM_STAGES ];
        static const float P[ PINK_NOISE_NUM_STAGES ];
};

const float PinkNoise::A[] = { 0.02109238, 0.07113478, 0.68873558 }; // rescaled by (1+P)/(1-P)
const float PinkNoise::P[] = { 0.3190, 0.7756, 0.9613 };
#endif

1.54.1 Comments

• Date: 2007-02-09 06:15:59
• By: ten.knilhtrae@6741emmartl

Many thanks to David Lowenfels for posting this implementation of the early experimental version. I recommend switching to the new algorithm form described in 'newpink.htm' -- better range to 9+ octaves, better accuracy to +-0.25 dB, and leveled computational loading. So where is MY submission to the archive? Um... well, it's coming... if he doesn't beat me to the punch again and post his code first! -- Larry Trammell (the RidgeRat)
1.55 Waveform generator using MinBLEPS

- **Author or source:** ku.oc.nomedi.gafpren@ekcol
- **Created:** 2002-08-05 18:44:50
- **Linked files:** MinBLEPS.zip

### Listing 94: notes

C code and project file for MSVC6 for a bandwidth-limited saw/square (with PWM) generator using MinBLEPS.

This code is based on Eli's MATLAB MinBLEP code and uses his original minblep.mat file. Instead of keeping a list of all active MinBLEPS, the output of each MinBLEP is stored in a buffer, in which all consequent MinBLEPS and the waveform output are added together. This optimization makes it fast enough to be used realtime.

Produces slight aliasing when sweeping high frequencies. I don't know whether Eli's original code does the same, because I don't have MATLAB. Any help would be appreciated.

The project name is 'hardsync', because it's easy to generate hardsync using MinBLEPS.

### Listing 95: code

1.55.1 Comments

- **Date:** 2004-07-02 22:31:36
- **By:** moc.oiduaesionetiehw@ofni

http://www.slack.net/~ant/bl-synth/windowed-impulse/

This page also describes a similar algorithm for generating waves. Could the aliasing be due to the fact that the blep only occurs after the discontinuity? On this page, the blep also occurs in the opposite direction as well, leading up to the discontinuity.

- **Date:** 2008-02-11 18:42:15
- **By:** kernel[@]audiospillage.com

The sawtooth is a nice oscillator but I can't seem to get the square wave to work properly. Anyone else had any luck with this? Also, it's worth noting that the code assumes it is running on a little endian architecture.

- **Date:** 2009-07-07 04:45:40
- **By:** moc.enecslatnemirepxe@leinad
I have written GPLv3 C++ source code for a MinBLEP oscillator and also public domain C++ source code for generating the MinBLEP without MatLab.

http://www.experimentalscene.com/source.php - Look in DarkWave / latest version / CoreMachines / VCO.cpp

1.56 Wavetable Synthesis

- **Author or source:** Robert Bristow-Johnson
- **Created:** 2002-05-07 18:46:18

Listing 96: notes

Wavetable synthesis AES paper by RBJ.

1.57 Weird synthesis

- **Author or source:** Andy M00cho
- **Created:** 2002-01-17 00:55:09

Listing 97: notes

(quoted from Andy’s mail...)  
What I've done in a soft-synth I've been working on is used what I've termed Fooglers, no reason, just liked the name :) Anyway all I've done is use a *VERY* short delay line of 256 samples and then use 2 controllable taps into the delay with High Frequency Damping, and a feedback parameter.

Using a tiny fixed delay size of approx. 4.8ms (really 256 samples/1k memory with floats) means this costs, in terms of cpu consumption practically nothing, and the filter is a real simple 1 pole low-pass filter. Maybe not DSP'litically correct but all I wanted was to avoid the high frequencies trashing the delay line when high feedbacks (99%->99.9%) are used (when the fun starts ;).  

I've been getting some really sexy sounds out of this idea, and of course you can have the delay line tuneable if you choose to use fractional taps, but I'm happy with it as it is.  

1 nice simple, yet powerful addition to the base oscillators.
In reality you don't need 2 taps, but I found that using 2 added that extra element of funkiness...

1.57.1 Comments

- **Date**: 2002-07-18 18:57:00
- **By**: moc.loa@attongamlihp

Andy:
I'm curious about your delay line. It's length is 4.8 m.sec.fixed. What are the variables in the two controllable taps and is the 6dB→filter variable frequency wise?

Phil

- **Date**: 2003-01-03 20:01:34
- **By**: moc.oohay@poportcele

What you have there is the core of a physical modelling algorithm. I have done virtually the same thing to model plucked string instruments in Reaktor. It's amazingly realistic. See http://joeorgren.com
2.1 Beat Detector Class

- **Author or source:** rf.eerf@etsaMPSD
- **Created:** 2005-05-12 14:35:52

Listing 1: notes

This class was designed for a VST plugin. Basically, it's just a 2nd order LP filter, followed by an envelope detector (thanks Bram), feeding a Schmitt trigger. The rising edge detector provides a 1-sample pulse each time a beat is detected. Code is self documented...

Note: The class uses a fixed comparison level, you may need to change it.

Listing 2: code

```cpp
// ***** BEATDETECTOR.H *****
#ifndef BeatDetectorH
#define BeatDetectorH

class TBeatDetector
{

private:
    float KBeatFilter;   // Filter coefficient
    float Filter1Out, Filter2Out;
    float BeatRelease;   // Release time coefficient
    float PeakEnv;       // Peak envelope follower
    bool BeatTrigger;    // Schmitt trigger output
    bool PrevBeatPulse;  // Rising edge memory

public:
    bool BeatPulse;      // Beat detector output

    TBeatDetector();
};
```

(continues on next page)
```cpp
tBeatDetector();
virtual void setSampleRate(float SampleRate);
virtual void AudioProcess (float input);
};
#endif

// ***** BEATDETECTOR.CPP *****
#include "BeatDetector.h"
#include "math.h"

#define FREQ_LP_BEAT 150.0f // Low Pass filter frequency
#define T_FILTER 1.0f/(2.0f*M_PI*FREQ_LP_BEAT) // Low Pass filter time constant
#define BEAT_RTIME 0.02f // Release time of enveloppe detector in second

TBeatDetector::TBeatDetector()
// Beat detector constructor
{
    Filter1Out=0.0;
    Filter2Out=0.0;
    PeakEnv=0.0;
    BeatTrigger=false;
    PrevBeatPulse=false;
    setSampleRate(44100);
}

TBeatDetector::~TBeatDetector()
{
    // Nothing specific to do...
}

void TBeatDetector::setSampleRate (float sampleRate)
// Compute all sample frequency related coeffs
{
    KBeatFilter=1.0/(sampleRate*T_FILTER);
    BeatRelease=(float)exp(-1.0f/(sampleRate*BEAT_RTIME));
}

void TBeatDetector::AudioProcess (float input)
// Process incoming signal
{
    float EnvIn;
    // Step 1 : 2nd order low pass filter (made of two 1st order RC filter)
    Filter1Out=Filter1Out+(KBeatFilter*(input-Filter1Out));
    Filter2Out=Filter2Out+(KBeatFilter*(Filter1Out-Filter2Out));
    // Step 2 : peak detector
    EnvIn=fabs(Filter2Out);
    if (EnvIn>PeakEnv) PeakEnv=EnvIn; // Attack time = 0
    else
    {
        PeakEnv*=BeatRelease;
        PeakEnv+=(1.0f-BeatRelease)*EnvIn;
    }
    // Step 3 : Schmitt trigger
```
\begin{verbatim}
    if (!BeatTrigger)
        
        if (PeakEnv>0.3) BeatTrigger=true;
    
    else
        
        if (PeakEnv<0.15) BeatTrigger=false;
    
    // Step 4 : rising edge detector
    BeatPulse=false;
    if ((BeatTrigger)&&(PrevBeatPulse))
        BeatPulse=true;
    PrevBeatPulse=BeatTrigger;
\end{verbatim}

\subsection{2.1.1 Comments}

- **Date**: 2005-05-18 22:59:08
- **By**: moc.yddaht@yddaht

\begin{verbatim}
    // Nice work!
    // Here's a Delphi and freepascal version:
    unit beattrigger;

    interface

    type
        TBeatDetector = class
            private
                KBeatFilter,      // Filter coefficient
                Filter1Out,      // Filter1 output
                Filter2Out,      // Filter2 output
                BeatRelease,     // Release time coefficient
                PeakEnv: single; // Peak enveloppe follower
                BeatTrigger,     // Schmitt trigger output
                PrevBeatPulse: Boolean; // Rising edge memory
            public
                BeatPulse: Boolean; // Beat detector output
            constructor Create;
            procedure setSampleRate(SampleRate: single);
            procedure AudioProcess (input: single);
            end;

            function fabs(value: single): Single;

    implementation

    const
        FREQ_LP_BEAT = 150.0; // Low Pass filter frequency
        T_FILTER = 1.0/(2.0 * PI*FREQ_LP_BEAT); // Low Pass filter time constant
        BEAT_RTIME = 0.02; // Release time of enveloppe detector in second
\end{verbatim}
constructor TBeatDetector.create;

// Beat detector constructor

begin
  inherited;
  Filter1Out:=0.0;
  Filter2Out:=0.0;
  PeakEnv:=0.0;
  BeatTrigger:=false;
  PrevBeatPulse:=false;
  setSampleRate(44100);
end;

procedure TBeatDetector.setSampleRate (sampleRate:single);

// Compute all sample frequency related coeffs

begin
  KBeatFilter:=1.0/(sampleRate*T_FILTER);
  BeatRelease:=exp(-1.0/(sampleRate*BEAT_RTIME));
end;

function fabs(value:single):Single;

asm
  fld value
  fabs
  fwait
end;

procedure TBeatDetector.AudioProcess (input:single);

var
  EnvIn:Single;

// Process incoming signal

begin
  // Step 1 : 2nd order low pass filter (made of two 1st order RC filter)
  Filter1Out:=Filter1Out+(KBeatFilter*(input-Filter1Out));
  Filter2Out:=Filter2Out+(KBeatFilter*(Filter1Out-Filter2Out));

  // Step 2 : peak detector
  EnvIn:=fabs(Filter2Out);

  if EnvIn>PeakEnv then PeakEnv:=EnvIn  // Attack time = 0
  else
    begin
      PeakEnv:=PeakEnv*BeatRelease;
      PeakEnv:=PeakEnv+(1.0-BeatRelease)*EnvIn;
    end;

  // Step 3 : Schmitt trigger
  if not BeatTrigger then
    begin
      if PeakEnv>0.3 then BeatTrigger:=true;
      end
  else
    begin
      if PeakEnv<0.15 then BeatTrigger:=false;
    end;

  // Step 4 : rising edge detector
  BeatPulse:=false;
  if (BeatTrigger = true) and not PrevBeatPulse then
    BeatPulse:=true;
2.2 Coefficients for Daubechies wavelets 1-38

- **Author or source:** Computed by Kazuo Hatano, Compiled and verified by Olli Niemitalo
- **Type:** wavelet transform
- **Created:** 2002-01-17 02:00:43
- **Linked files:** daub.h.

2.3 DFT

- **Author or source:** Andy Mucho
- **Type:** fourier transform
- **Created:** 2002-01-17 01:59:38

Listing 3: code

```c
AnalyseWaveform(float *waveform, int framesize)
{
    float aa[MaxPartials];
    float bb[MaxPartials];
    for(int i=0;i<partials;i++)
    {
        aa[i]=0;
        bb[i]=0;
    }
    int hfs=framesize/2;
    float pd=pi/hfs;
    for (i=0;i<framesize;i++)
    {
        float w=waveform[i];
        int im = i-hfs;
        for(int h=0;h<partials;h++)
        {
            float th=(pd*(h+1))*im;
            aa[h]+=w*cos(th);
            bb[h]+=w*sin(th);
        }
    }
    for (int h=0;h<partials;h++)
    amp[h]= sqrt(aa[h]*aa[h]+bb[h]*bb[h])/hfs;
}
```
2.4 Envelope detector

- **Author or source:** Bram
- **Created:** 2002-04-12 21:37:18

Listing 4: notes

Basicaly a one-pole LP filter with different coefficients for attack and release fed by the abs() of the signal. If you don't need different attack and decay settings, just use in->abs()->LP

Listing 5: code

```
1 //attack and release in seconds
2 float ga = (float) exp(-1/(SampleRate*attack));
3 float gr = (float) exp(-1/(SampleRate*release));

4 float envelope=0;
5 for(...)
6 {
7     //get your data into 'input'
8     EnvIn = std::abs(input);
9
10     if(envelope < EnvIn)
11     {
12         envelope *= ga;
13         envelope += (1-ga)*EnvIn;
14     }
15
16     else
17     {
18         envelope *= gr;
19         envelope += (1-gr)*EnvIn;
20     }
21 //envelope now contains.........the envelope ;)
22 }
```

2.4.1 Comments

- **Date:** 2005-05-17 13:58:11
- **By:** moc.liamg@sehtnysorpitna

```
// Slightly faster version of the envelope follower using one multiply form.
// attTime and relTime is in seconds

float ga = exp(-1.0f/(sampleRate*attTime));
float gr = exp(-1.0f/(sampleRate*relTime));

float envOut = 0.0f;
for( ... )
```

(continues on next page)
// get your data into 'input'
envIn = fabs(input);

if ( envOut < envIn )
    envOut = envIn + ga * (envOut - envIn);
else
    envOut = envIn + gr * (envOut - envIn);

// envOut now contains the envelope

2.5 Envelope follower with different attack and release

• Author or source: Bram
• Created: 2003-01-15 00:21:39

Listing 6: notes

xxxx_in_ms is xxxx in milliseconds ;-)
Here the definition of the attack/release time is the time for the envelope to fall from 100% to 1%.

In the other version, the definition is for the envelope to fall from 100% to 36.7%.

So in this one the envelope is about 4.6 times faster.

2.6 FFT

- **Author or source:** Toth Laszlo
- **Created:** 2002-02-11 17:43:15
- **Linked files:** rvfft.ps.
- **Linked files:** rvfft.cpp.

Listing 8: notes

A paper (postscript) and some C++ source for 4 different fft algorithms, compiled by Toth Laszlo from the Hungarian Academy of Sciences Research Group on Artificial Intelligence.

Toth says: "I've found that Sorensen's split-radix algorithm was the fastest, so I use this since then (this means that you may as well delete the other routines in my source - if you believe my results)."

2.6.1 Comments

- **Date:** 2011-01-22 20:56:46
- **By:** moc.oohay@ygobatem

Thank you very much, this was useful, and it worked right out of the box, so to speak. It's very efficient, and the algorithm is readable. It also includes some very useful functions.

2.7 FFT classes in C++ and Object Pascal

- **Author or source:** Laurent de Soras (Object Pascal translation by Frederic Vanmol)
- **Type:** Real-to-Complex FFT and Complex-to-Real IFFT
- **Created:** 2002-02-14 02:09:26
- **Linked files:** FFTReal.zip.
2.8 Fast in-place Walsh-Hadamard Transform

- **Author or source:** Timo H Tossavainen
- **Type:** wavelet transform
- **Created:** 2002-01-17 01:54:52

IIRC, They’re also called walsh-hadamard transforms. Basically like Fourier, but the basis functions are squarewaves with different sequences.
I did this for a transform data compression study a while back. Here’s some code to do a walsh hadamard transform on long ints in-place (you need to divide by n to get transform) the order is bit-reversed at output, IIRC.
The inverse transform is the same as the forward transform (expects bit-reversed input).
i.e. x = 1/n * FWHT(FWHT(x)) (x is a vector)

```c
void inline wht_bfly (long& a, long& b)
{
    long tmp = a;
    a += b;
    b = tmp - b;
}

// just a integer log2
int inline l2 (long x)
{
    int l2;
    for (l2 = 0; x > 0; x >>=1)
    {
        ++ l2;
    }
    return (l2);
}

void FWHT (std::vector<>& data)
{
    const int log2 = l2 (data.size()) - 1;
    for (int i = 0; i < log2; ++i)
    {
        for (int j = 0; j < (1 << log2); j += 1 << (i+1))
        {
            (continues on next page)
        }
    }
}
```
2.9 Frequency response from biquad coefficients

- **Author or source:** moc.feercinos@retep
- **Type:** biquad
- **Created:** 2004-11-29 09:49:47

Listing 12: notes

Here is a formula for plotting the frequency response of a biquad filter. Depending on the coefficients that you have, you might have to use negative values for the b-coefficients.

Listing 13: code

```c
//w = frequency (0 < w < PI)
//square(x) = x*x

y = 20*log((sqrt(square(a0*square(cos(w))-
    a0*square(sin(w))+a1*cos(w)+a2)+square(2*a0*cos(w)*sin(w)+a1*(sin(w))))/
sqrt(square(square(cos(w))-
    square(sin(w))+b1*cos(w)+b2)+square(2* cos(w)*sin(w)+b1*(sin(w))))));
```

2.9.1 Comments

- **Date:** 2006-03-16 19:36:32
- **By:** ude.drofnats.amrcc@lfd

This formula can have roundoff errors with frequencies close to zero... (especially a problem with high samplerate filters)

Here is a better formula:

from RBJ @ http://groups.google.com/group/comp.dsp/browse_frm/thread/8c0fa8d396aeb444/a1bc5b63ac56b686

20*log10(|H(e^jw)|) = 
10*log10[ (b0+b1+b2)^2 - 4*(b0*b1 + 4*b0*b2 + b1*b2)*phi + 16*b0*b2*phi^2 ]
-10*log10[ (a0+a1+a2)^2 - 4*(a0*a1 + 4*a0*a2 + a1*a2)*phi + 16*a0*a2*phi^2 ]
where \( \phi = \sin^2(w/2) \)

### 2.10 Java FFT

- **Author or source:** Loreno Heer
- **Type:** FFT Analysis
- **Created:** 2003-11-25 17:38:15

Listing 14: notes

May not work correctly ;-)  

Listing 15: code

```java
// WTest.java

/*
 * Copyright (C) 2003 Loreno Heer, (helohe at bluewin dot ch)
 *
 * This program is free software; you can redistribute it and/or modify
 * it under the terms of the GNU General Public License as published by
 * the Free Software Foundation; either version 2 of the License, or
 * (at your option) any later version.
 *
 * This program is distributed in the hope that it will be useful,
 * but WITHOUT ANY WARRANTY; without even the implied warranty of
 * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the
 * GNU General Public License for more details.
 *
 * You should have received a copy of the GNU General Public License
 * along with this program; if not, write to the Free Software
 * Foundation, Inc., 59 Temple Place, Suite 330, Boston, MA 02111-1307 USA
 */

public class WTest{

    private static double[] sin(double step, int size){
        double f = 0;
        double[] ret = new double[size];
        for(int i = 0; i < size; i++){
            ret[i] = Math.sin(f);
            f += step;
        }
        return ret;
    }

    private static double[] add(double[] a, double[] b){
        double[] c = new double[a.length];
        for(int i = 0; i < a.length; i++){
            c[i] = a[i] + b[i];
        }
        return c;
    }

}(continues on next page)
Musicdsp.org Documentation

(continued from previous page)

}

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private static double[] sub(double[] a, double[] b){
double[] c = new double[a.length];
for(int i = 0; i < a.length; i++){
c[i] = a[i] - b[i];
}
return c;
}

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private static double[] add(double[] a, double b){
double[] c = new double[a.length];
for(int i = 0; i < a.length; i++){
c[i] = a[i] + b;
}
return c;
}

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private static double[] cp(double[] a, int size){
double[] c = new double[size];
for(int i = 0; i < size; i++){
c[i] = a[i];
}
return c;
}

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private static double[] mul(double[] a, double b){
double[] c = new double[a.length];
for(int i = 0; i < a.length; i++){
c[i] = a[i] * b;
}
return c;
}

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private static void print(double[] value){
for(int i = 0; i < value.length; i++){
System.out.print(i + "," + value[i] + "\n");
}
System.out.println();
}

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private static double abs(double[] a){
double c = 0;
for(int i = 0; i < a.length; i++){
c = ((c * i) + Math.abs(a[i])) / (i + 1);
}
return c;
}

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private static double[] fft(double[] a, int min, int max, int step){
double[] ret = new double[(max - min) / step];
int i = 0;
for(int d = min; d < max; d = d + step){
double[] f = sin(fc(d), a.length);
double[] dif = sub(a, f);
ret[i] = 1 - abs(dif);
i++;

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Chapter 2. Analysis


2.11 LPC analysis (autocorrelation + Levinson-Durbin recursion)

- **Author or source:** ten.enegatum@liam
- **Created:** 2004-04-07 09:37:51
The autocorrelation function implements a warped autocorrelation, so that frequency resolution can be specified by the variable 'lambda'. Levinson-Durbin recursion calculates autoregression coefficients a and reflection coefficients (for lattice filter implementation) K. Comments for Levinson-Durbin function implement matlab version of the same function.

No optimizations.

Listing 17: code

```c
//find the order-P autocorrelation array, R, for the sequence x of length L and warping of lambda
//wAutocorrelate(spfSrc[stIndex], siglen, R, P, 0);
wAutocorrelate(float * x, unsigned int L, float * R, unsigned int P, float lambda) {
    double * dl = new double [L];
    double * Rt = new double [L];
    double r1, r2, rlt;
    R[0]=0;
    Rt[0]=0;
    r1=0;
    r2=0;
    rlt=0;
    for(unsigned int k=0; k<L;k++)
        Rt[0]=double(x[k])*double(x[k]);
        dl[k]=r1-double(lambda)*double(x[k]-r2);
        r1 = x[k];
        r2 = dl[k];
    for(unsigned int i=1; i<=P; i++)
        Rt[i]=0;
        r1=0;
        r2=0;
        for(unsigned int k=0; k<L;k++)
            Rt[i]=double(dl[k])*double(x[k]);
            rlt = dl[k];
            dl[k]=r1-double(lambda)*double(rlt-r2);
            r1 = rlt;
            r2 = dl[k];
    for(i=0; i<=P; i++)
        R[i]=float(Rt[i]);
    delete[] dl;
    delete[] Rt;
}
```
LevinsonRecursion(unsigned int P, float *R, float *A, float *K)
{
    double Am1[62];
    if(R[0]==0.0) {
        for(unsigned int i=1; i<=P; i++)
            { K[i]=0.0; A[i]=0.0; }
    }
    else {
        double km,Em1,Em;
        unsigned int k,s,m;
        for (k=0;k<=P;k++){
            A[0]=0;
            Am1[0]=0;
        }
        A[0]=1;
        Am1[0]=1;
        km=0;
        Em1=R[0];
        for (m=1;m<=P;m++) //m=2:N+1
        {
            double err=0.0f; //err = 0;
            for (k=1;k<=m-1;k++) //for k=2:m-1
                err += Am1[k]*R[m-k]; // err = err + am1(k)*R(m-
                                     \-k+1); 
            km = (R[m]-err)/Em1; //km=(R(m)-err)/Em1;
            K[m-1] = -float(km);
            A[m]=(float)km; //
            am(m)=km;
            for (k=1;k<=m-1;k++) //for k=2:m-1
                A[k]=float(Am1[k]-km*Am1[m-k]); // am(k)=am1(k)-km*am1(m-
                                              \-k+1);
            Em=(1-km*km)*Em1; //Em=(1-
                               \-km*km) *Em1;
            for(s=0;s<=P;s++) //for s=1:N+1
                Am1[s] = A[s]; // am1(s) = am(s)
            Em1 = Em; //Em1 =
        }
        return 0;
    }
}

2.11. LPC analysis (autocorrelation + Levinson-Durbin recursion)

2.11.1 Comments

• Date: 2005-03-31 15:16:20
• By: ed.luosfosruoivas@naitsirhC

// Blind Object Pascal Translation:
// --------------------------------
unit Levinson;
interface

type
  TDoubleArray = array of Double;
  TSingleArray = array of Single;

implementation

// find the P-order autocorrelation array, R, for the sequence x of length L and
// warping of lambda
procedure Autocorrelate(x, R : TSingleArray; P : Integer; lambda : Single; l : Integer;
  l = -1);
var
dl, Rt : TDoubleArray;
r1, r2, rlt : Double;
k, i : Integer;
begin
  // Initialization
  if l=-1 then l:=Length(x);
  SetLength(dl,l);
  SetLength(Rt,l);
  R[0]:=0;
  Rt[0]:=0;
  r1:=0;
  r2:=0;
  rlt:=0;

  for k:=0 to l-1 do
    begin
      Rt[0]:=Rt[0]+x[k]*x[k];
      dl[k]:=r1-lambda*(x[k]-r2);
      r1:= x[k];
      r2:= dl[k];
    end;

  for i:=1 to P do
    begin
      Rt[i]:=0;
      r1:=0;
      r2:=0;
      for k:=0 to L-1 do
        begin
          Rt[i]:=Rt[i]+dl[k]*x[k];
          rlt:= dl[k];
          dl[k]:=r1-lambda*(rlt-r2);
          r1:=rlt;
          r2:=dl[k];
        end;
    end;

  for i:=1 to P do R[i]:=Rt[i];
  setlength(Rt,0);
  setlength(dl,0);
end;

// Calculate the Levinson-Durbin recursion for the autocorrelation sequence
// R of length P+1 and return the autocorrelation coefficients a and reflection
// coefficients K
procedure LevinsonRecursion(P : Integer; R,A,K : TSingleArray);
var Am1 : TDoubleArray;
i,j,s,m : Integer;
km,Em1,Em : Double;
err : Double;
begin
  SetLength(Am1,62);
  if (R[0]=0.0) then
    begin
      for i:=1 to P do
        begin
          K[i]:=0.0;
          A[i]:=0.0;
        end;
    end
  else
    begin
      for j:=0 to P do
        begin
          A[0]:=0;
          Am1[0]:=0;
        end;
      A[0]:=1;
      Am1[0]:=1;
      km:=0;
      Em1:=R[0];
      for m:=1 to P do
        begin
          err:=0.0;
          for j:=1 to m-1 do err:=err+Am1[j]*R[m-j];
          km:=(R[m]-err)/Em1;
          K[m-1]:=-km;
          A[m]:=km;
          for j:=1 to m-1 do A[j]:=Am1[j]-km*Am1[m-j];
          Em:=(1-km*km)*Em1;
          for s:=0 to P do Am1[s]:=A[s];
          Em1:=Em;
        end;
    end;
end.

2.12 Look ahead limiting

- **Author or source:** Wilfried Welti
- **Created:** 2002-01-17 03:08:11

Listing 18: notes

use add_value with all values which enter the look-ahead area, and remove_value with all value which leave this area. to get the maximum value in the look-ahead area, use get_max_value.
in the very beginning initialize the table with zeroes.

If you always want to know the maximum amplitude in your look-ahead area, the thing becomes a sorting problem. Very primitive approach using a look-up table

Listing 19: code

```c
void lookup_add(unsigned section, unsigned size, unsigned value)
{
    if (section==value)
        lookup[section]++;
    else
    {
        size >>= 1;
        if (value>section)
        {
            lookup[section]++;
            lookup_add(section+size,size,value);
        }
        else
        {
            lookup_add(section-size,size,value);
        }
}

void lookup_remove(unsigned section, unsigned size, unsigned value)
{
    if (section==value)
        lookup[section]--;
    else
    {
        size >>= 1;
        if (value>section)
        {
            lookup[section]--;
            lookup_remove(section+size,size,value);
        }
        else
        {
            lookup_remove(section-size,size,value);
        }
    }

unsigned lookup_getmax(unsigned section, unsigned size)
{
    unsigned max = lookup[section] ? section : 0;
    size >>= 1;
    if (size)
    {
        if (max)
        {
            max = lookup_getmax((section+size),size);
            if (!max) max=section;
        }
        else
        {
            max = lookup_getmax((section-size),size);
        }
    return max;
}
```

(continues on next page)
void add_value(unsigned value)
{
  lookup_add(LOOKUP_VALUES>>1, LOOKUP_VALUES>>1, value);
}

void remove_value(unsigned value)
{
  lookup_remove(LOOKUP_VALUES>>1, LOOKUP_VALUES>>1, value);
}

unsigned get_max_value()
{
  return lookup_getmax(LOOKUP_VALUES>>1, LOOKUP_VALUES>>1);
}

2.13 Magnitude and phase plot of arbitrary IIR function, up to 5th order

• Author or source: George Yohng
• Type: magnitude and phase at any frequency
• Created: 2002-08-01 00:43:57

Listing 20: notes

Amplitude and phase calculation of IIR equation
run at sample rate "sampleRate" at frequency "F".

AMPLITUDE
----------
cf_mag(F,sampleRate,
a0,a1,a2,a3,a4,a5,
b0,b1,b2,b3,b4,b5)
----------

PHASE
----------
cf_phi(F,sampleRate,
a0,a1,a2,a3,a4,a5,
b0,b1,b2,b3,b4,b5)
----------

If you need a frequency diagram, draw a plot for
F=0...sampleRate/2

If you need amplitude in dB, use cf_lin2db(cf_mag(.......))

Set b0=-1 if you have such function:
y[n] = a0*x[n] + a1*x[n-1] + a2*x[n-2] + a3*x[n-3] + a4*x[n-4] + a5*x[n-5] +
     + b1*y[n-1] + b2*y[n-2] + b3*y[n-3] + b4*y[n-4] + b5*y[n-5];
Set \( b_0=1 \) if you have such function:

\[
y[n] = a_0\cdot x[n] + a_1\cdot x[n-1] + a_2\cdot x[n-2] + a_3\cdot x[n-3] + a_4\cdot x[n-4] + a_5\cdot x[n-5] + b_1\cdot y[n-1] - b_2\cdot y[n-2] - b_3\cdot y[n-3] - b_4\cdot y[n-4] - b_5\cdot y[n-5];
\]

Do not try to reverse engineer these formulae - they don't give any sense other than they are derived from transfer function, and they work. :)

---

Listing 21: code

```c
/*
 C file can be downloaded from
 http://www.yohng.com/dsp/cfsmp.c
*/

#define C_PI 3.14159265358979323846264

double cf_mag(double f, double rate,
               double a0, double a1, double a2, double a3, double a4, double a5,
               double b0, double b1, double b2, double b3, double b4, double b5)
{
    return sqrt((a0*a0 + a1*a1 + a2*a2 + a3*a3 + a4*a4 + a5*a5 +
                   2*(a0*a1 + a1*a2 + a2*a3 + a3*a4 + a4*a5)*cos((2*f*C_PI)/rate) +
                   2*(a0*a2 + a1*a3 + a2*a4 + a3*a5)*cos((4*f*C_PI)/rate) +
                   2*a0*a3*cos((6*f*C_PI)/rate) + 2*a1*a4*cos((6*f*C_PI)/rate) +
                   2*a2*a5*cos((8*f*C_PI)/rate) + 2*a0*a4*cos((10*f*C_PI)/rate))/
                   (b0*b0 + b1*b1 + b2*b2 + b3*b3 + b4*b4 + b5*b5 +
                    2*(b0*b1 + b1*b2 + b2*b3 + b3*b4 + b4*b5)*cos((2*f*C_PI)/rate) +
                    2*(b0*b2 + b1*b3 + b2*b4 + b3*b5)*cos((4*f*C_PI)/rate) +
                    2*b0*b3*cos((6*f*C_PI)/rate) + 2*b1*b4*cos((6*f*C_PI)/rate) +
                    2*b2*b5*cos((8*f*C_PI)/rate) + 2*b0*b4*cos((8*f*C_PI)/rate) +
                    2*b1*b5*cos((10*f*C_PI)/rate))/
                   (b0*b0 + b1*b1 + b2*b2 + b3*b3 + b4*b4 + b5*b5 +
                    2*(b0*b1 + b1*b2 + b2*b3 + b3*b4 + b4*b5)*cos((2*f*C_PI)/rate) +
                    2*(b0*b2 + b1*b3 + b2*b4 + b3*b5)*cos((4*f*C_PI)/rate) +
                    2*b0*b3*cos((6*f*C_PI)/rate) + 2*b1*b4*cos((6*f*C_PI)/rate) +
                    2*b2*b5*cos((8*f*C_PI)/rate) + 2*b0*b4*cos((8*f*C_PI)/rate) +
                    2*b1*b5*cos((10*f*C_PI)/rate)));
}

double cf_phi(double f, double rate,
              double a0, double a1, double a2, double a3, double a4, double a5,
              double b0, double b1, double b2, double b3, double b4, double b5)
{
    return atan2((a0*a0 + a1*a1 + a2*a2 + a3*a3 + a4*a4 + a5*a5 +
                   2*(a0*a1 + a1*a2 + a2*a3 + a3*a4 + a4*a5)*cos((2*f*C_PI)/rate) +
                   2*(a0*a2 + a1*a3 + a2*a4 + a3*a5)*cos((4*f*C_PI)/rate) +
                   2*a0*a3*cos((6*f*C_PI)/rate) + 2*a1*a4*cos((6*f*C_PI)/rate) +
                   2*a2*a5*cos((8*f*C_PI)/rate) + 2*a0*a4*cos((10*f*C_PI)/rate))/
                   (b0*b0 + b1*b1 + b2*b2 + b3*b3 + b4*b4 + b5*b5 +
                    2*(b0*b1 + b1*b2 + b2*b3 + b3*b4 + b4*b5)*cos((2*f*C_PI)/rate) +
                    2*(b0*b2 + b1*b3 + b2*b4 + b3*b5)*cos((4*f*C_PI)/rate) +
                    2*b0*b3*cos((6*f*C_PI)/rate) + 2*b1*b4*cos((6*f*C_PI)/rate) +
                    2*b2*b5*cos((8*f*C_PI)/rate) + 2*b0*b4*cos((8*f*C_PI)/rate) +
                    2*b1*b5*cos((10*f*C_PI)/rate))/
                   (b0*b0 + b1*b1 + b2*b2 + b3*b3 + b4*b4 + b5*b5 +
                    2*(b0*b1 + b1*b2 + b2*b3 + b3*b4 + b4*b5)*cos((2*f*C_PI)/rate) +
                    2*(b0*b2 + b1*b3 + b2*b4 + b3*b5)*cos((4*f*C_PI)/rate) +
                    2*b0*b3*cos((6*f*C_PI)/rate) + 2*b1*b4*cos((6*f*C_PI)/rate) +
                    2*b2*b5*cos((8*f*C_PI)/rate) + 2*b0*b4*cos((8*f*C_PI)/rate) +
                    2*b1*b5*cos((10*f*C_PI)/rate))/
                   (b0*b0 + b1*b1 + b2*b2 + b3*b3 + b4*b4 + b5*b5 +
                    2*(b0*b1 + b1*b2 + b2*b3 + b3*b4 + b4*b5)*cos((2*f*C_PI)/rate) +
                    2*(b0*b2 + b1*b3 + b2*b4 + b3*b5)*cos((4*f*C_PI)/rate) +
                    2*b0*b3*cos((6*f*C_PI)/rate) + 2*b1*b4*cos((6*f*C_PI)/rate) +
                    2*b2*b5*cos((8*f*C_PI)/rate) + 2*b0*b4*cos((8*f*C_PI)/rate) +
                    2*b1*b5*cos((10*f*C_PI)/rate)));
```
\[(b_0b_3 + b_1b_4 + b_2b_5)\cos((6f+\pi)/rate) +
(b_0b_4 + b_1b_5)\cos((8f+\pi)/rate) +
b_0b_5\cos((10f+\pi)/rate)),
\]

\[
(a_1b_0 + a_3b_0 + a_5b_0 - a_0b_1 + a_2b_1 + a_4b_1 - a_1b_2 +
a_3b_2 + a_5b_2 - a_0b_3 - a_2b_3 + a_4b_3 -
a_1b_4 - a_3b_4 + a_5b_4 - a_0b_5 - a_2b_5 - a_4b_5 +
2\cdot(a_3b_1 + a_5b_1 - a_0b_2 + a_4(b_0 + b_2) - a_1b_3 + a_5b_3 +
a_2(b_0 - b_4) - a_0b_4 - a_1b_5 - a_3b_5)\cos((2f+\pi)/rate) +
2\cdot(a_3b_0 + a_4b_1 + a_5(b_0 + b_2) - a_0b_3 - a_1b_4 - a_0b_5 - a_2b_5)\times
\cos((4f+\pi)/rate) + 2\cdot a_4b_0\cos((6f+\pi)/rate) +
2\cdot a_5b_1\cos((6f+\pi)/rate) - 2\cdot a_0b_4\cos((6f+\pi)/rate) -
2\cdot a_1b_5\cos((6f+\pi)/rate) - 2\cdot a_5b_0\cos((8f+\pi)/rate) -
2\cdot a_0b_5\cos((8f+\pi)/rate) - a_0b_3 - a_1b_4 - a_0b_5 - a_2b_5)\times
\cos((6f+\pi)/rate) + 2\cdot a_4b_0\cos((6f+\pi)/rate) +
2\cdot a_5b_1\cos((6f+\pi)/rate) - 2\cdot a_0b_4\cos((6f+\pi)/rate) -
2\cdot a_1b_5\cos((6f+\pi)/rate) - 2\cdot a_5b_0\cos((8f+\pi)/rate) -
2\cdot a_0b_5\cos((8f+\pi)/rate) - a_0b_3 - a_1b_4 - a_0b_5 - a_2b_5)\times
\cos((8f+\pi)/rate) + 2\cdot a_0b_5\cos((10f+\pi)/rate))/
(b_0b_0 + b_1b_1 + b_2b_2 + b_3b_3 + b_4b_4 + b_5b_5 +
2\cdot(b_0b_1 + b_1b_2 + b_2b_3 + b_3b_4 + b_4b_5)\cos((2f+\pi)/rate) +
2\cdot(b_0b_2 + b_1b_3 + b_2b_4 + b_3b_5)\cos((4f+\pi)/rate) +
2\cdot b_0b_3\cos((6f+\pi)/rate) + 2\cdot b_1b_4\cos((6f+\pi)/rate) +
2\cdot b_2b_5\cos((8f+\pi)/rate) + 2\cdot b_0b_4\cos((8f+\pi)/rate) +
2\cdot b_1b_5\cos((8f+\pi)/rate) + 2\cdot b_0b_5\cos((10f+\pi)/rate));
\]

\[
\text{double cf_lin2db(double lin)}
\]
\[
\begin{align*}
\text{if (lin<9e-51) return -1000; } & \text{ /* prevent invalid operation */ } \\
\text{return 20*log10(lin);} & \\
\end{align*}
\]

### 2.13.1 Comments

- **Date:** 2004-01-02 08:46:35  
  **By:** Rob
  
  ```
  % Actually it is simpler to simply take the zero-padded b and a coefficients and do
  % real->complex
  % FFT like this (matlab code):
  
  H_complex=fft(b,N)./fft(a,N);
  phase=angle(H_complex);
  Magn=abs(H_complex);
  
  % This will give you N/2 points from 0 to pi angle freq (or 0 to nyquist freq).
  % /Rob
  ```

- **Date:** 2004-10-01 00:55:09  
  **By:** ed.luosfosruoivas@naitsirhC
  
  ```
  // Here are the formulas if you only have a biquad. But i am not sure, if maybe the
  // phase is shifted with pi/2...
  20*Log10{
  \sqrt{a_0*a_0+a_1+a_1+a_2+a_2+}
  2\cdot(a_0+a_1+a_2)*\cos(w)+
  (continues on next page)
  ```

### 2.13. Magnitude and phase plot of arbitrary IIR function, up to 5th order

119
\[
\frac{2 \times (a_0 \times a_2) \times \cos(2w) \}
\]
\[
/ \)
\[
(1 + b_1 \times b_1 + b_2 \times b_2 +
2 \times (b_1 + b_1 \times b_2) \times \cos(w) +
2 \times b_2 \times \cos(2w)
)
\]
\[
)
\]
\[
\text{ArcTan2}(\}
\[
(\}
\[
(1+b_1 \times b_1 + b_2 \times b_2 +
2 \times
\{
(b_1 + b_1 \times b_2) \times \cos(w) + b_2 \times \cos(2w)
\}
\)
\]
\[
, \}
\[
(\}
\[
(a_0 + a_1 \times b_1 + a_2 \times b_2 +
(a_0 \times b_1 + a_1 \times (1+b_2) + a_2 \times b_1) \times \cos(w) +
(a_0 \times b_2 + a_2) \times \cos(2w)
)
\}
\]
\[
/ \)
\[
(1+b_1 \times b_1 + b_2 \times b_2 +
2 \times
\{
(b_1 + b_1 \times b_2) \times \cos(w) + b_2 \times \cos(2w)
\}
\)
\]
\[
, \}
\[
(\}
\[
(a_1 - a_0 \times b_1 + a_2 \times b_1 - a_1 \times b_2 +
2 \times (-a_0 \times b_2 + a_2) \times \cos(w)
\)
\]
\[
/ \)
\[
(1+b_1 \times b_1 + b_2 \times b_2 +
2 \times (b_1 + b_1 \times b_2) \times \cos(w) +
2 \times b_2 \times \cos(2w)
)
\]
\[
)
\]

- **Date:** 2005-03-28 22:43:17
- **By:** ed.luofosruoivas@naitsirhC

// Recursive Delphi Code with arbitrary order:

```delphi
unit Plot;

interface

type TArrayOfDouble = Array of Double;

function MagnitudeCalc(f, rate : Double; a, b : TArrayOfDouble): Double;

implementation
```

(continues on next page)
uses Math;

function MulVectCalc(const v: TArrayOfDouble; const Z, N : Integer) : Double;
begin
  if N=0 then result:=0
  else result:=(v[N-1]*v[N-1+Z])+MulVectCalc(v,Z,N-1);
end;

function MagCascadeCalc(const v: TArrayOfDouble; const w : double; N, Order : Integer) : Double;
begin
  if N=1 then result:=(MulVectCalc(v,0,Order))
  else result:=((MulVectCalc(v,N-1,1+Order-N)*(2*cos((N-1)*w))+MagCascadeCalc(v, w, N-1, Order )));
end;

function MagnitudeCalc(f,rate : Double; a,b : TArrayOfDouble): Double;
var
  w :
  Double;
begin
  w:=(2*f*pi)/rate;
  result:=sqrt(MagCascadeCalc(a, w, Length(a),Length(a))/MagCascadeCalc(b, w, Length(b),Length(b)));
end.

• Date: 2005-07-27 12:39:52
• By: ed.luosfosruoivas@naitsirhC

function CalcMagPart(w: Double; C : TDoubleArray): Double;
var
  i,j,l :
  Integer;
  temp :
  Double;
begin
  l:=Length(C);
  temp:=0;
  for j:=0 to l-1 do temp:=temp+C[j]*C[j];
  result:=temp;
  for i:=1 to l-1 do
  begin
    temp:=0;
    for j:=0 to l-i-1 do temp:=temp+C[j]*C[j+i];
    result:=Result+2*temp*cos(i*w);
  end;
end;

function CalcMagnitude_dB(const f,rate: Double; const A,B: TDoubleArray): Double;
var
  w :
  Double;
begin
  w:=(2*f*pi)/rate;
  result:=10*log10(CalcMagPart(w,A)/CalcMagPart(w,B));
end.

2.13. Magnitude and phase plot of arbitrary IIR function, up to 5th order
// Here's a really fast function for an arbitrary IIR with high order without stack overflows
// or recursion. And specially for John without sqrt.

2.14 Measuring interpolation noise

- Author or source: Jon Watte
- Created: 2002-01-17 02:00:09

Listing 22: notes

You can easily estimate the error by evaluating the actual function and evaluating your interpolator at each of the mid-points between your samples. The absolute difference between these values, over the absolute value of the "correct" value, is your relative error. \( \log_{10} \) of your relative error times 20 is an estimate of your quantization noise in dB. Example:

You have a table for every 0.5 "index units". The value at index unit 72.0 is 0.995 and the value at index unit 72.5 is 0.999. The interpolated value at index 72.25 is 0.997. Suppose the actual function value at that point was 0.998; you would have an error of 0.001 which is a relative error of 0.001002004. \( \log_{10}(\text{error}) \) is about -2.99913, which times 20 is about -59.98. Thus, that's your quantization noise at that position in the table. Repeat for each pair of samples in the table.

Note: I said "quantization noise" not "aliasing noise". The aliasing noise will, as far as I know, only happen when you start up-sampling without band-limiting and get frequency aliasing (wrap-around), and thus is mostly independent of what specific interpolation mechanism you're using.

2.15 QFT and DQFT (double precision) classes

- Author or source: Joshua Scholar
- Created: 2003-05-17 16:17:35
- Linked files: qft.tar_1.gz.

Listing 23: notes

Since it's a Visual C++ project (though it has relatively portable C++) I guess the main audience are PC users. As such I'm including a zip file. Some PC users wouldn't know what to do with a tgz file.

The QFT and DQFT (double precision) classes supply the following functions:

1. Real valued FFT and inverse FFT functions. Note that separate arrays are used for real and imaginary component of the resulting spectrum.

2. Decomposition of a spectrum into a separate spectrum of the even samples and a spectrum of the odd samples. This can be useful for building filter banks.
3. Reconstituting a spectrum from separate spectrums of the even samples and odd samples. This can be useful for building filter banks.

4. A discrete Sin transform (a QFT decomposes an FFT into a DST and DCT).

5. A discrete Cos transfrom.

6. Since a QFT does it's last stage calculating from the outside in the last part can be left unpacked and only calculated as needed in the case where the entire spectrum isn't needed (I used this for calculating correlations and convolutions where I only needed half of the results).
   ReverseNoUnpack()
   UnpackStep()
   and NegUnpackStep()
   implement this functionality

NOTE Reverse() normalizes its results (divides by one half the blocklength), but ReverseNoUnpack() does not.

7. Also if you only want the first half of the results you can call ReverseHalf()

NOTE Reverse() normalizes its results (divides by one half the blocklength), but ReverseHalf() does not.

8. QFT is less numerically stable than regular FFTs. With singleprecision, a block length of 2^15 brings the accuracy down to being barely accurate enough. At that size, single precision calculations tested sound files would occasionally have a sample off by 2, and a couple off by 1 per block. Full volume white noise would generate a few samples off by as much as 6 per block at the end, beginning and middle.

No matter what the inputs the errors are always at the same positions in the block. There some sort of cancelation that gets more delicate as the block size gets bigger.

For the sake of doing convolutions and the like where the forward transform is done only once for one of the inputs, I created a AccurateForward() function. It uses a regular FFT algorithm for blocks larger than 2^12, and decomposes into even and odd FFTs recursively.

In any case you can always use the double precision routines to get more accuracy. DQFT even has routines that take floats as inputs and return double precision spectrum outputs.

As for portability:

1. The files qft.cpp and dqft.cpp start with defines:
   #define _USE_ASM

If you comment those define out, then what's left is C++ with no assembly language.

2. There is unnecessary windows specific code in "criticalSection.h"
   I used a critical section because objects are not reentrant (each object has
permanent scratch pad memory), but obviously critical sections are operating
system specific. In any case that code can easily be taken out.

If you look at my code and see that there's an a test built in the examples
that makes sure that the results are in the ballpark of being right. It
wasn't that I expected the answers to be far off, it was that I uncommenting
the "no assembly language" versions of some routines and I wanted to make
sure that they weren't broken.

2.16 Simple peak follower

- **Author or source:** Phil Burk
- **Type:** amplitude analysis
- **Created:** 2002-01-17 01:57:19

Listing 24: notes

This simple peak follower will give track the peaks of a signal. It will rise rapidly
when the input is rising, and then decay exponentially when the input drops. It can be
used to drive VU meters, or used in an automatic gain control circuit.

Listing 25: code

```c
// halfLife = time in seconds for output to decay to half value after an impulse

static float output = 0.0;

float scalar = pow( 0.5, 1.0/(halfLife * sampleRate));

if( input < 0.0 )
    input = -input; /* Absolute value. */

if ( input >= output )
    /* When we hit a peak, ride the peak to the top. */
    output = input;
else
    /* Exponential decay of output when signal is low. */
    output = output * scalar;
    /*
    ** When current gets close to 0.0, set current to 0.0 to prevent FP underflow
    ** which can cause a severe performance degradation due to a flood
    ** of interrupts.
    */
    if( output < VERY_SMALL_FLOAT ) output = 0.0;
```
2.16.1 Comments

- Date: 2013-01-26 09:48:15
- By: moc.liamg@osoromaerfac

```c
#ifndef VERY_SMALL_FLOAT
#define VERY_SMALL_FLOAT 1.0e-30F
#endif
```

2.17 Tone detection with Goertzel

- Author or source: on.biu.ii@rnepse
- Type: Goertzel
- Created: 2004-04-07 09:37:10
- Linked files: http://www.ii.uib.no/~espenr/tonedetect.zip

Listing 26: notes

Goertzel is basically DFT of parts of a spectrum not the total spectrum as you normally do with FFT. So if you just want to check out the power for some frequencies this could be better. Is good for DTFM detection I've heard.

The WNk isn't calculated 100% correctly, but it seems to work so ;) Yeah and the code is C++ so you might have to do some small adjustment to compile it as C.

Listing 27: code

```c
/** Tone detect by Goertzel algorithm
 * 
 * This program basically searches for tones (sines) in a sample and reports the different dB it finds for different frequencies. Can easily be extended with some thresholding to report true/false on detection.
 * I'm far from certain goertzel it implemented 100% correct, but it works :)
 * 
 * Hint, the SAMPLERATE, BUFFERSIZE, FREQUENCY, NOISE and SIGNALVOLUME all affects the outcome of the reported dB. Tweak em to find the settings best for your application. Also, seems to be pretty sensitive to noise (whitenoise anyway) which is a bit sad. Also I don't know if the goertzel really likes float values for the frequency ... And using 44100 as samplerate for detecting 6000 Hz tone is kinda silly I know :)
 * 
 * Written by: Espen Riskedal, espenr@ii.uib.no, july-2002
 */

#include <iostream>
#include <cmath>
#include <cstdlib>
```

(continues on next page)
using std::rand;
// math stuff
using std::cos;
using std::abs;
using std::exp;
using std::log10;
// iostream stuff
using std::cout;
using std::endl;

#define PI 3.14159265358979323844
// change the defines if you want to
#define SAMPLERATE 44100
#define BUFFERSIZE 8820
#define FREQUENCY 6000
#define NOISE 0.05
#define SIGNALVOLUME 0.8

/** The Goertzel algorithm computes the k-th DFT coefficient of the input signal
   using a second-order filter.
   * Basically it just does a DFT of the frequency we want to check, and none of the
   * others (FFT calculates for all frequencies).
   */
float goertzel(float *x, int N, float frequency, int samplerate) {
    float Skn, Skn1, Skn2;
    Skn = Skn1 = Skn2 = 0;
    for (int i=0; i<N; i++) {
        Skn2 = Skn1;
        Skn1 = Skn;
        Skn = 2*cos(2*PI*frequency/samplerate)*Skn1 - Skn2 + x[i];
    }
    float WNk = exp(-2*PI*frequency/samplerate); // this one ignores complex stuff
    //float WNk = exp(-2*j*PI*k/N);
    return (Skn - WNk*Skn1);
}

/** Generates a tone of the specified frequency
 * Gotten from: http://groups.google.com/groups?hl=en&lr=&ie=UTF-8&oe=UTF-8&safe=off&
 * selm=3c641e%243jn%40uics1.cs1.cs1.uic.edu
 */
float *makeTone(int samplerate, float frequency, int length, float gain=1.0) {
    //y(n) = 2 * cos(A) * y(n-1) - y(n-2)
    //A= (frequency of interest) * 2 * PI / (sampling frequency)
    //A is in radians.
    // frequency of interest MUST be <= 1/2 the sampling frequency.
    float *tone = new float[length];
    float A = frequency*2*PI/samplerate;
    for (int i=0; i<length; i++) {
        if (i > 1) tone[i] = 2*cos(A)*tone[i-1] - tone[i-2];
        else if (i > 0) tone[i] = 2*cos(A)*tone[i-1] - (cos(A));
        else tone[i] = 2*cos(A)*cos(A) - cos(2*A);
    }
for (int i=0; i<length; i++) tone[i] = tone[i]*gain;

return tone;
}

//** adds whitenoise to a sample */
void *addNoise(float *sample, int length, float gain=1.0) {
    for (int i=0; i<length; i++) sample[i] += (2*(rand()/(float)RAND_MAX)-1)*gain;
}

//** returns the signal power/dB */
float power(float value) {
    return 20*log10(abs(value));
}

int main(int argc, const char* argv) {
    cout << "Samplerate: " << SAMPLERATE << "Hz\n";
    cout << "Buffersize: " << BUFFERSIZE << " samples\n";
    cout << "Correct frequency is: " << FREQUENCY << "Hz\n";
    cout << " - signal volume: " << SIGNALVOLUME*100 << "%\n";
    cout << " - white noise: " << NOISE*100 << "%\n";

    float *tone = makeTone(SAMPLERATE, FREQUENCY, BUFFERSIZE, SIGNALVOLUME);
    addNoise(tone, BUFFERSIZE,NOISE);

    int stepsize = FREQUENCY/5;
    for (int i=0; i<10; i++) {
        int freq = stepsize*i;
        cout << "Trying freq: " << freq << "Hz -> dB: " << power(goertzel(tone, BUFFERSIZE, freq, SAMPLERATE)) << endl;
        delete tone;
    }

    return 0;
}

2.17.1 Comments

- **Date:** 2004-04-12 22:03:56
- **By:** ed.luosfosruoivas@nraitsirhC

// yet untested Delphi translation of the algorithm:

function Goertzel(Buffer:Array of Single; frequency, samplerate: single):single;
var
    Skn, Skn1, Skn2 : Single;
    i : Integer;
    temp1, temp2 : Single;
begin
    skn:=0;
    skn1:=0;
    skn2:=0;
    temp1:=2*PI*frequency/samplerate;

(continues on next page)
\[ temp2 := \cos(temp1); \]
\[
\text{for } i := 0 \text{ to } \text{Length}(Buffer) \text{ do} \\
\text{begin} \\
\text{Skn2} = \text{Skn1}; \\
\text{Skn1} = \text{Skn}; \\
\text{Skn} = 2 \cdot \text{temp2} \cdot \text{Skn1} - \text{Skn2} + \text{Buffer}[i]; \\
\text{end}; \\
\text{Result} := (\text{Skn} - \exp(-\text{temp1}) \cdot \text{Skn1}); \\
\text{end}; \\
// \text{Maybe someone can use it...} \\
// \\
// \text{Christian}

2.18 Tone detection with Goertzel (x86 ASM)

- **Author or source:** ed.luosforsroivas@naitsirhC
- **Type:** Tone detection with Goertzel in x86 assembly
- **Created:** 2004-06-27 22:43:46

Listing 28: notes

This is an "assemblified" version of the Goertzel Tone Detector. It is about 2 times faster than the original code.

The code has been tested and it works fine.

Hope you can use it. I'm gonna try to build a Tuner (as VST-Plugin). I hope, that this will work :-\ If anyone is interested, please let me know.

Christian

Listing 29: code

```asm
function Goertzel_x87(Buffer : Psingle; BLength: Integer; frequency: Single;_samplerate: Single): Single;
asm
mov ecx, BLength
mov eax, Buffer
fld x2
fldpi
fmulp
fld frequency
fld samplerate
fld st(0)
fcos
fld x2
fmulp
fxch st(1)
fldz
fsub st(0), st(1)
fstp st(1)
```
2.18.1 Comments

- **Date:** 2005-08-17 17:20:02
- **By:** moc.yddaht@yddaht

```plaintext
// Here's a variant on the theme that compensates for harmonics:

Function Goertzel(Buffer: array of double; frequency, samplerate: double): double;
var
    Qkn, Qkn1, Qkn2, Wkn, Mk: double;
    i: integer;
begin
    Qkn:=0; Qkn1:=0;
    Wkn:=2*.PI*.frequency/samplerate;
    Mk:=2*.Cos(.Wkn);
    for i:=0 to High(.Buffer) do begin
        {continues on next page}
```
Qkn2: = Qkn1; Qkn1: = Qkn;
Qkn  := Buffer[.i ] + Mk*Qkn1 - Qkn2;
end;
Result: = sqrt(.Qkn*.Qkn + Qkn1*.Qkn1 - Mk*.Qkn*.Qkn1);
end;

// Posted on www.delphimaster.ru by Jeer

### 2.19 Vintage VU meters tutorial

- **Author or source:** moc.liamg@321tiloen
- **Created:** 2009-03-10 15:24:04

Listing 30: notes

Here is a short tutorial about vintage-styled VU meters:

3.1 1 pole LPF for smooth parameter changes

- **Author or source:** moc.liamg@odiugoiz
- **Type:** 1-pole LPF class
- **Created:** 2008-09-22 20:27:06

Listing 1: notes

This is a very simple class that I'm using in my plugins for smoothing parameter changes that directly affect audio stream. It's a 1-pole LPF, very easy on CPU.

Change the value of variable "a" (0-1) for slower or a faster response.

Of course you can also use it as a lowpass filter for audio signals.
class CParamSmooth
{
public:
    CParamSmooth() { a = 0.99f; b = 1.f - a; z = 0; };
    ~CParamSmooth();
    inline float Process(float in) { z = (in * b) + (z * a); return z; }
private:
    float a, b, z;
};

3.1.1 Comments

- Date: 2011-09-30 15:46:04
  - By: moc.oohay@ygobatem
  I've used this a lot, but here's an important thing: it won't work the same for multiple sample rates, so if you set a to 0.9995 for example, this will be lower if the sample rate is higher than you intended. I fix it by doing this:

/*must compensate this factor for sample rate change*/
float srCompensate;
srCompensate = sr/44100.0f;
float compensated_a;
compensated_a = powf(a, (1.0f/srCompensate));
    b = 1.0f-compensated_a;

Then if you start with a built in value (or range) designed for 44100hz, it will scale up with the sample rate so you will get the same amount of smoothing. I'm not sure if this is mathematically correct, but I came up with it very quickly and it works a charm for me.

Good work, very useful and easy to use filter.

- Date: 2011-09-30 15:47:29
  - By: moc.oohay@ygobatem
  *edit, a won't be LOWER if the sample rate changes, but it won't have the same effect.

- Date: 2014-12-16 12:14:59
  - By: moc.liamg@earixela
  New version, now you can specify the speed response of the parameter in ms. and sampling rate:
  
  class CParamSmooth
  {   
public:
    CParamSmooth(float smoothingTimeInMs, float samplingRate)
    {   
        const float c_twoPi = 6.283185307179586476925286766559f;
    }   
};
\[
a = \exp\left(-\frac{c\_twoPi}{\text{smoothingTimeInMs} \times 0.001f \times \text{samplingRate}}\right);
b = 1.0f - a;
z = 0.0f;
\]

~CParamSmooth()
{
}

inline float process(float in)
{
    z = (in * b) + (z * a);
    return z;
}

private:
    float a;
    float b;
    float z;
};

### 3.2 1-RC and C filter

- **Author or source:** ac.nortoediv@niarbdam
- **Type:** Simple 2-pole LP
- **Created:** 2004-11-14 22:42:18

Listing 3: notes

This filter is called 1-RC and C since it uses these two parameters. C and R\(_c\) correspond to raw cutoff and inverted resonance, and have a range from 0 to 1.
Listing 4: code

```c
//Parameter calculation
//cutoff and resonance are from 0 to 127

c = pow(0.5, (128-cutoff) / 16.0);
r = pow(0.5, (resonance+24) / 16.0);

//Loop:
v0 = (1-r*c)*v0 - (c) *v1 + c *input;
v1 = (1-r*c)*v1 + (c) *v0;
output = v1;
```

### 3.2.1 Comments

- **Date:** 2005-01-13 18:25:57
- **By:** yes

> input is not in 0 - 1 range.
> for cutoff i guess 128.
> for reso the same ?

- **Date:** 2006-08-31 14:28:33
- **By:** uh.ete.fni@yfoocs

> Nice. This is very similar to a state variable filter in many ways. Relationship between c and frequency:
> c = 2*sin(pi*freq/samplerate)

> You can approximate this (tuning error towards nyquist):
> c = 2*pi*freq/samplerate

> Relationship between r and q factor:
> r = 1/q

> This filter has stability issues for high r values. State variable filter stability limits seem to work fine here. It can also be oversampled for better stability and wider frequency range (use 0.5*original frequency):

```c```
//Loop:
v0 = (1-r*c)*v0 - c*v1 + c*input;
v1 = (1-r*c)*v1 + c*v0;
tmp = v1;
v0 = (1-r*c)*v0 - c*v1 + c*input;
v1 = (1-r*c)*v1 + c*v0;
```
output = (tmp+v1)*0.5;

-- peter schoffhauzer

3.3 18dB/oct resonant 3 pole LPF with tanh() dist

- **Author or source:** Josep M Comajuncosas
- **Created:** 2002-02-10 13:17:10
- **Linked files:** lpf18.zip.
- **Linked files:** lpf18.sme.

Listing 5: notes

| Implementation in CSound and Sync Modular... |

3.4 1st and 2nd order pink noise filters

- **Author or source:** moc.regimmu@regnimmu
- **Type:** Pink noise
- **Created:** 2004-04-07 09:36:23

Listing 6: notes

| Here are some new lower-order pink noise filter coefficients. |
| These have approximately equiripple error in decibels from 20hz to 20khz at a 44.1khz sampling rate. |

1st order, ~ +/- 3 dB error (not recommended!)
num = [0.05338071119116 -0.03752455712906]
den = [1.00000000000000 -0.97712493947102]

2nd order, ~ +/- 0.9 dB error
num = [ 0.04957526213389 -0.06305581334498 0.01483220320740 ]
den = [ 1.00000000000000 -1.80116083982126 0.80257737639225 ]

3.5 3 Band Equaliser

- **Author or source:** Neil C
- **Created:** 2006-08-29 20:34:25
Simple 3 band equaliser with adjustable low and high frequencies ...

Fairly fast algo, good quality output (seems to be acoustically transparent with all gains set to 1.0)

How to use ...

1. First you need to declare a state for your eq

    EQSTATE eq;

2. Now initialise the state (we'll assume your output frequency is 48Khz)

    set_3band_state(eq,880,5000,480000);

    Your EQ bands are now as follows (approximatley!)

    low band = 0Hz to 880Hz
    mid band = 880Hz to 5000Hz
    high band = 5000Hz to 24000Hz

3. Set the gains to some values ...

    eq.lg = 1.5; // Boost bass by 50%
    eq.mg = 0.75; // Cut mid by 25%
    eq.hg = 1.0; // Leave high band alone

4. You can now EQ some samples

    out_sample = do_3band(eq,in_sample)

Have fun and mail me if any problems ... etanza at lycos dot co dot uk

Neil C / Etanza Systems, 2006 :)

---

First the header file ....

//---

// EQ.H - Header file for 3 band EQ

// (c) Neil C / Etanza Systems / 2K6

// Shouts / Loves / Moans = etanza at lycos dot co dot uk

// This work is hereby placed in the public domain for all purposes, including
// use in commercial applications.

// The author assumes NO RESPONSIBILITY for any problems caused by the use of
// this software.

(continues on next page)
// ifndef __EQ3BAND__
#define __EQ3BAND__

// ------------
//| Structures |
// ------------

typedef struct
{
    // Filter #1 (Low band)
    double  lf;  // Frequency
    double  f1p0;  // Poles ...
    double  f1p1;
    double  f1p2;
    double  f1p3;

    // Filter #2 (High band)
    double  hf;  // Frequency
    double  f2p0;  // Poles ...
    double  f2p1;
    double  f2p2;
    double  f2p3;

    // Sample history buffer
    double  sdm1;  // Sample data minus 1
    double  sdm2;  // 2
    double  sdm3;  // 3

    // Gain Controls
    double  lg;  // low gain
    double  mg;  // mid gain
    double  hg;  // high gain
}
EQSTATE;

// ---------
//| Exports |
// ---------
extern void  init_3band_state(EQSTATE* es, int lowfreq, int highfreq, int mixfreq);
extern double do_3band(EQSTATE* es, double sample);

#endif // ifndef __EQ3BAND__
3 Band EQ :)  
// EQ.C - Main Source file for 3 band EQ  
// (c) Neil C / Etanza Systems / 2K6  
// Shouts / Loves / Moans = etanza at lycos dot co dot uk  
// This work is hereby placed in the public domain for all purposes, including  
// use in commercial applications.  
// The author assumes NO RESPONSIBILITY for any problems caused by the use of  
// this software.  
// Unsupported - Original filter code by Paul Kellet (musicdsp.pdf)  
// All four 2nd order filters in series, should give 24dB per octave  
// Now with P4 Denormal fix :)  

// NOTES :  
//  
//  
// | Includes |  
//  
#include <math.h>  
#include "eq.h"  

// Constants  
static double vsa = (1.0 / 4294967295.0);  
// Very small amount (Denormal Fix)  

// Initialise EQ  
// Recommended frequencies are ...  
//  
void init_3band_state(EQSTATE* es, int lowfreq, int highfreq, int mixfreq)  
{  
  // Clear state
memset(es, 0, sizeof(EQSTATE));

// Set Low/Mid/High gains to unity
es->lg = 1.0;
es->mg = 1.0;
es->hg = 1.0;

// Calculate filter cutoff frequencies
es->lf = 2 * sin(M_PI * ((double)lowfreq / (double)mixfreq));
es->hf = 2 * sin(M_PI * ((double)highfreq / (double)mixfreq));
}

// ---------------
//| EQ one sample |
// ---------------

// - sample can be any range you like :)

// Note that the output will depend on the gain settings for each band
//(especially the bass) so may require clipping before output, but you
// knew that anyway :)

double do_3band(EQSTATE* es, double sample)
{

    // Locals

double l, m, h;     // Low / Mid / High - Sample Values

    // Filter #1 (lowpass)
es->f1p0 += (es->lf * (sample - es->f1p0)) + vsa;
es->f1p1 += (es->lf * (es->f1p0 - es->f1p1));
es->f1p2 += (es->lf * (es->f1p1 - es->f1p2));
es->f1p3 += (es->lf * (es->f1p2 - es->f1p3));
l = es->f1p3;

    // Filter #2 (highpass)
es->f2p0 += (es->hf * (sample - es->f2p0)) + vsa;
es->f2p1 += (es->hf * (es->f2p0 - es->f2p1));
es->f2p2 += (es->hf * (es->f2p1 - es->f2p2));
es->f2p3 += (es->hf * (es->f2p2 - es->f2p3));
h = es->sdm3 - es->f2p3;

    // Calculate midrange (signal - (low + high))
m = es->sdm3 - (h + l);

    // Scale, combine and store
l *= es->lg;
m *= es->mg;
```c
h *= es->hg;

// Shuffle history buffer
es->sdm3 = es->sdm2;
es->sdm2 = es->sdm1;
es->sdm1 = sample;

// Return result
return (l + m + h);
```

3.5.1 Comments

- **Date:** 2007-03-28 03:33:04
  - **By:** moc.mot@lx_iruy
  
  Great Thanks!
  I have one problem the below:
  ```
  double f2p0; // Poles ...
double f2p1;
double f2p2;
double f2p3;
  ```
  that I want to know the starting value about f2p0, f2p1,...!

- **Date:** 2007-04-14 12:02:27
  - **By:** moc.oohay@knuf_red_retavttog_nuarb_semaj
  
  yuri:
  The invocation of memset() during the initialization method sets all the members of the struct to zero.

- **Date:** 2007-05-22 19:05:47
  - **By:** moc.liamtoh@cnamlleh
  
  This is great -- I want to develop a compressor/limiter/expander and have been looking long and hard for bandpass / eq filtering code. Here it is!

  I am sure we could easily expand this into an x band eq.

  Thanks!

- **Date:** 2007-07-05 06:49:45
  - **By:** tom tom
Hi!

I've just transposed your code under Delphi.

It works well if the gain is under 1, but if i put gain > 1 i get clipping (annoying sound clips), even at 1.1;

Is it normal?

I convert my smallint (44100 16 bits) to double before process, and convert the obtained value back to smallint with clipping (if < -32768 i set it to -32768, and if > 32768 i set it to 32768).

What did i do wrong?

Regards

Tom

• **Date:** 2007-07-21 14:24:53
  • **By:** ed.xmg@7trebreh

Hi.

Maybe the answer is quite easy. The upper limit is 32767 not 32768.

Regards

Herbert

• **Date:** 2007-08-23 02:39:23
  • **By:** moc.oohay@3617100aggna

Hi, Can U send me a full source code for this 3 band state eq from start to end ?? Please !!!!
I really need it for my study in school.
I hope you can send me, to my email.

thanks you.
regard

angga

• **Date:** 2009-05-05 16:37:21
  • **By:** moc.liamg@2156niahv

How can I expand this 3 Band EQ into X Band EQ..?!
Anybody answer me, or email me..

• **Date:** 2009-05-22 13:27:00
  • **By:** moc.boohay@bob

3.5. 3 Band Equaliser
For more bands, you could take the low-pass and repeat the process on that.

- **Date:** 2009-05-23 18:46:04
- **By:** moc.yabtsalb@pilihp

This is a great little filter, I am using it in an application but when I first started playing with it I noticed some problems. The mid range didn't seem to be calculated properly, a friend of mine who knows more about dsp than I do took a quick look at it and suggested the following change:

```c
m = es->sdm3 - (h + l);
```

Should be:

```c
m = sample - (h + l);
```

I've tested it with this small fix and everything works perfectly now. Just thought I'd bring this to your attention... Thanks for a great code snippet!

- **Date:** 2009-05-24 15:27:11
- **By:** moc.boohay@bob

What problems were you getting? Doesn't removing the delay cause phase problems?

- **Date:** 2009-06-25 10:34:44
- **By:** moc.limagy@ec.rahceb

Hi Great Stuff,

how to create 6 band equalizer, is any algorithm for 6 band same like 3 band, please help me if any one

thanks in advance

- **Date:** 2010-05-06 20:21:20
- **By:** moc.liamg@anesejiw

How to extend this to 6 band equalizer?

- **Date:** 2010-05-27 21:45:44
- **By:** moc.liamtoh@aanaibas_nairam

hello! thanks for your code!!
i tried to use the code in my project of guitar distortions in real time (in C) and i couldn't, i'm in linux using jack audio server, and it starts to have x-runs everytime i turn on the equalizer. do you any idea of how solving this? (from 5 to 50 milliseconds o x-runs)
i was thinking of coding it in assembler but i don't know if that would be the solution.

excuse me for my english, i'm from argentina and it's been a while since i last wrote in this language!

thanks in advance, hoping to see any answer!

mariano

- **Date:** 2010-11-03 14:19:25
Dev c++ can not run it? any sugerstions, how to run it?

• Date: 2011-02-23 13:24:53
• By: moc.liamg@kniniurb.tnecniv

This example is exactly what i've been looking for. This little piece of code executes faster then the one I have been using before.
FYI,
I will use the code in a 3 band compressor / limiter / clipper for FM broadcasting.
Thanks for sharing.
Best regards,
Vincent Bruinink.

• Date: 2011-03-21 18:03:15
• By: moc.liamg@liamtsil.mtp

I've got this filtering audio on iOS by running my sample through do_3band in the render callback. However, I'm getting a fair amount of distortion. Here's an example with my EQ3Band gains all set to 1.0:
http://www.youtube.com/watch?v=W_6JaNUvUjA

Here's the code for my implementation:
https://github.com/tassock/mixerhost/commit/4b8b87028bfff352ed67609f747858059a3e89b

I assume others using this aren't having this same distortion issue? If so, what sort of audio sample formats are you using (big/little endian, float/integer samples, etc). Thanks!

• Date: 2011-04-30 20:17:58
• By: moc.liamg@enohpi.senarab

hi,
I got also distortion even though my all my gains are set to 1. Please help
Lucie

• Date: 2012-06-05 07:19:56
• By: moc.liamg@solbaidcod

I've made an implementation of 3 band Equalizer to read a wave file, apply filtering and then save wave output file.
With your code I have a lot of distortion,I think the problem maybe coefficient calculation:
es->flp0 += (es->lf * (sample - es->flp0))+vsa ;
...

(continues on next page)
Can anyone resolve distortion?

- **Date**: 2013-01-11 16:43:12  
  - **By**: es.dnargvelk@nahoj

Works fine for me on iOS. Maybe you feed a interleaved stereo signal with the same EQSTATE instance (you’ll need one EQSTATE for each channel)?

- **Date**: 2013-04-07 17:50:46  
  - **By**: ta.erehtgir@liameon

It's all about WHERE you init you EQ. Try a little :) If you don't find out yourself, I'll help you.

- **Date**: 2013-06-18 14:00:45  
  - **By**: moc.laimtoh@inaam_riamu

I added this code to my xcode project. But where i can pass the values and method. May be its funny question for you guyz but please help me. Its loking good to me but in xcode , i am using avaudio player for play sound and making sound app. Thanks

- **Date**: 2013-07-01 23:07:05  
  - **By**: moc.liamg@iaznabi

The distortion will occur of you are trying to adapt this to stereo and do so by simply adding an outer loop per channel. Doing so will cause the filter values to compound and cause distortion. Instead, you will need to duplicate all the filter values and keep them separate from the other channel.

- **Date**: 2013-08-21 14:09:08  
  - **By**: moc.liamg@nurb.luap

Any good x-band equalizer equivalents for C# that I can use?

- **Date**: 2014-08-05 22:57:07  
  - **By**: ed.xmg@retsneum.ellak

s'cool thanks! have portet to c# works fine!

- **Date**: 2015-09-28 07:53:37  
  - **By**: az.oc.sseccadipar@sook

Converted Neil's C Code 3 band equalizer to Delphi class, for those who are interested.
1. Create instance of class
   Public
       eq:TEQ;

2. On form create

   eq := TEQ.Create;

   //Initialize
   init_3band_state(880,5000,44100,50,-25,0);

   //init_3band_state(lowfreq,highfreq,mixfreq:integer;BassGain,MidGain,
       →HighGain:Double);

3. process: pass Raw 16Bit PCM to eq

   eq.Equalize(const Data: Pointer; DataSize: DWORD);

   Works like a charm form me

**********************************************
TEq=Class
private
  lf,flp0,flp1,flp2,flp3:double;
  hf,f2p0,f2p1,f2p2,f2p3:double;
  sdm1,sm2,sm3:double;
  vsa:double;
  lg,mg,hg:double;
  Function do_3band(sample:Smallint):Smallint;
public
  constructor create;
  destructor destroy;override;
  procedure init_3band_state(lowfreq,highfreq,mixfreq:integer;BassGain,MidGain,
      →HighGain:Double);
  procedure Equalize(const Data: Pointer; DataSize: DWORD);
end;

constructor TEQ.create;
begin
  inherited create;
  vsa := (1.0 / 4294967295.0);
  lg := 1.0;
  mg := 1.0;
  hg := 1.0;
end;

destructor TEQ.destroy;
begin
  inherited destroy;
end;

procedure TEQ.init_3band_state(lowfreq,highfreq,mixfreq:integer;BassGain,MidGain,
     →HighGain:Double);

(continues on next page)
begin
{(880, 5000, 44100, 1.5, 0.75, 1.0)
eq.lg = 1.5; // Boost bass by 50%
eq.mg = 0.75; // Cut mid by 25%
eq.hg = 1.0; // Leave high band alone }

lg := 1+(BassGain/100);
mg := 1+(MidGain/100);
hg := 1+(HighGain/100);

// Calculate filter cutoff frequencies
lf := 2 * sin(PI * (lowfreq / mixfreq));
hf := 2 * sin(PI * (highfreq / mixfreq));
end;

Function TEQ.do_3band(sample:Smallint):Smallint;
var l,m,h:double;
res:integer;
begin

// Filter #1 (lowpass)
flp0 := flp0 + (lf * (sample - flp0)) + vsa;
flp1 := flp1 + (lf * (flp0 - flp1));
flp2 := flp2 + (lf * (flp1 - flp2));
flp3 := flp3 + (lf * (flp2 - flp3));

l := flp3;

// Filter #2 (highpass)
fp20 := fp20 + (hf * (sample - fp20)) + vsa;
fp21 := fp21 + (hf * (fp20 - fp21));
fp22 := fp22 + (hf * (fp21 - fp22));
fp23 := fp23 + (hf * (fp22 - fp23));

h := sdm3 - fp23;

// Calculate midrange (signal - (low + high))
m := sdm3 - (h + l);

// Scale, Combine and store
l := l * lg;
m := m * mg;
h := h * hg;

// Shuffle history buffer
sdm3 := sdm2;
sdm2 := sdm1;
sdm1 := sample;

// Return result

res := trunc(l+m+h);
if res > 32767 then res := 32767 else if res < -32768 then res := -32768;
result := res;
end;

procedure TEQ.Equalize(const Data: Pointer; DataSize: DWORD);
var pSample: PSmallInt;
begin
  pSample := Data;
  while DataSize > 0 do
  begin
    pSample^ := do_3band(pSample^);
    Inc(pSample);
    Dec(DataSize, 2);
  end;
end;

3.6 303 type filter with saturation

- **Author or source:** Hans Mikelson
- **Type:** Runge-Kutta Filters
- **Created:** 2002-01-17 02:07:37
- **Linked files:** filters001.txt

Listing 9: notes

I posted a filter to the Csound mailing list a couple of weeks ago that has a 303 flavor to it. It basically does wacky distortions to the sound. I used Runge-Kutta for the diff eq. simulation though which makes it somewhat sluggish.

This is a CSound score!!

3.7 4th order Linkwitz-Riley filters

- **Author or source:** moc.liamg@321tiloen
- **Type:** LP/HP - LR4
- **Created:** 2009-05-17 19:43:06

Listing 10: notes

Original from T. Lossius - ttblue project
Optimized version in pseudo-code.

[! The filter is unstable for fast automation changes in the lower frequency range.

(continues on next page)
Parameter interpolation and/or oversampling should fix this. ![]

The sum of the Linkwitz-Riley (Butterworth squared) HP and LP outputs, will result an all-pass filter at \( F_c \) and flat magnitude response - close to ideal for crossovers.

Lubomir I. Ivanov

Listing 11: code

```c
//------------------------------
// [code]
//------------------------------

//fc -> cutoff frequency
//pi -> 3.14285714285714
//srate -> sample rate

//================================================
// shared for both lp, hp; optimizations here
//================================================
wc=2*pi*fc;
w2=wc*wc;
w3=wc*wc2;
wc4=wc2*wc2;
k=wc/tan(pi*fc/srate);
k2=k*k;
k3=k2*k;
k4=k2*k2;

sqrt2=sqrt(2);

sq_tmp1=sqrt2*wc3*k;
sq_tmp2=sqrt2*wc*k3;
a_tmp=4*wc2*k2+2*sq_tmp1+k4+2*sq_tmp2+wc4;

b1=(4*(wc4+sq_tmp1-k4-sq_tmp2))/a_tmp;
b2=(6*wc4-8*wc2*k2+6*k4)/a_tmp;
b3=(4*(wc4-sq_tmp1+sq_tmp2-k4))/a_tmp;
b4=(k4-2*sq_tmp1+wc4-2*sq_tmp2+4*wc2*k2)/a_tmp;

//================================================
// low-pass
//================================================
a0=wc4/a_tmp;
a1=4*wc4/a_tmp;
a2=6*wc4/a_tmp;
a3=a1;
a4=a0;

//================================================
// high-pass
//================================================
a0=k4/a_tmp;
a1=-4*k4/a_tmp;
a2=6*k4/a_tmp;
a3=a1;
a4=a0;
```

(continues on next page)
47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63
//=====================================================  
// sample loop - same for lp, hp  
//=====================================================  
tempx=input;  
  
  
  
  
  tempy=a0*tempx+a1*xm1+a2*xm2+a3*xm3+a4*xm4-b1*ym1-b2*ym2-b3*ym3-b4*ym4;  
xm4=xm3;  
xm3=xm2;  
xm2=xm1;  
xm1=tempx;  
  
  
  
  
  ym4=ym3;  
ym3=ym2;  
ym2=ym1;  
ym1=tempy;  
output=tempy;

3.7.1 Comments

- **Date**: 2009-05-29 11:09:50
- **By**: moc.liamg@321tiloen

LR2 with DFII:

```plaintext
// -------------------------------  
// LR2  
// fc -> cutoff frequency  
// pi -> 3.14285714285714  
// srate -> sample rate  
// -------------------------------  
fpi = pi*fc;  
w = 2*fpi;  
w2 = wc*wc;  
w22 = 2*w2;  
k = wc/tan(fpi/srate);  
k2 = k*k;  
k22 = 2*k2;  
w2k2 = 2*w2*k;  
tmpk = (k2+w22+w2k2);  
// b shared  
b1 = (-k22+w22)/tmpk;  
b2 = (-w2k2+k2+w2)/tmpk;  
// low-pass  
// -------------------------------  
a0_lp = (w2)/tmpk;  
a1_lp = (w22)/tmpk;  
a2_lp = (w22)/tmpk;  
// high-pass  
// -------------------------------  
a0_hp = (k2)/tmpk;  
a1_hp = (-k22)/tmpk;
```

(continues on next page)
\[
a_{2,\text{hp}} = \frac{(k2)}{\text{tmpk}};
\]

//=========================  
// sample loop, in -> input  
//=========================  
//---lp  
lp_{out} = a_{0,lp}\cdot\text{in} + lp_{xm0};  
lp_{xm0} = a_{1,lp}\cdot\text{in} - b_{1}\cdot lp_{out} + lp_{xm1};  
lp_{xm1} = a_{2,lp}\cdot\text{in} - b_{2}\cdot lp_{out};  
//---hp  
hp_{out} = a_{0,hp}\cdot\text{in} + hp_{xm0};  
hp_{xm0} = a_{1,hp}\cdot\text{in} - b_{1}\cdot hp_{out} + hp_{xm1};  
hp_{xm1} = a_{2,hp}\cdot\text{in} - b_{2}\cdot hp_{out};

// the two are with 180 degrees phase shift,  
// so you need to invert the phase of one.  
out = lp_{out} + hp_{out}\cdot(-1);  
//result is allpass at Fc

• **Date:** 2011-07-13 11:48:20  
• **By:** moc.kauqkiuq@evad

I've converted this Linkwits Riley 4 into intrinsics. It's set up with the cross over point and the sample rate. The function 'ProcessSplit' returns the low and high parts. It uses _mm_malloc to align the variables to 16 bytes, as putting them into the class as __m128 vars doesn't guarantee alignment. Enjoy! :)

//--------------------------------------------------------------------------  
//--------------------------------------------------------------------------  
//--------------------------------------------------------------------------  
//FIL_Linkwitz_Riley4.h

#pragma once

#include <xmmintrin.h>

class FIL_Linkwitz_Riley4
{
  __m128 *ab;
  __m128 *al;
  __m128 *ah;
  __m128 *xm;
  __m128 *yml;
  __m128 *ymh;

  float a0l;
  float a0h;

public:
  FIL_Linkwitz_Riley4():FIL_Linkwitz_Riley4(float fc, float srate);
  ~FIL_Linkwitz_Riley4();
}
void ResetSplit();

__inline void FIL_Linkwitz_Riley4::ProcessSplit(const float in, float &low, float &high)
{
    __m128 m1;
    m1 = _mm_sub_ps(_mm_mul_ps(*al, *xm), _mm_mul_ps(*ab, *yml));
    low = a0l * in + m1.m128_f32[0] + m1.m128_f32[1] + m1.m128_f32[2] + m1.m128_f32[3];
    m1 = _mm_sub_ps(_mm_mul_ps(*ah, *xm), _mm_mul_ps(*ab, *ymh));
    high = a0h * in + m1.m128_f32[0] + m1.m128_f32[1] + m1.m128_f32[2] + m1.m128_f32[3];
    *xm = _mm_shuffle_ps(*xm, *xm, _MM_SHUFFLE(2,1,0,0));
    (*xm).m128_f32[0] = in;
    *yml = _mm_shuffle_ps(*yml, *yml, _MM_SHUFFLE(2,1,0,0));
    (*yml).m128_f32[0] = low;
    *ymh = _mm_shuffle_ps(*ymh, *ymh, _MM_SHUFFLE(2,1,0,0));
    (*ymh).m128_f32[0] = high;
}

extern void _mm_shuffle_ps(__m128, __m128, unsigned _MM_Shuffle);
float a_tmp = 4.0f * wc2 * k2 + 2.0f * sq_tmp1 + k4 + 2.0f * sq_tmp2 + wc4;

(*ab).m128_f32[0] = (4.0f *(wc4+sq_tmp1-k4-sq_tmp2))/a_tmp;
(*ab).m128_f32[1] = (6.0f *wc4-8*wc2*k2+6*k4)/a_tmp;
(*ab).m128_f32[2] = (4.0f *(wc4-sq_tmp1+sq_tmp2-k4))/a_tmp;
(*ab).m128_f32[3] = (k4 -2.0f * sq_tmp1 + wc4 - 2.0f * sq_tmp2 + 4.0f * wc2 * k2)/a_tmp;

//=================================================
// low-pass
//=================================================
a0l = wc4/a_tmp;
(*al).m128_f32[0] = 4.0f * wc4 / a_tmp;
(*al).m128_f32[3] = a0l;

//=================================================
// high-pass
//=================================================
a0h = k4 / a_tmp;
(*ah).m128_f32[0] = -4.0f * k4 / a_tmp;
(*ah).m128_f32[3] = a0h;

ResetSplit();
}
FIL_Linkwitz_Riley4::~FIL_Linkwitz_Riley4()
{
    _mm_free((void*)ab);
    _mm_free((void*)al);
    _mm_free((void*)ah);
    _mm_free((void*)xm);
    _mm_free((void*)yml);
    _mm_free((void*)ymh);
}

void FIL_Linkwitz_Riley4::ResetSplit()
{
    // Reset history...
    *xm = _mm_set1_ps(0.0f);
    *yml = _mm_set1_ps(0.0f);
    *ymh = _mm_set1_ps(0.0f);
}

• Date: 2011-07-13 15:00:08
• By: moc.kauqkiuq@evad

I've no idea why I'm accessing those pointers like that! But never mind. :)

• Date: 2012-07-04 13:45:19
Your pi value is wrong: 
pi -> 3.14285714285714
It should be 3.1415926535 ect.

Your pi value is wrong: 
pi -> 3.14285714285714
It should be 3.1415926535 ect.

Or even 3.1415926535!
LOL.

I don't think this is unstable for changes in frequency. It's unstable for low frequencies.

Here's my implementation.

```cpp
#include <iostream>
#include <stdio.h>
#include <math.h>
#include <assert.h>

class LRCrossoverFilter { // LR4 crossover filter
private:
    struct filterCoefficients {
        float a0, a1, a2, a3, a4;
    } lpco, hpco;
    float b1co, b2co, b3co, b4co;

    struct {
        float xm1 = 0.0f;
        float xm2 = 0.0f;
        float xm3 = 0.0f;
        float xm4 = 0.0f;
        float ym1 = 0.0f, ym2 = 0.0f, ym3 = 0.0f, ym4 = 0.0f;
    } hptemp, lptemp;

    float coFreqRunningAv = 100.0f;
public:
    void setup(float crossoverFrequency, float sr);
    void processBlock(float * in, float * outHP, float * outLP, int numSamples);
    void dumpCoefficients(struct filterCoefficients x) {
        std::cout << "a0: " << x.a0 << "\n";
        std::cout << "a1: " << x.a1 << "\n";
        std::cout << "a2: " << x.a2 << "\n";
        std::cout << "a3: " << x.a3 << "\n";
        std::cout << "a4: " << x.a4 << "\n";
    }
    void dumpInformation() {
        std::cout << "-----\nfrequency: " << coFreqRunningAv << "\n";
        std::cout << "lpco:\n";
    }
};
```

(continues on next page)
void LRCrossoverFilter::setup(float crossoverFrequency, float sr) {
    const float pi = 3.141f;
    coFreqRunningAv = crossoverFrequency;
    float cowc=2*pi*coFreqRunningAv;
    float cowc2=cowc*cowc;
    float cowc3=cowc2*cowc;
    float cowc4=cowc2*cowc2;
    float cok=cowc/tan(pi*coFreqRunningAv/sr);
    float cok2=cok*cok;
    float cok3=cok2*cok;
    float cok4=cok2*cok2;
    float sqrt2=sqrt(2);
    float sq_tmp1 = sqrt2 * cowc3 * cok;
    float sq_tmp2 = sqrt2 * cowc * cok3;
    float a_tmp = 4*cowc2*cok2 + 2*sq_tmp1 + cok4 + 2*sq_tmp2+cowc4;
    b1co=(4*(cowc4+sq_tmp1-cok4-sq_tmp2))/a_tmp;
    b2co=(6*cowc4-8*cowc2*cok2+6*cok4)/a_tmp;
    b3co=(4*(cowc4-sq_tmp1+sq_tmp2-cok4))/a_tmp;
    b4co=(cok4-2*sq_tmp1+cowc4-2*sq_tmp2+4*cowc2*cok2)/a_tmp;
    //================================================
    // low-pass
    //================================================
    lpco.a0=cowc4/a_tmp;
    lpco.a1=4*cowc4/a_tmp;
    lpco.a2=6*cowc4/a_tmp;
    lpco.a3=lpco.a1;
    lpco.a4=lpco.a0;
    //================================================
    // high-pass
    //================================================
}
void LRCrossoverFilter::processBlock(float * in, float * outHP, float * outLP, int numSamples) {

    float tempx, tempy;
    for (int i = 0; i < numSamples; i++) {
        tempx = in[i];

        // High pass
        tempy = hpco.a0 * tempx +
                hpco.a1 * hptemp.xml1 +
                hpco.a2 * hptemp.xml2 +
                hpco.a3 * hptemp.xml3 +
                hpco.a4 * hptemp.xml4 -
                b1co * hptemp.ym1 -
                b2co * hptemp.ym2 -
                b3co * hptemp.ym3 -
                b4co * hptemp.ym4;

        hptemp.xml4 = hptemp.xml3;
        hptemp.xml3 = hptemp.xml2;
        hptemp.xml2 = hptemp.xml1;
        hptemp.xml1 = tempx;
        hptemp.ym4 = hptemp.ym3;
        hptemp.ym3 = hptemp.ym2;
        hptemp.ym2 = hptemp.ym1;
        hptemp.ym1 = tempy;
        outHP[i] = tempy;

        assert(tempy < 10000000);

        // Low pass
        tempy = lpco.a0 * tempx +
                lpco.a1 * lptemp.xml1 +
                lpco.a2 * lptemp.xml2 +
                lpco.a3 * lptemp.xml3 +
                lpco.a4 * lptemp.xml4 -
                b1co * lptemp.ym1 -
                b2co * lptemp.ym2 -
                b3co * lptemp.ym3 -
                b4co * lptemp.ym4;

        lptemp.xml4 = lptemp.xml3; // these are the same as hptemp and could be optimised away
        lptemp.xml3 = lptemp.xml2;
        lptemp.xml2 = lptemp.xml1;
        lptemp.xml1 = tempx;
    }
}
\begin{verbatim}
lptemp.ym4=lptemp.ym3;
lptemp.ym3=lptemp.ym2;
lptemp.ym2=lptemp.ym1;
lptemp.ym1=tempy;
outLP[i] = tempy;
assert(!isnan(outLP[i]));
}
}

int main () {
    LR_CrossoverFilter filter;
    float data[2000];
    float lp[2000], hp[2000];
    filter.setup(50.0, 44100.0f);
    filter.dumpInformation();
    for (int i = 0; i<2000; i++) {
        data[i] = sinf(i/100.f);
    }
    filter.processBlock(data, hp, lp, 2000);
}

I'll try and fix it, but this kind of work is new to me, so all suggestions appreciated (Including "You Fool, you've copied the code wrong"). cheers!
\end{verbatim}

- **Date**: 2013-09-03 22:35:23
- **By**: ku.oc.9f.yrreksirhc@kc

I tried this code for a crossover - firstly the SSE intrinsics version then the full original version. Both have problems with the HPF output. With a crossover frequency of 200Hz and a pure sine tone input (any pitch) I get loud (-16dBFS) low frequency noise in the HPF output. This noise level reduces as the crossover frequency increases but it is unusable in its current state. Can anyone post a solution for this problem? Thanks.....Chris

- **Date**: 2013-09-04 10:37:34
- **By**: ku.oc.9f.yrreksirhc@kc

I also tried the LR2 code, this works better but there is still low frequency noise (-56dBFS & Xover 200Hz) in the HPF output. Seems there is a fundamental problem with the HPF coefficients in this code :( The LF Noise for both LR2 and LR4 appears to be a modulating DC offset - maybe that can guide the Filter Gurus to identify and solve the problem. Cheers.....Chris

### 3.8 All-Pass Filters, a good explanation

- **Author or source**: Olli Niemitalo
3.9 Another 4-pole lowpass...

- **Author or source:** ten.xmg@zlipzzuf
- **Type:** 4-pole LP/HP
- **Created:** 2004-09-06 08:40:52

Listing 12: notes

Vaguely based on the Stilson/Smith Moog paper, but going in a rather different direction from others I've seen here.

The parameters are peak frequency and peak magnitude (g below); both are reasonably accurate for magnitudes above 1. DC gain is 1.

The filter has some undesirable properties - e.g. it's unstable for low peak freqs if implemented in single precision (haven't been able to cleanly separate it into biquads or onepoles to see if that helps), and it responds so strongly to parameter changes that it's not advisable to update the coefficients much more rarely than, say, every eight samples during sweeps, which makes it somewhat expensive.

I like the sound, however, and the accuracy is nice to have, since many filters are not very strong in that respect.

I haven't looked at the HP again for a while, but IIRC it had approximately the same good and bad sides.

Listing 13: code

```c
double coef[9];
double d[4];
double omega; //peak freq
double g;  //peak mag

// calculating coefficients:

double k,p,q,a;
double a0,a1,a2,a3,a4;

k=(4.0*g-3.0)/(g+1.0);
p=1.0-0.25*k;p*=p;

// LP:
a=1.0/(tan(0.5*omega)*(1.0+p));
```

(continues on next page)
\[p = 1.0 + a;\]
\[q = 1.0 - a;\]
\[a_0 = \frac{1.0}{k + p \cdot p \cdot p \cdot p};\]
\[a_1 = 4.0 \cdot (k + p \cdot p \cdot q \cdot q);\]
\[a_2 = 6.0 \cdot (k + p \cdot q \cdot q \cdot q);\]
\[a_3 = 4.0 \cdot (k + p \cdot q \cdot q \cdot q);\]
\[a_4 = \frac{1.0}{k + q \cdot q \cdot q \cdot q};\]
\[p = a_0 \cdot (k + 1.0);\]
\[\text{coef}[0] = p;\]
\[\text{coef}[1] = 4.0 \cdot p;\]
\[\text{coef}[2] = 6.0 \cdot p;\]
\[\text{coef}[3] = 4.0 \cdot p;\]
\[\text{coef}[4] = p;\]
\[\text{coef}[5] = a_1 \cdot a_0;\]
\[\text{coef}[6] = a_2 \cdot a_0;\]
\[\text{coef}[7] = a_3 \cdot a_0;\]
\[\text{coef}[8] = a_4 \cdot a_0;\]

// or HP:
\[a = \tan(0.5 \cdot \omega) / (1.0 + p);\]
\[p = a + 1.0;\]
\[q = a - 1.0;\]
\[a_0 = \frac{1.0}{p \cdot p \cdot p \cdot k};\]
\[a_1 = 4.0 \cdot (p \cdot p \cdot p \cdot q - k);\]
\[a_2 = 6.0 \cdot (p \cdot p \cdot q \cdot q + k);\]
\[a_3 = 4.0 \cdot (p \cdot q \cdot q \cdot q - k);\]
\[a_4 = \frac{1.0}{q \cdot q \cdot q \cdot q + k};\]
\[p = a_0 \cdot (k + 1.0);\]
\[\text{coef}[0] = p;\]
\[\text{coef}[1] = -4.0 \cdot p;\]
\[\text{coef}[2] = 6.0 \cdot p;\]
\[\text{coef}[3] = -4.0 \cdot p;\]
\[\text{coef}[4] = p;\]
\[\text{coef}[5] = a_1 \cdot a_0;\]
\[\text{coef}[6] = a_2 \cdot a_0;\]
\[\text{coef}[7] = a_3 \cdot a_0;\]
\[\text{coef}[8] = a_4 \cdot a_0;\]

// per sample:
\[\text{out} = \text{coef}[0] \times \text{in} + \text{d}[0];\]
\[\text{d}[0] = \text{coef}[1] \times \text{in} + \text{coef}[5] \times \text{out} + \text{d}[1];\]
\[\text{d}[1] = \text{coef}[2] \times \text{in} + \text{coef}[6] \times \text{out} + \text{d}[2];\]
\[\text{d}[2] = \text{coef}[3] \times \text{in} + \text{coef}[7] \times \text{out} + \text{d}[3];\]
\[\text{d}[3] = \text{coef}[4] \times \text{in} + \text{coef}[8] \times \text{out};\]

### 3.9.1 Comments

- **Date:** 2005-04-04 20:39:55
- **By:** ed.luofosruivas@naitsirhC
Yet untested object pascal translation:

unit T4PoleUnit;

interface

type TFilterType=(ftLowPass, ftHighPass);

T4Pole=class(TObject)
private
  fGain : Double;
  fFreq : Double;
  fSR : Single;
protected
  fCoeffs : array[0..8] of Double;
  d : array[0..3] of Double;
  fFilterType : TFilterType;
procedure SetGain(s:Double);
procedure SetFrequency(s:Double);
procedure SetFilterType(v:TFilterType);
procedure Calc;
public
  constructor Create;
function Process(s:single):single;
published
  property Gain: Double read fGain write SetGain;
  property Frequency: Double read fFreq write SetFrequency;
  property SampleRate: Single read fSR write fSR;
  property FilterType: TFilterType read fFilterType write SetFilterType;
end;

implementation

uses math;

const kDenorm = 1.0e-25;

constructor T4Pole.Create;
begin
  inherited create;
  fFreq:=1000;
  fSR:=44100;
  Calc;
end;

procedure T4Pole.SetFrequency(s:Double);
begin
  fFreq:=s;
  Calc;
end;

procedure T4Pole.SetGain(s:Double);
begin
  fGain:=s;
  Calc;
end;

procedure T4Pole.SetFilterType(v:TFilterType);

(continues on next page)
begin
  fFilterType:=v;
  Calc;
end;

procedure T4Pole.Calc;
var k,p,q,b,s : Double;
a : array[0..4] of Double;
begin
  fGain:=1;
  if fFilterType=ftLowPass
    then s:=1
    else s:=-1;
  // calculating coefficients:
  k:=(4.0*fGain-3.0)/(fGain+1.0);
  p:=1.0-0.25*k;
  p:=p*p;
  if fFilterType=ftLowPass
    then b:=1.0/(tan(pi*fFreq/fSR)*(1.0+p))
    else b:=tan(pi*fFreq/fSR)/(1.0+p);
  p:=1.0+b;
  q:=s*(1.0-b);
  a[0] := 1.0/( k+p*p*p*p);
  a[1] := 4.0*(s*k+p*p*p*q);
  a[2] := 6.0*( k+p*p*q*q);
  a[3] := 4.0*(s*k+p*q*q*q);
  a[4] := 1.0/( k+q*q*q*q);
  p := a[0] *(k+1.0);
  fCoeffs[0]:=p;
  fCoeffs[1]:=4.0*p*s;
  fCoeffs[2]:=6.0*p;
  fCoeffs[3]:=4.0*p*s;
  fCoeffs[4]:=p;
  fCoeffs[5]:=-a[1]*a[0];
  fCoeffs[6]:=-a[2]*a[0];
  fCoeffs[7]:=-a[3]*a[0];
  fCoeffs[8]:=-a[4]*a[0];
end;

function T4Pole.Process(s:single):single;
begin
  Result:=fCoeffs[0]*s+d[0];
  d[0]:=fCoeffs[1]*s+fCoeffs[5]*Result+d[1];
  d[1]:=fCoeffs[2]*s+fCoeffs[6]*Result+d[2];
  d[2]:=fCoeffs[3]*s+fCoeffs[7]*Result+d[3];
  d[3]:=fCoeffs[4]*s+fCoeffs[8]*Result;
end;
end.

- **Date:** 2015-03-19 19:24:23
- **By:** ed.xmg@0891retep_repus
so bad that this filter is so unstable. i tested it and it has a really nice sound. but frequencies below 200 hz are not possible. :-(

### 3.10 Bass Booster

- **Author or source:** Johny Dupej
- **Type:** LP and SUM
- **Created:** 2006-08-11 12:47:34

**Listing 14: notes**

This function adds a low-passed signal to the original signal. The low-pass has a quite wide response.

**Params:**
- selectivity - frequency response of the LP (higher value gives a steeper one) [70.0 to 140.0 sounds good]
- ratio - how much of the filtered signal is mixed to the original
- gain2 - adjusts the final volume to handle cut-offs (might be good to set dynamically)

**Listing 15: code**

```c
#define saturate(x) __min(__max(-1.0,x),1.0)

float BassBooster(float sample)
{
    static float selectivity, gain1, gain2, ratio, cap;
    gain1 = 1.0/(selectivity + 1.0);
    cap = (sample + cap*selectivity)*gain1;
    sample = saturate((sample + cap*ratio)*gain2);
    return sample;
}
```

### 3.11 Biquad C code

- **Author or source:** Tom St Denis
- **Created:** 2002-02-10 12:33:52
- **Linked files:** biquad.c
3.12 Biquad, Butterworth, Chebyshev N-order, M-channel optimized filters

- **Author or source:** moc.oohay@nniveht
- **Type:** LP, HP, BP, BS, Shelf, Notch, Boost
- **Created:** 2009-11-16 08:46:34

//
/*
"A Collection of Useful C++ Classes for Digital Signal Processing"
By Vincent Falco

Please direct all comments to either the music-dsp mailing list or the DSP and Plug-in Development forum:
http://music.columbia.edu/cmc/music-dsp/
http://www.kvraudio.com/forum/

Support is provided for performing N-order Dsp floating point filter operations on M-channel data with a caller specified floating point type. The implementation breaks a high order IIR filter down into a series of cascaded second order stages. Tests conclude that numerical stability is maintained even at higher orders. For example the Butterworth low pass filter is stable at up to 53 poles.

Processing functions are provided to use either Direct Form I or Direct Form II of the filter transfer function. Direct Form II is slightly faster but can cause discontinuities in the output if filter parameters are changed during processing. Direct Form I is slightly slower, but maintains fidelity even when parameters are changed during processing.

To support fast parameter changes, filters provide two functions for adjusting parameters. A high accuracy Setup() function, and a faster form called SetupFast() that uses approximations for trigonometric functions. The approximations work quite well and should be suitable for most applications.

Channels are stored in an interleaved format with M samples per frame arranged contiguously. A single class instance can process all M channels simultaneously in an efficient manner. A 'skip' parameter causes the processing function to advance by skip additional samples in the destination buffer in between every frame. Through manipulation of the skip parameter it is possible to exclude channels from processing (for example, only processing the left half of stereo interleaved data). For multichannel data which is not interleaved, it will be necessary to instantiate multiple instance of
the filter and set skip=0.

There are a few other utility classes and functions included that may prove useful.

Classes:

Complex
CascadeStages
Biquad

BiquadLowPass
BiquadHighPass
BiquadBandPass1
BiquadBandPass2
BiquadBandStop
BiquadAllPass
BiquadPeakEq
BiquadLowShelf
BiquadHighShelf

PoleFilter
Butterworth

ButterLowPass
ButterHighPass
ButterBandPass
ButterBandStop

Chebyshev1

Cheby1LowPass
Cheby1HighPass
Cheby1BandPass
Cheby1BandStop

Chebyshev2

Cheby2LowPass
Cheby2HighPass
Cheby2BandPass
Cheby2BandStop

EnvelopeFollower
AutoLimiter

Functions:

zero()
copy()
mix()
scale()
interleave()
deinterleave()

Order for PoleFilter derived classes is specified in the number of poles, except for band pass and band stop filters, for which the number of pole pairs is specified.

For some filters there are two versions of Setup(), the one called SetupFast() uses approximations to trigonometric functions for speed. This is an option if you are doing frequent parameter changes to the filter.

There is an example function at the bottom that shows how to use the classes.
Filter ideas are based on a java applet (http://www.falstad.com/dfilter/) developed by Paul Falstad.

All of this code was written by the author Vincent Falco except where marked.

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*/
/*

To Do:

- Shelving, peak, all-pass for Butterworth, Chebyshev, and Elliptic.

  The Biquads have these versions and I would like the others to have them as well. It would also be super awesome if higher order filters could have a "Q" parameter for resonance but I'm not expecting miracles, it would require redistributing the poles and zeroes. But if there's a research paper or code out there...I could incorporate it.

- Denormal testing and fixing

  I'd like to know if denormals are a problem. And if so, it would be nice to have a small function that can reproduce the denormal problem. This way I can test the fix under all conditions. I will include the function as a "unit test" object in the header file so anyone can verify its correctness. But I'm a little lost.

- Optimized template specializations for stages=1, channels={1,2}

  There are some pretty obvious optimizations I am saving for "the end". I don't want to do them until the code is finalized.

- Optimized template specializations for SSE, other special instructions

- Optimized trigonometric functions for fast parameter changes
- Elliptic curve based filter coefficients
- More utility functions for manipulating sample buffers
- Need fast version of pow(10, x)

```
#ifndef __DSP_FILTER__
#define __DSP_FILTER__

#include <cmath>
#include <cfloat>
#include <cassert.h>
#include <memory.h>
#include <stdlib.h>

#ifdef DSP_USE_STD_COMPLEX
#include <complex>
#endif

#define DSP_SSE3_OPTIMIZED
#ifdef DSP_SSE3_OPTIMIZED
#ifndef __DSP_SSE3_OPTIMIZED__
#define __DSP_SSE3_OPTIMIZED__
#endif
#endif

namespace Dsp
{
    #define DSP_SSE3_OPTIMIZED
    #ifdef DSP_SSE3_OPTIMIZED
      /*
       * WARNING: Here there be templates
       *
       */

    typedef double CalcT;
    typedef int Int32; // Must be 32 bits
    typedef __int64 Int64; // Must be 64 bits

    const CalcT vsa=1.0 / 4294967295.0; // for CalcT as float

    // These constants are so important, I made my own copy. If you improve
    // the resolution of CalcT be sure to add more significant digits to these.
    const CalcT kPi = 3.1415926535897932384626433832795;

    // Regardless of the type of sample that the filter operates on (e.g.
    // float or double), all calculations are performed using double (or
    // better) for stability and accuracy. This controls the underlying
    // type used for calculations:
```

(continues on next page)
const CalcT kPi_2  =1.57079632679489661923;
const CalcT kLn2  =0.693147180559945309417;
const CalcT kLn10 =2.30258509299404568402;

// Some functions missing from <math.h>

template<typename T>
inline T acosh( T x )
{
    return log( x+:sqrt(x*x-1) );
}

// Fast Trigonometric Functions

// Three approximations for both sine and cosine at a given angle.
// The faster the routine, the larger the error.
// From http://lab.polygonal.de/2007/07/18/fast-and-accurate-sinecosine-
// approximation/

// Tuned for maximum pole stability. r must be in the range 0..pi
// This one breaks down considerably at the higher angles. It is
// included only for educational purposes.
inline void fastestsincos( CalcT r, CalcT *sn, CalcT *cs )
{
    const CalcT c=0.70710678118654752440; // sqrt(2)/2
    CalcT v=(2-4*c)*r*r+c;
    if(r<kPi_2)
    {
        *sn=v+r; *cs=v-r;
    }
    else
    {
        *sn=r+v; *cs=r-v;
    }
}

// Lower precision than ::fastsincos() but still decent
inline void fastersincos( CalcT x, CalcT *sn, CalcT *cs )
{
    //always wrap input angle to -PI..PI
    if (x < -kPi) x += 2*kPi;
    else if (x > kPi) x -= 2*kPi;
    //compute sine
    if (x < 0) *sn = 1.27323954 * x + 0.405284735 * x * x;
    else *sn = 1.27323954 * x - 0.405284735 * x * x;
    //compute cosine: sin(x + PI/2) = cos(x)
    x += kPi_2;
    if (x > kPi ) x -= 2*kPi;
    if (x < 0) *cs = 1.27323954 * x + 0.405284735 * x * x;
    else *cs = 1.27323954 * x - 0.405284735 * x * x;
}
// Slower than ::fastersincos() but still faster than sin(), and with the best accuracy of these routines.

inline void fastsincos( CalcT x, CalcT *sn, CalcT *cs )
{
    CalcT s, c;
    //always wrap input angle to -PI..PI
    if (x < -kPi) x += 2*kPi;
    else if (x > kPi) x -= 2*kPi;
    //compute sine
    if (x < 0)
    {
        s = 1.27323954 * x + .405284735 * x * x;
        if (s < 0) s = .225 * (s * -s - s) + s;
        else s = .225 * (s * s - s) + s;
    }
    else
    {
        s = 1.27323954 * x - 0.405284735 * x * x;
        if (s < 0) s = .225 * (s * -s - s) + s;
        else s = .225 * (s * s - s) + s;
    }
    *sn=s;
    //compute cosine: sin(x + PI/2) = cos(x)
    x += kPi_2;
    if (x > kPi ) x -= 2*kPi;
    if (x < 0)
    {
        c = 1.27323954 * x + 0.405284735 * x * x;
        if (c < 0) c = .225 * (c * -c - c) + c;
        else c = .225 * (c * c - c) + c;
    }
    else
    {
        c = 1.27323954 * x - 0.405284735 * x * x;
        if (c < 0) c = .225 * (c * -c - c) + c;
        else c = .225 * (c * c - c) + c;
    }
    *cs=c;
}

// Faster approximations to sqrt()
// From http://ilab.usc.edu/wiki/index.php/Fast_Square_Root
// The faster the routine, the more error in the approximation.

// Log Base 2 Approximation
// 5 times faster than sqrt()

inline float fastsqrt1( float x )
{
    union { Int32 i; float x; } u;
    u.x = x;
    u.i = (Int32(1)<<29) + (u.i >> 1) - (Int32(1)<<22);
    return u.x;
}

inline double fastsqrt1( double x )
{
union { Int64 i; double x; } u;
    u.x = x;
    u.i = (Int64(1)<<61) + (u.i >> 1) - (Int64(1)<<51);
    return u.x;
}

// Log Base 2 Approximation with one extra Babylonian Step
// 2 times faster than sqrt()
inline float fastsqrt2( float x )
{
    float v=fastsqrt1( x );
    v = 0.5f * (v + x/v); // One Babylonian step
    return v;
}

inline double fastsqrt2(const double x)
{
    double v=fastsqrt1( x );
    v = 0.5f * (v + x/v); // One Babylonian step
    return v;
}

// Log Base 2 Approximation with two extra Babylonian Steps
// 50% faster than sqrt()
inline float fastsqrt3( float x )
{
    float v=fastsqrt1( x );
    v = v + x/v;
    v = 0.25f* v + x/v; // Two Babylonian steps
    return v;
}

inline double fastsqrt3(const double x)
{
    double v=fastsqrt1( x );
    v = v + x/v;
    v = 0.25 * v + x/v; // Two Babylonian steps
    return v;
}

//--------------------------------------------------------------------------
// Complex
//--------------------------------------------------------------------------
#ifndef DSP_USE_STD_COMPLEX

    template<typename T>
    inline std::complex<T> polar( const T &m, const T &a )
    {
        return std::polar( m, a );
    }

#else

    template<typename T>
    inline std::complex<T> polar( const T &m, const T &a )
    {
        return std::polar( m, a );
    }

#endif

(continues on next page)
inline T norm( const std::complex<T> &c )
{
    return std::norm( c );
}

template<typename T>
inline T abs( const std::complex<T> &c )
{
    return std::abs(c);
}

template<typename T, typename To>
inline std::complex<T> addmul( const std::complex<T> &c, T v, const std::complex<T>& cl )
{
    return std::complex<T>( c.real()+v*cl.real(), c.imag()+v*cl.imag() );
}

template<typename T>
inline T arg( const std::complex<T> &c )
{
    return std::arg( c );
}

template<typename T>
inline std::complex<T> recip( const std::complex<T> &c )
{
    T n=1.0/Dsp::norm(c);
    return std::complex<T>( n*c.real(), n*c.imag() );
}

template<typename T>
inline std::complex<T> sqrt( const std::complex<T> &c )
{
    return std::sqrt( c );
}

typedef std::complex<CalcT> Complex;

#else

//--------------------------------------------------------------------------
// "Its always good to have a few extra wheels in case one goes flat."

template<typename T>
struct ComplexT
{
    ComplexT();
    ComplexT( T r_, T i_=0 );

template<typename To>
ComplexT( const ComplexT<To> &c );

    T imag ( void ) const;
    T real ( void ) const;

    ComplexT & neg ( void );

}(continues on next page)
ComplexT & conj ( void );

```cpp
template<typename To>
ComplexT & add ( const ComplexT<To> &c );
template<typename To>
ComplexT & sub ( const ComplexT<To> &c );
template<typename To>
ComplexT & mul ( const ComplexT<To> &c );
template<typename To>
ComplexT & div ( const ComplexT<To> &c );
template<typename To>
ComplexT & addmul ( T v, const ComplexT<To> &c );
```

ComplexT operator- ( void ) const;

ComplexT operator+ ( T v ) const;
ComplexT operator- ( T v ) const;
ComplexT operator* ( T v ) const;
ComplexT operator/ ( T v ) const;

ComplexT & operator+= ( T v );
ComplexT & operator-= ( T v );
ComplexT & operator*= ( T v );
ComplexT & operator/= ( T v );

```cpp
template<typename To>
ComplexT operator+ ( const ComplexT<To> &c ) const;
template<typename To>
ComplexT operator- ( const ComplexT<To> &c ) const;
template<typename To>
ComplexT operator* ( const ComplexT<To> &c ) const;
template<typename To>
ComplexT operator/ ( const ComplexT<To> &c ) const;
```

```cpp
private:
ComplexT & add ( T v );
ComplexT & sub ( T v );
ComplexT & mul ( T c, T d );
ComplexT & mul ( T v );
ComplexT & div ( T v );
```

```cpp
T r;
T i;
```

(continues on next page)
495 inline ComplexT<T>::ComplexT()  
496 {  
497 }  
498
499 template<typename T>  
500 inline ComplexT<T>::ComplexT( T r_, T i_ )  
501 {  
502     r=r_;  
503     i=i_;  
504 }  
505
506 template<typename T>  
507 template<typename To>  
508 inline ComplexT<T>::ComplexT( const ComplexT<To> &c )  
509 {  
510     r=c.r;  
511     i=c.i;  
512 }  
513
514 template<typename T>  
515 inline T ComplexT<T>::imag( void ) const  
516 {  
517     return i;  
518 }  
519
520 template<typename T>  
521 inline T ComplexT<T>::real( void ) const  
522 {  
523     return r;  
524 }  
525
526 template<typename T>  
527 inline ComplexT<T> &ComplexT<T>::neg( void )  
528 {  
529     r=-r;  
530     i=-i;  
531     return *this;  
532 }  
533
534 template<typename T>  
535 inline ComplexT<T> &ComplexT<T>::conj( void )  
536 {  
537     i=-i;  
538     return *this;  
539 }  
540
541 template<typename T>  
542 inline ComplexT<T> &ComplexT<T>::add( T v )  
543 {  
544     r+=v;  
545     return *this;  
546 }  
547
548 template<typename T>  
549 inline ComplexT<T> &ComplexT<T>::sub( T v )  
550 {  
551     r-=v;  
552 (continues on next page)
    return *this;
  }

  template<typename T>
  inline ComplexT<T> &ComplexT<T>::mul(T c, T d)
  {
    T ac=r*c;
    T bd=i*d;
    // must do i first
    i=(r+i)*(c+d)-(ac+bd);
    r=ac-bd;
    return *this;
  }

  template<typename T>
  inline ComplexT<T> &ComplexT<T>::mul(T v)
  {
    r*=v;
    i*=v;
    return *this;
  }

  template<typename T>
  template<typename To>
  inline ComplexT<T> &ComplexT<T>::div(T v)
  {
    r/=v;
    i/=v;
    return *this;
  }

  template<typename T>
  template<typename To>
  inline ComplexT<T> &ComplexT<T>::add(const ComplexT<To> &c)
  {
    r+=c.r;
    i+=c.i;
    return *this;
  }

  template<typename T>
  template<typename To>
  inline ComplexT<T> &ComplexT<T>::sub(const ComplexT<To> &c)
  {
    r-=c.r;
    i-=c.i;
    return *this;
  }

  template<typename T>
  template<typename To>
  inline ComplexT<T> &ComplexT<T>::mul(const ComplexT<To> &c)
  {
    return mul(c.r, c.i);
  }
inline ComplexT<T> &ComplexT<T>::div( const ComplexT<To> &c )
{
    T s=1.0/norm(c);
    return mul( c.r*s, -c.i*s );
}

template<typename T>
inline ComplexT<T> ComplexT<T>::operator-( void ) const
{
    return ComplexT<T>(*this).neg();
}

template<typename T>
inline ComplexT<T> ComplexT<T>::operator+( T v ) const
{
    return ComplexT<T>(*this).add( v );
}

template<typename T>
inline ComplexT<T> ComplexT<T>::operator-( T v ) const
{
    return ComplexT<T>(*this).sub( v );
}

template<typename T>
inline ComplexT<T> ComplexT<T>::operator*( T v ) const
{
    return ComplexT<T>(*this).mul( v );
}

template<typename T>
inline ComplexT<T> &ComplexT<T>::operator+=( T v )
{
    return add( v );
}

template<typename T>
inline ComplexT<T> &ComplexT<T>::operator-=( T v )
{
    return sub( v );
}

template<typename T>
inline ComplexT<T> &ComplexT<T>::operator*=( T v )
{
    return mul( v );
}

template<typename T>
inline ComplexT<T> &ComplexT<T>::operator/=( T v )
{
    // continue on next page
}
template<typename T>
template<typename To>
inline ComplexT<T> ComplexT<T>::operator+( const ComplexT<To> &c ) const
{
    return ComplexT<T>(*this).add(c);
}

template<typename T>
template<typename To>
inline ComplexT<T> ComplexT<T>::operator-( const ComplexT<To> &c ) const
{
    return ComplexT<T>(*this).sub(c);
}

template<typename T>
template<typename To>
inline ComplexT<T> ComplexT<T>::operator*( const ComplexT<To> &c ) const
{
    return ComplexT<T>(*this).mul(c);
}

template<typename T>
template<typename To>
inline ComplexT<T> ComplexT<T>::operator/( const ComplexT<To> &c ) const
{
    return ComplexT<T>(*this).div(c);
}

template<typename T>
template<typename To>
inline ComplexT<T> &ComplexT<T>::operator+=( const ComplexT<To> &c )
{
    return add( c );
}

template<typename T>
template<typename To>
inline ComplexT<T> &ComplexT<T>::operator-=( const ComplexT<To> &c )
{
    return sub( c );
}

template<typename T>
template<typename To>
inline ComplexT<T> &ComplexT<T>::operator*=( const ComplexT<To> &c )
{
    return mul( c );
}

template<typename T>
template<typename To>
inline ComplexT<T> &ComplexT<T>::operator/=( const ComplexT<To> &c )
{
    return div( c );
}
template<typename T>
inline ComplexT<T> polar(const T &m, const T &a)
{
    return ComplexT<T>(m*cos(a), m*sin(a));
}

template<typename T>
inline T norm(const ComplexT<T> &c)
{
    return c.real()*c.real()+c.imag()*c.imag();
}

template<typename T>
inline T abs(const ComplexT<T> &c)
{
    return ::sqrt(c.real()*c.real()+c.imag()*c.imag());
}

template<typename T, typename To>
inline ComplexT<T> addmul(const ComplexT<T> &c, T v, const ComplexT<To> &c1)
{
    return ComplexT<T>(c.real()+v*c1.real(), c.imag()+v*c1.imag());
}

template<typename T>
inline T arg(const ComplexT<T> &c)
{
    return atan2(c.imag(), c.real());
}

template<typename T>
inline ComplexT<T> recip(const ComplexT<T> &c)
{
    T n=1.0/norm(c);
    return ComplexT<T>(n*c.real(), -n*c.imag());
}

template<typename T>
inline ComplexT<T> sqrt(const ComplexT<T> &c)
{
    return polar(::sqrt(abs(c)), arg(c)*0.5);
}

typedef ComplexT<CalcT> Complex;

3.12. Biquad, Butterworth, Chebyshev N-order, M-channel optimized filters
// Implementation of Brent's Method provided by
// John D. Cook (http://www.johndcook.com/)

// The return value of Minimize is the minimum of the function f.
// The location where f takes its minimum is returned in the variable minLoc.
// Notation and implementation based on Chapter 5 of Richard Brent's book
// "Algorithms for Minimization Without Derivatives".

template<class TFunction>
CalcT BrentMinimize
{
    TFunction& f, // [in] objective function to minimize
    CalcT leftEnd, // [in] smaller value of bracketing interval
    CalcT rightEnd, // [in] larger value of bracketing interval
    CalcT epsilon, // [in] stopping tolerance
    CalcT& minLoc // [out] location of minimum
}

CalcT d, e, m, p, q, r, tol, t2, u, v, w, fu, fv, fw, fx;
static const CalcT c = 0.5*(3.0 - ::sqrt(5.0));
static const CalcT SQRT_DBL_EPSILON = ::sqrt(DBL_EPSILON);
CalcT& a = leftEnd; CalcT& b = rightEnd; CalcT& x = minLoc;

v = w = x = a + c*(b - a); d = e = 0.0;
fv = fw = fx = f(x);

loop: counter++;
m = 0.5*(a + b);
tol = SQRT_DBL_EPSILON*::fabs(x) + epsilon; t2 = 2.0*tol;
// Check stopping criteria
if (::fabs(x - m) > t2 - 0.5*(b - a))
{
p = q = r = 0.0;
if (::fabs(e) < tol)
{
    // fit parabola
    r = (x - w)*(fx - fv);
    q = (x - v)*(fx - fw);
    p = (x - v)*q - (x - w)*r;
    q = 2.0*(q - r);
    (q > 0.0) ? p = -p : q = -q;
    r = e; e = d;
}
if (::fabs(p) < ::fabs(0.5*q*r) && p < q*(a - x) && p < q*(b - x))
{
    // A parabolic interpolation step
    d = p/q;
    u = x + d;
    // f must not be evaluated too close to a or b
    if (u - a < t2 || b - u < t2)
        d = (x < m) ? tol : -tol;
}
else
{ // A golden section step
    e = (x < m) ? b : a;
    e -= x;
    d = c*e;
}

// f must not be evaluated too close to x
if (::fabs(d) >= tol)
    u = x + d;
else if (d > 0.0)
    u = x + tol;
else
    u = x - tol;
fu = f(u);
// Update a, b, v, w, and x
if (fu <= fx)
{
    (u < x) ? b = x : a = x;
    v = w; fv = fw;
    w = x; fw = fx;
    x = u; fx = fu;
}
else
{
    (u < x) ? a = u : b = u;
    if (fu <= fw || w == x)
    {
        v = w; fv = fw;
        w = u; fw = fu;
    }
    else if (fu <= fw || v == x || v == w)
    {
        v = u; fv = fu;
    }
}
goto loop; // Yes, the dreaded goto statement. But the code
            // here is faithful to Brent's orginal pseudocode.
            // The goto statement is used to avoid an explicit
            // return statement.

return fx;

// Infinite Impulse Response Filters

class CascadeFilter
{
public:
    // Process data in place using Direct Form I
    // skip is added after each frame.
    // Direct Form I is more suitable when the filter parameters
    // are changed often. However, it is slightly slower.

    // IIR filter implementation using multiple second-order stages.
template<typename T>
void ProcessI( size_t frames, T *dest, int skip=0 );

// Process data in place using Direct Form II
// skip is added after each frame.
// Direct Form II is slightly faster than Direct Form I,
// but changing filter parameters on stream can result
// in discontinuities in the output. It is best suited
// for a filter whose parameters are set only once.
template<typename T>
void ProcessII( size_t frames, T *dest, int skip=0 );

// Convenience function that just calls ProcessI.
// Feel free to change the implementation.
template<typename T>
void Process( size_t frames, T *dest, int skip=0 );

// Determine response at angular frequency (0<=w<=kPi)
Complex Response( CalcT w );

// Clear the history buffer.
void Clear( void );

protected:
struct Hist;
struct Stage;

// for m_nchan==2
#if defined DSP_SSE3_OPTIMIZED
template<typename T>
void ProcessISSEStageStereo( size_t frames, T *dest, Stage *stage, Hist *h, int skip );

template<typename T>
void ProcessISSEStereo( size_t frames, T *dest, int skip );
#endif

protected:
void Reset ( void );
void Normalize( CalcT scale );
void SetAStage( CalcT x1, CalcT x2 );
void SetBStage( CalcT x0, CalcT x1, CalcT x2 );
void SetStage( CalcT a1, CalcT a2, CalcT b0, CalcT b1, CalcT b2 );

protected:
struct Hist
{
    CalcT v[4];
};

struct Stage
{
    CalcT a[3];    // a[0] unused
    CalcT b[3];
    void Reset( void );
};
struct ResponseFunctor
{
    CascadeFilter *m_filter;
    CalcT operator()( CalcT w );
    ResponseFunctor( CascadeFilter *filter );
};

int m_nchan;
int m_nstage;
Stage * m_stagep;
Hist * m_histp;

// Template specialization for SSE optimizations

template<typename T>
void CascadeFilter::ProcessI( size_t frames, T *dest, int skip )
{
    #ifdef DSP_SSE3_OPTIMIZED
        if( m_nchan==2 )
            ProcessISSEStereo( frames, dest, skip );
    else
    #endif
    while( frames-- )
    {
        Hist *h=m_histp;
        for( int j=m_nchan; j>=0; j-- )
        {
            CalcT in=CalcT(*dest);
            Stage *s=m_stagep;
            for( int i=m_nstage; i>=0; i++, h++, s++ )
            {
                CalcT out;
                out=s->b[0]*in + s->b[1]*h->v[0] + s->b[2]*h->v[1] +
                h->v[1]=h->v[0]; h->v[0]=in;
                in=out;
            }
            *dest++=T(in);
        }
        dest+=skip;
    }
    #endif
    // A good compiler already produces code that is optimized even for
    // the general case. The only way to make it go faster is to
    // to implement it in assembler or special instructions. Like this:

    #ifdef DSP_SSE3_OPTIMIZED
    // ALL SSE OPTIMIZATIONS ASSUME CalcT as double
    template<typename T>
    inline void CascadeFilter::ProcessISSEStageStereo( size_t frames, T *dest, Stage *s, Hist *h, int skip )
    {
        assert( m_nchan==2 );
#if 1
CalcT b0=s->b[0];

__m128d m0=_mm_loadu_pd( &s->a[1] ); // a1 , a2
__m128d m1=_mm_loadu_pd( &s->b[1] ); // b1 , b2
__m128d m2=_mm_loadu_pd( s*h[0].v[0] ); // h->v[0] , h->v[1]
__m128d m3=_mm_loadu_pd( s*h[0].v[2] ); // h->v[2] , h->v[3]
__m128d m4=_mm_loadu_pd( s*h[1].v[0] ); // h->v[0] , h->v[1]
__m128d m5=_mm_loadu_pd( s*h[1].v[2] ); // h->v[2] , h->v[3]

while( frames-- )
{
    CalcT in, b0in, out;

    __m128d m6;
    __m128d m7;

    in=CalcT(*dest);
    b0in=b0*in;

    m6=_mm_mul_pd ( m1, m2 ); // b1*h->v[0] , b2*h->v[1]
    m7=_mm_mul_pd ( m0, m3 ); // a1*h->v[2] , a2*h->v[3]
    m6=_mm_add_pd ( m6, m7 ); // b1*h->v[0] + a1*h->v[2], b2*h->
                         
    m7=_mm_load_sd( &b0in ); // b0*in , 0
    m6=_mm_add_sd ( m6, m7 ); // b1*h->v[0] + a1*h->v[2] +
                         
    m6=_mm_addh_pd( m6, m7 ); // b1*h->v[0] + a1*h->v[2] +
    m6=_mm_storeh_pd( m6, m7 ); // out , in
    m6=_mm_addh_pd( m6, in ); // h->v[1]=in , h->v[0]
    m3=_mm_shufflepd( m6, m3, _MM_SHUFFLE2( 0, 1 ) ); // h->v[0]=in , h->v[2]=out,
    m6=_mm_shufflepd( m6, m3, _MM_SHUFFLE2( 0, 0 ) ); // h->v[3]=h->v[2]

    *dest++=T(out);

    in=CalcT(*dest);
    b0in=b0*in;

    m6=_mm_mul_pd ( m1, m2 ); // b1*h->v[0] , b2*h->v[1]
    m7=_mm_mul_pd ( m0, m5 ); // a1*h->v[2] , a2*h->v[3]
    m6=_mm_add_pd ( m6, m7 ); // b1*h->v[0] + a1*h->v[2], b2*h->
                         
    m7=_mm_load_sd( &b0in ); // b0*in , 0
    m6=_mm_add_sd ( m6, m7 ); // b1*h->v[0] + a1*h->v[2] +
                         
    m6=_mm_addh_pd( m6, m7 ); // b1*h->v[0] + a1*h->v[2] +
    m6=_mm_storeh_pd( m6, m7 ); // out , in
    m6=_mm_addh_pd( m6, in ); // h->v[1]=h->v[0]
    m4=_mm_shufflepd( m6, m4, _MM_SHUFFLE2( 0, 1 ) ); // h->v[0]=in , h->v[2]=out,
    m5=_mm_shufflepd( m6, m5, _MM_SHUFFLE2( 0, 0 ) ); // h->v[3]=h->v[2]

    (continues on next page)
*dest++=T(out);

    dest+=skip;

}  // move history from registers back to state

_mm_storeu_pd( &h[0].v[0], m2 );
_mm_storeu_pd( &h[0].v[2], m3 );
_mm_storeu_pd( &h[1].v[0], m4 );
_mm_storeu_pd( &h[1].v[2], m5 );

#else

// Template-specialized version from which the assembly was modeled
CalcT a1=s->a[1];
CalcT a2=s->a[2];
CalcT b0=s->b[0];
CalcT b1=s->b[1];
CalcT b2=s->b[2];
while ( frames-- )
{
    CalcT in, out;

    in=CalcT(*dest);
    out=b0*in+b1*h[0].v[0]+b2*h[0].v[1]+a1*h[0].v[2]+a2*h[0].v[3];
    h[0].v[1]=h[0].v[0]; h[0].v[0]=in;
    in=out;
    *dest++=T(in);

    in=CalcT(*dest);
    h[1].v[1]=h[1].v[0]; h[1].v[0]=in;
    in=out;
    *dest++=T(in);

    dest+=skip;
}
#endif

// Note there could be a loss of accuracy here. Unlike the original version
// of Process...() we are applying each stage to all of the input data.
// Since the underlying type T could be float, the results from this function
// may be different than the unoptimized version. However, it is much faster.

template<typename T>
void CascadeFilter::ProcessISSEStageStereo( size_t frames, T *dest, int skip )
{
    assert( m_nchan==2 );
    Stage *s=m_stagep;
    Hist *h=m_histp;
    for( int i=m_nstage;i--;i+=2,s++ )
    {
        ProcessISSEStageStereo( frames, dest, s, h, skip );
    }
}
#endif

```cpp
template<typename T>
void CascadeFilter::ProcessII( size_t frames, T *dest, int skip )
{
    while( frames-- )
    {
        Hist *h=m_histp;
        for( int j=m_nchan;j;j-- )
        {
            CalcT in=CalcT(*dest);
            Stage *s=m_stagep;
            for( int i=m_nstage;i;i--,h++,s++ )
            {
                CalcT d2=h->v[2]=h->v[1];
                CalcT d1=h->v[1]=h->v[0];
                CalcT d0=h->v[0]=
                    in+s->a[1]*d1 + s->a[2]*d2;
                in=s->b[0]*d0 + s->b[1]*d1 + s->b[2]*d2;
            }
            *dest++=T(in);
        }
        dest+=skip;
    }
}

template<typename T>
inline void CascadeFilter::Process( size_t frames, T *dest, int skip )
{
    ProcessII( frames, dest, skip );
}

inline Complex CascadeFilter::Response( CalcT w )
{
    Complex ch( 1 );
    Complex cbot( 1 );
    Complex czn1=polar( 1., -w );
    Complex czn2=polar( 1., -2*w );
    Stage *s=m_stagep;
    for( int i=m_nstage;i;i-- )
    {
        Complex ct( s->b[0] );
        Complex cb( 1 );
        ct=addmul( ct, s->b[1], czn1 );
        cb=addmul( cb, -s->a[1], czn1 );
        ct=addmul( ct, s->b[2], czn2 );
        cb=addmul( cb, -s->a[2], czn2 );
        ch*=ct;
        cbot*=cb;
        s++;
    }
    return ch/cbot;
}
(continues on next page)
inline void CascadeFilter::Clear( void )
{
    ::memset( m_histp, 0, m_nstage*m_nchan*sizeof(m_histp[0]) );
}

inline void CascadeFilter::Stage::Reset( void )
{
    a[1]=0; a[2]=0;
    b[0]=1; b[1]=0; b[2]=0;
}

inline void CascadeFilter::Stage::Reset( void )
{
    Stage *s=m_stagep;
    for( int i=m_nstage;i;i--,s++ )
        s->Reset();
}

// Apply scale factor to stage coefficients.
inline void CascadeFilter::Normalize( CalcT scale )
{
    // We are throwing the normalization into the first
    // stage. In theory it might be nice to spread it around
    // to preserve numerical accuracy.
    Stage *s=m_stagep;
    s->b[0]*=scale; s->b[1]*=scale; s->b[2]*=scale;
}

inline void CascadeFilter::SetAStage( CalcT x1, CalcT x2 )
{
    Stage *s=m_stagep;
    for( int i=m_nstage;i;i-- )
    {
        if( s->a[1]==0 && s->a[2]==0 )
            { s->a[1]=x1; s->a[2]=x2; s=0; break; }
        if( s->a[2]==0 && x2==0 )
            { s->a[2]=-s->a[1]*x1; s->a[1]+=x1; s=0; break; }
        s++;
    }
    assert( s==0 );
}

inline void CascadeFilter::SetBStage( CalcT x0, CalcT x1, CalcT x2 )
{
    Stage *s=m_stagep;
    for( int i=m_nstage;i;i-- )
    {
        if( s->a[1]==0 && s->a[2]==0 )
            { s->a[1]=x1; s->a[2]=x2; s=0; break; }
        if( s->a[2]==0 && x2==0 )
            { s->a[2]=-s->a[1]*x1; s->a[1]+=x1; s=0; break; }
        s++;
    }
    assert( s==0 );
}
```cpp
if ( s->b[1]==0 && s->b[2]==0 )
{
    s->b[0]=x0;
    s->b[1]=x1;
    s->b[2]=x2;
    s=0;
    break;
}
if ( s->b[2]==0 && x2==0 )
{
    // (b0 + z b1)(x0 + z x1) = (b0 x0 + (b1 x0+b0 x1) z + b1 ...
    →x1 z^2)
    s->b[2]=s->b[1]*x1;
    s->b[1]=s->b[1]*x0+s->b[0]*x1;
    s->b[0]*=x0;
    s=0;
    break;
}
}
```
template<int stages, int channels>
CascadeStages<stages, channels>::CascadeStages(void)
{
    m_nchan=channels;
    m_nstage=stages;
    m_stage=m_stage;
    m_hist=m_hist;
    Clear();
}

// Biquad Second Order IIR Filters
//
// Formulas from http://www.musicdsp.org/files/Audio-EQ-Cookbook.txt

template<int channels>
class Biquad : public CascadeStages<1, channels>
{
protected:
    void Setup(const CalcT a[3], const CalcT b[3] );
};

//

template<int channels>
inline void Biquad<channels>::Setup(const CalcT a[3], const CalcT b[3] )
{
    Reset();
    // transform Biquad coefficients
    CalcT ra0=1/a[0];
    SetAStage( -a[1]*ra0, -a[2]*ra0 );
    SetBStage( b[0]*ra0, b[1]*ra0, b[2]*ra0 );
}

//

template<int channels>
class BiquadLowPass : public Biquad<channels>
{
public:
    void Setup ( CalcT normFreq, CalcT q );
    void SetupFast ( CalcT normFreq, CalcT q );
protected:
    void SetupCommon ( CalcT sn, CalcT cs, CalcT q );
};

//

template<int channels>
inline void BiquadLowPass<channels>::SetupCommon( CalcT sn, CalcT cs, CalcT q )
{
    CalcT alph = sn / ( 2 * q );
    CalcT a0 = 1 / ( 1 + alph );
    CalcT b1 = 1 - cs;

(continues on next page)
CalcT b0 = a0 * b1 * 0.5;
CalcT a1 = 2 * cs;
CalcT a2 = alph - 1;
SetStage( a1*a0, a2*a0, b0, b1*a0, b0 );

//template<int channels>
void BiquadLowPass<channels>::Setup( CalcT normFreq, CalcT q )
{
  CalcT w0 = 2 * kPi * normFreq;
  CalcT cs = cos(w0);
  CalcT sn = sin(w0);
  SetupCommon( sn, cs, q );
}

//template<int channels>
void BiquadLowPass<channels>::SetupFast( CalcT normFreq, CalcT q )
{
  CalcT w0 = 2 * kPi * normFreq;
  CalcT sn, cs;
  fastsincos( w0, &sn, &cs );
  SetupCommon( sn, cs, q );
}

//----------------------------------------------------------------------------------

//template<int channels>
class BiquadHighPass : public Biquad<channels>
{
public:
  void Setup( CalcT normFreq, CalcT q );
  void SetupFast( CalcT normFreq, CalcT q );
protected:
  void SetupCommon( CalcT sn, CalcT cs, CalcT q );
};

//----------------------------------------------------------------------------------

template<int channels>
inline void BiquadHighPass<channels>::SetupCommon( CalcT sn, CalcT cs, CalcT q )
{
  CalcT alph = sn / ( 2 * q );
  CalcT a0 = -1 / ( 1 + alph );
  CalcT b1 = -( 1 + cs );
  CalcT b0 = a0 * b1 * -0.5;
  CalcT a1 = -2 * cs;
  CalcT a2 = 1 - alph;
  SetStage( a1*a0, a2*a0, b0, b1*a0, b0 );
}

//template<int channels>
void BiquadHighPass<channels>::Setup( CalcT normFreq, CalcT q )
{
  CalcT w0 = 2 * kPi * normFreq;
  CalcT cs = cos(w0);
  CalcT sn = sin(w0);
  SetupCommon( sn, cs, q );
}
template<int channels>
void BiquadHighPass<channels>::SetupFast( CalcT normFreq, CalcT q )
{
    CalcT w0 = 2 * kPi * normFreq;
    CalcT sn, cs;
    fastsincos( w0, &sn, &cs );
    SetupCommon( sn, cs, q );
}

// Constant skirt gain, peak gain=Q
template<int channels>
class BiquadBandPass1 : public Biquad<channels>
{
    public:
        void Setup( CalcT normFreq, CalcT q );
        void SetupFast( CalcT normFreq, CalcT q );
    protected:
        void SetupCommon( CalcT sn, CalcT cs, CalcT q );
};

template<int channels>
inline void BiquadBandPass1<channels>::SetupCommon( CalcT sn, CalcT cs, CalcT q )
{
    CalcT alph = sn / ( 2 * q );
    CalcT a0 = -1 / ( 1 + alph );
    CalcT b0 = a0 * ( sn * -0.5 );
    CalcT a1 = -2 * cs;
    CalcT a2 = 1 - alph;
    SetStage( a1*a0, a2*a0, b0, 0, -b0 );
}

template<int channels>
void BiquadBandPass1<channels>::Setup( CalcT normFreq, CalcT q )
{
    CalcT w0 = 2 * kPi * normFreq;
    CalcT cs = cos(w0);
    CalcT sn = sin(w0);
    SetupCommon( sn, cs, q );
}

template<int channels>
void BiquadBandPass1<channels>::SetupFast( CalcT normFreq, CalcT q )
{
    CalcT w0 = 2 * kPi * normFreq;
    CalcT sn, cs;
    fastsincos( w0, &sn, &cs );
    SetupCommon( sn, cs, q );
}

//--------------------------------------------------------------------------

3.12. Biquad, Butterworth, Chebyshev N-order, M-channel optimized filters
// Constant 0dB peak gain
template<int channels>
class BiquadBandPass2 : public Biquad<channels>
{
public:
    void Setup ( CalcT normFreq, CalcT q );
    void SetupFast ( CalcT normFreq, CalcT q );
protected:
    void SetupCommon ( CalcT sn, CalcT cs, CalcT q );
};

//--------------------------------------------------------------------------

template<int channels>
inline void BiquadBandPass2<channels>::SetupCommon( CalcT sn, CalcT cs, CalcT q )
{
    CalcT alph = sn / ( 2 * q );
    CalcT b0 = -alph;
    CalcT b2 = alph;
    CalcT a0 = -1 / ( 1 + alph );
    CalcT a1 = -2 * cs;
    CalcT a2 = 1 - alph;
    SetStage( a1*a0, a2*a0, b0*a0, 0, b2*a0 );
}

template<int channels>
void BiquadBandPass2<channels>::Setup( CalcT normFreq, CalcT q )
{
    CalcT w0 = 2 * kPi * normFreq;
    CalcT cs = cos(w0);
    CalcT sn = sin(w0);
    SetupCommon( sn, cs, q );
}

template<int channels>
void BiquadBandPass2<channels>::SetupFast( CalcT normFreq, CalcT q )
{
    CalcT w0 = 2 * kPi * normFreq;
    CalcT sn, cs;
    fastsincos( w0, &sn, &cs );
    SetupCommon( sn, cs, q );
}

//--------------------------------------------------------------------------

template<int channels>
class BiquadBandStop : public Biquad<channels>
{
public:
    void Setup ( CalcT normFreq, CalcT q );
    void SetupFast ( CalcT normFreq, CalcT q );
protected:
    void SetupCommon ( CalcT sn, CalcT cs, CalcT q );
};

//--------------------------------------------------------------------------

(continues on next page)
template<int channels>
inline void BiquadBandStop<channels>::SetupCommon( CalcT sn, CalcT cs, CalcT q )
{
    CalcT alph = sn / ( 2 * q );
    CalcT a0 = 1 / ( 1 + alph );
    CalcT b1 = a0 * ( -2 * cs );
    CalcT a2 = alph - 1;
    SetStage( -b1, a2*a0, a0, b1, a0 );
}

template<int channels>
void BiquadBandStop<channels>::Setup( CalcT normFreq, CalcT q )
{
    CalcT w0 = 2 * kPi * normFreq;
    CalcT cs = cos(w0);
    CalcT sn = sin(w0);
    SetupCommon( sn, cs, q );
}

void BiquadBandStop<channels>::SetupFast( CalcT normFreq, CalcT q )
{
    CalcT w0 = 2 * kPi * normFreq;
    CalcT sn, cs;
    fastsincos( w0, &sn, &cs );
    SetupCommon( sn, cs, q );
}

template<int channels>
class BiquadAllPass: public Biquad<channels>
{
public:
    void Setup( CalcT normFreq, CalcT q );
    void SetupFast( CalcT normFreq, CalcT q );
protected:
    void SetupCommon( CalcT sn, CalcT cs, CalcT q );
};

template<int channels>
void BiquadAllPass<channels>::SetupCommon( CalcT sn, CalcT cs, CalcT q )
{
    CalcT alph = sn / ( 2 * q );
    CalcT b2 = 1 + alph;
    CalcT a0 = 1 / b2;
    CalcT b0 = ( 1 - alph ) * a0;
    CalcT b1 = -2 * cs * a0;
    SetStage( -b1, -b0, b0, b1, b2*a0 );
}

template<int channels>
void BiquadAllPass<channels>::Setup( CalcT normFreq, CalcT q )
{
    CalcT w0 = 2 * kPi * normFreq;
}
template<int channels>
    void BiquadAllPass<channels>::SetupFast( CalcT normFreq, CalcT q )
    {
        CalcT w0 = 2 * kPi * normFreq;
        CalcT sn, cs;
        fastsincos( w0, &sn, &cs );
        SetupCommon( sn, cs, q );
    }

    template<int channels>
    class BiquadPeakEq: public Biquad<channels>
    {
        public:
            void Setup( CalcT normFreq, CalcT dB, CalcT bandWidth );
            void SetupFast( CalcT normFreq, CalcT dB, CalcT bandWidth );
        protected:
            void SetupCommon( CalcT sn, CalcT cs, CalcT alph, CalcT A );
    };
void BiquadPeakEq<channels>::SetupFast( CalcT normFreq, CalcT dB, CalcT bandWidth, 
   CalcT shelfSlope=1.0 )
{
  CalcT A = pow( 10, dB/40 );
  CalcT w0 = 2 * kPi * normFreq;
  CalcT sn, cs;
  fastsincos( w0, &sn, &cs );
  CalcT alph = sn * sinh( kLn2/2 * bandWidth * w0/sn );
  SetupCommon( sn, cs, alph, A );
}

template<int channels>
class BiquadLowShelf : public Biquad<channels>
{

  public:
    void Setup( CalcT normFreq, CalcT dB, CalcT shelfSlope=1.0 );
    void SetupFast( CalcT normFreq, CalcT dB, CalcT shelfSlope=1.0 );

  protected:
    void SetupCommon( CalcT cs, CalcT A, CalcT sa );

};

template<int channels>
inline void BiquadLowShelf<channels>::SetupCommon( 
  CalcT cs, CalcT A, CalcT sa )
{
  CalcT An = A-1;
  CalcT Ap = A+1;
  CalcT Ancs = An*cs;
  CalcT Apcs = Ap*cs;
  CalcT b0 = A * (Ap - Apcs + sa );
  CalcT b2 = A * (Ap - Apcs - sa );
  CalcT b1 = 2 * A * (An - Apcs);
  CalcT a2 = sa - (Ap + Apcs);
  CalcT a0 = 1 / (Ap + Apcs + sa );
  CalcT a1 = 2 * (An + Apcs);
  SetStage( a1*a0, a2*a0, b0*a0, b1*a0, b2*a0 );
}

template<int channels>
void BiquadLowShelf<channels>::Setup( CalcT normFreq, CalcT dB, CalcT shelfSlope )
{
  CalcT A = pow( 10, dB/40 );
  CalcT w0 = 2 * kPi * normFreq;
  CalcT cs = cos(w0);
  CalcT sn = sin(w0);
  CalcT al = sn / 2 * ::sqrt( (A + 1/A) * (1/shelfSlope - 1) + 2 );
  CalcT sa = 2 * ::sqrt( A ) * al;
  SetupCommon( cs, A, sa );
}

// This could be optimized further
template<int channels>
    void BiquadLowShelf<channels>::SetupFast( CalcT normFreq, CalcT dB, CalcT shelfSlope )
    {
        CalcT A = pow( 10, dB/40 );
        CalcT w0 = 2 * kPi * normFreq;
        CalcT sn, cs;
        fastsincos( w0, &sn, &cs );
        CalcT al = sn / 2 * fastsqrt1( (A + 1/A) * (1/shelfSlope - 1) + 2 );
        CalcT sa = 2 * fastsqrt1( A ) * al;
        SetupCommon( cs, A, sa );
    }

    //------------------------------------------------------------------------------

template<int channels>
    class BiquadHighShelf : public Biquad<channels>
    {
    public:
        void Setup( CalcT normFreq, CalcT dB, CalcT shelfSlope=1.0 );
        void SetupFast( CalcT normFreq, CalcT dB, CalcT shelfSlope=1.0 );
    protected:
        void SetupCommon( CalcT cs, CalcT A, CalcT sa );
    }

    //------------------------------------------------------------------------------

template<int channels>
    void BiquadHighShelf<channels>::SetupCommon( CalcT cs, CalcT A, CalcT sa )
    {
        CalcT An = A-1;
        CalcT Ap = A+1;
        CalcT Ancs = An*cs;
        CalcT Apcs = Ap*cs;
        CalcT b0 = A * (Ap + Ancs + sa );
        CalcT b1 = -2 * A * (An + Apcs);
        CalcT b2 = A * (Ap + Ancs - sa );
        CalcT a0 = (Ap - Ancs + sa );
        CalcT a2 = Ancs + sa - Ap;
        CalcT a1 = -2 * (An - Apcs);
        SetStage( a1/a0, a2/a0, b0/a0, b1/a0, b2/a0 );
    }

    template<int channels>
    void BiquadHighShelf<channels>::Setup( CalcT normFreq, CalcT dB, CalcT shelfSlope )
    {
        CalcT A = pow( 10, dB/40 );
        CalcT w0 = 2 * kPi * normFreq;
        CalcT cs = cos(w0);
        CalcT sn = sin(w0);

        CalcT alph = sn / 2 * ::sqrt( (A + 1/A) * (1/shelfSlope - 1) + 2 );
        CalcT sa = 2 * ::sqrt( A ) * alph;
    }
template<int channels>
void BiquadHighShelf<channels>::SetupFast( CalcT normFreq, CalcT dB, CalcT_
shelfSlope )
{
    CalcT A = pow( 10, dB/40 );
    CalcT w0 = 2 * kPi * normFreq;
    CalcT sn, cs;
    fastsincos( w0, &sn, &cs );
    CalcT alph = sn / 2 * fastsqrt1( (A + 1/A) * (1/shelfSlope - 1) + 2 );
    CalcT sa = 2 * fastsqrt1( A ) * alph;
    SetupCommon( cs, A, sa );
}

// General N-Pole IIR Filter

template<int stages, int channels>
class PoleFilter : public CascadeStages<stages, channels>
{
public:
    PoleFilter();

    virtual int CountPoles ( void )=0;
    virtual int CountZeroes ( void )=0;

    virtual Complex GetPole ( int i )=0;
    virtual Complex GetZero ( int i )=0;

protected:
    virtual Complex GetSPole ( int i, CalcT wc )=0;

protected:
    // Determines the method of obtaining
    // unity gain coefficients in the passband.
    enum Hint
    {
        // No normalizing
        hintNone,
        // Use Brent's method to find the maximum
        hintBrent,
        // Use the response at a given frequency
        hintPassband
    };

    Complex BilinearTransform ( const Complex &c );
    Complex BandStopTransform ( int i, const Complex &c );
    Complex BandPassTransform ( int i, const Complex &c );
    Complex GetBandStopPole ( int i );
    Complex GetBandStopZero ( int i );
    Complex GetBandPassPole ( int i );

(continues on next page)
Complex GetBandPassZero ( int i );
void Normalize ( void );
void Prepare ( void );

virtual void BrentHint ( CalcT *w0, CalcT *w1 );
virtual CalcT PassbandHint ( void );

protected:
    Hint m_hint;
    int m_n;
    CalcT m_wc;
    CalcT m_wc2;
};

//--------------------------------------------------------------------------
template<int stages, int channels>
inline PoleFilter<stages, channels>::PoleFilter( void )
{
    m_hint=hintNone;
}

template<int stages, int channels>
inline Complex PoleFilter<stages, channels>::BilinearTransform( const Complex &c )
{
    return (c+1.)/(-c+1.);
}

template<int stages, int channels>
inline Complex PoleFilter<stages, channels>::BandStopTransform( int i, const Complex &c )
{
    CalcT a=cos((m_wc+m_wc2) *0.5)/
        cos((m_wc-m_wc2)*0.5);
    CalcT b=tan((m_wc-m_wc2)*0.5);
    Complex c2(0);
    c2=addmul( c2, 4*(b*b-a*a-1), c );
    c2+=8*(b*b-a*a+1);
    c2+=a;
    c2=addmul( c2, -a, c );
    Complex c3( b+1 );
    c3=addmul( c3, b-1, c );
    return c2/c3;
}

template<int stages, int channels>
inline Complex PoleFilter<stages, channels>::BandPassTransform( int i, const Complex &c )
{
    CalcT a=cos((m_wc+m_wc2)*0.5)/
        cos((m_wc-m_wc2)*0.5);
    CalcT b=1/tan((m_wc-m_wc2)*0.5);
    Complex c2(0);
c2+=addmul( c2, 4*(b*b*(a*a-1)+1), c );
c2+=8*(b*b*(a*a-1)-1);
c2+=c;
c2+=4*(b*b*(a*a-1)+1);
c2=Dsp::sqrt( c2 );
if ((i < l) == 0)
c2=-c2;
c2+=2*a*b;
Complex c3(0);
c3+=2*(1+b);
return c2/c3;

template<int stages, int channels>
Complex PoleFilter<stages, channels>::GetBandStopPole ( int i )
{
  Complex c=GetSPole ( i/2, kPi_2 );
c=BilinearTransform ( c );
c=BandStopTransform ( i, c );
  return c;
}

template<int stages, int channels>
Complex PoleFilter<stages, channels>::GetBandStopZero ( int i )
{
  return BandStopTransform ( i, Complex ( -1 ) );
}

template<int stages, int channels>
Complex PoleFilter<stages, channels>::GetBandPassPole ( int i )
{
  Complex c=GetSPole ( i/2, kPi_2 );
c=BilinearTransform ( c );
c=BandPassTransform ( i, c );
  return c;
}

template<int stages, int channels>
Complex PoleFilter<stages, channels>::GetBandPassZero ( int i )
{
  return Complex ( (i>=m_n)?1:-1 );
}

template<int stages, int channels>
void PoleFilter<stages, channels>::Normalize ( void )
{
  switch ( m_hint )
  {
    default:
    case hintNone:
      break;
    case hintPassband:
      { CalcT w=PassbandHint();
        ...
      }
  }
ResponseFunctor f(this);
CalcT mag=-f(w);
CascadeStages::Normalize( 1/mag );

}  
break;

case hintBrent:
{
    ResponseFunctor f(this);
    CalcT w0, w1, wmin, mag;
    BrentHint( &w0, &w1 );
    mag=BrentMinimize( f, w0, w1, 1e-4, wmin );
    CascadeStages::Normalize( 1/mag );
    
}  
break;

}

template<int stages, int channels>
void PoleFilter<stages, channels>::Prepare( void )
{
    if( m_wc2<1e-8 )
        m_wc2=1e-8;
    if( m_wc>kPi-1e-8 )
        m_wc =kPi-1e-8;

    Reset();

    Complex c;
    int poles=CountPoles();
    for( int i=0;i<poles;i++ )
    {
        c=GetPole( i );
        if( ::abs(c.imag())<1e-6 )
            c=Complex( c.real(), 0 );
        if( c.imag()==0 )
            SetAStage( c.real(), 0 );
        else if( c.imag()>0 )
            SetAStage( 2*c.real(), -Dsp::norm(c) );
    }  

    int zeroes=CountZeroes();
    for( int i=0;i<zeroes;i++ )
    {
        c=GetZero( i );
        if( ::abs(c.imag())<1e-6 )
            c=Complex( c.real(), 0 );
        if( c.imag()==0 )
            SetBStage( -c.real(), 1, 0 );
        else if( c.imag()>0 )
            SetBStage( Dsp::norm(c), -2*c.real(), 1 );
    }  

    Normalize();
}

template<int stages, int channels>
void PoleFilter<stages, channels>::BrentHint( CalcT *w0, CalcT *w1 )
{
    // best that this never executes
    *w0=1e-4;
    *w1=kPi-1e-4;
}

template<int stages, int channels>
CalcT PoleFilter<stages, channels>::PassbandHint( void )
{
    // should never get here
    assert( 0 );
    return kPi_2;
}

// Butterworth filter response characteristic.
// Maximally flat magnitude response in the passband at the
// expense of a more shallow rolloff in comparison to other types.
template<int poles, int channels>
class Butterworth : public PoleFilter<int((poles+1)/2), channels>
{
public:
    Butterworth();

    // cutoffFreq = freq / sampleRate
    void Setup ( CalcT cutoffFreq );

    virtual int CountPoles ( void );
    virtual int CountZeros ( void );
    virtual Complex GetPole ( int i );

protected:
    Complex GetSPole ( int i, CalcT wc );
};

// Butterworth<poles, channels>::Butterworth( void )
{
    m_hint=hintPassband;
}

template<int poles, int channels>
void Butterworth<poles, channels>::Setup( CalcT cutoffFreq )
{
    m_n=poles;
    m_wc=2*kPi*cutoffFreq;
    Prepare();
}
// Low Pass Butterworth filter
// Stable up to 53 poles (frequency min=0.13% of Nyquist)

// High Pass Butterworth filter
// Maximally flat magnitude response in the passband.
// Stable up to 110 poles (frequency max=97% of Nyquist)
template<int poles, int channels>
class ButterHighPass : public Butterworth<poles, channels>
{
    public:
        Complex GetZero(int i);

    protected:
        CalcT PassbandHint ( void );
};

//----------------------------------------------------------

template<int poles, int channels>
Complex ButterHighPass<poles, channels>::GetZero(int i)
{
    return Complex(1);
}

template<int poles, int channels>
CalcT ButterHighPass<poles, channels>::PassbandHint(void)
{
    return kPi;
}

//------------------------------------------------------------------------------------------------------------------

// Band pass Butterworth filter
// Stable up to 80 pairs
template<int pairs, int channels>
class ButterBandPass : public Butterworth<pairs*2, channels>
{
    public:
        // centerFreq = freq / sampleRate
        // normWidth = freqWidth / sampleRate
        void Setup ( CalcT centerFreq, CalcT normWidth )
        {
            m_n = pairs;
            CalcT angularWidth = 2*kPi*normWidth;
            m_wc2 = 2*kPi*centerFreq-(angularWidth/2);
            m_wc = m_wc2+angularWidth;
            Prepare();
        }

    virtual int CountPoles ( void );
    virtual int CountZeroes ( void );
    virtual Complex GetPole ( int i );
    virtual Complex GetZero ( int i );

    protected:
        CalcT PassbandHint ( void );
};

//------------------------------------------------------------------------------------------------------------------
```cpp
// Band Stop Butterworth filter
// Stable up to 109 pairs
template <int pairs, int channels>
class ButterBandStop : public Butterworth<pairs*2, channels>
{
public:
    // centerFreq = freq / sampleRate
    // normWidth = freqWidth / sampleRate
    void Setup ( CalcT centerFreq, CalcT normWidth );

    virtual int CountPoles ( void );
    virtual int CountZeroes ( void );
    virtual Complex GetPole ( int i );
    virtual Complex GetZero ( int i );

protected:
    CalcT PassbandHint ( void );
};

//--------------------------------------------------------------------------
//template <int pairs, int channels>
void ButterBandStop<pairs, channels>::Setup( CalcT centerFreq, CalcT normWidth )
{ (continues on next page)
m_n=pairs;
CalcT angularWidth=2*kPi*normWidth;
m_wc2=2*kPi*centerFreq-(angularWidth/2);
m_wc =m_wc2+angularWidth;
Prepare();
}

template<int pairs, int channels>
int ButterBandStop<pairs, channels>::CountPoles( void )
{
    return pairs*2;
}

template<int pairs, int channels>
int ButterBandStop<pairs, channels>::CountZeros( void )
{
    return pairs*2;
}

template<int pairs, int channels>
Complex ButterBandStop<pairs, channels>::GetPole( int i )
{
    return GetBandStopPole( i );
}

template<int pairs, int channels>
Complex ButterBandStop<pairs, channels>::GetZero( int i )
{
    return GetBandStopZero( i );
}

calcT ButterBandStop<poles, channels>::PassbandHint( void )
{
    if( (m_wc+m_wc2)/2<kPi_2 )
        return kPi;
    else
        return 0;
}

//--------------------------------------------------------------------------------------------------------
// Chebyshev Response IIR Filter
//--------------------------------------------------------------------------------------------------------

// Type I Chebyshev filter characteristic.
// Minimum error between actual and ideal response at the expense of
// a user-definable amount of ripple in the passband.
template<int poles, int channels>
class Chebyshev1 : public PoleFilter<int((poles+1)/2), channels>
{
    public:

    // cutoffFreq = freq / sampleRate
    virtual void Setup( CalcT cutoffFreq, CalcT...
->rippleDb );
virtual int CountPoles (void);
virtual int CountZeroes (void);
virtual Complex GetPole (int i);
virtual Complex GetZero (int i);
protected:
    void SetupCommon (CalcT rippleDb);
    virtual Complex GetSPole (int i, CalcT wc);
protected:
    CalcT m_sgn;
    CalcT m_eps;

//--------------------------------------------------------------------------
template<int poles, int channels>
Chebyshev1<poles, channels>::Chebyshev1()
{
    m_hint = hintBrent;
}

template<int poles, int channels>
void Chebyshev1<poles, channels>::Setup (CalcT cutoffFreq, CalcT rippleDb)
{
    m_n = poles;
    m_wc = 2 * kPi * cutoffFreq;
    SetupCommon (rippleDb);
}

template<int poles, int channels>
void Chebyshev1<poles, channels>::SetupCommon (CalcT rippleDb)
{
    m_eps = ::sqrt (1 / ::exp (- rippleDb * 0.1 * kLn10 ) - 1);
    Prepare();
    // This moves the bottom of the ripples to 0dB gain
    // CascadeStages::Normalize( pow( 10, rippleDb/20.0 ) );
}

template<int poles, int channels>
int Chebyshev1<poles, channels>::CountPoles (void)
{
    return poles;
}

template<int poles, int channels>
int Chebyshev1<poles, channels>::CountZeroes (void)
{
    return poles;
}

template<int poles, int channels>
Complex Chebyshev1<poles, channels>::GetPole (int i)
{
    return BilinearTransform (GetSPole(i, m_wc)) * m_sgn;
}
template<unsigned int poles, unsigned int channels>
Complex Chebyshev1<poles, channels>::GetZero( int i )
{
    return Complex( -m_sgn );
}

template<unsigned int poles, unsigned int channels>
Complex Chebyshev1<poles, channels>::GetSPole( int i, CalcT wc )
{
    int n = m_n;
    CalcT ni = 1.0/n;
    CalcT alpha = 1/m_eps+::sqrt(1+1/(m_eps*m_eps));
    CalcT pn = pow( alpha, ni );
    CalcT nn = pow( alpha, -ni );
    CalcT a = 0.5*( pn - nn );
    CalcT b = 0.5*( pn + nn );
    CalcT theta = (2*i+1) * kPi/(2*n);
    Complex c = polar( tan( 0.5*(m_sgn==-1?(kPi-wc):wc) ), theta );
    return Complex( a*c.real(), b*c.imag() );
}

// Low Pass Chebyshev Type I filter

template<unsigned int poles, unsigned int channels>
class Cheby1LowPass : public Chebyshev1<poles, channels>
{
    public:
        Cheby1LowPass();

        void   Setup( CalcT cutoffFreq, CalcT rippleDb );

    protected:
        CalcT PassbandHint ( void );
};

//------------------------------------------------------------------------------

template<unsigned int poles, unsigned int channels>
Cheby1LowPass<poles, channels>::Cheby1LowPass()
{
    m_sgn=1;
    m_hint=hintPassband;
}

template<unsigned int poles, unsigned int channels>
void Cheby1LowPass<poles, channels>::Setup( CalcT cutoffFreq, CalcT rippleDb )
{
    Chebyshev1::Setup( cutoffFreq, rippleDb );
    // move peak of ripple down to 0dB
    if( !(poles&1) )
        CascadeStages::Normalize( pow( 10, -rippleDb/20.0 ) );
}

3.12. Biquad, Butterworth, Chebyshev N-order, M-channel optimized filters

(continues on next page)
{    return 0;
}

// High Pass Chebyshev Type I filter

template<int poles, int channels>
class Cheby1HighPass : public Chebyshev1<poles, channels> {
    public:
        Cheby1HighPass();
        void Setup ( CalcT cutoffFreq, CalcT rippleDb );

    protected:
        CalcT PassbandHint ( void );
};

template<int poles, int channels>
Cheby1HighPass<poles, channels>::Cheby1HighPass() {
    m_sgn=-1;
    m_hint=hintPassband;
}

template<int poles, int channels>
void Cheby1HighPass<poles, channels>::Setup( CalcT cutoffFreq, CalcT rippleDb ) {
    Chebyshev1::Setup( cutoffFreq, rippleDb );
    // move peak of ripple down to 0dB
    if( !(poles&1) )
        CascadeStages::Normalize( pow( 10, -rippleDb/20.0 ) );
}

template<int poles, int channels>
CalcT Cheby1HighPass<poles, channels>::PassbandHint( void ) {
    return kPi;
}

// Band Pass Chebyshev Type I filter

template<int pairs, int channels>
class Cheby1BandPass : public Chebyshev1<pairs*2, channels> {
    public:
        Cheby1BandPass();
        void Setup ( CalcT centerFreq, CalcT normWidth, CalcT rippleDb );

    int CountPoles ( void );
    int CountZeros ( void );
}
Complex GetPole ( int i );
Complex GetZero ( int i );

protected:
    void BrentHint ( CalcT *w0, CalcT *w1 );
    //CalcT PassbandHint ( void );

//--------------------------------------------------------------------------
template<int pairs, int channels>
Cheby1BandPass<pairs, channels>::Cheby1BandPass()
{
    m_sgn=1;
    m_hint=hintBrent;
}

template<int pairs, int channels>
void Cheby1BandPass<pairs, channels>::Setup( CalcT centerFreq, CalcT normWidth, CalcT rippleDb )
{
    m_n=pairs;
    CalcT angularWidth=2*kPi*normWidth;
    m_wc2=2*kPi*centerFreq-(angularWidth/2);
    m_wc =m_wc2+angularWidth;
    SetupCommon( rippleDb );
}

template<int pairs, int channels>
int Cheby1BandPass<pairs, channels>::CountPoles( void )
{
    return pairs*2;
}

template<int pairs, int channels>
int Cheby1BandPass<pairs, channels>::CountZeroes( void )
{
    return pairs*2;
}

template<int pairs, int channels>
Complex Cheby1BandPass<pairs, channels>::GetPole( int i )
{
    return GetBandPassPole( i );
}

template<int pairs, int channels>
Complex Cheby1BandPass<pairs, channels>::GetZero( int i )
{
    return GetBandPassZero( i );
}

template<int poles, int channels>
void Cheby1BandPass<poles, channels>::BrentHint( CalcT *w0, CalcT *w1 )
{
    CalcT d=1e-4*(m_wc-m_wc2)/2;
    *w0=m_wc2+d;
```cpp
// Unfortunately, this doesn't work at the frequency extremes
// Maybe we can inverse pre-warp the center point to make sure
// it stays put after bilinear and bandpass transformation.

template<int poles, int channels>
CalcT Cheby1BandPass<poles, channels>::PassbandHint( void )
{
    return (m_wc+m_wc2)/2;
}

/*-------------------------------------------------------------------------------
// Band Stop Chebyshev Type I filter

template<int pairs, int channels>
class Cheby1BandStop : public Chebyshev1<pairs*2, channels>
{
    public:
    
    void Setup ( CalcT centerFreq, CalcT normWidth, ...CalcT rippleDb );
    int CountPoles ( void );
    int CountZeroes ( void );
    Complex GetPole ( int i );
    Complex GetZero ( int i );

    protected:
    void BrentHint ( CalcT *w0, CalcT *wl );
    CalcT PassbandHint ( void );

    };

/*-------------------------------------------------------------------------------

template<int pairs, int channels>
Cheby1BandStop<pairs, channels>::Cheby1BandStop()
{
    m_sgn=1;
    m_hint=hintPassband;
}
```

### 3.12.1 Comments

- **Date:** 2010-06-18 10:53:04
- **By:** ten.nozirev@nuSL

These codes are just what I am looking for. Too bad they are incomplete as posted here. Could someone direct me to a complete version?
I *think* this is the project homepage:
http://code.google.com/p/dspfilterscpp/
although I haven't downloaded anything to verify it is and that the code is complete.

The project is here:
https://github.com/vinniefalco/DSPFilters.git

3.13 Butterworth Optimized C++ Class

• **Author or source:** neotec

• **Type:** 24db Resonant Lowpass

• **Created:** 2007-01-20 22:41:06

Listing 18: notes

This ist exactly the same as posted by "Zxform" (filters004.txt). The only difference is,
that this version is an optimized one.

Parameters:
Cutoff [0.f -> Nyquist.f]
Resonance [0.f -> 1.f]

There are some minima and maxima defined, to make ist sound nice in all situations.

This class is part of some of my VST Plugins, and works well and executes fast.

Listing 19: code

```cpp
// FilterButterworth24db.h

#pragma once

class CFilterButterworth24db
{
public:
    CFilterButterworth24db( void );
    ~CFilterButterworth24db( void );
    void SetSampleRate( float fs);
    void Set( float cutoff, float q );
    float Run( float input );

private:
    float t0, t1, t2, t3;
    float coef0, coef1, coef2, coef3;
    float history1, history2, history3, history4;
};
```

(continues on next page)
float gain;
float min_cutoff, max_cutoff;

// FilterButterworth24db.cpp
#include <math.h>
#define BUDDA_Q_SCALE 6.f
#include "FilterButterworth24db.h"

CFilterButterworth24db::CFilterButterworth24db(void)
{
    this->history1 = 0.f;
    this->history2 = 0.f;
    this->history3 = 0.f;
    this->history4 = 0.f;
    this->SetSampleRate(44100.f);
    this->Set(22050.f, 0.0);
}

CFilterButterworth24db::~CFilterButterworth24db(void)
{
}

void CFilterButterworth24db::SetSampleRate(float fs)
{
    float pi = 4.f * atanf(1.f);
    this->t0 = 4.f * fs * fs;
    this->t1 = 8.f * fs * fs;
    this->t2 = 2.f * fs;
    this->t3 = pi / fs;
    this->min_cutoff = fs * 0.01f;
    this->max_cutoff = fs * 0.45f;
}

void CFilterButterworth24db::Set(float cutoff, float q)
{
    if (cutoff < this->min_cutoff)
        cutoff = this->min_cutoff;
    else if (cutoff > this->max_cutoff)
        cutoff = this->max_cutoff;

    if (q < 0.f)
        q = 0.f;
    else if (q > 1.f)
        q = 1.f;

    float wp = this->t2 * tanf(this->t3 * cutoff);
    float bd, bd_tmp, b1, b2;
    q *= BUDDA_Q_SCALE;
    q += 1.f;
(continues on next page)
b1 = (0.765367f / q) / wp;
b2 = 1.f / (wp * wp);
bd_tmp = this->t0 * b2 + 1.f;
b = 1.f / (bd_tmp + this->t2 * b1);
this->gain = bd * 0.5f;
this->coef2 = (2.f - this->t1 * b2);
this->coef0 = this->coef2 * bd;
this->coef1 = (bd_tmp - this->t2 * b1) * bd;

b1 = (1.847759f / q) / wp;
b = 1.f / (bd_tmp + this->t2 * b1);
this->gain *= bd;
this->coef2 *= bd;
this->coef3 = (bd_tmp - this->t2 * b1) * bd;
}

float CFilterButterworth24db::Run(float input)
{
    float output = input * this->gain;
    float new_hist;

    output -= this->history1 * this->coef0;
    new_hist = output - this->history2 * this->coef1;

    output = new_hist + this->history1 * 2.f;
    output += this->history2;

    this->history2 = this->history1;
    this->history1 = new_hist;

    output -= this->history3 * this->coef2;
    new_hist = output - this->history4 * this->coef3;

    output = new_hist + this->history3 * 2.f;
    output += this->history4;

    this->history4 = this->history3;
    this->history3 = new_hist;

    return output;
}

3.13.1 Comments

- Date: 2007-01-22 18:38:23
- By: moc.oohay@bob
This sounds really nice, especially with resonance. Although it becomes unstable below 4K (at 44100 s/r), which explains why the min_cutoff value has been set quite high. Would using doubles help stabilise it? Also, I can't figure out how to get a high pass out of this, can anybody help? Cheers.

- **Date:** 2007-01-22 19:54:21
- **By:** neotec

I have checked the peak output of this filter and especially for low frequencies ... there is a simple fix, which makes it sound better with low frequencies: change the line in Set(...) that reads 'this->gain = bd * 0.5f;' to 'this->gain = bd;'

- **Date:** 2007-01-22 22:27:11
- **By:** moc.oohay@bob

Thanks for the quick reply. I've tried your change and it's made a slight tonal difference here, but the tests were not particularly scientific. I've discovered more detail in the problem, and it's one that has been commented on with other filters: If I sweep the filter quickly up or down the low frequencies it blows out really badly, even with zero Q. I'm new to filter math, so excuse my ignorance if this is a common thing with Butterworth.

- **Date:** 2007-01-23 12:54:03
- **By:** neotec

Yep ... this filter reacts very extreme on fast cutoff changes. I've added a function to my VST Synthesizer, which 'fades' the cutoff value from actual value to the desired one in about 0.05 seconds. My modulation envelopes do have similar restrictions concerning speed.

- **Date:** 2007-01-23 16:35:51
- **By:** neotec

If you want to know how this filter sounds, visit the kvraudio forum, and search here: "KVR Forum » Instruments" for "Cetone VST Plugins".

- **Date:** 2007-01-29 21:57:52
- **By:** moc.erehwon@ydobon

I'm wondering about that tanh in the "Set."

Could replace with a pade appromimation, maybe. What is the range of inputs going into it?

In other words, how small and big does this get?...

this->t3 * cutoff

- **Date:** 2007-01-29 22:06:28
- **By:** moc.dniftnacuoyerehwemos@tsaot
Possible small optimization. It depends on how smart your compiler is, but sections like this...

```c
output = new_hist + this->history3 * 2.f;
output += this->history4;
```
can be changed to this to change the multiply to an addition:

```c
output = this->history3;
output += output+new_Hist+this->history4;
```

- **Date:** 2007-01-30 03:05:05  
  **By:** moc.dniftnacuoyerehwemos@tsaot

While I'm at it, one of these divisions can easily be switched to a multiply...

```c
b1 = (1.847759f / q) / wp;
b1=(1.847759f/(q*wp));
```

- **Date:** 2007-02-04 19:32:55  
  **By:** moc.oohay@bob

Four times oversampling removes the problems with fast cut-off sweeps at low values.  
This filter has the same shape as a normal biquad filter, with a more pronounced resonance boost.

- **Date:** 2008-01-12 20:42:34  
  **By:** gro.lortnocdnim@gro.psdcisum

Why would oversampling solve the problem? If you over-sample, the poles have to reach even further into the relative frequencies, and stability would become more of a problem AFAICT.

- **Date:** 2008-01-21 14:58:55  
  **By:** moc.oohay@bob

It just seems to. If you 4X over-sample, then it gives it a 4X chance to recover from each sweep change, presuming you’re not changing the filter cut-off at 4X also.

- **Date:** 2008-01-25 14:46:31  
  **By:** erehwon.ku.oc.snosrapsd@psdcisum

thing is with 4X oversampling on this is that you'll be reducing precision on omega (wp here), and so should probably shift to double rather than float to help accuracy.

- **Date:** 2013-04-24 02:48:07  
  **By:** moc.liam@ttocs

Did anyone figure out how to get a high pass out of this?  
Thanks!
3.14 C++ class implementation of RBJ Filters

- **Author or source:** moc.xinortceletrams@urugra
- **Created:** 2002-12-13 01:37:52
- **Linked files:** CFxRbjFilter.h

Listing 20: notes

[WARNING: This code is not FPU undernormalization safe!]

3.15 C-Weighed Filter

- **Author or source:** ed.luofsruoivas@naitsirhC
- **Type:** digital implementation (after bilinear transform)
- **Created:** 2006-07-12 19:12:16

Listing 21: notes

unoptimized version!

Listing 22: code

```
1 First prewarp the frequency of both poles:
2
3 K1 = tan(0.5*Pi*20.6 / SampleRate) // for 20.6Hz
4 K2 = tan(0.5*Pi*12200 / SampleRate) // for 12200Hz
5
6 Then calculate the both biquads:
7
8 b0 = 1
9 b1 = 0
10 b2 =-1
11 a0 = ((K1+1)*(K1+1)*(K2+1)*(K2+1));
12 a1 =-4*(K1*K1*K2*K2+K1*K1*K2+K1*K2*K2-K1-K2-1)*t;
13 a2 =- ((K1-1) *(K1-1)*(K2-1)*(K2-1))*t;
14
15 and:

16 b3 = 1
17 b4 = 0
18 b5 =-1
19 a3 = ((K1+1)*(K1+1)*(K2+1)*(K2+1));
20 a4 =-4*(K1*K1*K2*K2+K1*K1*K2+K1*K2*K2-K1-K2-1)*t;
21 a5 =- ((K1-1) *(K1-1)*(K2-1)*(K2-1))*t;
22
23 Now use an equation for calculating the biquads like this:
24
25 Stage1 = b0*Input + State0;
26 State0 = + a1/a0*Stage1 + State1;
27 State1 = b2*Input + a2/a0*Stage1;
28
29 Output = b3*Stage1 + State2;
```

(continues on next page)
3.15.1 Comments

- **Date:** 2006-07-12 21:07:28
- **By:** ed.luosfosruoivas@naitsirhC

You might still need to normalize the filter output. You can do this easily by multiplying either the b0 and b2 or the b3 and b5 with a constant. Typically the filter is normalized to have a gain of 0dB at 1kHz

Also oversampling of this filter might be useful.

### 3.16 Cascaded resonant lp/hp filter

- **Author or source:** ed.bew@raeybot
- **Type:** lp+hp
- **Created:** 2002-12-16 19:02:11

#### Listing 23: notes

```plaintext
// Cascaded resonant lowpass/hipass combi-filter
// The original source for this filter is from Paul Kellet from the archive. This is a cascaded version in Delphi where the output of the lowpass is fed into the highpass filter.
// Cutoff frequencies are in the range of 0<=x<1 which maps to 0..nyquist frequency
// input variables are:
// cut_lp: cutoff frequency of the lowpass (0..1)
// cut_hp: cutoff frequency of the hipass (0..1)
// res_lp: resonance of the lowpass (0..1)
// res_hp: resonance of the hipass (0..1)
```

#### Listing 24: code

```delphi
var n1,n2,n3,n4: single; // filter delay, init these with 0!
fb_lp, fb_hp: single; // storage for calculated feedback
const p4=1.0e-24; // Pentium 4 denormal problem elimination

function dofilter(inp,cut_lp,res_lp,cut_hp,res_hp: single): single;
begin
fb_lp:=res_lp+res_lp/(1-cut_lp);
fb_hp:=res_hp+res_hp/(1-cut_lp);
n1:=n1+cut_lp*(inp-n1+fb_lp*(n1-n2))+p4;
n2:=n2+cut_lp*(n1-n2);
n3:=n3+cut_hp*(n2-n3+fb_hp*(n3-n4))+p4;
n4:=n4+cut_hp*(n3-n4);
end;
```

(continues on next page)
3.16.1 Comments

- **Date**: 2003-07-13 07:43:17  
  **By**: moc.biesnamreh@eciffo
  
  I guess the last line should read
  `result:=inp-n4;`
  
  Right?
  
  Bye,
  
  Hermann

- **Date**: 2003-12-26 19:56:21  
  **By**: moc.liamtoh@tsvreiruoc
  
  excuse me which type is? 6db/oct or 12 or what?
  
  thanks

- **Date**: 2004-02-02 15:43:00  
  **By**: ed.xmg@suahtlanairhc
  
  result := n2-n4
  
  ;)

- **Date**: 2011-01-25 17:52:08  
  **By**: ten.raenila@ssov
  
  WOW this is old but handy. Anyway what to do about the divide-by-zero caused by the feedback calc if the cutoff is set to 1.0?
  
  Also, should the feedback for the hpf be:
  
  `fb_hp:=res_hp+res_hp/(1-cut_hp);`
  
  not:
  
  `fb_hp:=res_hp+res_hp/(1-cut_lp);`
  
  ?
  
  Thanks
  
  NV

- **Date**: 2017-03-17 08:28:07  
  **By**: moc.liamg@dnuosG
Nobody can see?

There is two lowpass filters in series, no differences between them.

### 3.17 Cool Sounding Lowpass With Decibel Measured Resonance

- **Author or source:** ua.moc.ohay@renrew_bocaj_leinad
- **Type:** LP 2-pole resonant tweaked butterworth
- **Created:** 2004-09-01 17:56:44

#### Listing 25: notes

This algorithm is a modified version of the tweaked butterworth lowpass filter by Patrice Tarrabia posted on musicdsp.org’s archives. It calculates the coefficients for a second order IIR filter. The resonance is specified in decibels above the DC gain. It can be made suitable to use as a SoundFont 2.0 filter by scaling the output so the overall gain matches the specification (i.e. if resonance is 6dB then you should scale the output by -3dB). Note that you can replace the sqrt(2) values in the standard butterworth highpass algorithm with my "q =" line of code to get a highpass also. How it works: normally q is the constant sqrt(2), and this value controls resonance. At sqrt(2) resonance is 0dB, smaller values increase resonance. By multiplying sqrt(2) by a power ratio we can specify the resonant gain at the cutoff frequency. The resonance power ratio is calculated with a standard formula to convert between decibels and power ratios (the powf statement...).

Good Luck,
Daniel Werner
http://experimentalscene.com/
Listing 26: code

```c
float c, csq, resonance, q, a0, a1, a2, b1, b2;

c = 1.0f / (tanf(pi * (cutoff / samplerate)));
csq = c * c;
resonance = powf(10.0f, -(resonancedB * 0.05f));
q = sqrt(2.0f) * resonance;
a0 = 1.0f / (1.0f + (q * c) + (csq));
a1 = 2.0f * a0;
a2 = a0;
b1 = (2.0f * a0) * (1.0f - csq);
b2 = a0 * (1.0f - (q * c) + csq);
```

3.17.1 Comments

- **Date**: 2005-11-24 17:59:36  
  **By**: acid_mutant[aat]yahoo[doot]com

For some reason when I tested this algorithm, even though the frequency response looked OK in my graphs - i.e. it should resonate the output didn't seem to be very resonant - it could be a phase issue, I'll keep checking.

(BTW: I use an impulse, then FFT, then display the power bands returned)

- **Date**: 2006-03-09 18:38:39  
  **By**: moc.snad@snad

shouldn't it be

resonance = powf(10.0f, -(resonancedB * 0.05f));

instead of

resonance = powf(10.0f, -(resonancedB * 0.1f));

to get correct dB gain?

... since gain = 10^(dB/20) ...

- **Date**: 2007-01-06 04:29:10  
  **By**: uh.etle.fni@yfoocs

Agree with the last post.

- **Date**: 2007-08-21 14:00:21  
  **By**: moc.enecslatnemirepxe.ecnuob@ton.em.maps.renrewd

The algorithm was developed with a digital signal of 32-bit floating point pseudo-random white noise running through it. The level of resonance was measured by visually plotting the output of the FFT of the signal. I half agree with the second last post, i.e. dB in acoustics is not the same as dB in digital audio. Correct me if I am wrong, it is a long time since I thought about this.
there is something very wrong with this code as it is printed here, i don't expect anyone is going to make any effort to correct it or verify it.

You need to use 0.5 in the power function to convert from the db to the linear.

You can apply a GAIN reduction by doing the same thing but make it smaller.

\[ \text{GAIN} = \text{powf}(10.0f, -(\text{resonance} \times 0.25) \times 0.05) \];

The use the GAIN to the input of the filter. If you use it to the output and change resonance rapidly it will click.

For the gain you can change the 0.25 to 0.125 or 0.075 if you feel that it is too quiet when you turn the resonance up.

Correction to me previous post, I meant 0.05 in the first line.

Convert resonance as dB to q for use in filter, use this formula.

\[ q = \text{powf}(10.0f, -(\text{resonanceDb} \times 0.05)) \];

It will give you a value from 0 to 1. But for most butterworth you do not want zero and you want it to go a little more than one to fully exploit the resonance, so scale it like below.

For me this works to scale the q

\[ q = 0.1 + q \times 1.5 \]

For example, the 1.5 and 0.1 can be adjusted to suit your preference.

### 3.18 DC filter

- **Author or source:** hc.niweulb@lossor.ydna
- **Type:** 1-pole/1-zero DC filter
- **Created:** 2003-01-04 01:18:23

---

This is based on code found in the document: "Introduction to Digital Filters (DRAFT)"
Julius O. Smith III (jos@ccrma.stanford.edu)
(http://www-ccrma.stanford.edu/~jos/filters/)

(continues on next page)
Some audio algorithms (asymmetric waveshaping, cascaded filters, ...) can produce DC offset. This offset can accumulate and reduce the signal/noise ratio.

So, how to fix it? The example code from Julius O. Smith's document is:

```
...  
y(n) = x(n) - x(n-1) + R * y(n-1)  
// "R" between 0.9 .. 1  
// n=current (n-1)=previous in/out value  
...
```

"R" depends on sampling rate and the low frequency point. Do not set "R" to a fixed value (e.g. 0.99) if you don't know the sample rate. Instead set R to:

-3dB @ 40Hz:  
R = 1-(250/samplerate)

-3dB @ 30Hz:  
R = 1-(190/samplerate)

-3dB @ 20Hz:  
R = 1-(126/samplerate)

### 3.18.1 Comments

- **Date:** 2003-01-04 01:58:04  
  **By:** hc.niwulb@ losses.ydna

I just received a mail from a musicdsp reader:

'How to calculate "R" for a given (-3dB) low frequency point?'

R = 1 - (pi*2 * frequency /samplerate)

(pi=3.14159265358979)

- **Date:** 2003-05-10 09:11:42  
  **By:** ten.labolgfmas@jbr

particularly if fixed-point arithmetic is used, this simple high-pass filter can create it's own DC offset because of limit-cycles. to cure that look at http://www.dspguru.com/comp.dsp/tricks/alg/dc_block.htm 

this trick uses the concept of "noise-shaping" to prevent DC in any limit-cycles. 

r b-j

### 3.19 Delphi Class implementation of the RBJ filters

- **Author or source:** moc.liamtoh@retsbomygrgnayrev
- **Type:** Delphi class implementation of the RBJ filters
- **Created:** 2006-07-11 08:16:46
I haven't tested this code thoroughly as it's pretty much a straight conversion from Arguru c++ implementation.

Listing 29: code

```pascal
{ RBJ Audio EQ Cookbook Filters
A pascal conversion of arguru@smartelectronix.com's
 c++ implementation.

WARNING: This code is not FPU undernormalization safe.

Filter Types
0-LowPass
1-HiPass
2-BandPass CSG
3-BandPass CZPG
4-Notch
5-AllPass
6-Peaking
7-LowShelf
8-HiShelf
}
unit uRbjEqFilters;

interface

uses math;

type
TRbjEqFilter=class
private
 b0a0,b1a0,b2a0,a1a0,a2a0:single;
in1,in2,ou1,ou2:single;
fSampleRate:single;
fMaxBlockSize:integer;
fFilterType:integer;
fFreq,fQ,fDBGain:single;
fQIsBandWidth:boolean;
procedure SetQ(NewQ:single);
public
 out1:array of single;
 constructor create(SampleRate:single;MaxBlockSize:integer);
 procedure CalcFilterCoeffs(pFilterType:integer;pFreq,pQ,pDBGain:single;
 --pQIsBandWidth:boolean); overload;
 procedure CalcFilterCoeffs; overload;
 function Process(input:single):single; overload;
 function Process(Input:psingle;sampleframes:integer); overload;
 property FilterType:integer read fFilterType write fFilterType;
 property Freq:single read fFreq write fFreq;
 property q:single read fQ write SetQ;
 property DBGain:single read fDBGain write fDBGain;
 property QIsBandWidth:boolean read fQIsBandWidth write fQIsBandWidth;
end;
```

(continues on next page)
implementation

constructor TRbjEqFilter.create(SampleRate:single;MaxBlockSize:integer);
begin
  fMaxBlockSize:=MaxBlockSize;
  setLength(out1,fMaxBlockSize);
  fSampleRate:=SampleRate;
  fFilterType:=0;
  fFreq:=500;
  fQ:=0.3;
  fDBGain:=0;
  fQIsBandWidth:=true;
  in1:=0;
  in2:=0;
  ou1:=0;
  ou2:=0;
end;

procedure TRbjEqFilter.SetQ(NewQ:single);
begin
  fQ:=(1-NewQ)*0.98;
end;

procedure TRbjEqFilter.CalcFilterCoeffs(pFilterType:integer;pFreq,pQ,pDBGain:single;
  pQIsBandWidth:boolean);
begin
  FilterType:=pFilterType;
  Freq:=pFreq;
  Q:=pQ;
  DBGain:=pDBGain;
  QIsBandWidth:=pQIsBandWidth;
  CalcFilterCoeffs;
end;

procedure TRbjEqFilter.CalcFilterCoeffs;
var
  alpha,a0,a1,a2,b0,b1,b2,single;
  A,beta,omega,tsin,tcos:single;
begin
  //peaking, LowShelf or HiShelf
  if fFilterType>=6 then
    begin
      A:=power(10.0,(DBGain/40.0));
      omega:=2*pi*fFreq/fSampleRate;
      tsin:=sin(omega);
      tcos:=cos(omega);
      if fQIsBandWidth then
        alpha:=tsin*sinh(log2(2.0)/2.0*fQ*omega/tsin)
      else
        alpha:=tsin/(2.0*fQ);
      beta:=sqrt(A)/fQ;
    end
(continues on next page)
// peaking
if fFilterType=6 then
begin
  b0:=1.0+alpha*A;
  b1:=-2.0*tcos;
  b2:=1.0-alpha*A;
  a0:=1.0+alpha/A;
  a1:=-2.0*tcos;
  a2:=1.0-alpha/A;
end else
// lowshelf
if fFilterType=7 then
begin
  b0:=(A*((A+1.0)-(A-1.0)*tcos+beta*tsin));
  b1:=(2.0*A*((A-1.0)+(A+1.0)*tcos));
  b2:=(A*((A+1.0)-(A-1.0)*tcos-beta*tsin));
  a0:=((-2.0*((A-1.0)+(A+1.0)*tcos)));
  a1:=(A+1.0)+(A-1.0)*tcos-beta*tsin);
end;
// highshelf
if fFilterType=8 then
begin
  b0:=(A*((A+1.0)+(A-1.0)*tcos+beta*tsin));
  b1:=(-2.0*A*((A-1.0)+(A+1.0)*tcos));
  b2:=(A*((A+1.0)+(A-1.0)*tcos-beta*tsin));
  a0:=((A+1.0)-(A-1.0)*tcos+beta*tsin);
  a1:=(2.0*((A-1.0)-(A+1.0)*tcos));
  a2:=((A+1.0)-(A-1.0)*tcos-beta*tsin);
end;
end else // other filter types
begin
  omega:=2*pi*fFreq/fSampleRate;
  tsin:=sin(omega);
  tcos:=cos(omega);
  if fQIsBandWidth then
    alpha:=tsin*sinh(log2(2)/2*fQ*omega/tsin)
  else
    alpha:=tsin/(2*fQ);
  // lowpass
  if fFilterType=0 then
begin
    b0:=(1-tcos)/2;
    b1:=1-tcos;
    b2:=(1-tcos)/2;
    a0:=1+alpha;
    a1:=-2*tcos;
    a2:=1-alpha;
  end else // hi-pass
  if fFilterType=1 then
begin
    b0:=(1+tcos)/2;
    b1:=-(1+tcos);
    b2:=(1+tcos)/2;
    a0:=1+alpha;
    a1:=-2*tcos;
    a2:=1-alpha;
  end else // other filter types
begin
  omega:=2*pi*fFreq/fSampleRate;
  tsin:=sin(omega);
  tcos:=cos(omega);
  if fQIsBandWidth then
    alpha:=tsin*sinh(log2(2)/2*fQ*omega/tsin)
  else
    alpha:=tsin/(2*fQ);
  // lowpass
  if fFilterType=0 then
begin
    b0:=(1-tcos)/2;
    b1:=1-tcos;
    b2:=(1-tcos)/2;
    a0:=1+alpha;
    a1:=-2*tcos;
    a2:=1-alpha;
  end else // hi-pass
  if fFilterType=1 then
begin
    b0:=(1+tcos)/2;
    b1:=-(1+tcos);
    b2:=(1+tcos)/2;
    a0:=1+alpha;
    a1:=-2*tcos;
    a2:=1-alpha;
  end else // other filter types
begin
  omega:=2*pi*fFreq/fSampleRate;
  tsin:=sin(omega);
  tcos:=cos(omega);
  if fQIsBandWidth then
    alpha:=tsin*sinh(log2(2)/2*fQ*omega/tsin)
  else
    alpha:=tsin/(2*fQ);
  // lowpass
  if fFilterType=0 then
begin
    b0:=(1-tcos)/2;
    b1:=1-tcos;
    b2:=(1-tcos)/2;
    a0:=1+alpha;
    a1:=-2*tcos;
    a2:=1-alpha;
  end else // hi-pass
  if fFilterType=1 then
begin
    b0:=(1+tcos)/2;
    b1:=-(1+tcos);
    b2:=(1+tcos)/2;
    a0:=1+alpha;
    a1:=-2*tcos;
    a2:=1-alpha;
  end
end else // bandpass CSG
if fFilterType=2 then
begin
  b0:=tsin/2;
  b1:=0;
  b2:=-tsin/2;
  a0:=1+alpha;
  a1:=-1*tcos;
  a2:=1-alpha;
end else // bandpass CZPG
if fFilterType=3 then
begin
  b0:=alpha;
  b1:=0.0;
  b2:=-alpha;
  a0:=1.0+alpha;
  a1:=-2.0*tcos;
  a2:=1.0-alpha;
end else // notch
if fFilterType=4 then
begin
  b0:=1.0;
  b1:=-2.0*tcos;
  b2:=1.0;
  a0:=1.0+alpha;
  a1:=-2.0*tcos;
  a2:=1.0-alpha;
end else // allpass
if fFilterType=5 then
begin
  b0:=1.0-alpha;
  b1:=-2.0*tcos;
  b2:=1.0+alpha;
  a0:=1.0+alpha;
  a1:=-2.0*tcos;
  a2:=1.0-alpha;
end;

end;

b0a0:=b0/a0;
b1a0:=b1/a0;
b2a0:=b2/a0;
al0:=a1/a0;
a2a0:=a2/a0;
end;

function TRbjEqFilter.Process(input:single):single;
var
  LastOut:single;
begin
  // filter
  LastOut:= b0a0*input + b1a0*in1 + b2a0*in2 - ala0*ou1 - a2a0*ou2;
  // push in/out buffers
  in2:=in1;
  in1:=input;
end;
```delphi
ou2:=ou1;
ou1:=LastOut;
// return output
result:=LastOut;
end;

{ the process method is overloaded.
use Process(input:single):single;
for per sample processing
use Process(Input:psingle;sampleframes:integer);
for block processing. The input is a pointer to
the start of an array of single which contains
the audio data.
i.e.
RBJFilter.Process(@WaveData[0],256);
}

procedure TRbjEqFilter.Process(Input:psingle;sampleframes:integer);
var
  i:integer;
  LastOut:single;
begin
  for i:=0 to SampleFrames-1 do
    begin
      // filter
      LastOut:= b0a0*(input^)+ b1a0*in1 + b2a0*in2 - a1a0*ou1 - a2a0*ou2;
      //LastOut:=input^;
      // push in/out buffers
      in2:=in1;
      in1:=input^;
      ou2:=ou1;
      ou1:=LastOut;
      Out1[i]:=LastOut;
      inc(input);
    end;
  end;
end.
```

### 3.20 Digital RIAA equalization filter coefficients

- **Author or source:** Frederick Umminger
- **Type:** RIAA
- **Created:** 2002-10-14 16:33:34

Listing 30: notes

Use at your own risk. Confirm correctness before using. Don't assume I didn't goof something up.
The "turntable-input software" thread inspired me to generate some coefficients for a digital RIAA equalization filter. These coefficients were found by matching the magnitude response of the s-domain transfer function using some proprietary Matlab scripts. The phase response may or may not be totally whacked.

The s-domain transfer function is

\[
R3(1+R1*C1*s)(1+R2*C2*s)/(R1(1+R2*C2*s) + R2(1+R1*C1*s) + R3(1+R1*C1*s)(1+R2*C2*s))
\]

where

\[
R1 = 883.3k \\
R2 = 75k \\
R3 = 604 \\
C1 = 3.6n \\
C2 = 1n
\]

This is based on the reference circuit found in http://www.hagtech.com/pdf/riaa.pdf

The coefficients of the digital transfer function \(b(z^{-1})/a(z^{-1})\) in descending powers of \(z\), are:

- **44.1kHz**
  - \(b = [0.02675918611906, -0.04592084787595, 0.01921229297239]\)
  - \(a = [1.00000000000000, -0.73845850035973, -0.17951755477430]\)
  - Error +/- 0.25dB

- **48kHz**
  - \(b = [0.02675918611906, -0.04592084787595, 0.01921229297239]\)
  - \(a = [1.00000000000000, -0.73845850035973, -0.17951755477430]\)
  - Error +/- 0.15dB

- **88.2kHz**
  - \(b = [0.04872204977233, -0.09076930609195, 0.04202280710877]\)
  - \(a = [1.00000000000000, -0.85197860443215, -0.10921171201431]\)
  - Error +/- 0.01dB

- **96kHz**
  - \(b = [0.05265477122714, -0.09864197097385, 0.04596474352090]\)
  - \(a = [1.00000000000000, -0.85835597216218, -0.10600020417219]\)
  - Error +/- 0.006dB

### 3.20.1 Comments

- **Date**: 2007-02-24 13:55:58
- **By**: moc.liamtoh@0691_ptj
Hmm... since I'm having lack in knowledge of utilizing this type of 'data' in programming, could someone be kind and give a short code example of its usage (in some samplerate), lets say, using Basic/VB language (though, C-C++/Pascal-Delphi/Java goes as well)?

JT

• Date: 2007-03-01 13:20:51
  • By: ku.oc.snosrappedTUOEMEKAT@psdcisum

They are coefficients to plug into a std biquad. Look through the filters section of musicdsp you'll find a load of examples of biquads (essentially two quadratic equations which are solved together to do the DSP stuff).

It's of the form

\[
\text{out} = b0\times\text{in}[0] + b1\times\text{in}[1] + b2\times\text{in}[2] - a1\times\text{out}[1] - a2\times\text{out}[2]
\]

where \(\text{in}[0,-1,-2]\) are the current input and the previous 2; and \(\text{out}[1,-2]\) are the last two outputs.

Generally the previous output coefficients are subtracted, but sometimes the signs are swapped, and they are added like the inputs.

Some algorithms use a for ins and b for outs, others use them the other way around. Generally (but not always) there are 3 input and 2 output coeffs, so you can work out which is which.

HTH

DSP

• Date: 2007-03-02 03:31:08
  • By: moc.erehwon@ydobon

I don't get it. How do you set the frequency, Kenneth?

What frequencies are being passed?

• Date: 2007-03-03 09:09:29
  • By: moc.liamtoh@0691_ptj

Hmm...

Since no links allowed here, I have started a topic on this matter @ KVR

Topic number: 170235
Topic name: "Coefficients of the digital transfer function ... How to ?"

I tried the 44.1/48kHz version and it produced quite 'bad' results .. lots of rattle in audio and the RIAA curve form is not as it should be (should be: 20Hz; ±19.27dB .. 1kHz; ±0dB ... 20kHz; ±19.62dB). (Couple of pictures linked in KVR topic).

Also, .. if this is the result in anyway, this is the 'production curve' used in mastering process ... how can it be changed to 'opposite' ...

JT

3.20. Digital RIAA equalization filter coefficients
Thanks to all so far.

I found this quote from another forum:

QUOTE:
"All you should need to do to get the complementary curve is swap the a and b vectors, and then multiply both vectors by 1/a(0) to normalize. That will give the coefficients for the inverse filter.".
/QUOTE

w/ a note that it was taken from one of those OPs (Frederick Umminger's) postings ... but the reference link was dead so I couldn't read the whole story. If OP or anyone else can give some light in this matter of how to make that swap w/ normalization (fully) so I could try w/ higher SR data. I did try and got values like -20.1287341287123, etc..

I actually got the 44.1/48kHz curve managed w/ help from a post in another forum. But there were nothing explained fully.

QUOTE:
"Filter coefficients (48kHz) for RIAA curve from Frederick Umminger; see:
\[ b = [ 0.02675918611906 -0.04592084787595 0.01921229297239 ] \]
\[ a = [ 1.000000000000000 -0.73845850035973 -0.17951755477430 ] \]
error +/- 0.15dB

inverted filter for phono playback (48kHz):
\[b = [ 0.2275882473429072 -0.1680644758323426 -0.0408560856583673 ]\]
\[a = [ 1.000000000000000 1.7160778983199925 0.7179700042784745 ]\]
since a[1] is too large, it must be splitted into a1 and a2
\[b0=0.2275882473429072, b1=-0.1680644758323426, b2=-0.0408560856583673\]
\[a1=.85803894915999625, a2=-0.7179700042784745\]
"/QUOTE

just lots of numbers ....

JT

This seem to become a monologue but, ... I'm still having issues w/ those 88.2kHz and 96kHz filter coefficients when inverted.

Noticed that when those coefficients for 88.2kHz and 96kHz are inverted, in both cases, a1 and a2 gets values which maybe are not good in equation

\[y[i] = b0x[i] + b1x[i-1] + b2x[i-2] - a1y[i-1] - a2y[i-1]\]
because of, a1 gets a negative value and its decimal part is bigger than a2 is \( \Rightarrow \) " -
\(-a1y[i-1] - a2y[i-2]\)" looks like \( y[i] \) starts growing after every sample
\( \Rightarrow \) calculation. This is not an issue w/ data for 44.1kHz and 48kHz. When I change
\( \Rightarrow \) those a1/a2 decimal parts so that the abs(a1)-a2 =< 1 becomes true then filter
\( \Rightarrow \) works well (though not right recuits). Also, while analyzing the VST plugin, using
\( \Rightarrow \) C.W.Buddes VST PluginAnalyzer, Delphi tracer (Watch) shows \( y[i] \) become over 1.0
\( \Rightarrow \) after ~830 sampleframes and after 8192 sampleframes, \( y[i] \) has value of 2.
\( \Rightarrow \) 488847401e+11 already (i.e. 248884740100). This shouldn't be a coding problem since
\( \Rightarrow \) a friend of mine tested these w/ SynthMaker (no coding needed) and the results were
\( \Rightarrow \) equal.

If this "-a1x[i-1]-a2x[i-2] > 1" is an issue, are there any methods to get it fixed w/
\( \Rightarrow \) -o loosing the accuracy OP got into those original coefficients?

jtp

- **Date:** 2007-03-15 22:41:37
- **By:** ed.luosfsooruivas@naitisirhC

Try to plot the poles and zeroes. If there are poles outside the unit circle, your
\( \Rightarrow \) filter will be unstable!
To eliminate poles outside the unit circle, construct an allpass filter which has
\( \Rightarrow \) zeroes at the same position as the unwanted poles. They are now canceling out
\( \Rightarrow \) themself, so that you only have poles inside the unit circle. Your filter should be
\( \Rightarrow \) stable now!

All you need to know now is how to transform the filter coefficients into poles and
\( \Rightarrow \) zeroes and vice versa. If you're using delphi, you might want to have a look into
\( \Rightarrow \) the DFilter class of the open source project 'Delphi ASIO & VST Packages'.

- **Date:** 2007-03-24 11:53:25
- **By:** moc.liamtoh@0691_ptj

Thanks for your suggestion Christian.
I didn't try this allpass method because of
- I managed to get this issue rounded through another way (I have now 3rd-4th order
\( \Rightarrow \) filters working here as VST and standalone for all those four samplersates mentioned
\( \Rightarrow \) here and I'm also considering to add ones for 174.6 kHz and 192 kHz as well)
- as I'm learning these filter matters and delphi programming, I would have needed
\( \Rightarrow \) some good examples to do this

My final thoughts over those coefficients listed in F. Umminger's post:

As those coefficients needs to be inversed before getting the RIAA reproduction done,
\( \Rightarrow \) I can't say 100% sure if any of those works properly then (maybe one set does).
When inversion is done as was suggested elsewhere:
- swap a/b vectors,
- multiply all with 1/a0 and
- optional: 'normalize' b's by dividing every b with sum of b's
, only coefficients for 44.1kHz and 48kHz seem to become stable but, which one is the
\( \Rightarrow \) right one then since, those original coefficients are same for both? I suppose
\( \Rightarrow \) those can't be equal coefficients because this is sample accurate filter in
\( \Rightarrow \) question, or can those? If not then, which one is the correct one ... you can try
\( \Rightarrow \) it out by trying (least the resulting sound quality should tell this). Maybe Hannes
\( \Rightarrow \) tried this and found the right ones or just
\( \Rightarrow \) used those given for 48kHz (SoundBlaster DSP is internally 48kHz).
What's wrong with those others? It seems that both, 88.2kHz and 96kHz coefficients as inversed, produces unstable filter which won't work (see my previous post).

jtp

- Date: 2007-04-22 12:03:52
- By: moc.liamtoh@0691_ptj

FYI, here are working filter coefficients for biquad implementation of RIAA EQ:

Reproduction filters:

44.1kHz:
\[ a = [ 1.0000000000 \ -1.7007240000 \ 0.7029381524 ] \]
\[ b = [ 1.0000000000 \ -0.7218922000 \ -0.1860520545 ] \]
error ~0.23dB

48kHz:
\[ a = [ 1.0000000000 \ -1.7327655000 \ 0.7345534436 ] \]
\[ b = [ 1.0000000000 \ -0.7555521000 \ -0.1646257113 ] \]
error ~0.14dB

88.2kHz:
\[ a = [ 1.0000000000 \ -1.8554648000 \ 0.8559721393 ] \]
\[ b = [ 1.0000000000 \ -0.8479577000 \ -0.1127631993 ] \]
error 0.008dB

and 96kHz:
\[ a = [ 1.0000000000 \ -1.8666083000 \ 0.8670382873 ] \]
\[ b = [ 1.0000000000 \ -0.8535331000 \ -0.1104595113 ] \]
error ~0.006dB

NOTES:

# - By swapping the a1<->b1 and a2<->b2 you'll get the production filter.

# - All these given filter coefficients produces a bit gained filter (~+12.5dB or so)
so, if you like to adjust the 1 kHz = 0dB, it can be done quite accurately by
finding linear difference using software like Tobybear's FilterExplorer. Enter
coefficients into FilterExplorer, by moving mouse cursor over the plotted magnitude
curve in magnitude plot window, find/point the ~1kHz position and then check the
magnitude value (value inside the brackets) found in info field. Use this value as
divider for b coefficients.

jtp
jiiteepee@yahoo.se

- Date: 2009-08-07 18:43:49
- By: ude.nretsewhtron.ece@ztub

The amplitude response of Umminger's Fs = 48 kHz filter gives an excellent approximation to the RIAA amplitude response curve but Umminger suggests the phase response may be "totally whacked". Actually, the phase response is pretty good, provided "phase response" is interpreted properly.

(continues on next page)
Umminger's filters are carelessly presented. The 44.1 kHz version is not there at all, and the 88.2 kHz and 96 kHz cases have reproduction filter poles > 1 that should be replaced by their reciprocals. For that reason I shall use the coefficients given by jtp, though the general approach is Umminger's. When computing phase of the digital filter, a linear phase term may be added to the computation as convenient, as such a term corresponds to time shift. That is, two phase responses are for our practical purposes equivalent if they differ only by a phase linear in frequency \(f\). The RIAA analog filter has an asymptotic phase of \(-90\) deg and Umminger's asymptotic \((Fs/2)\) phase is 0, so one may conjecture that a term \(-2Df/Fs\) ought to be added to the computation of the digital filter phase, where \(D = -90\). Actually, there is no reason to restrict \(D\) to multiples of 90.

In jtp's Fs=44.1 kHz case, an adjustment to the computed phase using \(D = -65.5\) results in maximum computed phase error < 1.5 deg over the range 30 Hz - 10 kHz, while the computation using \(D = -75.75\) results in maximum computed phase error < 5 deg over the range 30 Hz - 20 kHz. Of course the digital filter itself is independent of \(D\), which is used only to interpret the phase response. One is, in effect, comparing the output of the digital filter with the output of the RIAA analog filter delayed by \(D/180\) sample intervals. The digital filter itself remains as given by jtp.

In jtp's Fs=48 kHz case use \(D = -68\) for a phase error < 1.2 deg over the range 30 Hz - 10 kHz, and \(D = -75\) for a phase error < 3.8 deg over the range 30 Hz - 20 kHz. In jtp's Fs=88.2 kHz case use \(D = -72\) for a phase error < 0.31 deg over the range 30 Hz - 10 kHz, and \(D = -72.8\) for a phase error < 0.5 deg over the range 30 Hz - 20 kHz.

In jtp's Fs=96 kHz case use \(D = -72.4\) for a phase error < 0.30 deg over the range 30 Hz - 10 kHz, and \(D = -72.8\) for a phase error < 0.375 deg over the range 30 Hz - 20 kHz.

In the Fs = 44.1 or 48 kHz cases, if a max phase error, over 30 Hz - 20 kHz, of about 0.5 deg is wanted, then one can double the sample rate in the usual way using a linear phase FIR interpolating filter, then do equalization at sample rate 88.2 or 96 kHz, decimating the output by a factor 2. August 7, 2009

### 3.21 Direct Form II biquad

- **Author or source:** es.tuanopx@kileib.trebor
- **Created:** 2009-11-16 08:46:12

#### Listing 32: notes

The nominal implementation for biquads is the Direct Form I variant. But the Direct Form II is actually more suited for calculating the biquad since it needs only 2 memory locations, and the multiplications can be pipelined better by the compiler. In release build, I've noted a considerable speedup when compared to DF I. When processing stereo, the code below was ~ 2X faster. Until I develop a SIMD biquad that is faster, this will do.

#### Listing 33: code

```plaintext
// b0, b1, b2, a1, a2 calculated via r.b-j's cookbook
// formulae.
```

(continues on next page)
// m1, m2 are the memory locations
// dn is the de-denormal coeff (=1.0e-20f)

void processBiquad(const float* in, float* out, unsigned length) {
    for(unsigned i = 0; i < length; ++i) {
        register float w = in[i] - a1*m1 - a2*m2 + dn;
        out[i] = b1*m1 + b2*m2 + b0*w;
        m2 = m1; m1 = w;
    }
    dn = -dn;
}

void processBiquadStereo(const float* inL, const float* inR, float* outL, float* outR, unsigned length) {
    for(unsigned i = 0; i < length; ++i) {
        register float wL = inL[i] - a1*m1L - a2*m2L + dn;
        register float wR = inR[i] - a1*m1R - a2*m2R + dn;
        outL[i] = b1*m1L + b2*m2L + b0*wL;
        m2L = m1L; m1L = wL;
        outR[i] = b1*m1R + b2*m2R + b0*wR;
        m2R = m1R; m1R = wR;
    }
    dn = -dn;
}

### 3.21.1 Comments

- **Date:** 2010-01-13 13:44:09
  - **By:** moc.suomyn@ona

true, this structure is faster. but it is also (even) more sensitive to coefficients changes, so it becomes unstable quite fast compared to the DF I form. I'd really like to know if there's a way to change coefficients and at the same time changing the history of the filter for avoiding instability.

- **Date:** 2012-01-31 20:43:12
  - **By:** earlevel

Use direct form I (single accumulation point) when using fixed-point processors. For floating point, use direct form II transposed, which has superior numerical characteristics to direct form II (non-transposed).

### 3.22 Direct form II

- **Author or source:** Fuzzpilz
I've noticed there's no code for direct form II filters in general here, though probably many of the filter examples use it. I haven't looked at them all to verify that, but there certainly doesn't seem to be a snippet describing this.

This is a simple direct form II implementation of a k-pole, k-zero filter. It's a little faster than (a naive, real-time implementation of) direct form I, as well as more numerically accurate.

Listing 34: notes

Listing 35: code

3.22.1 Comments

• Date: 2007-02-21 17:31:20
• By: uh.etle.fni@yfoocs

I think the per sample denormal number elimination on x87 FPUs is more difficult, since you need to check for denormals at 3 places instead of one (if I'm right).
Are the constants (a and b) wrong here. Don't they need to be switched? If you look →
→at like wikipedia that's the case and it makes more since. I'm trying to implement →
→a low pass filter at 25mhz passband edge. I'm getting alot of fluctuation in my →
→output more that expect. Any suggestions?

```c
int main(int argc, char *argv[]) {
    double b[3] = {1,2,1};
    double a1[3] = {1,-1.9995181705254206,0.99952100328066507};
    //double a1[3] = {1,-1.9252217796690612,0.95315661147483732};
    double a2[3] = {1,-1.9985996261556458,0.99860245760957123};
    double a3[3] = {1,-1.9977949691405856,0.99779779945453828};
    double a4[3] = {1,-1.9971690447494761,0.99717187417666975};
    double a5[3] = {1,-1.9967721889631873,0.9967750178281477};
    double a6[2] = {1,-0.99831813425055116};
    double d[3] = {0};
    double y[5][3] = {0};
    double out[2] = {0};
    double x[3]={0}, x1,x2,in;
    double i=0;
    char wait;
    while(i<10000000) {
        x1 = sin(2*10000*3.14159265*i);
        x2 = sin(2*10000*3.14159265*i-3.14159265);
        in = x1 * x2;
        x[0] = in * 7.0818881108085789e-7;
        y[0][0] = b[0]*x[0] + b[1]*x[1] + b[2]*x[2] - a1[1]*y[0][1] - a1[2]*y[0][1];
        y[0][1] = y[0][0];
        x[2] = x[1];
        x[1] = x[0];
        ////////////////////////////////////////////////////////////////////////////////////////////////
        y[0][0] = y[0][0] * 7.0786348128153693e-7;
        y[1][0] = b[0]*y[0][0] + b[1]*y[0][1] + b[2]*y[0][2] - a2[1]*y[1][1] - a2[2]*y[1][1];
        y[0][2] = y[0][1];
        y[0][1] = y[0][0];
        y[1][1] = y[1][0];
        ////////////////////////////////////////////////////////////////////////////////////////////////
        y[1][0] = y[1][0] * 7.0757848807506174e-7;
        y[2][0] = b[0]*y[1][0] + b[1]*y[1][1] + b[2]*y[1][2] - a3[1]*y[2][1] - a3[2]*y[2][1];
        y[1][2] = y[1][1];
        y[1][1] = y[1][0];
        y[2][1] = y[2][0];
        ////////////////////////////////////////////////////////////////////////////////////////////////
        y[2][0] = y[2][0] * 7.0735679834155469e-7;
        y[2][2] = y[2][1];
        y[2][1] = y[2][0];
        y[3][1] = y[3][0];
        ////////////////////////////////////////////////////////////////////////////////////////////////
        y[3][0] = y[3][0] * 7.0721624006526327e-007;
    }
}
```

(continues on next page)
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(continued from previous page)

y[3][2] = y[3][1];
y[3][1] = y[3][0];
y[4][1] = y[4][0];
//////////////////////////////////////////////////////////////////////////////////
/*y[4][0] = y[4][0]* 0.000840932874724457;
out[0] = 1*y[4][0] + 1*y[4][1] - a6[1]*out[1];
y[4][1] = y[4][0];
out[1] = out[0];*/
cout<<y[4][0]<<"\n";
i+=.1;
}

• Date: 2009-03-23 07:17:12
• By: es.tuanopx@kileib.trebor
Regarding denormals: Don't check for them. Prevent them by adding a small value (~1e˓→20) to the filter memory pipeline.

• Date: 2009-03-23 18:15:40
• By: es.tuanopx@kileib.trebor
Processing a single biquad doesn't benefit much (if any) from doing a DF II
˓→implementation. However, if you'd process stereo, the DF II variant is very
˓→suitable for interleaving of non-dependent calculations, making it easier for the
˓→compiler to generate effective code. Actually, the DF II stereo implementation
˓→below is more than 2 times faster than the naive DF I stereo one:
struct stereo_biquad
{
float b0,b1,b2,a1,a2 // From rb-j's cookbook with a0 normalized to 1.0
float lm1,lm2,rm1,rm2; // Filter state
float dn;
// de-denormal coeff (1.0e-20f)
};
void processStereoBiquadDF2(
struct stereo_biquad& bq,
const float* inL,
const float* inR,
float* outL,
float* outR,
unsigned length)
{
for (unsigned i = 0; i < length; ++i)
{
register float w1 = inL[i] - bq.a1*bq.lm1 - bq.a2*bq.lm2 + bq.dn;
register float w2 = inR[i] - bq.a1*bq.rm1 - bq.a2*bq.rm2 + bq.dn;
outL[i] = bq.b1*bq.lm1 + bq.b2*bq.lm2 + bq.b0*w1;
bq.lm2 = bq.lm1; bq.lm1 = w1;
outR[i] = bq.b1*bq.rm1 + bq.b2*bq.rm2 + bq.b0*w2;
bq.rm2 = bq.rm1; bq.rm1 = w2;
}
bq.dn = -bq.dn;
}

3.22. Direct form II

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### 3.23 Fast Downsampling With Antialiasing

- **Author or source:** moc.liamg@tramum
- **Created:** 2005-12-22 20:34:58

Listing 36: notes

A quick and simple method of downsampling a signal by a factor of two with a useful amount of antialiasing. Each source sample is convolved with \{ 0.25, 0.5, 0.25 \} before downsampling.

Listing 37: code

```c
int filter_state;

/* input_buf can be equal to output_buf */
void downsample( int *input_buf, int *output_buf, int output_count ) {
    int input_idx, input_end, output_idx, output_sam;
    input_idx = output_idx = 0;
    input_end = output_count * 2;
    while( input_idx < input_end ) {
        output_sam = filter_state + ( input_buf[ input_idx++ ] >> 1 );
        filter_state = input_buf[ input_idx++ ] >> 2;
        output_buf[ output_idx++ ] = output_sam + filter_state;
    }
}
```

### 3.23.1 Comments

- **Date:** 2006-01-06 11:22:36  
  **By:** ku.oc.mapson.snorapsd@psd

I see this is designed for integers; what are you thoughts on altering it to floats and doing simple division rather than bit shifts?

- **Date:** 2006-01-07 01:35:56  
  **By:** moc.liamg@tramum

It will work fine in floating point. I would probably use multiplication rather than division though, as I would expect that to be faster (i.e. \( \gg \) \( \cdot 0.5, \gg \) \( \cdot 0.25 \)).

- **Date:** 2006-03-12 01:55:30  
  **By:** ude.drofnats.amrcc@lfd

this triangular window is still not the greatest antialiaser... but it's probably fine for something like an oversampled lowpass filter!

- **Date:** 2006-03-17 23:36:31  
  **By:** moc.liamg@tramum
For my purposes (modelling a first-order-hold dac) it was fine. The counterpart to it →–I suppose is this one – a classic exponential decay, which gives a lovely warm →–sound. Each sample is convolved with { 0.5, 0.25, 0.125, ... etc }

int filter_state;

void downsample( int *input_buf, int *output_buf, int output_count ) {
    int input_idx, output_idx, input_ep1;
    output_idx = 0;
    input_idx = 0;
    input_ep1 = output_count * 2;
    while( input_idx < input_ep1 ) {
        filter_state = ( filter_state + input_buf[ input_idx ] ) >> 1;
        output_buf[ output_idx ] = filter_state;
        filter_state = ( filter_state + input_buf[ input_idx + 1 ] ) >> 1;
        input_idx += 2;
        output_idx += 1;
    }
}

I’m not a great fan of all these high-order filters, the mathematics are more than I →can cope with :)

Cheers,
Martin

• Date: 2008-11-05 14:12:10
• By: ed.bew@ehcsa-k

Hi @ all,

what is a good initialization value of filter_state?

Greetings

Karsten

• Date: 2009-05-02 23:38:31
• By: moc.liamg@tramum

filter_state is the previous input sample * 0.25, so zero is a good starting value for a non-periodic waveform.

• Date: 2009-07-07 12:02:32
• By: moc.oohay@bob

I’m curious – as you’re generating 1 sample for every 2, is it possible to then upsample with zero padding to get a half band filter at the original sample rate?

Cheers

B
3.24 Formant filter

- **Author or source:** Alex
- **Created:** 2002-08-02 18:26:59

Listing 38: code

```c
/*
  Public source code by alex@smartelectronix.com
  Simple example of implementation of formant filter
  Vowelnum can be 0,1,2,3,4 <=> A,E,I,O,U
  Good for spectral rich input like saw or square
*/
//-------------------------------------------------------------VOWEL COEFFICIENTS
const double coeff[5][11]= {
{ 8.11044e-06, 8.943665402, -36.83889529, 92.01697887, -154.337906, 181.6233289, -151.8651235, 89.09614114, -35.10298511, 8.388101016, -0.923313471 ///A
},
{4.36215e-06, 8.90438318, -36.55179099, 91.05750846, -152.422234, 179.1170248, -149.6496211, 87.78352223, -34.60687431, 8.282228154, -0.914150747 ///E
},
{ 3.33819e-06, 8.893102966, -36.49532826, 90.96543286, -152.4545478, 179.4835618, -150.315433, 88.43409371, -34.98612086, 8.407803364, -0.932568035 ///I
},
{1.13572e-06, 8.994734087, -37.2084849, 93.22900521, -156.6929844, 184.596544, -154.3755513, 90.49663749, -35.58964535, 8.478996281, -0.929252233 ///O
},
{4.09431e-07, 8.997322763, -37.20218544, 93.11385476, -156.2530937, 183.7080141, -153.2631681, 89.59539726, -35.12454591, 8.338655623, -0.910251753 ///U
};
//---------------------------------------------------------------------------------
static double memory[10]={0,0,0,0,0,0,0,0,0,0};
//---------------------------------------------------------------------------------
float formant_filter(float *in, int vowelnum)
{
  res= (float) ( coeff[vowelnum][0] *in +
               coeff[vowelnum][1] *memory[0] +
               coeff[vowelnum][2] *memory[1] +
               coeff[vowelnum][3] *memory[2] +
               coeff[vowelnum][4] *memory[3] +
               coeff[vowelnum][8] *memory[7] +
               coeff[vowelnum][9] *memory[8] +
               coeff[vowelnum][10] *memory[9] );
  memory[9]= memory[8];
  memory[8]= memory[7];
  memory[7]= memory[6];
}
```
(continues on next page)
memory[6] = memory[5];
memory[5] = memory[4];
memory[4] = memory[3];
memory[3] = memory[2];
memory[2] = memory[1];
memory[1] = memory[0];
memory[0] = (double) res;
return res;
}

3.24.1 Comments

- **Date:** 2002-08-21 04:47:36
  - **By:** moc.oohay@nosrednatehr

  Where did the coefficients come from? Do they relate to frequencies somehow? Are they male or female? Etc.

- **Date:** 2002-09-20 02:45:20
  - **By:** es.umugni@nhs89le

  And are the coeffiecients for 44klhz?
  /stefancrs

- **Date:** 2002-11-17 09:16:51
  - **By:** ten.ooleem@ooleem

  It seem to be ok at 44KHz although I get quite lot of distortion with this filter. There are typos in the given code too, the correct version looks like this i think:
  float formant_filter(float *in, int vowelnum)
  {
    float res = (float) ( coeff[vowelnum][0] * (*in) +
    coeff[vowelnum][1] *memory[0] +
    coeff[vowelnum][2] *memory[1] +
    coeff[vowelnum][3] *memory[2] +
    coeff[vowelnum][4] *memory[3] +
    coeff[vowelnum][8] *memory[7] +
    coeff[vowelnum][9] *memory[8] +
    coeff[vowelnum][10] *memory[9] );
    ...
    (missing type and asterisk in the first calc line ;).
  }

  I tried morphing from one vowel to another and it works ok except in between 'A' and 'U' as I get a lot of distortion and sometime (depending on the signal) the filter goes into auto-oscilation.

  Sebastien Metrot

- **Date:** 2002-12-17 20:22:08
How did you get the coefficients?
Did I miss something?
/Larsby

Yeah, morphing linearly between the coefficients works just fine. The distortion I only get when not lowering the amplitude of the input. So I lower it :)
Larsby, you can approximate filter curves quite easily, check your dsp literature :)

Correct, it is for sampling rate of 44kHz.
It supposed to be female (soprano), approximated with its five formants.
--Alex.

Can you tell us how you calculated the coefficients?

The distorting/sharp A vowel can be toned down easy by just changing the first coeff from 8.11044e-06 to 3.11044e-06. Sounds much better that way.

Hi, I get the last formant (U) to self-oscillate and distort out of control whatever I feed it with. all the other ones sound fine...
any sugestions?
Thanks,
Jonas

I was playing around this filter, and after hours of debugging finally noticed that converting those coefficients to float just won't do it. The resulting filter is not stable anymore. Doh...
I don't have any idea how to convert them, though.
• **Date:** 2008-10-29 00:35:27
  
  • **By:** mysterious T

> Fantastic, it's all I can say! Done the linear blending and open blending matrix (a-e, → a-i, a-o, a-u, e-i, e-o...etc..etc..). Too much fun!

Thanks a lot, Alex!

• **Date:** 2010-12-14 13:16:19
  
  • **By:** johnny

> What about input and output range? When I feed the filter with audio data in -1 to 1 range, output doesn't stay in the same range. Maybe the input or output needs to be scaled?

### 3.25 Frequency warped FIR lattice

• **Author or source:** ten.enegatum@liam

• **Type:** FIR using allpass chain

• **Created:** 2004-08-24 11:39:28

Listing 39: notes

Not at all optimized and pretty hungry in terms of arrays and overhead (function requires two arrays containing lattice filter’s internal state and outputs to another two arrays with their next states). In this implementation I think you'll have to juggle taps1/newtaps in your processing loop, alternating between one set of arrays and the other for which to send to wfirlattice).

A frequency-warped lattice filter is just a lattice filter where every delay has been replaced with an allpass filter. By adjusting the allpass filters, the frequency response of the filter can be adjusted (e.g., design an FIR that approximates some filter. Play with with warping coefficient to "sweep" the FIR up and down without changing any other coefficients). Much more on warped filters can be found on Aki Harma’s website (http://www.acoustics.hut.fi/~aqi/)

Listing 40: code

```c
float wfirlattice(float input, float *taps1, float *taps2, float *reflcoef, float *lambda, float *newtaps1, float *newtaps2, int P)
{
    // input is filter input
    // taps1,taps2 are previous filter states (init to 0)
    // reflcoef are reflection coefficients. abs(reflcoef) < 1 for stable filter
    // lambda is warping (0 = no warping, 0.75 is close to bark scale at 44.1 kHz)
    // newtaps1, newtaps2 are new filter states
    // P is the order of the filter
```

(continues on next page)
```c
float forward;
float topline;
forward = input;
topline = forward;

for (int i=0;i<P;i++)
{
    newtaps2[i] = topline;
    newtaps1[i] = float(lambda)*(-topline + taps1[i]) + taps2[i];
    topline = newtaps1[i]+forward*(reflcof[i]);
    forward += newtaps1[i]*reflcof[i];
    taps1[i]=newtaps1[i];
    taps2[i]=newtaps2[i];
}
return forward;
```

### 3.25.1 Comments

- **Date**: 2004-08-24 17:26:59  
  **By**: ten.xmg@zlipzzuf

Could'n't you easily do away with newtaps entirely? As in:

```c
for(int i=0;i&lt;P;i++)
{
    taps1[i]=lambda*(taps1[i]-topline)+taps2[i];
    taps2[i]=topline;
    topline=taps1[i]+forward*reflcof[i];
    forward+=taps1[i]*reflcof[i];
}
```

I haven't had time to try this in a plugin yet, but if Maple is to be trusted at all, that works.

(2WarpDelay is nice, by the way)

- **Date**: 2004-08-25 07:32:40  
  **By**: ten.enegatum@liam

haha, thanks, that's awesome! how embarassing ;)

(glad you like 2warpdelay! the warped IIR lattice is up on harma's site too, though you might save yourself time if you read the errata: http://www.acoustics.hut.fi/~aqi/papers/oops.html :(

- **Date**: 2008-11-12 01:15:07  
  **By**: moc.toohay@ttevad

This looks really interesting. How do I get the coeffs for it, and how do I invert it to get back to the original signal?
3.26 Hilbert Filter Coefficient Calculation

- **Author or source:** ed.luosfosruoivas@naitsirhC
- **Type:** Uncle Hilbert
- **Created:** 2005-04-17 19:05:37

Listing 41: notes

This is the delphi code to create the filter coefficients, which are needed to shift a signal by 90°. This may be useful for an envelope detector...

By windowing the filter coefficients you can trade phase response flatness with magnitude response flatness.

I had problems checking its response by using a dirac impulse. White noise works fine. Also this introduces a latency of N/2!

Listing 42: code

```delphi
type TSingleArray = Array of Single;

procedure UncleHilbert(var FilterCoefficients: TSingleArray; N: Integer);
var i, j: Integer;
begin
  SetLength(FilterCoefficients, N);
  for i := 0 to (N div 4) do
    begin
      FilterCoefficients[(N div 2)+(2*i-1)] := +2/(PI*(2*i-1));
      FilterCoefficients[(N div 2)-(2*i-1)] := -2/(PI*(2*i-1));
    end;
end;
```

3.27 High quality /2 decimators

- **Author or source:** Paul Sernine
- **Type:** Decimators
- **Created:** 2006-07-28 17:59:03
These are /2 decimators, just instantiate one of them and use the `Calc` method to obtain one sample while inputing two. There is 5, 7 and 9 tap versions. They are extracted/adapted from a tutorial code by Thierry Rochebois. The optimal coefficients are excerpts of Traitement numérique du signal, 5eme edition, M. Bellanger, Masson pp. 339-346.

```cpp
//Filtres décimateurs
// T.Rochebois
// Based on
class Decimateur5{
    private:
        float R1, R2, R3, R4, R5;
        const float h0;
        const float h1;
        const float h3;
        const float h5;
    public:
        Decimateur5(): h0(346/692.0f), h1(208/692.0f), h3(-44/692.0f), h5(9/692.0f) {
            R1=R2=R3=R4=R5=0.0f;
        }
        float Calc(const float x0, const float x1) {
            float h5x0=h5*x0;
            float h3x0=h3*x0;
            float h1x0=h1*x0;
            float R6=R5+h5x0;
            R5=R4+h3x0;
            R4=R3+h1x0;
            R3=R2+h1x0+x0*x1;
            R2=R1+h3x0;
            R1=h5x0;
            return R6;
        }
};

class Decimateur7{
    private:
        float R1, R2, R3, R4, R5, R6, R7;
        const float h0, h1, h3, h5, h7;
    public:
        Decimateur7(): h0(802/1604.0f), h1(490/1604.0f), h3(-116/1604.0f), h5(33/1604.0f), h7(-6/1604.0f) {
            R1=R2=R3=R4=R5=R6=R7=0.0f;
        }
        float Calc(const float x0, const float x1) {
            float h7x0=h7*x0;
```
3.28 Karlsen

- **Author or source:** Best Regards, Ove Karlsen
- **Type:** 24-dB (4-pole) lowpass
- **Created:** 2003-04-05 06:57:19
There's really not much voodoo going on in the filter itself, it's a simple as possible:

text

Most of you can probably understand that math, it's very similar to how an analog condenser works. Although, I did have to do some JuJu to add resonance to it. While studying the other filters, I found that the feedback phase is very important to how the overall resonance level will be, and so I made a dynamic feedback path, and constant Q approximation by manipulation of the feedback phase. A bonus with this filter, is that you can "overdrive" it... Try high input levels.

Listing 45: notes

Listing 46: code

```cpp
// Karlsen 24dB Filter by Ove Karlsen / Synergy-7 in the year 2003.
// b_f = frequency 0..1
// b_q = resonance 0..50
// b_in = input
// to do bandpass, subtract poles from eachother, highpass subtract with input.

float b_inSH = b_in // before the while statement.

while (b_oversample < 2) { //2x oversampling (@44.1khz)
    float prevfp;
    prevfp = b_fp;
    if (prevfp > 1) {prevfp = 1;} // Q-limiter

    b_fp = (b_fp * 0.418) + ((b_q * pole4) * 0.582); // dynamic feedback
    float intfp;
    intfp = (b_fp * 0.36) + (prevfp * 0.64); // feedback phase
    b_in = b_inSH - intfp; // inverted feedback

    pole1 = (b_in * b_f) + (pole1 * (1 - b_f)); // pole 1
    if (pole1 > 1) {pole1 = 1;} else if (pole1 < -1) {pole1 = -1;} // pole 1 clipping

    pole2 = (pole1 * b_f) + (pole2 * (1 - b_f)); // pole 2
    pole3 = (pole2 * b_f) + (pole3 * (1 - b_f)); // pole 3
    pole4 = (pole3 * b_f) + (pole4 * (1 - b_f)); // pole 4

    b_oversample++;
}
lowpassout = b_in;
```

Chapter 3. Filters
3.28.1 Comments

• Date: 2003-08-08 18:35:52
  • By: moc.7-ygrenys@evo

Hi.
Seems to be a slight typo in my code.
lowpassout = pole4; // ofcourse :)

Best Regards,
Ove Karlsen

• Date: 2003-09-20 15:31:19
  • By: moc.tidosha@ttam

Hi Ove, we spoke once on the #AROS IRC channel... I'm trying to put this code into a
→filter object, but I'm wandering what datatype the input and output should be?
I'm processing my audio data in packets of 8000 signed words (16 bits) at a time. can
→I put one audio sample words into this function? Since it seems to require a
→floating point input!
Thanks

• Date: 2004-05-17 18:49:43
  • By: moc.tsv-nashi@edoc_evo

Hi Matt.
Yes, it does indeed need float inputs.

Best Regards,
Ove Karlsen.

• Date: 2005-03-20 11:36:07
  • By: se.arret@htrehgraknu

Can somebody explain exactly howto make the band Pass and high pass, i tried as
→explained and don't work exactly as expected
highpass = in - pole4
make "some kind of highpass", but not as expected
cut frequency
and for band pass, how we substract the poles between them ?
pole4-pole3-pole2-pole1 ?
pole1-pole2-pole3-pole4 ?
Also, is there a way to get a Notch ?

• Date: 2005-03-22 14:14:21
  • By: ed.luosfrosruivas@naitsirhC
Below you will find an object pascal version of the filter.

L = Lowpass
H = Highpass
N = Notch
B = Bandpass

Regards,

Christian

--

unit KarlsenUnit;

interface
type
 TKarlsen = class
    private
      fQ   : Single;
      fF1,fF : Single;
      fFS  : Single;
      fTmp : Double;
      fOS  : Byte;
      fPole : Array[1..4] of Single;
    procedure SetFrequency(v:Single);
    procedure SetQ(v:Single);
    public
      constructor Create;
      destructor Destroy; override;
      procedure Process(const I : Single; var L,B,N,H: Single);
      property Frequency: Single read fF write SetFrequency;
      property SampleRate: Single read fFS write fFS;
      property Q: Single read fQ write SetQ;
      property OverSample: Byte read fOS write fOS;
  end;
implementation
uses sysutils;
const kDenorm = 1.0e-24;

constructor TKarlsen.Create;
begin
  inherited;
  fFS:=44100;
  Frequency:=1000;
  fOS:=2;
  Q:=1;
end;

destructor TKarlsen.Destroy;
begin
  inherited;
end;
procedure TKarlsen.SetFrequency(v:Single);
begin
  if fFS<=0 then raise exception.create('Sample Rate Error!');
  if v<>fF then
  begin
    fF:=v;
    fF1:=fF/fFs; // fF1 range from 0..1
    end;
end;

procedure TKarlsen.SetQ(v:Single);
begin
  if v<>fQ then
  begin
    if v<0 then fQ:=0 else
    if v>50 then fQ:=50 else
    fQ:=v;
    end;
end;

procedure TKarlsen.Process(const I : Single; var L,B,N,H: Single);
var prevfp : Single;
  intfp : Single;
  o : Integer;
begin
  for o:=0 to fOS-1 do
  begin
    prevfp:=fTmp;
    if (prevfp > 1) then prevfp:=1; // Q-limiter
    fTmp:=(fTmp*0.418)+(((fQ*fPole[4])*0.582); // dynamic feedback
    intfp:=(fTmp*0.36)+(prevfp*0.64); // feedback phase
    fPole[1]:= (((I+kDenorm)-intfp) * fF1) + (fPole[1] * (1 - fF1));
    if (fPole[1] > 1)
      then fPole[1]:= 1
    else if fPole[1] < -1
      then fPole[1]:= -1;
    fPole[2]:= (fPole[1]*fF1)+(fPole[2]*(1-fF1)); // pole 2
    fPole[3]:= (fPole[2]*fF1)+(fPole[3]*(1-fF1)); // pole 3
    fPole[4]:= (fPole[3]*fF1)+(fPole[4]*(1-fF1)); // pole 4
    end;
  L:=fPole[4];
  B:=fPole[4]-fPole[1];
  N:=I-fPole[1];
  H:=I-fPole[4]-fPole[1];
end;
end.

• Date: 2005-03-29 12:24:17
• By: se.sarret@htrehgraknu

Thanks Christian!!

Anyway, i tried something similar and seems that what you call Notch is really a Bandpass and the bandpass makes something really strange
Anyway i'm having other problems with this filter too. It seems to cut too low for low pass and too high for high pass. Also, resonance sets a peak far away from the cut frequency. And last but not least, the slope isn't 24 db/oct, really is much lesser, but not in a consistent way: sometimes is 6, sometimes 12, sometimes 20, etc.

Any ideas?

- **Date**: 2005-07-20 12:28:44  
  **By**: moc.psd-nashi@liam

Your problem sounds a bit strange, maybe you should check your implementation.

Nice to see a pascal version too, Christian!

Although I really recommend one set a lower denormal threshold, maybe a 1/100, it really affects the sound of the filter. The best is probably tweaking that value in realtime to see what sounds best. Also, doubles for the buffers.. :)

Very Best Regards,  
Ove Karlsen

- **Date**: 2005-09-20 12:26:37  
  **By**: ku.oc.snosrapsd@psdcisum

Christian, shouldn't your code end:

L:=fPole[4];
B:=fPole[4]-fPole[1];
//CWB posted
//N:=I-fPole[1];
//B:=I-fPole[4]-fPole[1];

//DSP posted
H:=I-fPole[4]; //Surely pole 4 would give a 24dB/Oct HP, rather than the 6dB version posted
N:=I-fPole[4]-fPole[1]; //Inverse of BP

Any thoughts, anyone?

DSP

- **Date**: 2005-09-23 11:15:32  
  **By**: moc.psd-nashi@liam

This filter was really written mostly to demonstrate the Q-limiter though, and also, to write it in the most computationally efficient way.

Here is a little more featured version.

-----------------------------
// Karlsen, Second Order SVF type filter.

// _b_in1, _b_in2 stereo input
// _fvar01 cutoff
// _fvar02 slope
// _fvar03 mode
// _fvar04 res
// fvar05 cutoff/res compensation
// inits, all doubles
// b_noise = 19.1919191919191919191919191919191919191919;  
// filterbuffers = 0;

b_noise = b_noise * b_noise;
int i_noise = b_noise;
b_noise = b_noise - i_noise;

double b_lnoise = (b_noise - 0.5) * 2;
double b_rnoise = ((1-b_noise) - 0.5) * 2;

b_noise = b_noise + 19;

b_lnoise = b_lnoise * 65536;
b_rnoise = b_rnoise * 65536;
if (b_lnoise > 1) {b_lnoise = 1;} else if (b_lnoise < -1) {b_lnoise = -1;}
if (b_rnoise > 1) {b_rnoise = 1;} else if (b_rnoise < -1) {b_rnoise = -1;}

b_lnoise = b_lnoise * 1e-24;  // find optimal value
b_rnoise = b_rnoise * 1e-24;

b_in1 = b_in1 + (b_lnoise);  // denormal prevention (also doubling as dither and analog noise).
b_in2 = b_in2 + (b_rnoise);

float b_slope = (1-fvar2) + 0.5;
float b_cut = ((fvar1 * fvar1) + ((fvar1 / (b_slope)) * (1 - fvar1))) / ((1 * fvar1) + ((1 / b_slope) * (1 - fvar1)));

b_cut = b_cut*b_cut;  // linearize this
float b_res = fvar4 * 100;
int i_kmode = fvar3 * 100;

if (b_cut > 1) {b_cut = 1;}
if (b_cut < 0) {b_cut = 0;}

b_in1 = (b_in1 + b_lbuffb1);
b_in2 = (b_in2 + b_lbuffb2);

b_lbuf09 = ((b_in1 * b_cut) + ((b_lbuf09 / b_slope) * (1 - b_cut))) / ((1 * b_cut) + ((1 / b_slope) * (1 - b_cut)));
b_lbuf10 = ((b_in2 * b_cut) + ((b_lbuf10 / b_slope) * (1 - b_cut))) / ((1 * b_cut) + ((1 / b_slope) * (1 - b_cut)));

b_lbuf11 = ((b_lbuf09 * b_cut) + ((b_lbuf11 / b_slope) * (1 - b_cut))) / ((1 * b_cut) + ((1 / b_slope) * (1 - b_cut)));
b_lbuf12 = ((b_lbuf10 * b_cut) + ((b_lbuf12 / b_slope) * (1 - b_cut))) / ((1 * b_cut) + ((1 / b_slope) * (1 - b_cut)));

if (i_kmode == 0) {  // lowpass
    b_in1 = b_lbuf11;
    b_in2 = b_lbuf12;
}
else if (i_kmode == 1) {  // bandpass
    b_in1 = b_lbuf09 - b_lbuf11;
    b
b_in2 = b_lbuf10 - b_lbuf12;
}
else if (i_kmode == 2)  // highpass
  b_in1 = b_in1 - b_lbuf11;
  b_in2 = b_in2 - b_lbuf12;
}

b_lbuffb1 = ((b_lbuf09 - b_lbuf11) * ((b_cut * fvar5) + 1)) * b_res;
b_lbuffb2 = ((b_lbuf10 - b_lbuf12) * ((b_cut * fvar5) + 1)) * b_res;

b_lbuffb1 = atan(b_lbuffb1);
b_lbuffb2 = atan(b_lbuffb2);

---------------------------------------------
Works really well with control signals, where you keep the cutoff at a constant level. Also, a bit more useful with audio, if you linearize the cutoff.

Best Regards,
Ove Karlsen.

• Date: 2005-10-13 14:00:39
• By: ku.oc.snorsrapsd@psdcisum

I was looking at the b_cut assignment, and was going through looking at optimising it and found this:

float b_cut = ((fvar1 * fvar1) + ((fvar1 / (b_slope)) * (1 - fvar1)))
/ ((1 * fvar1) + ((1 / (b_slope)) * (1 - fvar1)));

Rename for convenience and clarity
fvar1=co
b_slope=sl

=> (co^2+(co(1-co)))
     -------
    sl
    --------
   (1*co)+(1-co)
     ---
    sl

multiply numerator & denominator by sl to even things up

=> (sl*co^2+(co(1-co)))
    -------------
   (sl*co)+(1-co)

expand brackets

=> sl*co^2+co-co^2
    --------------
   sl*co+1-co

refactor

=> co(sl*co+1-co)
    ---------
\[(sl \cdot co + 1 - co)\] cancels out, leaving ..

\[=> co\]

if I've got anything wrong here, please pipe up..

Duncan

- **Date:** 2005-10-13 14:06:02
- **By:** ku.oc.snosrapsd@psdcisum

(continues on next page)

- **Date:** 2006-02-17 13:23:47
- **By:** moc.psd-nashi@liam


```c
// Fast differential amplifier approximation

double b_inr = b_in * b_filterdrive;
if (b_inr < 0) {b_inr = -b_inr;}
double b_inrns = b_inr;
if (b_inr > 1) {b_inr = 1;}
double b_dax = b_inr - ((b_inr * b_inr) * 0.5);
b_dax = b_dax - b_inr;
b_inr = b_inr + b_dax;
b_inr = b_inr * 0.24;
if (b_inr > 1) {b_inr = 1;}
b_dax = b_inr - ((b_inr * 0.33333333) * (b_inr * b_inr));
b_dax = b_dax - b_inr;
b_inr = b_inr + b_dax;
b_inr = b_inr / 0.24;

double b_mul = b_inrns / b_inr; // beware of zero
b_sbuf1 = ((b_sbuf1 - (b_sbuf1 * 0.4300)) + (b_mul * 0.4300));

b_mul = b_sbuf1 + ((b_mul - b_sbuf1) * 0.6910);
b_in = b_in / b_mul;

// This method sounds the best here..
// About denormals, it does not seem to be much of an issue here, probably because I
\[\rightarrow\] input the filters with oscillators, and not samples, or other, where the level may
\[\rightarrow\] drop below the denormal threshold for extended periods of time. However, if you do,
\[\rightarrow\] you probably want to quantize out the information below the threshold, in the
\[\rightarrow\] buffers, and raise/lower the inputlevel before/after the filter. Adding low levels
\[\rightarrow\] of noise may be effective aswell. This is described somewhere else on this site.

    double b_cutsc = pow(1024,b_cut) / 1024; // perfect tracking..
```

(continues on next page)
\[
\begin{align*}
b_{fbuf1} &= ((b_{fbuf1} - (b_{fbuf1} \times b_{cutsc})) + (b_{in} \times b_{cutsc})); \\
b_{in} &= b_{fbuf1}; \\
b_{fbuf2} &= ((b_{fbuf2} - (b_{fbuf2} \times b_{cutsc})) + (b_{in} \times b_{cutsc})); \\
b_{in} &= b_{fbuf2}; \\
b_{fbuf3} &= ((b_{fbuf3} - (b_{fbuf3} \times b_{cutsc})) + (b_{in} \times b_{cutsc})); \\
b_{in} &= b_{fbuf3}; \\
b_{fbuf4} &= ((b_{fbuf4} - (b_{fbuf4} \times b_{cutsc})) + (b_{in} \times b_{cutsc})); \\
b_{in} &= b_{fbuf4};
\end{align*}
\]

Soundwise, it’s somewhere between a transistor ladder, and a diode ladder.

Enjoy!

Ove Karlsen.

PS: I prefer IRL communication these days, so if you need to reach me, please dial my cellphone, +047 928 50 803.

---

I can be reached by email @ 1a2r4i54f5o5v2ek1a1r5ls6en03ho2tm6a111.c5o6m!no!nums

---

As you may know, The traditional 4-pole Ladder found in vintage hardware synths, had a particular sound. The nonlinearities inherent in the suboptimal components, often added a particular flavour to the sound.

Digital does mathematical calculations much better than any analog solution, and therefore, when the filter was emulated by digital filter types, some of the character got lost.

I believe this mainly boils down to the resonance limiting occuring in the analog version.

Therefore I have written a very fast ladder approximation, not emulating any of what may seem neccesary, such as pole saturation, which in turn results in nonlinear cutoff frequency, and loss of volume at lower cutoffs. However this can be implemented, if wanted, by putting the neccesary saturation functions inside the code. If you seek the true analog sound, you may want to do a full differential amplifier emulation aswell.

But - I believe in the end, you would end up wanting a perfect filter, with just the touch that makes it sound analog, resonance limiting.

So here it is, Karlsen Ladder, v4. A very resource efficient ladder. Can furthermore be optimized with asm.

\[
\begin{align*}
rez &= \text{pole4} \times \text{rezamount}; \text{if} (rez > 1) \ (rez = 1); \\
input &= \text{input} - rez; \\
pole1 &= \text{pole1} + ((-\text{pole1} + \text{input}) \times \text{cutoffreq}); \\
pole2 &= \text{pole2} + ((-\text{pole2} + \text{pole1}) \times \text{cutoffreq}); \\
pole3 &= \text{pole3} + ((-\text{pole3} + \text{pole2}) \times \text{cutoffreq}); \\
pole4 &= \text{pole4} + ((-\text{pole4} + \text{pole3}) \times \text{cutoffreq}); \\
output &= \text{pole4};
\end{align*}
\]

I can be reached by email @ 1a2r4i54f5o5v2ek1a1r5ls6en03ho2tm6a111.c5o6m!no!nums
Please see
http://musicdsp.org/showArchiveComment.php?ArchiveID=240
for the ultimate development of this filter.

Peace Be With You,
Ove Karlsen

3.29 Karlsen Fast Ladder

• Author or source: moc.liamtoh@neslrakevofira
• Type: 4 pole ladder emulation
• Created: 2007-01-08 10:49:56

Listing 47: notes

ATTN Admin: You should remove the old version named "Karlsen" on your website, and
rather include this one instead.

Listing 48: code

1 // An updated version of "Karlsen 24dB Filter"
2 // This time, the fastest incarnation possible.
3 // The very best greetings, Arif Ove Karlsen.
4 // arifovekarlsen->hotmail.com
5
6 b_rscl = b_buf4; if (b_rscl > 1) {b_rscl = 1;}
7 b_in = (-b_rscl * b_rez) + b_in;
8 b_buf1 = ((-b_buf1 + b_in1) * b_cut) + b_buf1;
9 b_buf2 = ((-b_buf2 + b_buf1) * b_cut) + b_buf2;
10 b_buf3 = ((-b_buf3 + b_buf2) * b_cut) + b_buf3;
11 b_buf4 = ((-b_buf4 + b_buf3) * b_cut) + b_buf4;
12 b_lpout = b_buf4;

3.29.1 Comments

• Date: 2007-01-08 18:42:24
• By: moc.erehwon@ydobon

Where are the coefficients? How do I set the cutoff frequency?

• Date: 2007-01-09 09:49:18
• By: uh.etle.fni@yfoocs

The parameters are:
b_cut - cutoff freq

(continues on next page)
b_rez - resonance
b_in1 - input

Cutoff is normalized frequency in rads (2*pi*cutoff/samplerate). Stability limit for
→ b_cut is around 0.7-0.8.

There's a typo, the input is sometimes b_in, sometimes b_in1. Anyways why do you use,
→ a b_ prefix for all your variables? Wouldn't it be more easy to read like this:

resoclip = buf4; if (resoclip > 1) resoclip = 1;
in = in - (resoclip * res);
buf1 = ((in - buf1) * cut) + buf1;
buf2 = ((buf1 - buf2) * cut) + buf2;
buf3 = ((buf2 - buf3) * cut) + buf3;
buf4 = ((buf3 - buf4) * cut) + buf4;
lpout = buf4;

Also note that asymmetrical clipping gives you DC offset (at least that's what I get),
→ so symmetrical clipping is better (and gives a much smoother sound).

-- peter schoffhauzer

• Date: 2007-06-26 16:23:57
• By: moc.psd8rts@fira

Tee b_prefix is simply a procedure I began using when I started programming C..
→ Influenced by the BEOS operating system. However it seemed to also make my code,
→ more readable, atleast to me. So I started using various prefixes for various,
→ things, making the variables easily recognizable. Peter, everyone, I am now,
→ reachable on www.str8dsp.com - Do also check out the plugin offers there!

• Date: 2007-07-17 20:21:47
• By: moc.psd8rts@koa

Here's even another filter, I will probably never get around to making any product,
→ with this one so here it is, pseudo-vintage diode ladder.

Diode Ladder, (unbuffered)

// limit resonance, rzl, tweak smearing with fltw, 0.3230 seems
→ to be a good vintage sound.
in = in - rzl;
in = in + ((-in + kbuf1) * cutoff);
kbuf1 = in + ((-in + kbuf1) * fltw);
in = in + ((-in + kbuf2) * cutoff);
kbuf2 = in + ((-in + kbuf2) * fltw);
etc..

• Date: 2007-09-09 22:37:08
• By: moc.oiduatniopxf@ved

"Cutoff is normalized frequency in rads (2*pi*cutoff/samplerate):

This seems to be valid for very low ( < 200 Hz ) frequencies - higher sample rates,
→ seem to be "Closer"
I also did a 9th order gaussian filter (minimal phase), using only 5 orders, for my limiter, which is released under the GPL LICENCE. http://www.paradoxuncreated.com

Hi, I have now generalized the ladder filter, into fast code, and with the desired aspects of analog, but retaining digital perfectness.

Please see my blog: http://paradoxuncreated.com/Blog/wordpress/?p=1360

Peace Be With You.

I have also moved domains now, and consolidated the information on this ultimate digital filter, with "analog sound", here:

http://ovekarlsen.com/Blog/abdullah-filter/

Peace Be With You!

Karlsen Fast Ladder III - inspired by "transistors set to work as diode" type Roland filters. The best fast and non-nonsensical approximation of popular analog filter sound, as in for instance Roland SH-5, and the smaller TB-303.

//Coupled with oversampling and simple oscs you will probably get the best analog approximation.

// for nice low sat, or sharper type low deemphasis saturation, one can use a onepole shelf before the filter.
// b_lf = b_lf + ((-b_lf + b_v) * b_lfcut); // b_lfcut 0..1
// double b_lfhp = b_v - b_lf;
// b_v = b_lf + (b_lfhp * ((b_lfgain*0.5)+1));

double b_rez = b_aflt4 - b_v; // no attenuation with rez, makes a stabler filter.
// b_v = b_v - (b_rez*b_fres); // b_fres = resonance amount. 0..4 typical = "to selfoscillation", 0.6 covers a more saturated range.

double b_vnc = b_v; // clip, and adding back some nonclipped, to get a dynamic like analog.
if (b_v > 1) {b_v = 1;} else if (b_v < -1) {b_v = -1;}
//
// b_v = b_vnc + ((-b_vnc + b_v) * 0.9840);

(continues on next page)
Hey Ove

I am wondering about the last filter the Fast ladder diode III. Where is the input supposed to go?

Sorry, I am still learning and thanks for some great filters, btw :)

Thanks, Jakob

---

### 3.30 LP and HP Filter

- **Author or source:** Patrice Tarrabia
- **Type:** biquad, tweaked butterworth
- **Created:** 2002-01-17 02:13:47

Listing 49: code

```plaintext
1 r = rez amount, from sqrt(2) to ~ 0.1
2 f = cutoff frequency
3 (from ~0 Hz to SampleRate/2 - though many synths seem to filter only up to SampleRate/4)
4
5 The filter algo:
6 out(n) = a1 * in + a2 * in(n-1) + a3 * in(n-2) - b1*out(n-1) - b2*out(n-2)
7
8 **Lowpass:**
9 c = 1.0 / tan(pi * f / sample_rate);
10 a1 = 1.0 / ( 1.0 + r * c + c * c);
11 a2 = 2* a1;
12 a3 = a1;
13 b1 = 2.0 * ( 1.0 - c*c) * a1;
14 b2 = ( 1.0 - r * c + c * c) * a1;
15
16 **Hi-pass:**
17 c = tan(pi * f / sample_rate);
18 a1 = 1.0 / ( 1.0 + r * c + c * c);
```
Ok, the filter works, but how to use the resonance parameter (r)? The range from $\sqrt{2}$-lowest to 0.1 (highest res.) is Ok for a LP with Cutoff > 3 or 4 KHz, but for lower cutoff frequencies and higher res you will get values much greater than 1! (And this means clipping like hell)

So, has anybody calculated better parameters (for r, b1, b2)?

Below is my attempt to implement the above lowpass filter in c#. I'm just a beginner at this so it's probably something that I've messed up. If anybody can offer a suggestion of what I may be doing wrong please help. I'm getting a bunch of staticky noise as my output of this filter currently.

```
public class LowPassFilter {
    /// <summary>
    /// rez amount, from sqrt(2) to ~ 0.1
    /// </summary>
    float r;
    /// <summary>
    /// cutoff frequency
    /// (from ~0 Hz to SampleRate/2 - though many
    /// synths seem to filter only up to SampleRate/4)
    /// </summary>
    float f;
    float c;
    float a1;
    float a2;
    float a3;
    float b1;
    float b2;
    float in0 = 0;
    float in1 = 0;
    float in2 = 0;
    float out0;
```

(continues on next page)
float out1 = 0;
float out2 = 0;
private int _SampleRate;

public LowPassFilter(int sampleRate)
{
    _SampleRate = sampleRate;
    // SetParams(_SampleRate / 2f, 0.1f);
    SetParams(_SampleRate / 8f, 1f);
}

public float Process(float input)
{
    float output = a1 * input +
                a2 * in1 +
                a3 * in2 -
                b1 * out1 -
                b2 * out2;

    in2 = in1;
    in1 = input;

    out2 = out1;
    out1 = output;

    Console.WriteLine(input + "", " + output);
    return output;
}

/// <summary>
///
/// </summary>
public float CutoffFrequency
{
    set
    {
        f = value;
        c = (float) (1.0f / Math.Tan(Math.PI * f / _SampleRate));
        SetParams();
    }
    get
    {
        return f;
    }
}

### Date: 2003-04-03 10:25:39

### By: moc.liamtoh@rahniak
public float Resonance
{
    set
    {
        r = value;
        SetParams();
    }
    get
    {
        return r;
    }
}

public void SetParams(float cutoffFrequency, float resonance)
{
    r = resonance;
    CutoffFrequency = cutoffFrequency;
}

/// <summary>
/// TODO rename
/// </summary>
/// <param name="c"></param>
/// <param name="resonance"></param>
private void SetParams()
{
    a1 = 1f / (1f + r*c + c*c);
    a2 = 2 * a1;
    a3 = a1;
    b1 = 2f * (1f - c*c) * a1;
    b2 = (1f - r*c + c*c) * a1;
}

• Date: 2003-04-03 11:58:51
  • By: moc.liamtoh@trahniak

Nevermind I think I solved my problem. I was missing parens around the coefficients ...and the variables ...((a1 * input)...
AFAIK there's no separate bandpass and bandstop version of Butterworth filters. Instead, bandpass is usually done by cascading a HP and a LP filter, and bandstop is the mixed output of a HP and a LP filter. However, there's bandpass biquad code (for example RBJ biquad filters). Cheers Peter

• Date: 2006-05-28 20:15:48
  • By: uh.etle.fni@yfoocs

You can save two divisions for lowpass using
  
  ```
  c = tan((0.5 - (f * inv_samplerate))*pi);
  ```

  instead of
  
  ```
  c = 1.0 / tan(pi * f / sample_rate);
  ```

where inv_samplerate is 1.0/samplerate precalculated. (mul is faster than div)

However, the latter form can be approximated very well below 4kHz (at 44kHz)

```
  c = 1.0 / (pi * f * inv_sample_rate);
```

which is far better than both of the previous two equations, because it does not use any transcendental functions. So, an optimized form is:

```
  f0 = f * inv_sample_rate;
  if (f0 < 0.1) c = 1.0 / (f0 * pi); // below 4.4k
  else c = tan((0.5 - f0) * pi);
```

This needs only about ~60% CPU below 4.4kHz. Probably using lookup tables could make it even faster...

Mapping resonance range 0..1 to 0..self-osc:

```
  float const sqrt_two = 1.41421356;
  r = sqrt_two - resonance * sqrt_two;
```

Setting resonance in the conventional q form (like in RBJ biquads):

```
  r = 1.0/q;
```

Cheers, Peter

• Date: 2006-05-28 20:43:28
  • By: uh.etle@yfoocs

However I find that this algorythm has a slight tuning error regardless of using approximation or not. 'inv_samplerate = 0.95 * samplerate' seems to give a more accurate frequency tuning.

• Date: 2006-05-29 15:50:13
  • By: uh.etle.fni@yfoocs

You can use the same trick for highpass:

precalc when setting up the filter:

```
  inv_samplerate = 1.0 / samplerate * 0.957;
```

(multiplying by 0.957 seems to give the most precise tuning)

and then calculating c:

```
  f0 = f * inv_samplerate;
```
if (f0 < 0.05) c = (f0 * pi);
else c = tan(f0 * pi);

Now I used 0.05 instead of 0.1, thats 0.05 * 44100 = 2.2k instead of 4.4k. So, this
is a bit more precise than 0.1, because around 3-4k it had a slight error, however,
only noticeable on the analyzer when compared to the original version. This is
still about two third of the logarithmic frequency scale, so its quite a bit of a
speed improvement. You can use either precision for both lowpass and highpass.

For calculating tan(), you can take some quick sin() approximation, and use:
\[ \tan(x) = \sin(x) / \sin(half\_pi - x) \]

There are many good pieces of code for that in the archive.

I tried to make some 1/x based approximations for 1.0/tan(x), here is one:

```c
inline float tan_inv_approx(float x)
{
    float const two_div_pi = 2.0f/3.141592654f;
    if (x<0.5f) return 1.0f/x;
    else return 1.467f*(1.0f/x-two_div_pi);
}
```

This one is pretty fast, however it is a quite rough estimate; it has some 1-2
semitones frequency tuning error around 5-8 kHz and above 10kHz. Might be usable
for synths, however, or somewhere where scientific precision is not needed.

Cheers, Peter

• Date: 2006-05-30 21:12:13
• By: uh.etle.fnj@yfoocs

Sorry, forget the * 0.957 tuning, this algorithm is precise without that, the mistake
was in my program. Everything else is valid, I hope.

• Date: 2008-03-11 13:31:52
• By: ur.kb@sexof

Optimization for Hipass:

```c
c = tan(pi * f / sample_rate);

c = ( c + r ) * c;
a1 = 1.0 / ( 1.0 + c );
b1 = ( 1.0 - c );
out(n) = ( a1 * out(n-1) + in - in(n-1) ) * b1;
```

### 3.31 LPF 24dB/Oct

• Author or source: ed.luofosruoivas@naitsirhC
• Type: Chebyshev
First calculate the prewarped digital **frequency**:

```c
K = tan(Pi * Frequency / Samplerate);
```

Now we calc some **Coefficients**:

```c
gs = Sinh(PassbandRipple);
gc = Cosh(PassbandRipple);
gc *= gc;
Coeff[0] = 1 / (gc-0.85355339059327376220042218105097);
Coeff[1] = K * Coeff[0]*gs*1.847759065022573512256366378792;
Coeff[2] = 1 / (gc-0.1464466094067262377957781894758);
Coeff[3] = K * Coeff[2]*gs*0.76536686473017954345691996806;
K *= K; // (just to optimize it a little bit)
```

Calculate the first **biquad**:

```c
A0 = (Coeff[1]+K+Coeff[0]);
A1 = 2*(Coeff[0]-K)*t;
A2 = (Coeff[1]-K-Coeff[0]) *t;
B0 = t*K;
B1 = 2*B0;
B2 = B0;
```

Calculate the second **biquad**:

```c
A4 = 2*(Coeff[2]-K)*t;
A5 = (Coeff[3]-K-Coeff[2]) *t;
B3 = t*K;
B4 = 2*B3;
B5 = B3;
```

Then calculate the output as **follows**:

```c
Stage1 = B0*Input + State0;
State0 = B1*Input + A1/A0*Stage1 + State1;
State1 = B2*Input + A2/A0*Stage1;
Output = B3*Stage1 + State2;
State2 = B4*Stage1 + A4/A3*Output + State2;
State3 = B5*Stage1 + A5/A3*Output;
```

### 3.31.1 Comments

- **Date**: 2006-09-14 10:36:43
- **By**: musicdsp@Nospam dsparsons.co.uk

You've used two notations here (as admitted on KVR!).. Updated calculation code reads:
Calculate the first biquad:

```c
//A0 = (Coeff[1]+K+Coeff[0]);
t = 1/(Coeff[1]+K+Coeff[0]);
A1 = 2*(Coeff[0]-K)*t;
A2 = (Coeff[1]-K-Coeff[0])*t;
B0 = t*K;
B1 = 2*B0;
B2 = B0;
```

Calculate the second biquad:

```c
t = 1/(Coeff[3]+K+Coeff[2]);
A4 = 2*(Coeff[2]-K)*t;
A5 = (Coeff[3]-K-Coeff[2])*t;
B3 = t*K;
B4 = 2*B3;
B5 = B3;
```

Then calculate the output as follows:

```c
Stage1 = B0*Input + State0;
State0 = B1*Input + A1*Stage1 + State1;
Stage1 = B2*Input + A2*Stage1;
Output = B3*Stage1 + State2;
State2 = B4*Stage1 + A4*Output + State2;
State3 = B5*Stage1 + A5*Output;
```

Hope that clears up any confusion for future readers :-)

---

• **Date:** 2008-06-24 13:57:19  
  **By:** moc.liamg@tnemelCssoR

The variable State3 is assigned a value, but is never used anywhere. Is there a reason for this?

---

• **Date:** 2008-10-17 00:40:33  
  **By:** moc.liamg@321tiloen

Just ported this into Reaper's native JesuSonic.

There are errors in both of the codes above :D

Use this:

```c
//start
A0 = 1/(Coeff[1]+K+Coeff[0]);
A1 = 2*(Coeff[0]-K)*A0;
```

(continues on next page)
\[
A_2 = (\text{Coeff}[1]-K-\text{Coeff}[0]) \times A_0;
B_0 = A_0 \times K;
B_1 = 2 \times B_0;
B_2 = B_0;
\]
\[
A_3 = 1/(\text{Coeff}[3]+K+\text{Coeff}[2]);
A_4 = 2 \times (\text{Coeff}[2]-K) \times A_3;
A_5 = (\text{Coeff}[3]-K-\text{Coeff}[2]) \times A_3;
B_3 = A_3 \times K;
B_4 = 2 \times B_3;
B_5 = B_3;
\]
\[
\text{Stage1} = B_0 \times \text{Input} + \text{State0};
\text{State0} = B_1 \times \text{Input} + A_1 \times \text{Stage1} + \text{State1};
\text{State1} = B_2 \times \text{Input} + A_2 \times \text{Stage1};
\text{Output} = B_3 \times \text{Stage1} + \text{State2};
\text{State2} = B_4 \times \text{Stage1} + A_4 \times \text{Output} + \text{State3};
\text{State3} = B_5 \times \text{Stage1} + A_5 \times \text{Output};
\]

@RossClement[ AT ]gmail[ DOT ]com
'State3' should be added in this line
-> State2 = B_4 \times \text{Stage1} + A_4 \times \text{Output} + \text{State3};

### 3.32 Lowpass filter for parameter edge filtering

- **Author or source:** Olli Niemitalo
- **Created:** 2002-01-17 02:06:29
- **Linked files:** filter001.gif.

Listing 51: notes

use this filter to smooth sudden parameter changes
(see linkfile!)

Listing 52: code

```c
/* - Three one-poles combined in parallel */
/* - Output stays within input limits */
/* - 18 dB/oct (approx) frequency response rolloff */
/* - Quite fast, 2x3 parallel multiplications/sample, no internal buffers */
/* - Time-scalable, allowing use with different samplerates */
/* - Impulse and edge responses have continuous differential */
/* - Requires high internal numerical precision */
{
    /* Parameters */
    // Number of samples from start of edge to halfway to new value
    const double scale = 100;
    // 0 < Smoothness < 1. High is better, but may cause precision problems
    const double smoothness = 0.999;
}  
```
/* Precalc variables */
double a = 1.0 - (2.4 / scale); // Could also be set directly
double b = smoothness; // _-_
double acoef = a;
double bcoef = a * b;
double ccoef = a * b * b;

double mastergain = 1.0 / (-1.0 / (log(a) + 2.0 * log(b)) + 2.0 / (log(a) + log(b)) - 1.0 / log(a));

double again = mastergain;
double bgain = mastergain * (log(a * b * b) * (log(a) - log(a * b)) / ((log(a * b * b) - log(a * b)) * log(a * b))
    - log(a) / log(a * b));
double cgain = mastergain * (-log(a) - log(a * b)) / (log(a * b * b) - log(a * b));

/* Runtime variables */
long streamofs;
double areg = 0;
double breg = 0;
double creg = 0;

/* Main loop */
for (streamofs = 0; streamofs < streamsize; streamofs++)
{
    /* Update filters */
    areg = acoef * areg + fromstream[streamofs];
    breg = bcoef * breg + fromstream[streamofs];
    creg = ccoef * creg + fromstream[streamofs];

    /* Combine filters in parallel */
    long temp = again * areg
                + bgain * breg
                + cgain * creg;

    /* Check clipping */
    if (temp > 32767)
    {
        temp = 32767;
    }
    else if (temp < -32768)
    {
        temp = -32768;
    }

    /* Store new value */
tostream[streamofs] = temp;
}

3.32.1 Comments
- Date: 2007-01-06 04:19:27
- By: uh.etle.fni@yfoocs
Wouldn't just one pole with a low cutoff suit this purpose? At least that's what I usually do for smoothing parameter changes, and it works fine.

- **Date:** 2014-07-14 22:02:46
- **By:** moc.liamg@uttrep.imas

Works nicely, thanks. The gain calculations can be simplified quite a bit, to just one gain parameter.

\[ \text{gain} = 1.0 / (-1.0 / \log(a) + 2.0 / \log(a * b) - 1.0 / \log(a * b * b)) \]

Then,

\[ \text{again} = \text{gain}, \]
\[ \text{bgain} = -2.0 * \text{gain}, \]
\[ \text{cgain} = \text{gain}. \]

### 3.33 MDCT and IMDCT based on FFTW3

- **Author or source:** moc.liamg@gnahz.auhuhs
- **Type:** analysis and synthesis filterbank
- **Created:** 2009-07-31 06:37:37

Listing 53: notes

MDCT/IMDCT is the most widely used filterbank in digital audio coding, e.g. MP3, AAC, WMA, OGG Vorbis, ATRAC.

suppose input \( x \) and \( N = \text{size}(x,1)/2 \). the MDCT transform matrix is

\[ C = \cos(\pi/N*(\left[0:2*N-1\right]'+.5+.5*N)\star(\left[0:N-1\right]+.5)); \]

then MDCT spectrum for input \( x \) is

\[ y = C'\times x; \]

A well known fast algorithm is based on FFT :

(1) fold column-wisely the 2\( \times N \) rows into \( N \) rows
(2) complex arrange the \( N \) rows into \( N/2 \) rows
(3) pre-twiddle, \( N/2 \)-point complex fft, post-twiddle
(4) reorder to form the MDCT spectrum

in fact, (2)-(4) is a fast DCT-IV algorithm.

Implementation of the algorithm can be found in faac, but a little bit mess to extract for standalone use, and I ran into that problem. So I wrote some c codes to implement MDCT/IMDCT for any length that is a multiple of 4. Hopefully they will be useful to people here.

I benchmarked the codes using 3 FFT routines, FFT in faac, kiss_fft, and the awful FFTW.

MDCT based on FFTW is the fastest, 2048-point MDCT single precision 10^5 times in 1.54s, about 50% of FFT in faac on my Petium IV 3G Hz.

(continues on next page)
An author of the FFTW, Steven G. Johnson, has a hard-coded fixed size MDCT of 256 input samples (http://jdj.mit.edu/~stevenj/mdct_128nr.c). My code is 13% slower than his.

Using the codes is very simple:
1. init (declare first "extern void* mdctf_init(int)")
   void* m_plan = mdctf_init(N);
2. run mdct/imdct as many times as you wish
   mdctf(freq, time, m_plan);
3. free
   mdctf_free(m_plan);

Of course you need the the fftw library. On Linux, gcc options are "-O2 -lfftw3f -lm". This is single precision.

Enjoy :)

Listing 54: code

```c
/*********************************************************
MDCT/IMDCT of 4x length, Single Precision, based on FFTW
shuhua dot zhang at gmail dot com
Dept. of E.E., Tsinghua University
***********************************************************/

#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <fftw3.h>

typedef struct {
    int N;       // Number of time data points
    float* twiddle; // Twiddle factor
    fftwf_complex* fft_in; // fft workspace, input
    fftwf_complex* fft_out; // fft workspace, output
    fftwf_plan fft_plan; // fft configuration
} mdctf_plan;

mdctf_plan* mdctf_init(int N);
void mdctf_free(mdctf_plan* m_plan);
void mdctf(float* mdct_line, float* time_signal, mdctf_plan* m_plan);
void imdctf(float* time_signal, float* mdct_line, mdctf_plan* m_plan);

mdctf_plan* mdctf_init(int N)
{
    mdctf_plan* m_plan;
    double alpha, omiga, scale;
    int n;
    if( 0x00 != (N & 0x03))
    {
    }
```

(continues on next page)
36    fprintf(stderr, " Expecting N a multiple of 4\n");
37    return NULL;
38  }
39
40  m_plan = (mdctf_plan*) malloc(sizeof(mdctf_plan));
41  m_plan->N = N;
42
43  m_plan->twiddle = (float*) malloc(sizeof(float) * N >> 1);
44  alpha = 2.f * M_PI / (8.f * N);
45  omiga = 2.f * M_PI / N;
46  scale = sqrt(sqrt(2.f / N));
47  for(n = 0; n < (N >> 2); n++)
48      {  
49        m_plan->twiddle[2*n+0] = (float) (scale * cos(omiga * n + alpha));
50        m_plan->twiddle[2*n+1] = (float) (scale * sin(omiga * n + alpha));
51      }
52
53  m_plan->fft_in = (fftwf_complex*) fftwf_malloc(sizeof(fftwf_complex) * N >> 2);
54  m_plan->fft_out = (fftwf_complex*) fftwf_malloc(sizeof(fftwf_complex) * N >> 2);
55  m_plan->fft_plan = fftwf_plan_dft_1d(N >> 2,
56                                       m_plan->fft_in,
57                                       m_plan->fft_out,
58                                       FFTW_FORWARD,
59                                       FFTW_MEASURE);
60
61  return m_plan;
62 }
63
64 void mdctf_free(mdctf_plan* m_plan)
65 {
66      fftwf_destroy_plan(m_plan->fft_plan);
67      fftwf_free(m_plan->fft_in);
68      fftwf_free(m_plan->fft_out);
69      free(m_plan->twiddle);
70      free(m_plan);
71  }
72
73 void mdctf(float* mdct_line, float* time_signal, mdctf_plan* m_plan)
74 {
75      float *xr, *xi, r0, i0;
76      float *cos_tw, *sin_tw, c, s;
77      int N4, N2, N34, N54, n;
78  
79      N4 = (m_plan->N) >> 2;
80      N2 = 2 * N4;
81      N34 = 3 * N4;
82      N54 = 5 * N4;
83      
84      cos_tw = m_plan->twiddle;
85      sin_tw = cos_tw + 1;
86      /* odd/even folding and pre-twiddle */
87      xr = (float*) m_plan->fft_in;
88
3.33. MDCT and IMDCT based on FFTW3

void imdctf(float* time_signal, float* mdct_line, mdctf_plan* m_plan)
{
    float *xr, *xi, r0, i0, r1, i1;
    float *cos_tw, *sin_tw, c, s;
    int N4, N2, N34, N54, n;

    N4 = (m_plan->N) >> 2;
    N2 = 2 * N4;
    N34 = 3 * N4;
    N54 = 5 * N4;
    cos_tw = m_plan->twiddle;

    for(n = 0; n < N4; n += 2)
    {
        r0 = time_signal[N34-1-n] + time_signal[N34+n];
        i0 = time_signal[N4+n] - time_signal[N4-1-n];

        c = cos_tw[n];
        s = sin_tw[n];

        xr[n] = r0 * c + i0 * s;
        xi[n] = i0 * c - r0 * s;
    }

    for(n = 0; n < N2; n += 2)
    {
        r0 = time_signal[N34-1-n] - time_signal[-N4+n];
        i0 = time_signal[N4+n] + time_signal[N54-1-n];

        c = cos_tw[n];
        s = sin_tw[n];

        xr[n] = r0 * c + i0 * s;
        xi[n] = i0 * c - r0 * s;
    }

    /* complex FFT of N/4 long */
    fftwf_execute(m_plan->fft_plan);

    /* post-twiddle */
    xr = (float*) m_plan->fft_out;
    xi = xr + 1;
    for(n = 0; n < N2; n += 2)
    {
        r0 = xr[n];
        i0 = xi[n];

        c = cos_tw[n];
        s = sin_tw[n];

        mdct_line[n] = - r0 * c - i0 * s;
        mdct_line[N2-1-n] = - r0 * s + i0 * c;
    }
}
150  sin_tw = cos_tw + 1;
151
152  /* pre-twiddle */
153  xr = (float*) m_plan->fft_in;
154  xi = xr + 1;
155  for(n = 0; n < N2; n += 2)
156  {
157      r0 = mdct_line[n];
158      i0 = mdct_line[N2-1-n];
159      c = cos_tw[n];
160      s = sin_tw[n];
161      xi[n] = -2.f * (i0 * c - r0 * s);
162      xr[n] = -2.f * (i0 * s + r0 * c);
163  }
164
165  /* complex FFT of N/4 long */
166  fftwf_execute(m_plan->fft_plan);
167
168  /* odd/even expanding and post-twiddle */
169  xr = (float*) m_plan->fft_out;
170  xi = xr + 1;
171  for(n = 0; n < N4; n += 2)
172  {
173      r0 = xr[n];
174      i0 = xi[n];
175      c = cos_tw[n];
176      s = sin_tw[n];
177      r1 = r0 * c + i0 * s;
178      i1 = r0 * s - i0 * c;
179      time_signal[N34-1-n] = r1;
180      time_signal[N34+n] = r1;
181      time_signal[N4+n] = i1;
182      time_signal[N4-1-n] = -i1;
183  }
184
185  for(n = 0; n < N2; n += 2)
186  {
187      r0 = xr[n];
188      i0 = xi[n];
189      c = cos_tw[n];
190      s = sin_tw[n];
191      r1 = r0 * c + i0 * s;
192      i1 = r0 * s - i0 * c;
193      time_signal[N34-1-n] = r1;
194      time_signal[-N4+n] = -r1;
195      time_signal[N4+n] = i1;
196      time_signal[N54-1-n] = i1;
197  }
198
209
270
3.33.1 Comments

- **Date:** 2009-08-05 14:42:44
- **By:** none

Hi, your "freq, time" example in your comments feed into the main function as "mdct_line, time_signal" float pointers. Can you explain what these are?

Thanks

D

- **Date:** 2009-08-11 05:11:59
- **By:** moc.liamg@gnahz.auhuhs

Hi,

Here I past a complete test bench for the MDCT/IMDCT routine. Suppose the MDCT/IMDCT routines named "mdctf.c" and the following benchmark routine named "ftestbench.c", the gcc compilation command will be:
gcc -o ftestbench -O2 ftestbench.c mdctf.c -lfftw3f -lm

Shuhua Zhang, Aug. 11, 2009

/* benchmark MDCT and IMDCT, floating point */
#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <time.h>
extern void* mdctf_init(int);

int main(int argc, char* argv[])
{
    int N, r, i;
    float* time;
    float* freq;
    void* m_plan;
    clock_t t0, t1;
    if(3 != argc)
    {
        fprintf(stderr, " Usage: %s <MDCT_SIZE> <run_times> \n", argv[0]);
        return -1;
    }
    sscanf(argv[1], "%d", &N);
    sscanf(argv[2], "%d", &r);
    time = (float*)malloc(sizeof(float) * N);
    freq = (float*)malloc(sizeof(float) * (N >> 1));
    for(i = 0; i < N; i++)
        time[i] = 2.f * rand() / RAND_MAX - 1.f;
    /* MDCT/IMDCT floating point initialization */
    m_plan = mdctf_init(N);

    (continues on next page)
if(NULL == m_plan)
{
    free(freq);
    free(time);
    return -1;
}
/* benchmark MDCT floating point*/
t0 = clock();
for(i = 0; i < r; i++)
    mdctf(freq, time, m_plan);
t1 = clock();
fprintf(stdout, "MDCT of size %d, float, running %d times, uses %.2e s\n",
        N, r, (float) (t1 - t0) / CLOCKS_PER_SEC);
/* benchmark IMDCT floating point*/
t0 = clock();
for(i = 0; i < r; i++)
    imdctf(time, freq, m_plan);
t1 = clock();
fprintf(stdout, "IMDCT of size %d, float, running %d times, uses %.2e s\n",
        N, r, (float) (t1 - t0) / CLOCKS_PER_SEC);
/* free MDCT/IMDCT workspace */
mdctf_free(m_plan);
free(freq);
free(time);
return 0;
}

3.34 Moog Filter

- **Author or source:** ed.luosfosruoivas@naitsirhC
- **Type:** Antti’s version (nonlinearities)
- **Created:** 2005-04-27 08:54:50

Listing 55: notes

Here is a Delphi/Object Pascal translation of Antti’s Moog Filter.

Antti wrote:

"At last DAFX I published a paper presenting a non-linear model of the Moog ladder. For that, see http://dafx04.na.infn.it/WebProc/Proc/P_061.pdf

I used quite different approach in that one. A half-sample delay ([0.5 0.5] FIR filter basically) is inserted in the feedback loop. The remaining tuning and resonance error are corrected with polynomials. This approach depends on using at least 2X oversampling — the
response after nyquist/2 is abysmal but that's taken care of by the oversampling.

Victor Lazzarini has implemented my model in CSound:

In summary: You can use various methods, but you will need some numerically derived correction to realize exact tuning and resonance control. If you can afford 2X oversampling, use Victor's CSound code - the tuning has been tested to be very close ideal.

Ps. Remember to use real oversampling instead of the "double sampling" the CSound code uses."

I did not implemented real oversampling, but i inserted additional noise, which simulates the resistance noise and also avoids denormal problems...

Listing 56: code

http://www.savioursofsoul.de/Christian/MoogFilter.pas

3.34.1 Comments

- Date: 2005-04-27 18:08:06
- By: ed.luosfusoivas@naitsirhC

You can also listen to it (Windows-VST) here: http://www.savioursofsoul.de/Christian/VST/MoogVST.zip

- Date: 2005-05-06 21:57:17
- By: rlindner@gmx .dot.. net

and here is the same thing written in C. It was written while translating the CSound Code into code for the synthmaker code module as an intermediate step to enable debugging thru gdb. The code was written to be easy adoptable for the synthmaker code module (funny defines, static vars, single sample tick function,...) Has some room for improvements, but nothing fancy for seasoned C programmers.

#include <memory.h>
#include <stdio.h>
#include <math.h>

#define polyin float
#define polyout float
#define BUFSIZE 64

float delta_func [BUFSIZE];
float out_buffer [BUFSIZE];

(continues on next page)
void tick ( float in, float cf, float reso, float *out ) {

// start of sm code

// filter based on the text "Non linear digital implementation of the moog ladder\textendash filter" by Antti Houvilainen
// adopted from Csound code at http://www.kunstmusik.com/udo/cache/moogladder.udo
polyin input;
polyin cutoff;
polyin resonance;
polyout sigout;

// remove this line in sm
input = in; cutoff = cf; resonance = reso;

// resonance [0..1]
// cutoff from 0 (0Hz) to 1 (nyquist)
float pi; pi = 3.1415926535;
float v2; v2 = 40000; // twice the 'thermal voltage of a transistor'
float sr; sr = 22100;

float cutoff_hz;
cutoff_hz = cutoff * sr;

static float az1;
static float az2;
static float az3;
static float az4;
static float az5;
static float ay1;
static float ay2;
static float ay3;
static float ay4;
static float amf;

float x;       // temp var: input for taylor approximations
float xabs;
float exp_out;
float tanh1_out, tanh2_out;
float kfc;
float kf;
float kfcr;
float kacr;

(continues on next page)
float k2vg;

kfc = cutoff_hz/sr; // sr is half the actual filter sampling rate
kf = cutoff_hz/(sr*2);
// frequency & amplitude correction
kfcr = 1.8730*(kfc*kfc*kfc) + 0.4955*(kfc*kfc) - 0.6490*kfc + 0.9988;
kacr = -3.9364*(kfc*kfc) + 1.8409 *kfc + 0.9968;

x = -2.0 * pi * kfcr * kf;
exp_out = expf(x);

k2vg = v2*(1-exp_out); // filter tuning

// cascade of 4 Ist order sections
float x1 = (input - 4*resonance*amf*kacr) / v2;
float tanh1 = tanhf (x1);
float x2 = az1/v2;
float tanh2 = tanhf (x2);
ay1 = az1 + k2vg * ( tanh1 - tanh2);

// ay1 = az1 + k2vg * ( tanh( (input - 4*resonance*amf*kacr) / v2) - tanh(az1/v2) );
az1 = ay1;

ay2 = az2 + k2vg * ( tanh(ay1/v2) - tanh(az2/v2) );
az2 = ay2;

ay3 = az3 + k2vg * ( tanh(ay2/v2) - tanh(az3/v2) );
az3 = ay3;

ay4 = az4 + k2vg * ( tanh(ay3/v2) - tanh(az4/v2) );
az4 = ay4;

// 1/2-sample delay for phase compensation
amf = (ay4+az5)*0.5;
az5 = ay4;

// oversampling (repeat same block)
ay1 = az1 + k2vg * ( tanh( (input - 4*resonance*amf*kacr) / v2) - tanh(az1/v2) );
az1 = ay1;

ay2 = az2 + k2vg * ( tanh(ay1/v2) - tanh(az2/v2) );
az2 = ay2;

ay3 = az3 + k2vg * ( tanh(ay2/v2) - tanh(az3/v2) );
az3 = ay3;

ay4 = az4 + k2vg * ( tanh(ay3/v2) - tanh(az4/v2) );
az4 = ay4;

// 1/2-sample delay for phase compensation
amf = (ay4+az5)*0.5;
az5 = ay4;
sigout = amf;

// end of sm code

*out = sigout;

} // tick

int main ( int argc, char *argv[] ) {

// set delta function
memset ( delta_func, 0, sizeof(delta_func));
delta_func[0] = 1.0;

int i = 0;
for ( i = 0; i < BUFSIZE; i++ ) {
tick ( delta_func[i], 0.6, 0.7, out_buffer+i );
}
for ( i = 0; i < BUFSIZE; i++ ) {
printf ("%f;", out_buffer[i] );
}
printf ("\n");

} // main

• Date: 2005-05-07 03:56:13
• By: eb.tenyks@didid

I think that a better speed optimization of Tanh2 would be to extract the sign bit→(using integer) instead of abs, and add it back to the final result, to avoid FABS,→FCOMP and the branching

• Date: 2005-05-08 19:03:40
• By: ed.luosfosruoivas@naitsirhC

After reading some more assembler documents for university, i had the same idea... Now: Coding!

• Date: 2005-05-08 22:42:55
• By: eb.tenyks@didid

Btw1, is the idea to get rid of the "*0.5" in the "1/2 sample delay" block by using→*2 instead of *4 in the first filter?

Btw2, following the same simplification, you can also precompute "-2*fQ*fAcr" outside.

• Date: 2005-05-09 01:49:49
• By: eb.tenyks@didid
Forget the sign bit thing, actually your Tanh could already have been much faster at the source:

\[
a := f\_abs(x);
\]
\[
a := a \times (6 + a \times (3 + a));
\]
\[
\text{if } (x < 0) \text{ then Result} := -a / (a + 12)
\]
\[
\text{else Result} := a / (a + 12);
\]

can be written as the much simpler:

\[
\text{Result} := x \times (6 + \text{Abs}(x) \times (3 + \text{Abs}(x)) / (\text{Abs}(x) + 12)
\]

..so in asm:

```pascal
function Tanh2(x: Single): Single;
const
c3 : Single = 3;
c6 : Single = 6;
c12: Single = 12;
Asm
  FL D x
  FL D ST(0)
  FABS
  FL D c3
  FADD ST(0), ST(1)
  FMUL ST(0), ST(1)
  FADD c6
  FMUL ST(0), ST(2)
  FXCH ST(1)
  FADD c12
  FDIVP ST(1), ST(0)
  FSTP ST(1)
End;
```

..but it won't be much faster than your code, because:
- of the slow FDIV
- it's still a function call. Since our dumb Delphi doesn't support assembler macro's,
- you waste a lot in the function call. You can still try to inline a plain pascal code, but since our dumb Delphi isn't good at compiling float code neither..

Solutions:
- a lookup table for the TanH
- you write the filter processing in asm as well, and you put the TanH code in a separate file (without the header, and assuming in & out are ST(0)). You then $I to insert that file when the function call is needed. Poorman's macro's in Delphi :)

Still, that's a lot of FDIV for a filter..

- **Date:** 2005-05-09 03:24:44
- **By:** eb.tenyks@didid

forget it, I was all wrong :)
gonna re-post a working version later

still I think that most of the CPU will always be wasted by the division.
function Tanh2(x:Single):Single;
const c3 :Single=3;
c6 :Single=6;
c12 :Single=12;
Asm
  FLD x
  FLD ST(0)
  FABS // a
  FLD c3
  FADD ST(0),ST(1)
  FMUL ST(0),ST(1)
  FADD c6 // b
  FMUL ST(2),ST(0) // x*b
  FMULP ST(1),ST(0) // a*b
  FADD c12
  FDIVP ST(1),ST(0)
End;

That code is nice and very fast! But it's not that accurate. But indeed very fast!" Thanks for the code. My approach was a lot slower.

But it should be as accurate as the one in your pascal code: it's the same approximation as Tanh2_pas2. Of course we're still talking about a Tanh approximation. You can still take it up to /24 for cheap. Of course, don't try the first one I posted, it's completely wrong.

Btw it's also more accurate than pascal code, since it keeps values in the 80bit FPU registers, while the Delphi compiler will put them back to the 32bit variables in-between.

Btw2 I implemented the {$I macro.inc} trick, works pretty well. The whole thing speeded up the code by almost 2. For more you could 3DNow 2 Tanh at once, it'd be easy in that filter.

OK, it's indeed my tanh2_pas2 approximation, but i've plotted both functions once and i found out, that the /24 version is much more accurate and that it is worth to calculate the additional macc operation.

But of course the assembler version is much more accurate indeed.
After assembler optimization, I could only speed up the whole thing to a factor of 1.5 → the speed (measured with an impulse) and up to a factor of 1.7 measured with noise. → and the initial version with the branch.

I will now do the 3DNow/SSE optimisation, let's see how it can be speeded up further → more...

- **Date:** 2005-05-11 04:19:47
- **By:** eb.tenyks@didid

something bugs me about this filter.. I was assuming that it was made for a standard - → 1..1 normalized input. But looking at the 1/40000 drive gain, isn't it made for a - → 32768..32767 input? Otherwise I don't see what the Tanh drive is doing, it's → basically linear for such low values, and I can't hear any difference with or → without it.

- **Date:** 2005-05-11 11:00:39
- **By:** ed.luososruoivas@naitsirhC

Usually the tanh component wasn't a desired feature in the analog filter design. They → try to keep the input of a differential amplifier very low to retain the linearity.
I have uploaded some plots from my VST Plugin Analyser Pro:
http://www.savioursofsoul.de/Christian/VST/filter4.png (with -1..+1)
http://www.savioursofsoul.de/Christian/VST/filter5.png (with -32768..+32767)
http://www.savioursofsoul.de/Christian/VST/filter1.png (other...)
http://www.savioursofsoul.de/Christian/VST/filter2.png (other...)
http://www.savioursofsoul.de/Christian/VST/filter3.png (other...)

Additionally i have updated the VST with a new slider for a gain multiplication → (http://www.savioursofsoul.de/Christian/VST/MoogVST.zip)

- **Date:** 2005-11-28 10:09:19
- **By:** moc.liamg@dwod_niatnif

There is an error in the C implementation above,

sr = 44100Hz, half the rate of the filter which is oversampled at a rate of 88200Hz. → So the 22100 needs to be changed.

Christians MoogFilter.pas implements it correctly.

### 3.35 Moog VCF

- **Author or source:** CSound source code, Stilson/Smith CCRMA paper.
- **Type:** 24db resonant lowpass
- **Created:** 2002-01-17 02:02:40
Digital approximation of Moog VCF. Fairly easy to calculate coefficients, fairly easy to process algorithm, good sound.

```
//Init
cutoff = cutoff freq in Hz
fs = sampling frequency  //(e.g. 44100Hz)
res = resonance [0 - 1]  //(minimum - maximum)

f = 2 * cutoff / fs;  //[0 - 1]
k = 3.6*f - 1.6*f*f -1;  //(Empirical tuning)
p = (k+1)*0.5;
scale = e^((1-p)*1.386249;
r = res*scale;
y4 = output;
y1=y2=y3=y4=oldx=oldy1=oldy2=oldy3=0;

//Loop
//--Inverted feed back for corner peaking
x = input - r*y4;

//Four cascaded onepole filters (bilinear transform)
y1=x*p + oldx*p - k*y1;
y2=y1*p+oldy1*p - k*y2;
y3=y2*p+oldy2*p - k*y3;
y4=y3*p+oldy3*p - k*y4;

//Clipper band limited sigmoid
y4 = y4 - (y4^3)/6;
oldx = x;
oldy1 = y1;
oldy2 = y2;
oldy3 = y3;
```

### 3.35.1 Comments

- **Date:** 2004-10-14 10:18:59  
  **By:** ed.xmg@resiaknegah

I guess the input is supposed to be between -1..1

- **Date:** 2007-02-05 00:30:04  
  **By:** moc.erehwon@ydobon

Still working on this one. Anyone notice it's got a few syntax problems? Makes me wonder if it's even been tried.

Missing parenthesis. Uses ^ twice. If I get it to work, I'll post usable code.
OK. Can't guarantee this is a 100% translation to real C++, but it does work. Aside from possible mistakes, I mucked hard with the coefficient translation, so that there is a slight difference in the numbers.

1. What kind of filter ends up with \( \exp() \) in the coefficient calculation instead of the usual \( \sin(), \cos(), \tan() \) transcendentals? If someone can explain where the \( e \) to the \( x \) comes from, I'd appreciate it.

2. Since I didn't understand the origin of the coefficients, I saw the whole section as an excercise in algebra. There were some superfluous multiplications and additions.

First I implemented the \( e \) to the \( x \) with \( \text{pow}() \). That was stupid. I switched to \( \exp() \). Hated that too. Checked out the range of inputs and decided on a common approximation for \( \exp() \).

I think it's now one of the fastest filter coefficient calcs you'll see for a 4 pole. Go ahead--put the cutoff on an envelope and the q on an LFO. Hell, FM the Q if you want!

A pretty good filter. Watch the res (aka Q). Above 9, squeals like a pig. Not in a good way.

Needs more work, I think, to stand up with the better LPs in the real VST world. But an awfully cool starting place.

If I did something awful here in the translation, or if you have a question about how to use it, best to ask me (mistertoast) over at KvRaudio.com in the dev section.

I'm toying with the idea of wedging this into TobyBear's filter designer as a flt file. If you manage first, let me know. I'm mistertoast.

---

MoogFilter.h:

```cpp
class MoogFilter
{
public:
    MoogFilter();
    void init();
    void calc();
    float process(float x);
    ~MoogFilter();
    float getCutoff();
    void setCutoff(float c);
    float getRes();
    void setRes(float r);
    protected:
    float cutoff;
    float res;
    float fs;
    float y1,y2,y3,y4;
};
```

(continues on next page)
```cpp
float oldx;
float oldy1, oldy2, oldy3;
float x;
float r;
float p;
float k;
};

void MoogFilter::init()
{
    // initialize values
    y1 = y2 = y3 = y4 = oldx = oldy1 = oldy2 = oldy3 = 0;
    calc();
};

void MoogFilter::calc()
{
    float f = (cutoff + cutoff) / fs; // [0 - 1]
    p = f * (1.8f - 0.8f * f);
    k = p + p - 1.f;
    float t = (1.f - p) * 1.386249f;
    float t2 = 12.f + t * t;
    r = res * (t2 + 6.f * t) / (t2 - 6.f * t);
};

float MoogFilter::process(float input)
{
    // process input
    x = input - r * y4;

    // Four cascaded onepole filters (bilinear transform)
    y1 = x * p + oldx * p - k * y1;
    y2 = y1 * p + oldy1 * p - k * y2;
    y3 = y2 * p + oldy2 * p - k * y3;
    y4 = y3 * p + oldy3 * p - k * y4;

    // Clipper band limited sigmoid
```

**Date:** 2007-02-05 17:22:43

**By:** moc.erhown@tsaot


```cpp
y4 == (y4*y4*y4)/6.f;
oldx = x; oldy1 = y1; oldy2 = y2; oldy3 = y3;
return y4;
}

float MoogFilter::getCutoff()
{ return cutoff; }

void MoogFilter::setCutoff(float c)
{ cutoff = c; calc(); }

float MoogFilter::getRes()
{ return res; }

void MoogFilter::setRes(float r)
{ res = r; calc(); }
```

---

**Date:** 2007-02-05 22:04:51  
**By:** moc.dniftnacuoyerehwemos@tsaot

I see where the exp() comes from. It just models the resonance. I think it needs more work. At high frequencies it goes into self-oscillation much more quickly than at low frequencies.

---

**Date:** 2012-01-31 12:29:16  
**By:** moc.llun@ved

A much better tuning seems to be  
k = 2*sin(f*pi/2) - 1;

(within a 0.1 cent up to 4kHz, at 44.1kHz sample rate)

---

**Date:** 2014-03-26 21:16:08  
**By:** ten.eroctsid@alub

This filter works and sounds fine in my VST. I've re-written the code using templates, which makes life easier when switching between <float> and <double> implementation.

```cpp
#pragma once

namespace DistoCore
{
  template<class T>
  class MoogFilter
  {
    public:
      MoogFilter();
      ~MoogFilter() {};

      T getSampleRate() const { return sampleRate; }
      void setSampleRate(T fs) { sampleRate = fs; calc(); }
  }
```

(continues on next page)
T getResonance() const { return resonance; }
void setResonance(T filterRezo) { resonance = filterRezo; calc(); }
T getCutoff() const { return cutoff; }
T getCutoffHz() const { return cutoff * sampleRate * 0.5; }
void setCutoff(T filterCutoff) { cutoff = filterCutoff; calc(); }

void init();
void calc();
T process(T input);
// filter an input sample using normalized params
T filter(T input, T cutoff, T resonance);

protected:
  // cutoff and resonance [0-1]
  T cutoff;
  T resonance;
  T sampleRate;
  T fs;
  T y1,y2,y3,y4;
  T oldx;
  T oldy1,oldy2,oldy3;
  T x;
  T r;
  T p;
  T k;
};

/**
 * Construct Moog-filter.
 */
template<class T>
MoogFilter<T>::MoogFilter()
: sampleRate(T(44100.0))
, cutoff(T(1.0))
, resonance(T(0.0))
{
  init();
}

/**
 * Initialize filter buffers.
 */
template<class T>
void MoogFilter<T>::init()
{
  // initialize values
  y1=y2=y3=y4=oldx=oldy1=oldy2=oldy3=T(0.0);
  calc();
}

/**
 * Calculate coefficients.
 */
template<class T>
void MoogFilter<T>::calc()
{
  // TODO: replace with your constant
const double kPi = 3.1415926535897931;

// empirical tuning
p = cutoff * (T(1.8) - T(0.8) * cutoff);
// k = p + p - T(1.0);
// A much better tuning seems to be:
k = T(2.0) * sin(cutoff * kPi * T(0.5)) - T(1.0);

T t1 = (T(1.0) - p) * T(1.386249);
T t2 = T(12.0) + t1 * t1;
r = resonance * (t2 + T(6.0) * t1) / (t2 - T(6.0) * t1);
};

/**
 * Process single sample.
 */
template<class T>
T MoogFilter<T>::process(T input)
{
    // process input
    x = input - r * y4;

    // four cascaded one-pole filters (bilinear transform)
y1 = x * p + oldx * p - k * y1;
y2 = y1 * p + oldy1 * p - k * y2;
y3 = y2 * p + oldy2 * p - k * y3;
y4 = y3 * p + oldy3 * p - k * y4;

    // clipper band limited sigmoid
    y4 -= (y4 * y4 * y4) / T(6.0);

    oldx = x; oldy1 = y1; oldy2 = y2; oldy3 = y3;

    return y4;
}

/**
 * Filter single sample using specified params.
 */
template<class T>
T MoogFilter<T>::filter(T input, T filterCutoff, T filterRezo)
{
    // set params first
    cutoff = filterCutoff;
    resonance = filterRezo;
    calc();

    return process(input);
}

• Date: 2014-05-27 19:30:12
• By: ten.enignepot@derf

Why samplerate is missing in calc function?

• Date: 2015-11-12 08:14:23
This code works great. I already had a filter in my program so sticking this in only took about an hour. The sound is just what I hoped it would be. I started putting some really gnarly low frequency square waves through it and it returns that super chewy sound you can get from a Moog. Thanks for this.

• Date: 2016-06-23 02:27:27
• By: moc.poon@poon

This filter works just fine and sweeps just fine almost all the way down, cutoff easily goes below 40 Hz without issue. I implemented it in Numerical Python (Jupyter notebook) just to be able to see it working and fiddle with it (renders sound to .wav in non realtime of course).

Cutoff sweep sounds good enough, a bit on the clean side compared to the analog Moog filters I’ve heard. It starts to ring around res=0.7 and self oscillates fine for almost any res above 1.0. I find this filter's ringing sounds a bit tinny, thin and rather irritating though. This seems to be a common problem in DSP filters. It needs something, a je ne sais quoi of some kind.

Any suggestions how to modify it?

3.36 Moog VCF, variation 1

• Author or source: CSound source code, Stilson/Smith CCRMA paper., Paul Kellett version
• Type: 24db resonant lowpass
• Created: 2002-01-17 02:03:52

Listing 59: notes

The second "q =" line previously used exp() - I'm not sure if what I've done is any faster, but this line needs playing with anyway as it controls which frequencies will self-oscillate. I think it could be tweaked to sound better than it currently does.

Highpass / Bandpass :

They are only 6dB/oct, but still seem musically useful - the 'fruity' sound of the 24dB/oct lowpass is retained.

Listing 60: code

```c
// Moog 24 dB/oct resonant lowpass VCF
// References: CSound source code, Stilson/Smith CCRMA paper.
// Modified by paul.kellett@maxim.abel.co.uk July 2000

float f, p, q; //filter coefficients
float b0, b1, b2, b3, b4; //filter buffers (beware denormals!)
float t1, t2; //temporary buffers
// Set coefficients given frequency & resonance [0.0...1.0]
```

(continues on next page)
\begin{equation*}
\begin{align*}
q &= 1.0f - \text{frequency}; \\
p &= \text{frequency} + 0.8f \times \text{frequency} \times q; \\
f &= p + p - 1.0f; \\
q &= \text{resonance} \times (1.0f + 0.5f \times q \times (1.0f - q + 5.6f \times q \times q)); \\
\end{align*}
\end{equation*}
\[// \text{Filter (in [-1.0...+1.0])}\]
\begin{equation*}
\begin{align*}
in &= q \times b4; \quad //\text{feedback} \\
t1 &= b1; \quad b1 = (in + b0) \times p - b1 \times f; \\
t2 &= b2; \quad b2 = (b1 + t1) \times p - b2 \times f; \\
t1 &= b3; \quad b3 = (b2 + t2) \times p - b3 \times f; \\
b4 &= b3 + t1; \quad b4 = (b3 + t1) \times p - b4 \times f; \\
b4 &= b4 - b4 \times b4 \times 0.166667f; \quad //\text{clipping} \\
b0 &= \text{in}; \\
\end{align*}
\end{equation*}
\[// \text{Lowpass output: } b4\]
\[// \text{Highpass output: } \text{in} - \text{b4};\]
\[// \text{Bandpass output: } 3.0f \times (b3 - b4);\]

\subsection{3.36.1 Comments}

- **Date**: 2005-01-06 00:57:41
  - **By**: ten.xmg@42nitram.leinad

  I just tried the filter code and it seems like the highpass output is the same as the lowpass output, or at least another lowpass...
  But I'm still testing the filter code...

- **Date**: 2005-01-06 01:30:37
  - **By**: ten.xmg@42nitram.leinad

  Sorry for the Confusion, it works....
  I just had a typo in my code.
  One thing i did to get the HP sound nicer was
  HP output: \((\text{in} - 3.0f \times (b3 - b4)) - b4\)
  But I'm a newbie to DSP Filters...

- **Date**: 2005-08-19 00:17:24
  - **By**: ten.epacsten@0002skcuswodniw

  Hey, thanks for this code. I'm a bit confused as to the range to the frequency and resonance. Is it really 0.0-1.0? If so, how so I specify a certain frequency, such as... 400Hz? THANKS!

- **Date**: 2005-08-20 13:28:54
  - **By**: ed.luofosruoivas@naitsirhC

\section{3.36. Moog VCF, variation 1}
frequency * nyquist
or
frequency * samplerate
don't know the exact implementation.

- **Date:** 2007-02-05 18:28:48
- **By:** moc.erehwon@ydobon

>>Hey, thanks for this code. I'm a bit confused as to the range to the frequency and resonance. Is it really 0.0-1.0? If so, how so I specify a certain frequency, such as... 400Hz? THANKS!

I'd guess it would be:
frequency/(samplerate/2.f)

- **Date:** 2009-10-23 19:05:04
- **By:** moc.erehwon@yugsiht

The domain seems to be 0-nyquest (samplerate/2.0), but the range is 0-1

A better way to get smoother non-linear mapping of frequency would be this:
give you a range of 20Hz to 20kHz

defqinhz = 20.f * 1000.f ^ range;
then
frequency = freqinhz * (1.f/(samplerate/2.0f));

- **Date:** 2012-02-24 13:45:09
- **By:** ed.redienhcsslin@psdcisum

I like the sound of this one, unfortunately, it breaks quite fast, causing the internal values b1-b4 to be "infinity". Any hints?

### 3.37 Moog VCF, variation 2

- **Author or source:** CSound source code, Stilson/Smith CCRMA paper., Timo Tossavainen (?) version
- **Type:** 24db resonant lowpass
- **Created:** 2002-01-17 02:04:57

Listing 61: notes

in[x] and out[x] are member variables, init to 0.0 the controls:

fc = cutoff, nearly linear [0,1] -> [0, fs/2]
res = resonance [0, 4] -> [no resonance, self-oscillation]
Listing 62: code

```cpp
tdouble MoogVCF::run(double input, double fc, double res)
{
    double f = fc * 1.16;
    double fb = res * (1.0 - 0.15 * f * f);
    input -= out4 * fb;
    input *= 0.35013 * (f * f) * (f * f);
    out1 = input + 0.3 * in1 + (1 - f) * out1; // Pole 1
    in1 = input;
    out2 = out1 + 0.3 * in2 + (1 - f) * out2; // Pole 2
    in2 = out1;
    out3 = out2 + 0.3 * in3 + (1 - f) * out3; // Pole 3
    in3 = out2;
    out4 = out3 + 0.3 * in4 + (1 - f) * out4; // Pole 4
    in4 = out3;
    return out4;
}
```

### 3.37.1 Comments

- **Date:** 2003-03-29 21:50:47  
  **By:** rf.oohay@elahwyksa

This one works pretty well, thanks!

- **Date:** 2003-11-08 06:14:19  
  **By:** moc.liamtoh@serpudr

Could somebody explain, what means this

```cpp
input -= out4 * fb;
input *= 0.35013 * (f * f) * (f * f);
```

is "input-" and "input *" the name of an variable ??  
or is this an Csound specific parameter ??  
I want to translate this piece to Assembler code  
Robert Dupres

- **Date:** 2003-11-11 11:05:42  
  **By:** ten.bjc.fieltnabpop@cnahoj

Input is name of a variable with type double.  
Input -= out4 * fb;  
is just a shorter way for writing:  
input = input - out4 * fb;  
and the *= operator is works similar:
input *= 0.35013 * (f*f)*(f*f);

is equal to

input = input * 0.35013 * (f*f)*(f*f);

/ Johan

- **Date**: 2004-07-12 22:11:20
- **By**: ude.drofnats.amrcc@lfd

I've found this filter is unstable at low frequencies, namely when changing quickly from high to low frequencies...

- **Date**: 2004-07-17 13:39:23
- **By**: moc.kisu@kmailliw

I'm trying to double-sample this filter, like the Variable-State one. But so far no success, any tips?

Wk

- **Date**: 2004-08-25 08:51:08
- **By**: ten.ennegatum@liam

What do you mean no success? What happens? Have you tried doing the usual oversampling tricks (sinc/hermite/mix-with-zeros-and-filter), call the moogVCF twice (with fc = fc*0.5) and then filter and decimate afterwards?

I'm been trying to find a good waveshaper to put in the feedback path but haven't found a good sounding stable one yet. I had one version of the filter that tracked the envelope of out4 and used it to control the degree to which values below some threshold (say 0.08) would get squashed towards zero. That sounded ok (actually quite good for very high inputs), but wasn't entirely stable and was glitching for low frequencies. Then I tried a *out4 = (1+d)* (*out4)/(1 + d* (*out4)) waveshaper, but that just aliased horribly and made the filter sound mushy and noisy.

Plain old polynomial (x = x-x*x*x) saturation sounds dull. There must be something better out there, though... and I'd much prefer not to have to oversample to get it, though I guess that might be unavoidable.

- **Date**: 2006-01-30 15:52:54
- **By**: moc.liamg@fleezes

Excuse me but just a basic question from a young developper in line " input -= out4 * fb; "

I don't understand when and how "out4" is initialised

is it the "out4" return by the previous execution?

which initialisation for the first execution?

- **Date**: 2006-01-31 17:15:24
- **By**: musicdsp@[remove this]dparsons.co.uk
all the outs should be initialised to zero, so first time around, nothing is
\( \rightarrow \) subtracted. However, thereafter, the previous output is multiplied and subtracted
\( \rightarrow \) from the input.

HTH

- **Date**: 2009-11-10 16:02:55
- **By**: moc.liang@gulcidrab

YAND (Yet Another Newbie Developer) here –

This filter sounds good, and with the addition of a 2nd harmonic waveshaper in the
\( \rightarrow \) feedback loop, it sounds VERY good.

I was hoping I could make it into a HP filter through the normal return in\-out4 - but
\( \rightarrow \) that strategy doesn't work for this method. I'm afraid I'm at a loss as to what to
\( \rightarrow \) try next - anyone have a suggestion?

--Coz

- **Date**: 2010-01-08 19:32:16
- **By**: http://www.myspace.com/paradoxuncreated

You have to subtract each filter, from the input in the cascade.

Check also the Karlsen filters, which I made a few years ago, when going through this
\( \rightarrow \) stage in DSP.

- **Date**: 2012-03-02 12:05:25
- **By**: moc.llun@ved

The best sounding LP i've found here. Any suggestions how to extract HP/BP?

in - out4 doesn't work, as stated above, but "You have to subtract each filter, from
\( \rightarrow \) the input in the cascade", what does this mean?

in - out4 - out3 - out2 - out1 doesn't work either

### 3.38 Notch filter

- **Author or source**: Olli Niemitalo
- **Type**: 2 poles 2 zeros IIR
- **Created**: 2002-01-17 02:11:07

Listing 63: notes

Creates a muted spot in the spectrum with adjustable steepness. A complex conjugate
\( \rightarrow \) pair of zeros on the z- plane unit circle and neutralizing poles approaching at the same
\( \rightarrow \) angles from inside the unit circle.
Listing 64: code

```c
Parameters:
0 <= freq <= samplerate/2
0 <= q < 1 (The higher, the narrower)

double pi = 3.141592654;
double sqrt2 = sqrt(2.0);

double freq = 2050; // Change! (zero & pole angle)
double q = 0.4; // Change! (pole magnitude)

double z1x = cos(2*pi*freq/samplerate);
double a0a2 = (1-q)*(1-q)/(2*(fabs(z1x)+1)) + q;
double a1 = -2*z1x*a0a2;
double b1 = -2*z1x*q;
double b2 = q*q;
double reg0, reg1, reg2;

unsigned int streamofs;
reg1 = 0;
reg2 = 0;

/* Main loop */
for (streamofs = 0; streamofs < streamsize; streamofs++)
{
    reg0 = a0a2 * ((double)fromstream[streamofs]
    + fromstream[streamofs+2])
    + a1 * fromstream[streamofs+1]
    - b1 * reg1
    - b2 * reg2;

    reg2 = reg1;
    reg1 = reg0;

    int temp = reg0;

    /* Check clipping */
    if (temp > 32767) { temp = 32767; }
    else if (temp < -32768) temp = -32768;

    /* Store new value */
    tostream[streamofs] = temp;
}
```

### 3.38.1 Comments

- **Date:** 2006-09-27 09:53:49
- **By:** moc.liamtoh@18recnuor

i tried implementing it, failed,
and its wierd how it looks further in time
instead of backwards, you cant use it in

(continues on next page)
a running rendered stream cause the end of
it stuffs up....

- Date: 2006-09-27 11:43:49
- By: musicdsp@Nospam dsparsons.co.uk

I think it's a type, and should be
=-=-
reg0 = a0a2 * ((double)fromstream[streamofs] + fromstream[streamofs-2])
+ a1 * fromstream[streamofs-1]
- b1 * reg1
- b2 * reg2;
=-=-
In which case there is some rangechecking to be done when streamofs<2

You could just use the coeffs, and stick them into whatever biquad code you have_
—hanging around :)

DSP

- Date: 2007-02-17 10:44:00
- By: moc.loa@561kluafla

Still doesn't work. Either way its looking one each side of a centre value, so it_
—doesn't change the maths. Not sure what the code should be. Ideas???

- Date: 2009-04-24 16:34:32
- By: moc.liamg@naecohsife

does this code work with float output?
I really need a notch filter, i will try the code.

- Date: 2011-05-12 11:22:57
- By: moc.oohay@skinyela

yes, there are some errors in this source.

Here is the correct version:

// (C) Sergey Aleynik. aleyniks@yahoo.com

    // BW_Coeff is changing from 0.0 to 1.0 (excluded) and the more the narrow:
    // | BW_Coeff | Real BandWidth (approxim.) |
    // | 0.975 | 0.00907 * Sampling_Frequency |
    // | 0.95 | 0.01814 * Sampling_Frequency |
    // | 0.9 | 0.03628 * Sampling_Frequency |

void Notch_Filter_Test(short int *Data_In, 
                        short int *Data_Out, 
                        long nData_Length, 
                        double Sampling_Frequency, 
                        double CutOff_Frequency, 
                        (continues on next page)
double BW_Coeff)
{
    // If wrong parameters:
    if((NULL == Data_In)||(Data_Out)||(nData_Length <= 0)) return;
    if((Sampling_Frequency < 0.0)||(CutOff_Frequency < 0.0)) return;
    if(CutOff_Frequency > (Sampling_Frequency/2)) return;
    if((BW_Coeff <= 0.0)||(BW_Coeff >= 1.0)) return;

    static const double pi = 3.141592654;

    // Filter coefficients:
    double z1x = cos(2*pi*CutOff_Frequency/Sampling_Frequency);
    double b0 = (1-BW_Coeff)*(1-BW_Coeff)/(2*(fabs(z1x)+1)) + BW_Coeff;
    double b2 = b0;
    double b1 = -2*z1x*b0;
    double a1 = -2*z1x*BW_Coeff;
    double a2 = BW_Coeff*BW_Coeff;

    // Filter internal vars:
    double y=0, y1=0, y2=0;
    double x0=0, x1=0, x2=0;
    long i;
    for(i=0; i<nData_Length; i++)
    {
        y = b0 * x0 + b1 * x1 + b2 * x2 - a1 * y1 - a2 * y2;
        y2 = y1;
        y1 = y;
        x2 = x1;
        x1 = x0;
        x0 = Data_In[i];

        if( y > 32767) y = 32767;
        else if (y < -32768) y = -32768;
        Data_Out[i] = (short int)y;
    }
}

• Date: 2011-11-11 03:30:26
• By: rf.liamtoh@abe.yrduabreivilo

Just an idea on coef notch:
  a0 = 1;
  a1 = -2 * cs;
  a2 = 1;
  b0 = 1 + alpha;
  b1 = -2 * cs;
  b2 = 1 - alpha;
notch: \( H(s) = \frac{(s^2 + 1)}{(s^2 + s/Q + 1)} \); 
\( \omega = 2\pi c_f/s\text{ample rate}; \)
\( sn = \sin(\omega); \)
\( cs = \cos(\omega); \)
\( alpha = sn/(2\times Q); \)
3.39 One pole LP and HP

- **Author or source:** Bram
- **Created:** 2002-08-26 23:33:27

### Listing 65: code

```cpp
LP:
  recursion: tmp = (1-p)*in + p*tmp with output = tmp
  coefficient: p = (2-cos(x)) - sqrt((2-cos(x))^2 - 1) with x = 2*pi*cutoff/samplerate
  coefficient approximation: p = (1 - 2*cutoff/samplerate)^2

HP:
  recursion: tmp = (p-1)*in - p*tmp with output = tmp
  coefficient: p = (2+cos(x)) - sqrt((2+cos(x))^2 - 1) with x = 2*pi*cutoff/samplerate
  coefficient approximation: p = (2*cutoff/samplerate)^2
```

### 3.39.1 Comments

- **Date:** 2006-03-23 15:39:07
- **By:** moc.liamtoh@wta_sohpyks

```
coefficient: p = (2-cos(x)) - sqrt((2-cos(x))^2 - 1) with x = 2*pi*cutoff/samplerate
p is always -1 using the formula above. The square eliminates the squareroot and (2-cos(x)) - (2-cos(x)) is 0.
```

- **Date:** 2006-03-24 09:37:19
- **By:** q@q

```
Look again. The -1 is inside the sqrt.
```

- **Date:** 2008-08-11 09:34:07
- **By:** batlord[A.T]o2[D.O.T]pl

```
skyphos:
sqrt((2-cos(x))^2 - 1) doesn't equal
sqrt((2-cos(x))^2) + sqrt(-1)
s0
-1 can be inside the sqrt, because (2-cos(x))^2 will be always >= one.
```

- **Date:** 2009-07-13 01:22:43
- **By:** No

```
HP is wrong!
Or at least it does not work here. It acts like a lofi low-shelf. However this works:
HP:
  recursion: tmp = (1-p)*in + p*tmp with output = in-tmp
  coefficient: p = (2-cos(x)) - sqrt((2-cos(x))^2 - 1) with x = 2*pi*cutoff/samplerate
  coefficient approximation: p = (1 - 2*cutoff/samplerate)^2
```
3.40 One pole filter, LP and HP

• Author or source: uh.etle.fni@yfoocs
• Type: Simple 1 pole LP and HP filter
• Created: 2006-10-08 14:53:38

Listing 66: notes

Slope: 6dB/Oct
Reference: www.dspguide.com

Listing 67: code

```
Process loop (lowpass):
out = a0*in - b1*tmp;
tmp = out;

Simple HP version: subtract lowpass output from the input (has strange behaviour towards nyquist):
out = a0*in - b1*tmp;
tmp = out;
hp = in-out;

Coefficient calculation:
x = exp(-2.0*pi*freq/samplerate);
a0 = 1.0-x;
b1 = -x;
```

3.40.1 Comments

• Date: 2007-01-05 11:43:21
• By: moc.liamtoh@ojer_jd

Why don't you just say:
Process loop (lowpass):
out = a0*in + b1*tmp;
tmp = out;

Simple HP version: subtract lowpass output from the input (has strange behaviour towards nyquist):
out = a0*in + b1*tmp;
tmp = out;
hp = in-out;

Coefficient calculation:
x = exp(-2.0*pi*freq/samplerate);
a0 = 1.0-x;
b1 = x;

• Date: 2007-01-06 04:12:56
• By: uh.etle.fni@yfoocs
There's a tradition among digital filter designers that the pole coefficients have a negative sign. Of course the other one is also valid, and sometimes these notations are mixed up.

If you're worried about the extra negation operation, then you could say

\[ b1 = -x; \]
\[ a0 = 1.0+b1; \]

so that there's no additional operation overhead.

-- peter schoffhauzer

- Date: 2007-01-06 16:26:27
- By: moc.erehwon@ydobon

Of course, you don't need tmp.

Process loop (lowpass):
\[ \text{out} = a0 \times \text{in} + b1 \times \text{out}; \]

- Date: 2007-02-16 19:27:48
- By: uh.etle.fnli@yfoocs

Indeed.

- Date: 2009-06-18 17:29:20
- By: moc.boohay@bob

Or...
\[ \text{out} += a0 \times (\text{in} - \text{out}); \]

;

3.41 One pole, one zero LP/HP

- Author or source: ti.dniwni@tretsim
- Created: 2002-08-26 23:34:48

Listing 68: code

```c
void SetLPF(float fCut, float fSampling) {
    float w = 2.0 * fSampling;
    float Norm;
    fCut *= 2.0F * PI;
    Norm = 1.0 / (fCut + w);
    b1 = (w - fCut) * Norm;
    a0 = a1 = fCut * Norm;
}
```

(continues on next page)
void SetHPF(float fCut, float fSampling) {
    float w = 2.0 * fSampling;
    float Norm;
    fCut *= 2.0F * PI;
    Norm = 1.0 / (fCut + w);
    a0 = w * Norm;
    a1 = -a0;
    b1 = (w - fCut) * Norm;
}

Where
out[n] = in[n]*a0 + in[n-1]*a1 + out[n-1]*b1;

3.41.1 Comments

- **Date:** 2006-01-15 01:12:26
  - **By:** ten.tramepyh@renietsretep
  - what is n? lol...sorry but i mean this seriously! ;)

- **Date:** 2006-01-16 14:17:35
  - **By:** ku.oc.snosrapsd@psdcisum
  - n is the index of sample being considered.
  - out[] is an array of samples being output, and in[] is the input array. you would
    →construct a loop such that:
    [Pseudocode]
    loop n{0..numsamples-1}
    → out[n] = in[n]*a0 + in[n-1]*a1 + out[n-1]*b1;
    end loop;
    [/Pseudocode]
  - You will need some cleverness so that [n-1] doesn't cause an index error when n=0,
    →but I'll leave that to you ;)

- **Date:** 2006-01-18 09:28:30
  - **By:** ten.tramepyh@renietsretep
  - whoops - sorry, of course n = number... stupid me ;)
  - interesting code, i will see if can adapt that to delphi, shouldn't be a big deal ;)
  - i assume i dont need to place either setHPF or LPF into the samples loop, just the
    →block itself?

- **Date:** 2006-01-23 10:57:26
  - **By:** ku.oc.snosrapsd@psdcisum
absolutey - set the coefficients outside of the loop. There is the case of changes being made whilst the loop is running, depends what platform/host you are writing for.

I'm a delphi code as well. Feel free to use my posted address if you need to :) DSP

• **Date:** 2006-07-21 09:07:12  
  • **By:** moc.oohay@keelanej

Shouldn't that be float w = 2*PI*fSampling; ???

In which case we can simplify:

```c
void SetLPF(float fCut, float fSampling) {
    a0 = fCut/(fSampling+fCut);
    a1 = a0;
    b1 = (fSampling-fCut)/(fSampling+fCut);
}

void SetHPF(float fCut, float fSampling) {
    a0 = fSampling/(fSampling+fCut);
    a1 = -a0;
    b1 = (fSampling-fCut)/(fSampling+fCut);
}
```

You can keep the norm = 1/(fSampling+fCut) if you like.

• **Date:** 2020-05-23  
  • **By:** JoergBitzer

The equation of the original contributor is correct. It is a first order Butterworth-Filter H(s') = 1/(1+s') and then denormalized s' = s/wcut and transformed by the bilinear transform s = 2f_s (z-1)/(z+1). Only the tan-prewarp is missing for fcutfcutoff/wcut.

### 3.42 One zero, LP/HP

• **Author or source:** Bram  
• **Created:** 2002-08-29 23:18:43

Listing 69: notes

LP is only 'valid' for cutoffs > samplerate/4  
HP is only 'valid' for cutoffs < samplerate/4

Listing 70: code

```c
theta = cutoff*2*pi / samplerate
(continues on next page)```
3.43 One-Liner IIR Filters (1st order)

- **Author or source:** moc.edocseira@sirhc
- **Type:** IIR 1-pole
- **Created:** 2009-01-18 10:53:44

**Listing 71: notes**

Here is a collection of one liner IIR filters. Each filter has been transformed into a single C++ expression.

The filter parameter is f or g, and the state variable that needs to be kept around between iterations is s.

- Christian

**Listing 72: code**

```
101 Leaky Integrator

    a0 = 1
    b1 = 1 - f

    out = s += in - f * s;

102 Basic Lowpass (all-pole)

    A first order lowpass filter, by finite difference approximation,
    →(differentials -->> differences).

    a0 = f
    b1 = 1 - f

    out = s += f * ( in - s );

103 Lowpass with inverted control

    Same as above, except for different filter parameter is now inverted.
```
In this case, g equals the location of the pole.

\[
\begin{align*}
a_0 &= g - 1 \\
b_1 &= g \\
\text{out} &= s = \text{in} + g \times (s - \text{in});
\end{align*}
\]

104 Lowpass with zero at Nyquist

A first order lowpass filter, by via the conformal map of the z-plane (0..\(\rightarrow\)infinity --> 0..Nyquist).

\[
\begin{align*}
a_0 &= f \\
a_1 &= f \\
b_1 &= 1 - 2 \times f \\
s &= \text{temp} + (\text{out} = s + (\text{temp} = f \times (\text{in} - s)));
\end{align*}
\]

105 Basic Highpass (DC-blocker)

Input complement to basic lowpass, yields a finite difference highpass filter.

\[
\begin{align*}
a_0 &= 1 - f \\
a_1 &= f - 1 \\
b_1 &= 1 - f \\
\text{out} &= \text{in} - (s += f \times (\text{in} - s));
\end{align*}
\]

106 Highpass with forced unity gain at Nyquist

Input complement to filter 104, yields a conformal map highpass filter.

\[
\begin{align*}
a_0 &= 1 - f \\
a_1 &= f - 1 \\
b_1 &= 1 - 2 \times f \\
\text{out} &= \text{in} + \text{temp} - (s += 2 \times (\text{temp} = f \times (\text{in} - s)));
\end{align*}
\]

107 Basic Allpass

This corresponds to a first order allpass filter, where g is the location of the pole in the range -1..1.

\[
\begin{align*}
a_0 &= -g \\
a_1 &= 1 \\
b_1 &= g \\
s &= \text{in} + g \times (\text{out} = s - g \times \text{in});
\end{align*}
\]

3.43.1 Comments

- Date: 2016-03-31 14:21:04
Great help, although could you advise as to where the parameters a0, a1 and b1 are used for the high pass filter 105? Thanks

### 3.44 Output Limiter using Envelope Follower in C++

**Author or source:** moc.oohay@nniveht

**Created:** 2009-04-27 08:46:35

---

Here's a Limiter class that will automatically compress a signal if it would cause clipping.

You can control the attack and decay parameters of the limiter. The attack determines how quickly the limiter will respond to a sudden increase in output level. I have found that attack=10ms and decay=500ms works very well for my application.

This C++ example demonstrates the use of template parameters to allow the same piece of code to work with either floats or doubles (without needing to make a duplicate of the code). As well as allowing the same code to work with interleaved audio data (any number of channels) or linear, via the "skip" parameter. Note that even in this case, the compiler produces fully optimized output in the case where the template is instantiated for a compile-time constant value of skip.

In Limiter::Process() you can see the envelope class getting called for one sample, this shows how even calling a function for a single sample can get fully optimized out by the compiler if code is structured correctly.

While this is a fairly simple algorithm, I wanted to share the technique for using template parameters to develop routines that can work with any size floating point representation or multichannel audio data, while still remaining fully optimized.

These classes were based on ideas found in the musicdsp.org archives.

---

```cpp
class EnvelopeFollower
{
public:
    EnvelopeFollower();
    void Setup(double attackMs, double releaseMs, int sampleRate);
};
```

(continues on next page)
template<class T, int skip>
void Process( size_t count, const T *src );

double envelope;

protected:
  double a;
  double r;
};

//----------
inline EnvelopeFollower::EnvelopeFollower()
{
  envelope=0;
}

inline void EnvelopeFollower::Setup( double attackMs, double releaseMs, int sampleRate )
{
  a = pow( 0.01, 1.0 / ( attackMs * sampleRate * 0.001 ) );
  r = pow( 0.01, 1.0 / ( releaseMs * sampleRate * 0.001 ) );
}

template<class T, int skip>
void EnvelopeFollower::Process( size_t count, const T *src )
{
  while( count-- )
  {
    double v=::fabs( *src );
    src+=skip;
    if( v>envelope )
      envelope = a * ( envelope - v ) + v;
    else
      envelope = r * ( envelope - v ) + v;
  }
}

//----------

struct Limiter
{
  void Setup( double attackMs, double releaseMs, int sampleRate );

  template<class T, int skip>
  void Process( size_t nSamples, T *dest );

private:
  EnvelopeFollower e;
};

//----------
inline void Limiter::Setup( double attackMs, double releaseMs, int sampleRate )
{
  e.Setup( attackMs, releaseMs, sampleRate );
}
template<class T, int skip>
void Limiter::Process( size_t count, T *dest )
{
    while( count-- )
    {
        T v=*dest;
        // don't worry, this should get optimized
        e.Process<T, skip>( 1, &v );
        if( e.envelope>1 )
            *dest=*dest/e.envelope;
        dest+=skip;
    }
}

3.45 Peak/Notch filter

- **Author or source:** ed.bew@raebybot
- **Type:** peak/notch
- **Created:** 2002-12-16 19:01:28

Listing 75: notes

// Peak/Notch filter
// I don't know anymore where this came from, just found it on
// my hard drive :-)
// Seems to be a peak/notch filter with adjustable slope
// steepness, though slope gets rather wide the lower the
// frequency is.
// "cut" and "steep" range is from 0..1
// Try to feed it with white noise, then the peak output does
// rather well eliminate all other frequencies except the given
// frequency in higher frequency ranges.

Listing 76: code

```
var f,r:single;
outp,outp1,outp2:single; // init these with 0!
const p4=1.0e-24; // Pentium 4 denormal problem elimination

function PeakNotch(inp,cut,steep:single;ftype:integer):single;
begin
    r:=steep*0.99609375;
    f:=cos(pi*cut);
    a0:=(1-r)*sqrt(r*(r-4*(f*f)+2)+1);
    b1:=2*f*r;
    b2:=-r*r;
    outp:=a0*inp+b1*outp1+b2*outp2+p4;
    outp2:=outp1;
    outp1:=outp;
    if ftype=0 then
        result:=outp //peak
```

else
  result:=inp-outp; //notch
end;

3.45.1 Comments

- **Date:** 2010-03-02 03:19:21
- **By:** slo77y (at) yahoo.de

This code sounds bitcrushed like hell translated to c++, any suggestions?

```c
float pi = 3.141592654;
float r = dQFactor*0.99609375;
float f = cos(pi*iFreq);
float a0 = (1-r) * sqrt ( r * ( r-4 * ( f * f ) + 2 ) + 1);
float b1 = 2 * f * r;
float b2 = - ( r * r);
float outp = 0.0, outp1 = 0.0, outp2 = 0.0;

for (i = 0; i < iSamples; i++)
{
  float inp = fInput[i];
  outp = a0 * inp + b1 * outp1 + b2 * outp2 + p4;
  outp2 = outp1;
  outp1 = outp;
  fOutput[i] = (inp-outp); //notch
}
```

- **Date:** 2012-05-05 08:22:08
- **By:** ten.xoc@53namhsima

After about 3 hours wondering why I was getting back the original un-altered audio, I finally got this version of a keeper filter, which I used with absurdly good success on a power grid comb filter. When the power grid filter was fed with audio from a lamp cord with one 1 Megohm resistor on each prong, all sorts of cool sounds become audio when the output is amplified 40 dB. For wall cord audio, use 60.0 for the cutoff.

---the function is below---

double keeper_1(double input, double cutoff,double rate,double *magnitude)
{
  const double steepness=1.0;
  const double p4=1.0e-24;
  static unsigned char first=1;
  static double nfreq=0.1;
  static double old_cutoff=0.0;
  static double the_magnitude=0;
  static double average=0.0;
  static int average_count=0;
  static double a=0.0;
  static double r=0.0;
  static double coeff=0.0;
  static double delay[3]={0.0,0.0,0.0};
```
static double delay1[3]={0.0,0.0,0.0};
static double delay2[3]={0.0,0.0,0.0};
static double delay3[3]={0.0,0.0,0.0};
static double b[3]={0.0,0.0,0.0};
if(first==1 || cutoff!=old_cutoff )
{
   r=steepness * 0.99609375;
   nfreq=(cutoff/(double)rate) * 2.0 ;
   coeff= cos( M_PI * nfreq);
   a=(1.0 - r) * sqrt(r * (r - 4 * (coeff * coeff) + 2) +1);
   b[1]=2 * coeff * r;
   b[2]=-(r * r);
   first=0;
}
delay3[2]=delay3[1];
delay3[1]=delay3[0];

delay2[2]=delay2[1];
delay2[1]=delay2[0];

delay1[2]=delay1[1];
delay1[1]=delay1[0];

delay[2]=delay[1];
delay[1]=delay[0];
average+=delay[0];
average_count++;
if(average_count>dft_size-1)
{
   double aver=average/(double)dft_size;
   the_magnitude=sqrt(aver * aver); /* we're only interested in the root mean square */
   average=0.0;
   average_count=0;
}
magnitude[0]=the_magnitude;
old_cutoff=cutoff;
return delay[0];
}
3.46 Perfect LP4 filter

- **Author or source:** rf.eerf@aipotreza
- **Type:** LP
- **Created:** 2008-03-13 10:40:46

### Listing 77: notes

hacked from the exemple of user script in FL Edison

### Listing 78: code

```pascal
TLP24DB = class
c enters
  procedure process(inp: Single; Frq: Single; Res: Single; SR: Integer);
private
  t, t2, x, f, k, p, r, y1, y2, y3, y4, oldx, oldy1, oldy2, oldy3: Single;
public
  outlp: Single;
end;
----------------------------------------
implementation
constructor TLP24DB.create;
begin
  y1 := 0;
  y2 := 0;
  y3 := 0;
  y4 := 0;
  oldx := 0;
  oldy1 := 0;
  oldy2 := 0;
  oldy3 := 0;
end;
procedure TLP24DB.process(inp: Single; Frq: Single; Res: Single; SR: Integer);
begin
  f := (Frq + Frq) / SR;
  p := f * (1.8 - 0.8 * f);
  k := p + p - 1.0;
  t := (1.0 - p) * 1.386249;
  t2 := 12.0 + t * t;
  r := res * (t2 + 6.0 * t) / (t2 - 6.0 * t);
  x := inp - r * y4;
  y1 := x * p + oldx * p - k * y1;
  y2 := y1 * p + oldy1 * p - k * y2;
  y3 := y2 * p + oldy2 * p - k * y3;
  y4 := y3 * p + oldy3 * p - k * y4;
  y4 := y4 - ((y4 * y4 * y4) / 6.0);
  oldx := x;
  oldy1 := y1 + _kd;
  oldy2 := y2 + _kd;
  oldy3 := y3 + _kd;
  outlp := y4;
end;

// the result is in outlp
```

(continues on next page)
// 1/ call MyTLP24DB.Process
// 2/ then get the result from outlp.
// this filter have a fantastic sound w/a very special res
// _kd is the denormal killer value.

3.46.1 Comments

- **Date:** 2008-10-20 07:44:35
- **By:** moc.liamg@321tiloen

This is basically a Moog filter.

- **Date:** 2010-09-16 23:07:30
- **By:** moc.liamG@0356orbratiug

Same as http://www.musicdsp.org/showArchiveComment.php?ArchiveID=24 but seems to be in pascal.

3.47 Pink noise filter

- **Author or source:** Paul Kellett
- **Created:** 2002-02-11 17:40:39
- **Linked files:** pink.txt.

Listing 79: notes

(see linked file)

3.47.1 Comments

- **Date:** 2005-02-10 12:23:55
- **By:** ed.ap-ymot@ymoT

Hi, first of all thanks a lot for this parameters.
I'm new to digital filtering, and need a 3dB highpass to correct a pink spectrum which is used for measurement back to white for displaying the impulse response. I checked some pages, but all demand a fixed ratio between d0 and d1 for a 6db lowpass. But this ratio is not given on your filters, so I'm not able to transform them into highpasses.
Any hints?
Tomy

- **Date:** 2005-02-10 19:58:16
- **By:** ed.ap-ymot@ymoT
Hi, first of all thanks a lot for this parameters. I'm new to digital filtering, and need a 3dB highpass to correct a pink spectrum which is used for measurement back to white for displaying the impulseresponse. I checked some pages, but all demand a fixed ratio between d0 and d1 for a 6db lowpass. But this ratio is not given on your filters, so I'm not able to transform them into highpasses. Any hints?

Tomy

If computing power doesn't matter, than you may want do design the pink noise in the frequency domain and transform it back to timedomain via fft.

Christian

HI, could you please give me a code matlab to have a pink noise. I tested a code where one did all into frequential mode then made an ifft. Thank you

moc.liamg@321tiloen

3.47. Pink noise filter
\[ f_1 = 8621.096; \]
\[ f_2 = 8555.228; \]
\[ f_3 = 8292.754; \]
\[ f_4 = 518.334; \]
\[ f_5 = 163.712; \]
\[ f_6 = 240.241; \]

\[ \text{//samplerate} \geq 192000\text{hz} \]
\[ f_0 = 10000; \]
\[ f_1 = 10000; \]
\[ f_2 = 10000; \]
\[ f_3 = 10000; \]
\[ f_4 = 544.948; \]
\[ f_5 = 142.088; \]
\[ f_6 = 211.616; \]

\[ \text{//calculate coefficients} \]
\[ k_0 = \exp(-2\times\pi\times f_0/sr); \]
\[ k_1 = \exp(-2\times\pi\times f_1/sr); \]
\[ k_2 = \exp(-2\times\pi\times f_2/sr); \]
\[ k_3 = \exp(-2\times\pi\times f_3/sr); \]
\[ k_4 = \exp(-2\times\pi\times f_4/sr); \]
\[ k_5 = \exp(-2\times\pi\times f_5/sr); \]
\[ k_6 = \exp(-2\times\pi\times f_6/sr); \]

\[ \text{--- sample loop ---} \]
\[ \text{white - noise input} \]
\[ b_0 = k_0 \times \text{white} + k_0 \times b_0; \]
\[ b_1 = k_1 \times \text{white} + k_1 \times b_1; \]
\[ b_2 = k_2 \times \text{white} + k_2 \times b_2; \]
\[ b_3 = k_3 \times \text{white} + k_3 \times b_3; \]
\[ b_4 = k_4 \times \text{white} + k_4 \times b_4; \]
\[ b_5 = k_5 \times \text{white} + k_5 \times b_5; \]
\[ b_6 = k_6 \times \text{white} + k_6 \times b_6; \]
\[ \text{pink} = (b_0 + b_1 + b_2 + b_3 + b_4 + b_5 + \text{white} - b_6); \]

\[ \text{output} = \text{pink}; \]
\[ \text{--- sample loop ---} \]

Basically if you use the same coefficients, if comparing some outputs, you would notice a degradation in the filter at higher sample rates - Thus the different ranges. But the quality of your white noise (PRNG) may be important also.

These 'should' work...They do fairly well, at least mathematically for rendered outputs.

Lubomir

### 3.48 Plot Filter (Analyze filter characteristics)

- **Author or source:** ku.oc.oohay@895rennacs
- **Type:** Test
- **Created:** 2007-11-26 14:05:40
As a newbie, and one that has very, very little mathematical background, I wanted to see what all the filters posted here were doing to get a feeling of what was going on here. So with what I picked up from this site, I wrote a little filter test program. Hope it is of any use to you.

```cpp
#include <stdio.h>
#include <stdlib.h>
#include <float.h>
#include <math.h>

#define myPI 3.1415926535897932384626433832795
#define FP double
#define DWORD unsigned long
#define CUTOFF 5000
#define SAMPLERATE 48000

#define TESTSAMPLES (SAMPLERATE/20) * 2

class Filter {
    FP sdm1;   // sample data minus 1
    FP a0;     // multiply factor on current sample
    FP b1;     // multiply factor on sdm1
public:
    Filter (void) { (continues on next page)
sdm1 = 0;
    // init on no filtering
    a0 = 1;
    b1 = 0;
}
void init(FP freq, FP samplerate) {
    FP x;
    x = exp(-2.0 * myPI * freq / samplerate);
    sdm1 = 0;
    a0 = 1.0 - x;
    b1 = -x;
}
FP getSample(FP sample) {
    FP out;
    out = (a0 * sample) - (b1 * sdm1);
    sdm1 = out;
    return out;
}
;

int main(void)
{
    DWORD freq;
    DWORD spos;
    double sIn;
    double sOut;
    double tIn;
    double tOut;
    double dB;
    DWORD tmp;

    // define the test filter
    Filter filter;

    printf(" 9dB  6dB  3dB  0dB\n    ...");
    printf(" freq  dB | | | | \n    ...");

    // test frequencies 20 - 20020 with 100 herz steps
    for (freq=20; freq<20020; freq+=100) {

        // (re)initialize the filter
        filter.init(CUTOFF, SAMPLERATE);

        // let the filter do it's thing here
        tIn = tOut = 0;
        for (spos=0; spos<TESTSAMPLES; spos++) {
            sIn = sin((2 * myPI * spos * freq) / SAMPLERATE);
            sOut = filter.getSample(sIn);
            if ((sOut>1) || (sOut<-1)) {
                // If filter is no good, stop the test
                printf("Error! Clipping!\n");
                return(1);
            }
            if (sIn >0) tIn += sIn;
    }
if (sIn < 0) tIn -= sIn;
if (sOut > 0) tOut += sOut;
if (sOut < 0) tOut -= sOut;
}

// analyse the results
dB = 20 * log(tIn / tOut);
printf("%5d %5.1f ", freq, dB);
tmp = (DWORD)(60.0 / pow(2, (dB / 3)));
while (tmp) {
    putchar('#');
    tmp--;
}
putchar('\n');
return 0;
}

3.48.1 Comments

- **Date**: 2008-01-01 20:45:13
- **By**: niels m.

You need to change the log() to log10() to get the correct answer in dB's.

You can also replace the if(sIn > 0) .. -= sOut; by:

tIn += sIn * sIn;
tOut += sOut * sOut;

this will measure signal power instead of amplitude. If you do this, you also need to change 20 * log10() to 10 * log10().

Nice and useful tool for exploring filters. Thanks!

3.49 Plotting R B-J Equalisers in Excel

- **Author or source**: Web Surf
- **Created**: 2006-03-07 09:32:57
- **Linked files**: rbj_eq.xls.

Listing 82: notes

Interactive XL sheet that shows frequency response of the R B-K high pass/low pass, Peaking and Shelf filters

Useful if --
--You want to validate your implementation against mine
--You want to convert given Biquad coefficients into Fo/Q/Dbgain by visual curve_fitting.

(continues on next page)
-- You want the Coefficients to implement a particular fixed filter
-- Educational aid

Many thanks to R B-J for his personal support !!
Web Surf  WebsurffATgmailDOTcom

Listing 83: code

see attached file

3.49.1 Comments

- **Date:** 2006-04-14 07:07:00
  - **By:** rf.liamtoh@57eninreS_luaP

It also works perfectly with the openoffice2.02 suite :-)

- **Date:** 2007-07-24 15:00:09
  - **By:** jackmattson at gmial

Ok, so I'm about to make my first filter so I really have no idea about coefficients,...
...yet but damn this is the coolest .xls I've ever seen! And I see a bunch every day. ...
...

- **Date:** 2007-09-13 05:54:54
  - **By:** WebsurffATgmailDOTcom

Thanks,

It's just an implementation of the R B-J cookbook formulae for parametric equalisers.

→ RB-J personally assisted me while I was writing this XLS. The real Kudos goes out,
→ to him !!!!

I wrote this as an intermediate tool while I was writing some Guitar effect DSP
→ routines.

One prob it has : If the Q is too sharp, the peak filters have a very sharp tip. It
→ is possible then as you slide the F sliders, that the chosen F is not one of the,
→ data points that I am plotting.

The net result is that the peak of a hi-Q filter seems to increase/decrease as you
→ move F. This is a shortcoming of the way I programmed my XLS and is not a problem,
→ with the R B-J equations.

PS : I saw the same problem with other similar S/W on the net !!!

PS : Anyone know how to do curve fitting so that we enter in some points through
→ which the frequency response must pass, and it generates best set of F,G,Q ?

- **Date:** 2011-04-18 02:30:51
Just wanted to complement you on the good work. I came across your RBJ filter plotter spreadsheet, and it's quite good.

The version I have is dated Feb. 2006, so this may have been addressed already but I did notice a small issue with the sample frequency input.

 Anything other than 44.1 KHz would cause the response curves to peak at incorrect values on the x axis. The normalized frequency 'w' was being referenced to 44100, and not to the Fs cell. I modified the formula to absolute reference B56 and it solved that problem.

Thanks for your great work,
- robert

3.50 Polyphase Filters

- Author or source: C++ source code by Dave from Muon Software
- Type: polyphase filters, used for up and down-sampling
- Created: 2002-01-17 02:14:53
- Linked files: BandLimit.cpp.
- Linked files: BandLimit.h.

3.50.1 Comments

- Date: 2005-02-16 00:14:08
- By: ed.bew@ihsugat.aranoias

Can someone give me a hint for a paper where this stuff is from?

- Date: 2005-03-29 20:39:59
- By: ABC

From there: http://www.cmsa.wmin.ac.uk/~artur/Poly.html

There is also this library, implementing the same filter, but optimised for down/upsampling and ported to SSE and 3DNow!:
http://ldesoras.free.fr/prod.html#src_hiir

- Date: 2005-07-27 09:22:16
- By: ku.oc.nez@mahcleb.bor
There is an error in the 12th order, steep filter coefficients. Having checked the output against that produced by HIIR (see previous comment), I have identified the source of the error - the 4th b coefficient 0.06329609551399348, should be 0.6329609551399348.

**Date:** 2008-04-06 08:58:52

**By:** bla

You also need to delete the pointers inside the array:

```cpp
CAllPassFilterCascade::~CAllPassFilterCascade()
{
    for (int i=0;i<numfilters;i++)
    {
        delete allpassfilter[i];
    }
    delete[] allpassfilter;
};
```

**Date:** 2008-11-05 14:50:18

**By:** moc.tob.3gall1pso1dua@0fn1

Some questions.. is it normal for these halfband filters to cause significant gain loss? Sonogram analysis shows a decrease in SNR if I have read the results correctly.

If using these filters for oversampling and I do this:

```
upsample
halfband filter
*process*
halfband filter
decimate (discard samples)
```

Then presumably the second halfband filter does the antialiasing at half the new sampling rate?

**Date:** 2009-02-26 21:39:21

**By:** moc.toohay@bob

Hello, I'm getting the high pass from the function by subtracting the 'oldout' variable.

```cpp
output=(filter_a->process(input)-oldout)*0.5;
```

But this does not make an ideal QMF, I'm getting pass-band aliasing, so I guessing the phase is off slightly between the low and high.

Is this the correct way of getting the high band?

Cheers,
Dave P

**Date:** 2010-01-21 19:31:46

**By:** bobby
Is the cutoff at 20kHz? What sample rate are these coefficients for? How would I calculate suitable coefficients for arbitrary sample rates?

- **Date:** 2011-06-11 18:13:28
- **By:** moc.psdallahlav@naes

It is worth noting that if these filters are being used for upsampling/downsampling, the "noble identity" can be used to reduce the CPU cost. The basic idea is that operations that can be expressed in the form:

- filter that uses $z^{-N}$ for its states -> downsample by N

can be rearranged to use the form:

- downsample by N -> filter that uses $z^{-1}$ for its states


For the above code, this would entail creating an alternative allpass process function, that uses the $z^{-1}$ for its states, and then rearranging some of the operations.

### 3.51 Polyphase Filters (Delphi)

- **Author or source:** moc.liamtoh@retsbomyrgnayrev
- **Type:** polyphase filters, used for up and down-sampling
- **Created:** 2006-07-05 20:13:50

Listing 84: notes

Pascal conversion of C++ code by Dave from Muon Software. Conversion by Shannon Faulkner.

Listing 85: code

```pascal
{

polyphase filters, used for up and down-sampling
original c++ code by Dave from Muon Software found
at MusicDSP.
rewritten in pascal by Shannon Faulkner, 4/7/06.
}

unit uPolyphase;

interface
```

(continues on next page)
type
  TAllPass=class
  private
    a,x0,x1,x2,y0,y1,y2:single;
  public
    constructor create(coefficient:single);
    function Process(input:single):single;
  end;

TAllPassFilterCascade=class
private
  AllPassFilters:array of TAllPass;
  fOrder:integer;
public
  constructor create(coefficients:psingle;Order:integer);
  function Process(input:single):single;
end;

THalfBandFilter=class
private
  fOrder:integer;
  OldOut:single;
  aCoeffs,bCoeffs:array of single;
  FilterA,FilterB:TAllPassFilterCascade;
public
  constructor create(order:integer;Steep:boolean);
  function process(input:single):single;
end;

implementation

//----------- AllPass Filter -------------------
//----------- AllPass Filter ----------------------------------------------
//----------- AllPass Filter ----------------------------------------------
constructor TAllPass.create(coefficient:single);
begin
  a:=coefficient;
  x0:=0;
  x1:=0;
  x2:=0;
  y0:=0;
  y1:=0;
  y2:=0;
end;

var output:single;
begin
  //shuffle inputs
  x2:=x1;
  x1:=x0;
  x0:=input;
  //shuffle outputs
  y2:=y1;
  output:=y2;
end;

var output:single;
begin
  //shuffle inputs
  x2:=x1;
  x1:=x0;
  x0:=input;
  //shuffle outputs
  y2:=y1;
end;
71  y1:=y0;
72  //allpass filter 1
73  output:=x2+((input-y2)*a);
74  y0:=output;
75  result:=output;
76  end;
77
78  constructor TAllPassFilterCascade.create(coefficients:psingle;Order:integer);
79  var i:integer;
80  begin
81    fOrder:=Order;
82    setlength(AllPassFilters,fOrder);
83    for i:=0 to fOrder-1 do
84      begin
85        AllPassFilters[i]:=TAllPass.create(coefficients^);
86        inc(coefficients);
87      end;
88  end;
89
91  var output:single;
92  begin
93    output:=input;
94    for i:=0 to fOrder-1 do
95      begin
96        output:=allpassfilters[i].Process(output);
97      end;
98    result:=output;
99  end;

100 constructor THalfBandFilter.create(order:integer;Steep:boolean);
101  begin
102    fOrder:=order;
103    setlength(aCoeffs,Order div 2);
104    setlength(bCoeffs,Order div 2);
105    if steep=true then
106      begin
107        if (order=12) then //rejection=104dB, transition band=0.01
108          begin
109            aCoeffs[0]:=0.036681502163648017;
110            aCoeffs[1]:=0.2746317593794541;
111            aCoeffs[2]:=0.56109896978791948;
112            aCoeffs[3]:=0.769741833862266;
113            aCoeffs[4]:=0.8922608180038789;
114            aCoeffs[5]:=0.962094548378084;
115            bCoeffs[0]:=0.13654762463195771;
116          end;
117      end;
118  end;
bCoeffs[1] := 0.4231386174365667;
bCoeffs[2] := 0.6775404499741616;
bCoeffs[3] := 0.83989624849638;
bCoeffs[4] := 0.9315419599631839;
bCoeffs[5] := 0.9878163707328971;
end
else if (order=10) then //rejection=86dB, transition band=0.01
begin
aCoeffs[0] := 0.051457617441190984;
aCoeffs[1] := 0.35978656070567017;
aCoeffs[2] := 0.6725475931034693;
aCoeffs[3] := 0.8590849282499399;
aCoeffs[4] := 0.9540209867860787;

bCoeffs[0] := 0.18621906251989334;
bCoeffs[1] := 0.529951372847964;
bCoeffs[2] := 0.781025727489514;
bCoeffs[3] := 0.9141815687605308;
bCoeffs[4] := 0.985475023014907;
end
else if (order=8) then //rejection=69dB, transition band=0.01
begin
aCoeffs[0] := 0.07711507983241622;
aCoeffs[1] := 0.4820706250610472;
aCoeffs[2] := 0.7968204713315797;
aCoeffs[3] := 0.9412514277740471;

bCoeffs[0] := 0.2659685265210946;
bCoeffs[1] := 0.6651041532634957;
bCoeffs[2] := 0.8841015085506159;
bCoeffs[3] := 0.9820054141886075;
end
else if (order=6) then //rejection=51dB, transition band=0.01
begin
aCoeffs[0] := 0.1271414136264853;
aCoeffs[1] := 0.6528245886369117;
aCoeffs[2] := 0.9176942834328115;

bCoeffs[0] := 0.40056789819445626;
bCoeffs[1] := 0.8204163891923343;
bCoeffs[2] := 0.9763114515836773;
end
else if (order=4) then //rejection=53dB, transition band=0.05
begin
aCoeffs[0] := 0.12073211751675449;
aCoeffs[1] := 0.6632020224193995;

bCoeffs[0] := 0.3903621872345006;
bCoeffs[1] := 0.890786832653497;
end
else //order=2, rejection=36dB, transition band=0.1
begin
aCoeffs[0] := 0.23647102099689224;
bCoeffs[0] := 0.7145421497126001;
end;
if (order=12) then //rejection=104dB, transition band=0.01

begin
  aCoeffs[0]:=0.01677466677723562;
  aCoeffs[1]:=0.13902148819717805;
  aCoeffs[2]:=0.3325011117394731;
  aCoeffs[3]:=0.537661053144888;
  aCoeffs[4]:=0.7214184024215805;
  aCoeffs[5]:=0.8821858402078155;
  bCoeffs[0]:=0.06501319274445962;
  bCoeffs[1]:=0.23094129990840923;
  bCoeffs[2]:=0.4364942348420355;

  //bug fix - coefficient changed,
  //bCoeffs[3]:=0.06329609551399348; //original coefficient
  bCoeffs[3]:=0.6329609551399348; //correct coefficient

  bCoeffs[4]:=0.8037808679411126;
  bCoeffs[5]:=0.9599687404800694;
end

else if (order=10) then //rejection=86dB, transition band=0.01

begin
  aCoeffs[0]:=0.02366831419883467;
  aCoeffs[1]:=0.18989476227180174;
  aCoeffs[2]:=0.43157318062118555;
  aCoeffs[3]:=0.6632020224193995;
  aCoeffs[4]:=0.860015542499582;
  bCoeffs[0]:=0.09056555904993387;
  bCoeffs[1]:=0.3078575723749043;
  bCoeffs[2]:=0.5516782402507934;
  bCoeffs[3]:=0.7652146863779808;
  bCoeffs[4]:=0.95247728378667541;
end

else if (order=8) then //rejection=69dB, transition band=0.01

begin
  aCoeffs[0]:=0.03583278843106211;
  aCoeffs[1]:=0.2720401433964576;
  aCoeffs[2]:=0.5720571972357003;
  aCoeffs[3]:=0.827124761997324;
  bCoeffs[0]:=0.1340901419430669;
  bCoeffs[1]:=0.4243248712718685;
  bCoeffs[2]:=0.7062921421386394;
  bCoeffs[3]:=0.9415030941737551;
end

else if (order=6) then //rejection=51dB, transition band=0.01

begin
  aCoeffs[0]:=0.06029739095712437;
  aCoeffs[1]:=0.4125907203610563;
  aCoeffs[2]:=0.772156537429234;
  bCoeffs[0]:=0.21597144456092948;
  bCoeffs[1]:=0.6043586264658363;
  bCoeffs[2]:=0.9238861386532906;
end

(continues on next page)
else if (order=4) then //rejection=53dB, transition band=0.05
begin
    aCoeffs[0]:=0.07986642623635751;
    aCoeffs[1]:=0.5453536510711322;
    bCoeffs[0]:=0.28382934487410993;
    bCoeffs[1]:=0.8344118914807379;
end else  //order=2, rejection=36dB, transition band=0.1
begin
    aCoeffs[0]:=0.23647102099689224;
    bCoeffs[0]:=0.7145421497126001;
end;
end;
end.

3.52 Poor Man’s FIWIZ

• Author or source: moc.oohay@ljbliam
• Type: Filter Design Utility
• Created: 2007-03-22 15:02:29

FIWIZ is a neat little filter design utility that uses a genetic programming technique called Differential Evolution. As useful as it is, it looks like it took about a week to write, and is thus very undeserving of the $70 license fee. So I decided to write my own. There’s a freely available optimizer class that uses Differential Evolution and I patched it together with some filter-specific logic.

Use of the utility requires the ability to do simple coding in C, but you need only revise a single function, which basically describes your filter specification. There’s a big comment in the main source file that clarifies things a bit more.

Although it’s not as easy to use as FIWIZ, it’s arguably more powerful because your specifications are limited only by what you can express in C, whereas FIWIZ is completely
GUI based.

Another thing: I'm afraid that due to the use of \_kbhit and \_getch, the code is a bit Microsofty, but you can take those out and the code will still be basically usable.

Listing 87: code

```cpp
// First File: DESolver.cpp

#include <stdio.h>
#include <memory.h>
#include <conio.h>
#include "DESolver.h"

#define Element(a,b,c) a[b*nDim+c]
#define RowVector(a,b) (&a[b*nDim])
#define CopyVector(a,b) memcpy((a),(b),nDim*sizeof(double))

DESolver::DESolver(int dim, int popSize) :
    nDim(dim), nPop(popSize),
    generations(0), strategy(stRand1Exp),
    scale(0.7), probability(0.5), bestEnergy(0.0),
    trialSolution(0), bestSolution(0),
    popEnergy(0), population(0)
{
    trialSolution = new double[nDim];
    bestSolution = new double[nDim];
    popEnergy = new double[nPop];
    population = new double[nPop * nDim];

    return;
}

DESolver::~DESolver(void)
{
    if (trialSolution) delete trialSolution;
    if (bestSolution) delete bestSolution;
    if (popEnergy) delete popEnergy;
    if (population) delete population;

    trialSolution = bestSolution = popEnergy = population = 0;
    return;
}

void DESolver::Setup(double *min, double *max,
    int deStrategy, double diffScale, double _
    --crossoverProb)
{
    int i;

    strategy = deStrategy;
    scale = diffScale;
    probability = crossoverProb;

    for (i=0; i < nPop; i++)
    {
    
    }

(continues on next page)
```

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for (int j=0; j < nDim; j++)
    Element(population, i, j) = RandomUniform(min[j], max[j]);

    popEnergy[i] = 1.0E20;
}

for (i=0; i < nDim; i++)
    bestSolution[i] = 0.0;

switch (strategy)
{
    case stBest1Exp:
        calcTrialSolution = &DESolver::Best1Exp;
        break;

    case stRand1Exp:
        calcTrialSolution = &DESolver::Rand1Exp;
        break;

    case stRandToBest1Exp:
        calcTrialSolution = &DESolver::RandToBest1Exp;
        break;

    case stBest2Exp:
        calcTrialSolution = &DESolver::Best2Exp;
        break;

    case stRand2Exp:
        calcTrialSolution = &DESolver::Rand2Exp;
        break;

    case stBest1Bin:
        calcTrialSolution = &DESolver::Best1Bin;
        break;

    case stRand1Bin:
        calcTrialSolution = &DESolver::Rand1Bin;
        break;

    case stRandToBest1Bin:
        calcTrialSolution = &DESolver::RandToBest1Bin;
        break;

    case stBest2Bin:
        calcTrialSolution = &DESolver::Best2Bin;
        break;

    case stRand2Bin:
        calcTrialSolution = &DESolver::Rand2Bin;
        break;
}

return;

bool DESolver::Solve(int maxGenerations)
```c
int generation;
int candidate;
bool bAtSolution;
int generationsPerLoop = 10;

bestEnergy = 1.0E20;
bAtSolution = false;

for (generation=0;
    (generation < maxGenerations) && !bAtSolution && (0 == _kbhit());
    generation++)
{
    for (candidate=0; candidate < nPop; candidate++)
    {
        (this->*calcTrialSolution)(candidate);
        trialEnergy = EnergyFunction(trialSolution,bAtSolution);
        if (trialEnergy < popEnergy[candidate])
        {
            // New low for this candidate
            popEnergy[candidate] = trialEnergy;
            CopyVector(RowVector(population,candidate),trialSolution);

            // Check if all-time low
            if (trialEnergy < bestEnergy)
            {
                bestEnergy = trialEnergy;
                CopyVector(bestSolution,trialSolution);
            }
        }
    }

    if ((generation % generationsPerLoop) == (generationsPerLoop - 1))
    {
        printf("Gens %u Cost %.15g\n", generation+1, Energy());
    }
}

if (0 != _kbhit())
{
    _getch();
}

generations = generation;
return (bAtSolution);
}

void DESolver::Best1Exp(int candidate)
{
    int r1, r2;
    int n;

    SelectSamples(candidate,&r1,&r2);
    n = (int)RandomUniform(0.0,(double)nDim);
    CopyVector(trialSolution,RowVector(population,candidate));
    for (int i=0; (RandomUniform(0.0,1.0) < probability) && (i < nDim); i++)
```

(continues on next page)
{
    trialSolution[n] = bestSolution[n] + scale * (Element(population, r1, -n) - Element(population, r2, n));
    n = (n + 1) % nDim;
}

return;
}

void DESolver::Rand1Exp(int candidate)
{
    int r1, r2, r3;
    int n;

    SelectSamples(candidate, &r1, &r2, &r3);
    n = (int)RandomUniform(0.0, (double)nDim);

    CopyVector(trialSolution, RowVector(population, candidate));
    for (int i=0; (RandomUniform(0.0, 1.0) < probability) && (i < nDim); i++)
    {
        trialSolution[n] = Element(population, r1, n) + scale * (Element(population, r2, -n) - Element(population, r3, n));
        n = (n + 1) % nDim;
    }

    return;
}

void DESolver::RandToBest1Exp(int candidate)
{
    int r1, r2;
    int n;

    SelectSamples(candidate, &r1, &r2);
    n = (int)RandomUniform(0.0, (double)nDim);

    CopyVector(trialSolution, RowVector(population, candidate));
    for (int i=0; (RandomUniform(0.0, 1.0) < probability) && (i < nDim); i++)
    {
        trialSolution[n] += scale * (bestSolution[n] - trialSolution[n]) + scale * (Element(population, r1, -n) - Element(population, r2, n));
        n = (n + 1) % nDim;
    }

    return;
}

void DESolver::Best2Exp(int candidate)
{
    int r1, r2, r3, r4;
    int n;
(continues on next page)
SelectSamples(candidate,&r1,&r2,&r3,&r4);
    n = (int)RandomUniform(0.0,(double)nDim);

    CopyVector(trialSolution,RowVector(population,candidate));
    for (int i=0; (RandomUniform(0.0,1.0) < probability) && (i < nDim); i++)
    {
        trialSolution[n] = bestSolution[n] +
            scale * (Element(population,r1,n) +
            Element(population,r2,n) -
            Element(population,r3,n) -
            Element(population,r4,n));
        n = (n + 1) % nDim;
    }
    return;
}
void DESolver::Rand2Exp(int candidate)
{
    int r1, r2, r3, r4, r5;
    int n;
    SelectSamples(candidate,&r1,&r2,&r3,&r4,&r5);
    n = (int)RandomUniform(0.0,(double)nDim);
    CopyVector(trialSolution,RowVector(population,candidate));
    for (int i=0; (RandomUniform(0.0,1.0) < probability) && (i < nDim); i++)
    {
        trialSolution[n] = Element(population,r1,n) + scale * (Element(population,r2,n) -
        Element(population,r3,n) -
        Element(population,r4,n) -
        Element(population,r5,n));
        n = (n + 1) % nDim;
    }
    return;
}
void DESolver::Best1Bin(int candidate)
{
    int r1, r2;
    int n;
    SelectSamples(candidate,&r1,&r2);
    n = (int)RandomUniform(0.0,(double)nDim);
    CopyVector(trialSolution,RowVector(population,candidate));
    for (int i=0; i < nDim; i++)
{  
    if ((RandomUniform(0.0,1.0) < probability) || (i == (nDim - 1)))
    trialSolution[n] = bestSolution[n]  
    + scale *
    -> Element(population,r1,n)
    -> Element(population,r2,n));  
    n = (n + 1) % nDim;  
}
return;
}

void DESolver::Rand1Bin(int candidate)  
{  
    int r1, r2, r3;  
    int n;
    SelectSamples(candidate,&r1,&r2,&r3);
    n = (int)RandomUniform(0.0, (double)nDim);  
    CopyVector(trialSolution,RowVector(population,candidate));  
    for (int i=0; i < nDim; i++)  
    {  
        if ((RandomUniform(0.0,1.0) < probability) || (i == (nDim - 1)))  
        trialSolution[n] = Element(population,r1,n)  
        -> Element(population,r3,n));  
        n = (n + 1) % nDim;  
    }
return;
}

void DESolver::RandToBest1Bin(int candidate)  
{  
    int r1, r2;  
    int n;
    SelectSamples(candidate,&r1,&r2);
    n = (int)RandomUniform(0.0, (double)nDim);  
    CopyVector(trialSolution,RowVector(population,candidate));  
    for (int i=0; i < nDim; i++)  
    {  
        if ((RandomUniform(0.0,1.0) < probability) || (i == (nDim - 1)))  
        trialSolution[n] += scale * (bestSolution[n] - trialSolution[n])  
        + scale *
        -> Element(population,r2,n)
        -> - Element(population,r3,n));  
        n = (n + 1) % nDim;  
    }
    return;
}
```cpp
void DESolver::Best2Bin(int candidate)
{
    int r1, r2, r3, r4;
    int n;

    SelectSamples(candidate,&r1,&r2,&r3,&r4);
    n = (int)RandomUniform(0.0,(double)nDim);

    CopyVector(trialSolution,RowVector(population,candidate));
    for (int i=0; i < nDim; i++)
    {
        if ((RandomUniform(0.0,1.0) < probability) || (i == (nDim - 1)))
            trialSolution[n] = bestSolution[n] + scale * (Element(population,r1,n) + Element(population,r2,n) - Element(population,r3,n) - Element(population,r4,n));
        n = (n + 1) % nDim;
    }

    return;
}

void DESolver::Rand2Bin(int candidate)
{
    int r1, r2, r3, r4, r5;
    int n;

    SelectSamples(candidate,&r1,&r2,&r3,&r4,&r5);
    n = (int)RandomUniform(0.0,(double)nDim);

    CopyVector(trialSolution,RowVector(population,candidate));
    for (int i=0; i < nDim; i++)
    {
        if ((RandomUniform(0.0,1.0) < probability) || (i == (nDim - 1)))
            trialSolution[n] = Element(population,r1,n) + scale * (Element(population,r2,n) + Element(population,r3,n) - Element(population,r4,n) - Element(population,r5,n));
        n = (n + 1) % nDim;
    }

    return;
}

void DESolver::SelectSamples(int candidate, int *r1, int *r2,
```
```c
int *r3, int *r5
{
    if (r1)
    {
        do
        {
            *r1 = (int)RandomUniform(0.0, (double)nPop);
        }
        while (*r1 == candidate);
    }
    if (r2)
    {
        do
        {
            *r2 = (int)RandomUniform(0.0, (double)nPop);
        }
        while ((*r2 == candidate) || (*r2 == *r1));
    }
    if (r3)
    {
        do
        {
            *r3 = (int)RandomUniform(0.0, (double)nPop);
        }
        while ((*r3 == candidate) || (*r3 == *r2) || (*r3 == *r1));
    }
    if (r4)
    {
        do
        {
            *r4 = (int)RandomUniform(0.0, (double)nPop);
        }
        while ((*r4 == candidate) || (*r4 == *r3) || (*r4 == *r2) || (*r4 == *r1));
    }
    if (r5)
    {
        do
        {
            *r5 = (int)RandomUniform(0.0, (double)nPop);
        }
        while ((*r5 == candidate) || (*r5 == *r4) || (*r5 == *r3) || (*r5 == *r2) || (*r5 == *r1));
    }
    return;
}

/*------Constants for RandomUniform()---------------------------------------*/
#define SEED 3
#define IM1 2147483563
```

(continues on next page)
```cpp
#define IM2 2147483399
#define AM (1.0/IM1)
#define IMM1 (IM1-1)
#define IA1 40014
#define IA2 40692
#define IQ1 53668
#define IQ2 52774
#define IR1 12211
#define IR2 3791
#define NTAB 32
#define NDIV (1+IMM1/NTAB)
#define EPS 1.2e-7
#define RNMX (1.0-EPS)

double DESolver::RandomUniform(double minValue, double maxValue)
{
    long j;
    long k;
    static long idum;
    static long idum2=123456789;
    static long iy=0;
    static long iv[NTAB];
    double result;

    if (iy == 0)
        idum = SEED;

    if (idum <= 0)
    {
        if (-idum < 1)
            idum = 1;
        else
            idum = -idum;

        idum2 = idum;

        for (j=NTAB+7; j>=0; j--)
        {
            k = idum / IQ1;
            idum = IA1 * (idum - k*IQ1) - k*IR1;
            if (idum < 0) idum += IM1;
            if (j < NTAB) iv[j] = idum;
        }
        iy = iv[0];
    }

    k = idum / IQ1;
    idum = IA1 * (idum - k*IQ1) - k*IR1;

    if (idum < 0)
        idum += IM1;

    k = idum2 / IQ2;
    idum2 = IA2 * (idum2 - k*IQ2) - k*IR2;

    if (idum2 < 0)
```

(continues on next page)

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idum2 += IM2;

j = iy / NDIV;
iy = iv[j] - idum2;
iv[j] = idum;

if (iy < 1)
    iy += IMM1;
result = AM * iy;
if (result > RNMX)
    result = RNMX;
result = minValue + result * (maxValue - minValue);
return(result);
}

// END FIRST FILE

// BEGIN SECOND FILE: DESolver.h

// Differential Evolution Solver Class
// Based on algorithms developed by Dr. Rainer Storn & Kenneth Price
// Written By: Lester E. Godwin
// PushCorp, Inc.
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// Created: 6/8/98
// Last Modified: 6/8/98
// Revision: 1.0

#if !defined(_DESOLVER_H)
#define _DESOLVER_H

#define stBest1Exp 0
#define stRand1Exp 1
#define stRandToBest1Exp 2
#define stBest2Exp 3
#define stRand2Exp 4
#define stBest1Bin 5
#define stRand1Bin 6
#define stRandToBest1Bin 7
#define stBest2Bin 8
#define stRand2Bin 9

class DESolver;

typedef void (DESolver::*StrategyFunction)(int);

class DESolver
{
public:
    DESolver(int dim, int popSize);
    ~DESolver(void);

    // Setup() must be called before solve to set min, max, strategy etc.

(continues on next page)
void Setup(double min[], double max[], int deStrategy, double diffScale, double crossoverProb);

// Solve() returns true if EnergyFunction() returns true.
// Otherwise it runs maxGenerations generations and returns false.
virtual bool Solve(int maxGenerations);

// EnergyFunction must be overridden for problem to solve
// testSolution[] is nDim array for a candidate solution
// setting bAtSolution = true indicates solution is found
// and Solve() immediately returns true.
virtual double EnergyFunction(double testSolution[], bool &bAtSolution) = 0;

int Dimension(void) { return nDim; }
int Population(void) { return nPop; }

// Call these functions after Solve() to get results.
double Energy(void) { return bestEnergy; }
double *Solution(void) { return bestSolution; }
int Generations(void) { return generations; }

protected:
    void SelectSamples(int candidate, int *r1, int *r2=0, int *r3=0,
    int *r4=0, int *r5=0);
    double RandomUniform(double min, double max);
    int nDim;
    int nPop;
    int generations;
    int strategy;
    StrategyFunction calcTrialSolution;
    double scale;
    double probability;
    double trialEnergy;
    double bestEnergy;
    double *trialSolution;
    double *bestSolution;
    double *popEnergy;
    double *population;

private:
    void Best1Exp(int candidate);
    void Rand1Exp(int candidate);
    void RandToBest1Exp(int candidate);
    void Best2Exp(int candidate);
    void Rand2Exp(int candidate);
    void Best1Bin(int candidate);
    void Rand1Bin(int candidate);
    void RandToBest1Bin(int candidate);
    void Best2Bin(int candidate);
    void Rand2Bin(int candidate);
// I added the following stuff 19 March 2007
// Brent Lehman

struct ASpectrum
{
    unsigned mNumValues;
    double* mReals;
    double* mImags;
};

bool ComputeSpectrum(double* evenZeros, unsigned numEvenZeros, double* oddZero,
                      double* evenPoles, unsigned numEvenPoles, double* oddPole,
                      double gain, ASpectrum* spectrum);

class FilterSolver : public DESolver
{
    public:
    FilterSolver(int dim, int popSize, int spectrumSize,
                 unsigned numZeros, unsigned numPoles, bool minimumPhase) :
        DESolver(dim, popSize)
    {
        mSpectrum.mNumValues = spectrumSize;
        mSpectrum.mReals = new double[spectrumSize];
        mSpectrum.mImags = new double[spectrumSize];
        mNumZeros = numZeros;
        mNumPoles = numPoles;
        mMinimumPhase = minimumPhase;
    }
    virtual ~FilterSolver()
    {
        delete[] mSpectrum.mReals;
        delete[] mSpectrum.mImags;
    }
    virtual double EnergyFunction(double testSolution[], bool& bAtSolution);
    virtual ASpectrum* Spectrum() { return &mSpectrum; }
    private:
    unsigned mNumZeros;
    unsigned mNumPoles;
    bool mMinimumPhase;
    ASpectrum mSpectrum;
};
* 16 March 2007
*
* /

////////////////////////////////////////////////////////////////////
// // The idea is that an optimization algorithm passes a bunch of //
// different filter specifications to the function //
// "EnergyFunction" below. That function is supposed to //
// compute an "error" or "cost" value for each specification //
// it receives, which the algorithm uses to decide on other //
// filter specifications to try. Over the course of several //
// thousand different specifications, the algorithm will //
// eventually converge on a single best one. This one has the //
// lowest error value of all possible specifications. Thus, //
// you effectively tell the optimization algorithm what it's //
// looking for through code that you put into EnergyFunction. //
// // //
// Look for a note in the code like this one to see what part //
// you need to change for your own uses. //
// //
////////////////////////////////////////////////////////////////////

#include <stdlib.h>
#include <stdio.h>
#include <memory.h>
#include <conio.h>
#include <math.h>
#include <time.h>
#include "DESolver.h"

#define kIntIsOdd(x) (((x) & 0x00000001) == 1)

double FilterSolver::EnergyFunction(double testSolution[], bool& bAtSolution)
{
    unsigned i;
    double tempReal;
    double tempImag;

    // You probably will want to keep this if statement and its contents
    if (mMinimumPhase)
        
    // Make sure there are no zeros outside the unit circle
    unsigned lastEvenZero = (mNumZeros & 0xffffffff) - 1;
    for (i = 0; i <= lastEvenZero; i+=2)
        
        tempReal = testSolution[i];
        tempImag = testSolution[i+1];
        if ((tempReal*tempReal + tempImag*tempImag) > 1.0)
            
            return 1.0e+300;
    (continues on next page)
if (kIntIsOdd(mNumZeros))
{
    tempReal = testSolution[mNumZeros - 1];
    if ((tempReal * tempReal) > 1.0)
    {
        return 1.0e+300;
    }
}

// Make sure there are no poles on or outside the unit circle
// You probably will want to keep this too
unsigned lastEvenPole = mNumZeros + (mNumPoles & 0xffffffff) - 2;
for (i = mNumZeros; i <= lastEvenPole; i+=2)
{
    tempReal = testSolution[i];
    tempImag = testSolution[i+1];
    if ((tempReal*tempReal + tempImag*tempImag) > 0.999999999)
    {
        return 1.0e+300;
    }
}

// If you keep the for loop above, keep this too
if (kIntIsOdd(mNumPoles))
{
    tempReal = testSolution[mNumZeros + mNumPoles - 1];
    if ((tempReal * tempReal) > 1.0)
    {
        return 1.0e+300;
    }
}

double* evenZeros = &{testSolution[0]};
double* evenPoles = &{testSolution[mNumZeros]};
double* oddZero = NULL;
double* oddPole = NULL;
double gain = testSolution[mNumZeros + mNumPoles];

if (kIntIsOdd(mNumZeros))
{
    oddZero = &{testSolution[mNumZeros - 1]};
}

if (kIntIsOdd(mNumPoles))
{
    oddPole = &{testSolution[mNumZeros + mNumPoles - 1]};
}

ComputeSpectrum(evenZeros, mNumZeros & 0xffffffff, oddZero,
      evenPoles, mNumPoles & 0xffffffff, oddPole,
      gain, &mSpectrum);

unsigned numPoints = mSpectrum.mNumValues;

(continues on next page)
/// Use the impulse response, held in the variable "mSpectrum", to compute a score for the solution that has been passed into this function. You probably don’t want to touch any of the code above this point, but from here to the end of this function, it’s all you!

#define kLnTwoToThe127 88.02969193111305
#define kRecipLn10 0.4342944819032518

// Compute square sum of errors for magnitude
double magnitudeError = 0.0;
double magnitude = 0.0;
double logMagnitude = 0.0;
tempReal = mSpectrum.mReals[0];
tempImag = mSpectrum.mImags[0];
magnitude = tempReal*tempReal + tempImag*tempImag;
if (0.0 == magnitude)
    baseMagnitude = -kLnTwoToThe127;
else
    baseMagnitude = log(magnitude) * kRecipLn10;
    baseMagnitude *= 0.5;

for (i = 0; i < numPoints; i++)
{
    tempReal = mSpectrum.mReals[i];
    tempImag = mSpectrum.mImags[i];
magnitude = tempReal*tempReal + tempImag*tempImag;
    if (0.0 == magnitude)
        logMagnitude = -kLnTwoToThe127;
    else
        logMagnitude = log(magnitude) * kRecipLn10;
        logMagnitude *= 0.5; // Half the log because it’s mag squared

    logMagnitude -= baseMagnitude;
    magnitudeError += logMagnitude * logMagnitude;
}

// Compute errors for phase
double phaseError = 0.0;
double phase = 0.0;
double componentError = 0.0;
double degree = 1; //((mNumZeros + 1) & 0xffffffff) - 1;
double angleSpacing = -3.141592653589793 * 0.5 / numPoints * degree;
double targetPhase = 0.0;

(continues on next page)
double oldPhase = 0.0;
double phaseDifference = 0;
double totalPhaseTraversal = 0.0;
double traversalError = 0.0;
for (i = 0; i < (numPoints - 5); i++)
{
    tempReal = mSpectrum.mReals[i];
    tempImag = mSpectrum.mImags[i];
    oldPhase = phase;
    phase = atan2(tempImag, tempReal);
    phaseDifference = phase - oldPhase;
    if (phaseDifference > 3.141592653589793)
    {
        phaseDifference -= 3.141592653589793;
        phaseDifference -= 3.141592653589793;
    }
    else if (phaseDifference < -3.141592653589793)
    {
        phaseDifference += 3.141592653589793;
        phaseDifference += 3.141592653589793;
    }
    totalPhaseTraversal += phaseDifference;
    componentError = cosh(200.0*(phaseDifference - angleSpacing)) - 0.5;
    phaseError += componentError * componentError;
    targetPhase += angleSpacing;
    if (targetPhase < -3.141592653589793)
    {
        targetPhase += 3.141592653589793;
        targetPhase += 3.141592653589793;
    }
    }
traversalError = totalPhaseTraversal - angleSpacing * numPoints;
traversalError *= traversalError;

double baseMagnitudeError = baseMagnitude * baseMagnitude;

// Compute weighted sum of the two subtotals
// Take square root
return sqrt(baseMagnitudeError*1.0 + magnitudeError*100.0 +
    phaseError*400.0 + traversalError*4000000.0);
else
{
    if (0 == atoi(argv[1]))
    {
        minimumPhase = false;
    }
    else
    {
        minimumPhase = true;
    }
}

numZeros = (unsigned)atoi(argv[2]);
if (0 == numZeros)
{  
    numZeros = 1;
}

numPoles = (unsigned)atoi(argv[3]);
}

unsigned vectorLength = numZeros + numPoles + 1;
unsigned populationSize = vectorLength * 10;
FilterSolver theSolver(vectorLength, populationSize, 200,
    numZeros, numPoles, minimumPhase);

double* minimumSolution = new double[vectorLength];
unsigned i;
if (minimumPhase)
{
    for (i = 0; i < numZeros; i++)
    {
        minimumSolution[i] = -sqrt(0.5);
    }
}
else
{
    for (i = 0; i < numZeros; i++)
    {
        minimumSolution[i] = -10.0;
    }
}

for (; i < (vectorLength - 1); i++)
    {  
        minimumSolution[i] = -sqrt(0.5);  
    }

minimumSolution[vectorLength - 1] = 0.0;

double* maximumSolution = new double[vectorLength];
if (minimumPhase)
{
    for (i = 0; i < numZeros; i++)
    {
        maximumSolution[i] = sqrt(0.5);
    }
}
else {
    for (i = 0; i < numZeros; i++)
        maximumSolution[i] = 10.0;
}

for (i = 0; i < (vectorLength - 1); i++)
    maximumSolution[i] = sqrt(0.5);

maximumSolution[vectorLength - 1] = 2.0;

theSolver.Setup(minimumSolution, maximumSolution, 0, 0.5, 0.75);
theSolver.Solve(1000000);

double* bestSolution = theSolver.Solution();
printf("\nZeros:\n");
unsigned numEvenZeros = numZeros & 0xffffffff;
for (i = 0; i < numEvenZeros; i+=2)
    printf("%.10f +/- %.10fi\n", bestSolution[i], bestSolution[i+1]);

if (kIntIsOdd(numZeros))
    printf("%.10f\n", bestSolution[numZeros-1]);

printf("Poles:\n");
unsigned lastEvenPole = numZeros + (numPoles & 0xffffffff) - 2;
for (i = numZeros; i <= lastEvenPole; i+=2)
    printf("%.10f +/- %.10fi\n", bestSolution[i], bestSolution[i+1]);

unsigned numRoots = numZeros + numPoles;
if (kIntIsOdd(numPoles))
    printf("%.10f\n", bestSolution[numRoots-1]);

double gain = bestSolution[numRoots];
printf("Gain: %.10f\n", gain);

_getch();
unsigned j;
ASpectrum* spectrum = theSolver.Spectrum();
double logMagnitude;
printf("Magnitude Response, millibels:\n");
for (i = 0; i < 20; i++)
    for (j = 0; j < 10; j++)
        }
logMagnitude = kRecipLn10 * 
    log(spectrum->mReals[i*10 + j] * spectrum->mReals[i*10 + j] + 
    spectrum->mImags[i*10 + j] * spectrum->mImags[i*10 + j]);
if (logMagnitude < -9.999) {
    logMagnitude = -9.999;
} 
printf("%+5.0f ", logMagnitude*1000);
printf("\n");
}

_getch();

double phase;
printf("Phase Response, milliradians:\n");
for (i = 0; i < 20; i++) {
    for (j = 0; j < 10; j++)
    { 
        phase = atan2(spectrum->mImags[i*10 + j], spectrum->mReals[i*10 + j]);
        printf("%+5.0f ", phase*1000);
    }
    printf("\n");
}

_getch();
printf("Biquad Sections:\n");
unsigned numBiquadSections =
    (numZeros > numPoles) ? ((numZeros + 1) >> 1) : ((numPoles + 1) >> 1);
double x0, x1, x2;
double y0, y1, y2;
if (numZeros >=2) {
    x0 = (bestSolution[0]*bestSolution[0] + bestSolution[1]*bestSolution[1]) * 
        gain;
    x1 = 2.0 * bestSolution[0] * gain;
    x2 = gain;
} 
else if (1 == numZeros)
    { 
        x0 = bestSolution[0] * gain;
        x1 = gain;
        x2 = 0.0;
    }
else
    {
        x0 = gain;
        x1 = 0.0;
        x2 = 0.0;
    }
if (numPoles >= 2) {
    y0 = (bestSolution[numZeros]*bestSolution[numZeros] + 
        bestSolution[numZeros+1]*bestSolution[numZeros+1]);
    y1 = 2.0 * bestSolution[numZeros];
    y2 = 1.0;
```c
else if (1 == numPoles)
{
    y0 = bestSolution[numZeros];
    y1 = 1.0;
    y2 = 0.0;
}
else
{
    y0 = 1.0;
    y1 = 0.0;
    y2 = 0.0;
}
}

x0 /= y0;
x1 /= y0;
x2 /= y0;
y1 /= y0;
y2 /= y0;

printf("y[n] = %.10fx[n]", x0);
if (numZeros > 0)
{
    printf(" + %.10fx[n-1]", x1);
}
if (numZeros > 1)
{
    printf(" + %.10fx[n-2]", x2);
}
printf("\n");

if (numPoles > 0)
{
    printf(" + %.10fy[n-1]", y1);
}
if (numPoles > 1)
{
    printf(" + %.10fy[n-2]", y2);
}
if (numPoles > 0)
{
    printf("\n");
}

int numRemainingZeros = numZeros - 2;
int numRemainingPoles = numPoles - 2;
for (i = 1; i < numBiquadSections; i++)
{
    if (numRemainingZeros >= 2)
    {
        x0 = (bestSolution[i*2] * bestSolution[i*2] +
             bestSolution[i*2+1] * bestSolution[i*2+1]);
        x1 = -2.0 * bestSolution[i*2];
        x2 = 1.0;
    }
    else if (numRemainingZeros >= 1)
    {
```
x0 = bestSolution[i*2];
x1 = 1.0;
x2 = 0.0;
}
else
{
  x0 = 1.0;
  x1 = 0.0;
  x2 = 0.0;
}

if (numRemainingPoles >= 2)
{
  y0 = (bestSolution[i*2+numZeros] * bestSolution[i*2+numZeros] +
       bestSolution[i*2+numZeros+1] * bestSolution[i*2+numZeros+1]);
  y1 = -2.0 * bestSolution[i*2+numZeros];
  y2 = 1.0;
}
else if (numRemainingPoles >= 1)
{
  y0 = bestSolution[i*2+numZeros];
  y1 = 1.0;
  y2 = 0.0;
}
else
{
  y0 = 1.0;
  y1 = 0.0;
  y2 = 0.0;
}

x0 /= y0;
x1 /= y0;
x2 /= y0;
y1 /= y0;
y2 /= y0;

printf("y[n] = %.10fx[n]", x0);
if (numRemainingZeros > 0)
{
  printf(" + %.10fx[n-1]", x1);
}
if (numRemainingZeros > 1)
{
  printf(" + %.10fx[n-2]", x2);
}
printf("\n");
if (numRemainingPoles > 0)
{
  printf(" + %.10fy[n-1]", -y1);
}
if (numRemainingPoles > 1)
{
  printf(" + %.10fy[n-2]", -y2);
}
if (numRemainingPoles > 0)
{  
  printf("\n");
}
  
numRemainingZeros -= 2;
numRemainingPoles -= 2;
}

_getch();
printf("Full Expansion:\n");

double* xpolynomial = new double[numRoots + 1];
memset(xpolynomial, 0, sizeof(double) * (numRoots + 1));
xpolynomial[0] = 1.0;
if (numZeros >= 2) {  
xpolynomial[0] = bestSolution[0] * bestSolution[0] +
  bestSolution[1] * bestSolution[1];
xpolynomial[1] = -2.0 * bestSolution[0];
xpolynomial[2] = 1.0;
} else if (numZeros == 1) {  
xpolynomial[0] = bestSolution[0];
xpolynomial[1] = 1.0;
} else {  
xpolynomial[0] = 1.0;
}

for (i = 2, numRemainingZeros = numZeros; numRemainingZeros >= 2;
  i += 2, numRemainingZeros-=2) {
  x2 = 1.0;
x1 = -2.0 * bestSolution[i];
x0 = bestSolution[i] * bestSolution[i] +
  bestSolution[i+1] * bestSolution[i+1];
  for (j = numRoots; j > 1; j--)
    {  
xpolynomial[j] = xpolynomial[j-2] + xpolynomial[j-1] * x1 +
      xpolynomial[j] * x0;
    }
xpolynomial[1] = xpolynomial[0] * x1 + xpolynomial[1] * x0;
xpolynomial[0] *= x0;
}

if (numRemainingZeros > 0) {
  x1 = 1.0;
x0 = bestSolution[numZeros-1];
  for (j = numRoots; j > 0; j--)
    {  
xpolynomial[j] = xpolynomial[j-1] + xpolynomial[j] * x0;
    }
xpolynomial[0] *= x0;
}
```c
#define double_float numRoots + 1];
memset(ypolynomial, 0, sizeof(double) * (numRoots + 1));
ypolynomial[0] = 1.0;
if (numPoles >= 2)
  {  
    ypolynomial[0] = bestSolution[numZeros] * bestSolution[numZeros] +
          bestSolution[numZeros+1] * bestSolution[numZeros+1];
    ypolynomial[1] = -2.0 * bestSolution[numZeros];
    ypolynomial[2] = 1.0;
  }
else if (numPoles == 1)
  {  
    ypolynomial[0] = bestSolution[numZeros];
    ypolynomial[1] = 1.0;
  }
else
  {  
    xpolynomial[0] = 1.0;
  }
for (i = 2, numRemainingPoles = numPoles; numRemainingPoles >= 2;
  i += 2, numRemainingPoles-=2)
  {  
    y2 = 1.0;
    y1 = -2.0 * bestSolution[numZeros+i];
    y0 = bestSolution[numZeros+i] * bestSolution[numZeros+i] +
         bestSolution[numZeros+i+1] * bestSolution[numZeros+i+1];
    for (j = numRoots; j > 1; j--)
      {  
                        ypolynomial[j] * y0;
      }
    ypolynomial[1] = ypolynomial[0] * y1 + ypolynomial[1] * y0;
    ypolynomial[0] *= y0;
  }
if (numRemainingPoles > 0)
  {  
    y1 = 1.0;
    y0 = bestSolution[numZeros+numPoles-1];
    for (j = numRoots; j > 0; j--)
      {  
        ypolynomial[j] = ypolynomial[j-1] + ypolynomial[j] * y0;
      }
    ypolynomial[0] *= y0;
  }
y0 = ypolynomial[0];
for (i = 0; i <= numRoots; i++)
  {  
    xpolynomial[i] /= y0;
    ypolynomial[i] /= y0;
  }
printf("y[n] = %.10fx[n]", xpolynomial[0]*gain);
for (i = 1; i <= numZeros; i++)
  {
    printf("x[n] = %.10fx[n]", xpolynomial[i]*gain);
  }
```
printf(" + %.10fx[n-%d]", xpolynomial[i]*gain, i);
if ((i % 3) == 2)
    printf("\n");
}

if ((i % 3) != 0)
{
    printf("\n");
}

if (numPoles > 0)
{
    printf(" ");
}
for (i = 1; i <= numPoles; i++)
{
    printf(" + %.10fy[n-%d]", -ypolynomial[i], i);
    if ((i % 3) == 2)
    {
        printf("\n");
    }
}
if ((i % 3) != 0)
{
    printf("\n");
}
delete[] minimumSolution;
delete[] maximumSolution;
delete[] xpolynomial;
delete[] ypolynomial;
}

bool ComputeSpectrum(double* evenZeros, unsigned numEvenZeros, double* oddZero,
                      double* evenPoles, unsigned numEvenPoles, double* oddPole,
                      double gain, ASpectrum* spectrum)
{
    unsigned i, j;
    // For equally spaced points on the unit circle
    unsigned numPoints = spectrum->mNumValues;
    double spacingAngle = 3.141592653589793 / (numPoints - 1);
    double pointArgument = 0.0;
    double pointReal = 0.0;
    double pointImag = 0.0;
    double rootReal = 0.0;
    double rootImag = 0.0;
    double differenceReal = 0.0;
    double differenceImag = 0.0;
    double responseReal = 1.0;
    double responseImag = 0.0;
    double recipSquareMagnitude = 0.0;
double recipReal = 0.0;
double recipImag = 0.0;
double tempRealReal = 0.0;
double tempRealImag = 0.0;
double tempImagReal = 0.0;
double tempImagImag = 0.0;

for (i = 0; i < numPoints; i++)
{
    responseReal = 1.0;
    responseImag = 0.0;

    // The imaginary component is negated because we're using 1/z, not z
    pointReal = cos(pointArgument);
    pointImag = -sin(pointArgument);

    // For each even zero
    for (j = 0; j < numEvenZeros; j+=2)
    {
        rootReal = evenZeros[j];
        rootImag = evenZeros[j + 1];
        // Compute distance from that zero to that point
        differenceReal = pointReal - rootReal;
        differenceImag = pointImag - rootImag;
        // Multiply that distance by the accumulating product
        tempRealReal = responseReal * differenceReal;
        tempRealImag = responseReal * differenceImag;
        tempImagReal = responseImag * differenceReal;
        tempImagImag = responseImag * differenceImag;
        responseReal = tempRealReal - tempImagImag;
        responseImag = tempRealImag + tempImagReal;
        // Do the same with the conjugate root
        differenceImag = pointImag + rootImag;
        tempRealReal = responseReal * differenceReal;
        tempRealImag = responseReal * differenceImag;
        tempImagReal = responseImag * differenceReal;
        tempImagImag = responseImag * differenceImag;
        responseReal = tempRealReal - tempImagImag;
        responseImag = tempRealImag + tempImagReal;

    // The following way is little faster, if any
    // response *= (1/z - r) * (1/z - conj(r))
    // *= r*conj(r) - (r + conj(r))/z + 1/(z*z)
    // *= real(r)*real(r) + imag(r)*imag(r) - 2*real(r)/z + 1/(z*z)
    // *= ... - 2*real(r)*conj(z) + conj(z)*conj(z)
    // *= ... - 2*real(r)*real(z) + 2i*real(r)*imag(z) +
    // real(z)*real(z) - 2i*real(z)*imag(z) + imag(z)*imag(z)
    // *= real(r)*real(r) + imag(r)*imag(r) - 2*real(r)*real(z) +
    // real(z)*real(z) + imag(z)*imag(z) +
    // 2i * imag(z) * (real(r) - real(z))
    // *= (real(r) - real(z))^2 + imag(r)^2 + imag(z)^2 +
    // 2i * imag(z) * (real(r) - real(z))
    // This ends up being 8 multiplications, 6 additions
    }

    if (NULL != oddZero)
    {
        rootReal = *oddZero;
    }
}
// Compute distance from that zero to that point
differenceReal = pointReal - rootReal;
differenceImag = pointImag;

// Multiply that distance by the accumulating product
tempRealReal = responseReal * differenceReal;
tempRealImag = responseReal * differenceImag;
tempImgReal = responseImag * differenceReal;
tempImgImag = responseImag * differenceImag;
responseReal = tempRealReal - tempImgImag;
responseImag = tempRealImag + tempImgReal;
}

// For each pole
for (j = 0; j < numEvenPoles; j+=2)
{
    rootReal = evenPoles[j];
    rootImag = evenPoles[j + 1];
    // Compute distance from that pole to that point
differenceReal = pointReal - rootReal;
differenceImag = pointImag - rootImag;
    // Multiply the reciprocal of that distance by the accumulating product
    recipSquareMagnitude = 1.0 / (differenceReal * differenceReal +
        differenceImag * differenceImag);
    recipReal = differenceReal * recipSquareMagnitude;
    recipImg = -differenceImag * recipSquareMagnitude;
    tempRealReal = responseReal * recipReal;
    tempRealImag = responseReal * recipImg;
    tempImgReal = responseImag * recipReal;
    tempImgImag = responseImag * recipImg;
    responseReal = tempRealReal - tempImgImag;
    responseImag = tempRealImag + tempImgReal;
    // Do the same with the conjugate root
    differenceImag = pointImag + rootImag;
    recipSquareMagnitude = 1.0 / (differenceReal * differenceReal +
        differenceImag * differenceImag);
    recipReal = differenceReal * recipSquareMagnitude;
    recipImg = -differenceImag * recipSquareMagnitude;
    tempRealReal = responseReal * recipReal;
    tempRealImag = responseReal * recipImg;
    tempImgReal = responseImag * recipReal;
    tempImgImag = responseImag * recipImg;
    responseReal = tempRealReal - tempImgImag;
    responseImag = tempRealImag + tempImgReal;
}

if (NULL != oddPole)
{
    rootReal = *oddPole;
    // Compute distance from that point to that zero
differenceReal = pointReal - rootReal;
differenceImag = pointImag;
    // Multiply the reciprocal of that distance by the accumulating product
    recipSquareMagnitude = 1.0 / (differenceReal * differenceReal +
        differenceImag * differenceImag);
    recipReal = differenceReal * recipSquareMagnitude;
    recipImg = -differenceImag * recipSquareMagnitude;
    tempRealReal = responseReal * recipReal;
    tempRealImag = responseReal * recipImg;
    tempImgReal = responseImag * recipReal;
    tempImgImag = responseImag * recipImg;
    responseReal = tempRealReal - tempImgImag;
    responseImag = tempRealImag + tempImgReal;
}
tempRealImag = responseReal * recipImag;
    tempImagReal = responseImag * recipReal;
    tempImagImag = responseImag * recipImag;
    responseReal = tempRealReal - tempImagImag;
    responseImag = tempRealImag + tempImagReal;
  }

  // Multiply by the gain
  responseReal *= gain;
  responseImag *= gain;
  spectrum->mReals[i] = responseReal;
  spectrum->mImags[i] = responseImag;
  pointArgument += spacingAngle;
}

return true;
}

// Half-band lowpass
//
#define kLnTwoToThe127 88.02969193111305
#define kRecipLn10 0.4342944819032518

// Compute square sum of errors for bottom half band
unsigned numLoBandPoints = numPoints >> 1;
double loBandError = 0.0;
double magnitude = 0.0;
double logMagnitude = 0.0;
for (i = 0; i < numLoBandPoints; i++)
{
    tempReal = mSpectrum.mReals[i];
    tempImag = mSpectrum.mImags[i];
    magnitude = tempReal*tempReal + tempImag*tempImag;
    if (0.0 == magnitude)
    {
        logMagnitude = -kLnTwoToThe127;
    }
    else
    {
        logMagnitude = log(magnitude) * kRecipLn10;
        logMagnitude *= 0.5; // Half the log because it's mag squared
    }
    loBandError += logMagnitude * logMagnitude;
}

// Compute errors for top half of band
double hiBandError = 0.0;
for ( ; i < numPoints; i++)
{
    tempReal = mSpectrum.mReals[i];
    tempImag = mSpectrum.mImags[i];
    magnitude = tempReal*tempReal + tempImag*tempImag;
    hiBandError += magnitude; // Already a squared value
}
3.53 Prewarping

- **Author or source:** robert bristow-johnson (better known as “rbj”)
- **Type:** explanation
- **Created:** 2002-01-17 02:10:26

Listing 88: notes

prewarping is simply recognizing the warping that the BLT introduces.

To determine frequency response, we evaluate the digital $H(z)$ at $z=\exp(j*w*T)$ and we evaluate the analog $Ha(s)$ at $s=j*W$. The following will confirm the $jw$ to unit circle mapping and will show exactly what the mapping is (this is the same stuff in the textbooks):

the BLT says: $s = \frac{(2/T) \times (z-1)/(z+1)}$

substituting: $s = j*W = \frac{(2/T) \times (\exp(j*w*T) - 1)}{\exp(j*w*T) + 1}$

$j*W = \frac{(2/T) \times (\exp(j*w*T/2) - \exp(-j*w*T/2))}{\exp(j*w*T/2) + \exp(-j*w*T/2)}$

$= \frac{(2/T) \times (j*2*sin(w*T/2))}{2*cos(w*T/2)}$

$= j \times \frac{(2/T) \times tan(w*T/2)}{2}$

or

analog $\tilde{W} = \frac{(2/T) \times tan(w*T/2)}{2}$

so when the real input frequency is $w$, the digital filter will behave with the same amplitude gain and phase shift as the analog filter will have at a hypothetical frequency of $\tilde{W}$. As $w*T$ approaches $\pi$ (Nyquist) the digital filter behaves as the analog filter does as $\tilde{W} \rightarrow \infty$. For each degree of freedom that you have in your design equations, you can adjust the analog design frequency to be just right so that when the deterministic BLT warping does its thing, the resultant warped frequency comes out just right. For a simple LPF, you have only one degree of freedom, the cutoff frequency. You can precompensate it so that the true cutoff comes out right but that is it, above the cutoff, you will see that the LPF dives down to $-\infty$ dB faster than an equivalent analog at the same frequencies.

3.54 RBJ Audio-EQ-Cookbook

- **Author or source:** Robert Bristow-Johnson
- **Type:** EQ filter kookbook
Listing 89: notes

Equations for creating different equalization filters.
see linked file

3.54.1 Comments

• Date: 2006-08-30 22:14:22
• By: ude.odu@grebnesie.nitram

rbj writes with regard to shelving filters:

> _or_ S, a "shelf slope" parameter (for shelving EQ only). When S = 1,
> the shelf slope is as steep as it can be and remain monotonically
> increasing or decreasing gain with frequency. The shelf slope, in
> dB/octave, remains proportional to S for all other values for a
> fixed f0/Fs and dBgain.

The precise relation for both low and high shelf filters is

\[
S = -s \cdot \log_2(10)/40 \cdot \sin(w0)/w0 \cdot (A^2+1)/(A^2-1)
\]

where s is the true shelf midpoint slope in dB/oct and \( w0, A \) are defined in
the Cookbook just below the quoted paragraph. It's your responsibility to keep
the overshoots in check by using sensible s values. Also make sure that s has
the right sign -- negative for low boost or high cut, positive otherwise.

To find the relation I first differentiated the dB magnitude response of the
general transfer function in eq. 1 with regard to log frequency, inserted the
low shelf coefficient expressions, and evaluated at \( w0 \). Second, I equated this
derivative to s and solved for alpha. Third, I equated the result to rbj's
expression for alpha and solved for S yielding the above formula. Finally
I checked it with the high shelf filter.

• Date: 2006-08-31 17:08:27
• By: ude.odu@grebnesie.nitram

Sorry, a slight correction: rewrite the formula as

\[
S = s \cdot \log_2(10)/40 \cdot \sin(w0)/w0 \cdot (A^2+1)/\text{abs}(A^2-1)
\]

and make s always positive.

• Date: 2013-10-05 18:06:20
• By: moc.liamg@56rekojbm

This is a very famous article. I saw many are asking what is the relationship between

"Q" and the resonance in low-pass and hi-pass filters.

By experimenting, I found that Q should always be >= 1/2. Value < 1/2 seems to alter,

\( f0 \) "wherever it's happenin', man", cutting off frequencies not where it was planned.

In fact Q = 1/2 is the value for which H(s) = 1 / (s^2 + s/Q + 1) gets

real and coincident. In other words the filter becomes like two 1st order filters

in cascade, with no resonance at all.

3.54. RBJ Audio-EQ-Cookbook

351
When Q tends to infinite the poles get close to the unit circle, the gain around the cutoff frequency increases, creating resonance.

3.55 RBJ Audio-EQ-Cookbook

- **Author or source:** Robert Bristow-Johnson
- **Created:** 2005-05-04 20:33:31
- **Linked files:** EQ-Coefficients.pdf

Listing 90: notes

see attached file

3.55.1 Comments

- **Date:** 2005-05-14 06:35:17
- **By:** eb.tenyks@didid

Hi

In your most recent version, you write:

```plaintext
--
  alpha = sin(w0)/(2*Q)  (case: Q)
  = sin(w0)*sinh( ln(2)/2 * BW * w0/sin(w0) )  (case: BW)
  = sin(w0)/2 * sqrt( (A + 1/A)*(1/S - 1) + 2 )  (case: S)
--
```

But the 'slope' case doesn't seem to work for me. It results in some kind of bad resonance at higher samplerates.

Now I found this 'beta' in an older version of your paper (I think), describing:

```plaintext
--
  beta = sqrt(A)/Q  (for shelving EQ filters only)
  = sqrt(A)*sqrt[ (A + 1/A)*(1/S - 1) + 2 ]  (if shelf slope is specified)
  = sqrt[ (A^2 + 1)/S - (A-1)^2 ]
--
```

..and here the

sqrt(A)*sqrt[ (A + 1/A)*(1/S - 1) + 2 ]

formula works perfectly for me.

I must say I don't understand half of the theory, so it's probably my fault somewhere. But why the change in the newer version?

- **Date:** 2005-05-20 20:56:45
- **By:** moc.noitanigamoidua@jbr
But why the change in the newer version?
----------------------------------------------------------
i wanted to get rid of an extraneous intermediate variable and there was enough
→similarity between alpha and beta that i changed the lowShelf and highShelf
→coefficient equations to be in terms of alpha rather than beta.

i believe if you use the new version as shown, in terms of alpha (but remember the
→coef equations are changed accordingly from the old version), it will come up with
→the same coefficients given the same boost gain, Q (or S), and shelf frequency (and
→same Fs). lemme know if you still have trouble.

r b-j

3.56 Remez Exchange Algorithm (Parks/McClellan)

- **Author or source:** ed.luosfosruoivas@naitsirhC
- **Type:** Linear Phase FIR Filter
- **Created:** 2006-05-06 08:40:18
- **Linked files:** http://www.savioursofsoul.de/Christian/Remez.zip

Listing 91: notes

Here is an object pascal / delphi translation of the Remez Exchange Algorithm by
Parks/McClellan
There is at least one small bug in it (compared to the C++ version), which causes the
result to be slightly different to the C version.

Listing 92: code

http://www.savioursofsoul.de/Christian/Remez.zip

3.57 Remez Remez (Parks/McClellan)

- **Author or source:** ed.luosfosruoivas@naitsirhC
- **Type:** FIR Remez (Parks/McClellan)
- **Created:** 2005-06-28 21:06:53

Listing 93: notes

Below you can find a Object Pascal / Delphi Translation of the Remez (Parks/
→McClellan) FIR
Filter Design algorithm.
It behaves slightly different from the c++ version, but the results work very well.

Listing 94: code

http://www.savioursofsoul.de/Christian/remez.zip
3.58 Resonant IIR lowpass (12dB/oct)

- **Author or source:** Olli Niemitalo
- **Type:** Resonant IIR lowpass (12dB/oct)
- **Created:** 2002-01-17 02:05:38

Listing 95: notes

Hard to calculate coefficients, easy to process algorithm

Listing 96: code

```c
resofreq = pole frequency
amp = magnitude at pole frequency (approx)

double pi = 3.141592654;

/* Parameters. Change these! */
double resofreq = 5000;
double amp = 1.0;

DOUBLEWORD streamofs;

double w = 2.0*pi*resofreq/samplerate; // Pole angle
double q = 1.0-w/(2.0*(amp+0.5/(1.0+w))+w-2.0); // Pole magnitude
double r = q*q;
double c = r+1.0-2.0*cos(w)*q;
double vibrapos = 0;
double vibraspeed = 0;

/* Main loop */
for (streamofs = 0; streamofs < streamsize; streamofs++) {

    /* Accelerate vibra by signal-vibra, multiplied by lowpasscutoff */
    vibraspeed += (fromstream[streamofs] - vibrapos) * c;

    /* Add velocity to vibra's position */
    vibrapos += vibraspeed;

    /* Attenuate/amplify vibra's velocity by resonance */
    vibraspeed *= r;

    /* Check clipping */
    temp = vibrapos;
    if (temp > 32767) {
        temp = 32767;
    } else if (temp < -32768) temp = -32768;

    /* Store new value */
    tostream[streamofs] = temp;
}
```

3.58.1 Comments

- **Date:** 2002-05-05 08:59:19
This looks similar to the low-pass filter I used in FilterKing (http://home.attbi.com/~spaztek4/) Can you cruft up a high-pass example for me?

Thanks,
__e

**Date:** 2006-05-18 17:01:21

**By:** faster init

thank you! works nicely...
here a simplified init version for faster changes of the filter properties for amps = -1.0

```c
void init( double resofreq )
{
    static const double FAC = pi * 2.0 /samplerate;
    double q, w;
    w = FAC * resofreq;
    q = 1.0f - w / ( ( 3.0 /( 1.0+w ) ) + w - 2.0 );
    _r = q * q;
    _c = r + 1.0f - 2.0f * cos(w) * q;
}
```

### 3.59 Resonant filter

**Author or source:** Paul Kellett

**Created:** 2002-01-17 02:07:02

**Listing 97: notes**

This filter consists of two first order low-pass filters in series, with some of the difference between the two filter outputs fed back to give a resonant peak.

You can use more filter stages for a steeper cutoff but the stability criteria get more complicated if the extra stages are within the feedback loop.
Listing 98: code

```
//set feedback amount given f and q between 0 and 1
fb = q + q/(1.0 - f);

//for each sample...
buf0 = buf0 + f * (in - buf0 + fb * (buf0 - buf1));
buf1 = buf1 + f * (buf0 - buf1);
out = buf1;
```

3.59.1 Comments

- **Date:** 2006-01-18 10:59:55  
  **By:** mr.just starting  
  very nice! how could i turn that into a HPF?

- **Date:** 2006-01-23 10:53:41  
  **By:** ku.oc.mapson.snosrapsd@psd  
  The cheats way is to use HPF = sample - out;  
  If you do a plot, you'll find that it isn't as good as designing an HPF from scratch,  
  but it's good enuff for most ears.  
  This would also mean that you have a quick method for splitting a signal and  
  operating on the (in)discreet parts separately. :) DSP

- **Date:** 2006-09-12 14:42:25  
  **By:** uh.etle.fni@yfoocs  
  This filter calculates bandpass and highpass outputs too during calculation, namely  
  bandpass is buf0 - buf1 and highpass is in - buf0. So, we can rewrite the algorithm:

```
// f and fb calculation
f = 2.0*sin(pi*freq/samplerate);  
/* you can approximate this with f = 2.0*pi*freq/samplerate with tuning error towards  
  nyquist */
fb = q + q/(1.0 - f);

// loop
hp = in - buf0;
bp = buf0 - buf1;
buf0 = buf0 + f * (hp + fb * bp);
buf1 = buf1 + f * (buf0 - buf1);
out = buf1; // lowpass
out = bp; // bandpass
out = hp; // highpass
```

The slope of the highpass out is not constant, it varies between 6 and 12 dB/Octave  
with different f and q settings. I'd be interested if anyone derived a proper  
highpass output from this algorithm.

-- peter schoffhauzer
3.60 Resonant low pass filter

- **Author or source:** “Zxform”
- **Type:** 24dB lowpass
- **Created:** 2002-01-17 02:09:31
- **Linked files:** filters004.txt

3.61 Reverb Filter Generator

- **Author or source:** Stephen McGovern
- **Type:** FIR
- **Created:** 2006-09-01 07:07:58

Listing 99: notes

This is a MATLAB function that makes a rough calculation of a room's impulse response. The output can then be convolved with an audio clip to produce good and realistic-sounding reverb. I have written a paper discussing the theory used by this algorithm. It is available at http://stevem.us/rir.html.

**NOTES:**

1) Large values of N will use large amounts of memory.
2) The output is normalized to the largest value of the output.

Listing 100: code

```matlab
function [h]=rir(fs, mic, n, r, rm, src);
%HIR Room Impulse Response.
% [h] = RIR(FS, MIC, N, R, RM, SRC) performs a room impulse
% response calculation by means of the mirror image method.
% FS = sample rate.
% MIC = row vector giving the x,y,z coordinates of
% the microphone.
% N = The program will account for (2*N+1)^3 virtual sources
% R = reflection coefficient for the walls, in general -1<R<1.
% RM = row vector giving the dimensions of the room.
% SRC = row vector giving the x,y,z coordinates of
% the sound source.
% EXAMPLE:
% >>fs=44100;
% >>mic=[19 18 1.6];
% >>n=12;
% >>r=0.3;
% >>rm=[20 19 21];
% >>src=[5 2 1];
```

(continues on next page)
% >>h=rir(fs, mic, n, r, rm, src);
% NOTES:
% 1) All distances are in meters.
% 2) The output is scaled such that the largest value of the
% absolute value of the output vector is equal to one.
% 3) To implement this filter, you will need to do a fast
% convolution. The program FCONV.m will do this. It can be
% found on the Mathworks File Exchange at
% www.mathworks.com/matlabcentral/fileexchange/. It can also
% be found at www.2pi.us/code/fconv.m
% 4) A paper has been written on this model. It is available at:
% www.2pi.us/rir.html

%Version 3.4.1
%Copyright © 2003 Stephen G. McGovern

%Some of the following comments are references to equations the my paper.
nn=-n:1:n; % Index for the sequence
rms=nn+0.5-0.5*(-1).^nn; % Part of equations 2,3, & 4
srcs=(-1).^(nn); % part of equations 2,3, & 4
xi=srcs*src(1)+rms*rm(1)-mic(1); % Equation 2
yj=srcs*src(2)+rms*rm(2)-mic(2); % Equation 3
zk=srcs*src(3)+rms*rm(3)-mic(3); % Equation 4

[i,j,k]=meshgrid(xi,yj,zk); % convert vectors to 3D matrices
d=sqrt(i.^2+j.^2+k.^2); % Equation 5
time=round(fs*d/343)+1; % Similar to Equation 6

c=r.^(abs(e)+abs(f)+abs(g)); % Equation 9
e=c./d; % Equivalent to Equation 10

h=full(sparse(time(:),1,e(:))); % Equivalent to equation 11
h=h/max(abs(h)); % Scale output

3.62 Simple Tilt equalizer

- **Author or source:** moc.liamg@321tiloen
- **Type:** Tilt
- **Created:** 2009-05-29 15:13:21

Listing 101: notes

There are a few ways to implement this. (crossover, shelves, morphing shelves [hs->lp, ls->hp] ...etc)
This particular one tries to mimic the behavior of the "Niveau" filter from the
"Elysia: mPressor" compressor.
[The 'Tilt' filter]:
It uses a center frequency (F0) and then boosts one of the ranges above or below F0,
while doing the opposite with the other range.

In the case of the "mPressor" - more extreme settings turn the filter into first order low-pass or high-pass. This is achieved with the gain factor for one band going close to -1. (ex: +6db -> lp; -6db -> hp)

Lubomir I. Ivanov

```
//=======================
// tilt eq settings
//
// srate -> sample rate
// f0 -> 20-20khz
// gain -> -6 / +6 db
//=======================
amp = 6/log(2);
denorm = 10^-30;
pi = 22/7;
sr3 = 3*srate;

// condition:
// gfactor is the proportional gain
//
// gfactor = 5;
if (gain > 0) {
    g1 = -gfactor*gain;
    g2 = gain;
} else {
    g1 = -gain;
    g2 = gfactor*gain;
};

//two separate gains
lgain = exp(g1/amp)-1;
hgain = exp(g2/amp)-1;

//filter
omega = 2*pi*f0;
n = 1/(sr3 + omega);
a0 = 2*omega*n;
b1 = (sr3 - omega)*n;

//=======================
// sample loop
// in -> input sample
// out -> output sample
//=======================
lp_out = a0*in + b1*lp_out;
out = in + lgain*lp_out + hgain*(in - lp_out);
```
3.62.1 Comments

- **Date**: 2009-05-29 19:16:18
- **By**: moc.liamg@321tiloen

**correction:**

(ex: +6db -> hp; -6db -> lp)

- **Date**: 2017-04-01 09:05:48
- **By**: moc.liamg@59hsielgladsemaj

Where is the denorm value meant to be used in the code? The code works regardless by noise is created when the gain control being used, it may be a result of the denorm value not being used?

### 3.63 Simple biquad filter from apple.com

- **Author or source**: moc.liamg@321tiloen
- **Type**: LP
- **Created**: 2008-10-27 10:15:16

Listing 103: notes

Simple Biquad LP filter from the AU tutorial at apple.com

Listing 104: code

```c
//cutoff_slider range 20-20000hz
//res_slider range -25/25db
//srate - sample rate

//init
mX1 = 0;
mX2 = 0;
my1 = 0;
my2 = 0;
pi = 22/7;

//coefficients
cutoff = cutoff_slider;
res = res_slider;
cutoff = 2 * cutoff_slider / srate;
res = pow(10, 0.05 * -res_slider);
k = 0.5 * res * sin(pi * cutoff);
c1 = 0.5 * (1 - k) / (1 + k);
c2 = (0.5 + c1) * cos(pi * cutoff);
c3 = (0.5 + c1 - c2) * 0.25;

mA0 = 2 * c3;
mA1 = 2 * 2 * c3;
```

(continues on next page)
here are coefficients for the hp version.
the br,bp & peak are also easy to calculate:

\[ k = 0.5 \times \text{res} \times \sin(\pi \times \text{cutoff}); \]
\[ c1 = 0.5 \times (1-k)/(1+k); \]
\[ c2 = (0.5+c1) \times \cos(\pi \times \text{cutoff}); \]
\[ c3 = (0.5+c1+c2) \times 0.25; \]
\[ a0 = 2 \times c3; \]
\[ a1 = -4 \times c3; \]
\[ a2 = 2 \times c3; \]
\[ b1 = -2 \times c2; \]
\[ b2 = 2 \times c1; \]

if you wish to create a cascade, use the this:

```python
//----sample loop
//mem: buffer array
//N: number of biquads, n=4 -> 48dB/oct
//set input here
for (i=0; i<N; i++) {
    output = a0 * input + a1 * mem[4*i+1] + a2 * mem[4*i+2] - b1 * mem[4*i+3] - b2 * mem[4*i+4];
    mem[4*i+2] = mem[4*i+1];
    mem[4*i+1] = input;
    mem[4*i+4] = mem[4*i+3];
    mem[4*i+3] = output;
}
//----sample loop
```

### 3.63.1 Comments

- **Date**: 2009-03-05 13:44:24
- **By**: moc.liamg@321tiloen

- **Date**: 2009-04-20 11:44:26
- **By**: moc.liamg@321tiloen

3.63. Simple biquad filter from apple.com

---
i've missed a line:

```c
mem[4*i+3] = output;

//>>> insert here
input = output;
//>>> insert here
```

//----sample loop

```
lubomir
```

## 3.64 Spuc’s open source filters

- **Author or source:** moc.liamg@321tiloen
- **Type:** Elliptic, Butterworth, Chebyshev
- **Created:** 2008-10-27 10:14:41

### Listing 105: notes


Spuc has good C++ versions of some classic filter models.

Download full package from:
http://spuc.sourceforge.net

## 3.65 State Variable Filter (Chamberlin version)

- **Author or source:** Hal Chamberlin, “Musical Applications of Microprocessors,” 2nd Ed, Hayden Book Company 1985. pp 490-492.
- **Created:** 2003-04-14 18:33:53

### Listing 106: code

```c
// Input/Output
I - input sample
L - lowpass output sample
B - bandpass output sample
H - highpass output sample
N - notch output sample
F1 - Frequency control parameter
Q1 - Q control parameter
D1 - delay associated with bandpass output
D2 - delay associated with low-pass output

// parameters:
```

(continues on next page)
QL = 1/Q
// where Q1 goes from 2 to 0, ie Q goes from .5 to infinity

// simple frequency tuning with error towards nyquist
// F is the filter's center frequency, and Fs is the sampling rate
F1 = 2*pi*F/Fs

// ideal tuning:
F1 = 2 * sin( pi * F / Fs )

// algorithm
// loop
L = D2 + F1 * D1
H = I - L - Q1*D1
B = F1 * H + D1
N = H + L

// store delays
D1 = B
D2 = L

// outputs
L,H,B,N

3.65.1 Comments

- Date: 2005-03-21 00:08:03
- By: ed.luofosruoivas@nait.sirhC

Object Pascal Implementation
---------------------------
-denormal fixed
-not optimized

unit SVFUnit;

interface
type
TFrequencyTuningMethod= (ftmSimple, ftmIdeal);
TSVF = class
private
  fQ1,fQ : Single;
fF1,fF : Single;
fFS : Single;
fD1,fD2 : Single;
fFTM : TFrequencyTuningMethod;
procedure SetFrequency(v:Single);
procedure SetQ(v:Single);
public
  constructor Create;
destructor Destroy; override;
procedure Process(const I : Single; var L,B,N,H: Single);
property Frequency: Single read fF write SetFrequency;
property SampleRate: Single read fFS write fFS;
property Q: Single read fQ write SetQ;
property FrequencyTuningMethod: TFrequencyTuningMethod read fFTM write fFTM;
end;

implementation

uses sysutils;

const kDenorm = 1.0e-24;

constructor TSVF.Create;
beg
inherited;
fQ1:=1;
fF1:=1000;
fFS:=44100;
fFTM:=ftmIdeal;
end;

destructor TSVF.Destroy;
beg
inherited;
end;

procedure TSVF.SetFrequency(v:Single);
beg
if fFS<=0 then raise exception.create('Sample Rate Error!');
if v<>fF then
begin
fF:=v;
case fFTM of
ftmSimple:
begin
// simple frequency tuning with error towards nyquist
// F is the filter's center frequency, and Fs is the sampling rate
fF1:=2*pi*fF/fFS;
end;
ftmIdeal:
begin
// ideal tuning:
fF1:=2*sin(pi*fF/fFS);
end;
end;
end;

procedure TSVF.SetQ(v:Single);
beg
if v<>fQ then
begin
if v>=0.5 then fQ:=v
else fQ:=0.5;
fQ1:=1/fQ;
end;
procedure TSVF.Process(const I : Single; var L,B,N,H: Single);
begin
L:=fD2+fF1*fD1-kDenorm;
H:=I-L-fQ1*fD1;
B:=fF1*H+fD1;
N:=H+L;
// store delays
fD1:=B;
fD2:=kDenorm+L;
end;
end.

• Date: 2005-03-21 14:32:24
• By: ed.luosfosruivas@naitsirhC

Ups, there are still denormal bugs in it...
(zu früh gefreut...)

3.66 State Variable Filter (Double Sampled, Stable)

• Author or source: Andrew Simper
• Type: 2 Pole Low, High, Band, Notch and Peaking
• Created: 2003-10-11 01:57:00

Listing 107: notes
Thanks to Laurent de Soras for the stability limit
and Steffan Diedrichsen for the correct notch output.

Listing 108: code

input = input buffer;
output = output buffer;
fs = sampling frequency;
fc = cutoff frequency normally something like:
  440.0*pow(2.0, (midi_note - 69.0)/12.0);
res = resonance 0 to 1;
drive = internal distortion 0 to 0.1
freq = 2.0*sin(PI*MIN(0.25, fc/(fs*2))); // the fs*2 is because it's double sampled
damp = MIN(2.0*(1.0 - pow(res, 0.25)), MIN(2.0, 2.0/freq - freq*0.5));
notch = notch output
low = low pass output
high = high pass output
band = band pass output
peak = peaking output = low - high
--
double sampled svf loop:
for (i=0; i<numSamples; i++)
```c
{  
in  = input[i];
notch = in - damp*band;
low  = low + freq*band;
high = notch - low;
band = freq*high + band - drive*band*band*band;
out  = 0.5*(notch or low or high or band or peak);
notch = in - damp*band;
low  = low + freq*band;
high = notch - low;
band = freq*high + band - drive*band*band*band;
out += 0.5*(same out as above);
output[i] = out;
}
```

### 3.66.1 Comments

- **Date:** 2004-11-19 13:30:07  
  **By:** eb.tenyks@didid

Correct me if I’m wrong, but the double-sampling here looks like doubling the input,  
which is a bad resampling introducing aliasing, followed by an averaging of the 2  
outputs, thus filtering that aliasing.

It works, but I think it (the averaging) has the side effect of smoothing up the high  
freqs in the source material, thus with this filter you can’t really fully open it  
and have the original signal.

At least, it’s what seems to happen practically in my tests.

Problem is that this SVF indeed has a crap stability near nyquist, but I can’t think  
of any better way to make it work better, unless you use a better but much more  
costy upsampling/downsampling.

Anyone confirms?

- **Date:** 2004-11-26 09:45:28  
  **By:** kd.utd.xaspmak@mj

Interesting that this question pops up right now. Lately I have been wondering about  
the same thing, not so much about the (possibly limited) frequency range, but about  
stability problems of the filter that I have had (even when using smoothed control  
signals). The non-linearity introduced by the "drive\*band\*band\*band" factor does  
not seem to be covered by the stability measurements.

In particular I would like to know, how the filter graphs in http://vellocet.com/dsp/  
svf/svf-stability.html and http://www-2.cs.cmu.edu/~eli/tmp/svf/stability.png were  
obtained? Would you like to post the code that generated the stability graph to the  
musicdsp archive?

For the double-sampling scheme, wouldn’t it make more sense to zero-stuff the input  
signal (that is interleave all input samples with zeros) instead of doubling the  
samples?

- **Date:** 2004-11-27 00:07:09  
  **By:** kd.utd.xaspmak@mj
Oh, just noticed that Eli’s SVF stability measurement code has already been made available at http://www-2.cs.cmu.edu/~eli/tmp/svf/

However, I think it is up to him to decide whether he wants to include it in the archive or not.

• Date: 2007-12-13 11:01:38
  • By: moc.kisuw@kmailliw

I was having problems with this filter when DRIVE is set to MAX and Resonance is set to MIN. A quick way to fix it was to make DRIVE*REZO, so when there’s no resonance, there’s no need for DRIVE anyway. That fixed the problem.

• Date: 2017-05-11 21:39:28
  • By: moc.liamg@libojyr

Here is how I am handling the resampling. I know from trying this zero padding is nasty (terrible noise) without a good filter for downsampling back to base rate.

Below the input is linear interpolated input. This is a slight improvement on what Nigel Redmon suggests here: http://www.earlevel.com/main/2003/03/02/the-digital-state-variable-filter/

Which is simply to tick the filter twice per sample with the same input. This is very similar to above code except that there should not be averaging of the two outputs. You just tick the filter twice with the same input and take the output. The state variables take care of the band limiting. Remember the aliased terms are multiples of the sample rate so they fall on 0 and Nyquist frequencies, not really having more severe artefacts than what you get from running the filter at base sample rate.

For the low pass and bandpass outputs the filter itself performs the band-limiting necessary for clean decimation. Intuitively the high pass output is due to a phase cancellation with the dual-integrator loop, so it should be about as clean as the LP and BP outputs. The dual integrator is band-limiting in nature... just some thoughts.

//-- Here’s the Code --//
//x[i] = input
//x1 = x[i-1] = last input
//Run 1 : Linear interlopolate between x[n-1] and x[i]
lpf = lpf + f* bpf;
hpf = 0.5 * g * (x[i] + x1) - lpf - q*bpf;
bpf = f* hpf + bpf;

//Run 2
lpf = lpf + f* bpf;
hpf = g * x[i] - lpf - q*bpf;
bpf = f* hpf + bpf;

x1 = x[i];

// Coefficients on each state variable
// allows for any filter response function possible
// with a biquad filter structure
x[i] = lmix*lpf + hmix*hpf + bmix*bpf;

3.66. State Variable Filter (Double Sampled, Stable)
3.67 State variable

- **Author or source:** Effect Design Part 1, Jon Dattorro, J. Audio Eng. Soc., Vol 45, No. 9, 1997 September
- **Type:** 12db resonant low, high or bandpass
- **Created:** 2002-01-17 02:01:50

**Listing 109: notes**

Digital approximation of Chamberlin two-pole low pass. Easy to calculate coefficients, easy to process algorithm.

**Listing 110: code**

```plaintext
1 cutoff = cutoff freq in Hz
2 fs = sampling frequency // (e.g. 44100Hz)
3 f = 2 sin (pi * cutoff / fs) // [approximately]
4 q = resonance/bandwidth [0 < q <= 1] most res: q=1, less: q=0
5 low = lowpass output
6 high = highpass output
7 band = bandpass output
8 notch = notch output
9
10 scale = q
11
12 low=high=band=0;
13
14 //--beginloop
15 low = low + f * band;
16 high = scale * input - low - q*band;
17 band = f * high + band;
18 notch = high + low;
19 //--endloop
```

3.67.1 Comments

- **Date:** 2006-01-11 15:06:56
  - **By:** nope
  
  Wow, great. Sounds good, thanks.

- **Date:** 2007-02-13 13:45:02
  - **By:** es.aelp@maps.on
  
  The variable "high" doesn't have to be initialised, does it? It looks to me like the _only_ variables that need to be kept around between iterations are "low" and "band".

- **Date:** 2007-02-13 15:28:30
  - **By:** moc.erehwon@ydobon
  
  Right. High and notch are calculated from low and band every iteration.

- **Date:** 2007-07-18 11:34:21
Anyone know what the difference is between q and scale?

• Date: 2007-07-29 17:17:16
  • By: moc.liamtoh@rebbadrebbaj

"most res: q=1, less: q=0"

Someone correct me if I'm wrong, but isn't that backwards? q=0 is max res, q=1 is min res.

q and scale are the same value. What the algorithm is doing is scaling the input the higher the resonance is turned up to prevent clipping. One reason why I think 0 equals max resonance and 1 equals no resonance.

So as q approaches zero, the input is attenuated more and more. In other words, as you turn up the resonance, the input is turned down.

• Date: 2007-11-16 12:58:03
  • By: rettam.ton@seod

```plaintext
scale = sqrt(q);
and
//value (0;100) - for example
q = sqrt(1.0 - atan(sqrt(value)) * 2.0 / PI);
f = frqHz / sampleRate*4.;

uffffffff :)
Now enjoy!
```

• Date: 2008-11-29 20:04:47
  • By: gro.ybbek@bk

One drawback of this is that the cutoff frequency can only go up to SR/4 instead of SR/2 - but you can easily compensate it by using 2x oversampling, eg. simply running this thing twice per sample (apply input interpolation or further output filtering ad lib, but from my experience simple linear interpolation of the input values (in and (in+lastin)/2) works well enough).

• Date: 2009-03-05 13:24:35
  • By: moc.liamg@321tiloen

here is the filter with 2x oversampling + some x,y pad functionality to morph between states:
like this fx (uses different filter)
http://img299.imageshack.us/img299/4690/statevariable.png

smoothing with interpolation is suggest for most parameters:
```plaintext
//sr: samplerate;
```

(continues on next page)
//cutoff: 20 - 20k;
//qvalue: 0 - 100;
//x, y: 0 - 1
q = sqrt(1 - atan(sqrt(qvalue)) * 2 / pi);
scale = sqrt(q);
f = slider1 / sr * 2; // * 2 here instead of 4

//----------sample loop
//set 'input' here
//os x2
for (i=0; i<2; i++) {
    low = low + f * band;
    high = scale * input - low - q * band;
    band = f * high + band;
    notch = high + low;
}

// x,y pad scheme
//
// high -- notch
// |     |
// |     |
// low ---- band
//
// use two pairs

//low, high
pair1 = low * y + high * (1-y);
//band, notch
pair2 = band * y + notch * (1-y);

//out
out = pair2 * x + pair1 * (1-x);

//----------sample loop

3.68 Stilson's Moog filter code

- **Author or source**: DFL
- **Type**: 4-pole LP, with fruity BP/HP
- **Created**: 2003-05-15 14:23:51

Listing 111: notes

Mind your p's and Q's...

This code was borrowed from Tim Stilson, and rewritten by me into a pd extern (moog~) available here:
http://www-ccrma.stanford.edu/~dfl/pd/index.htm
I ripped out the essential code and pasted it here...

Listing 112: code

```
WARNING: messy code follows ;)

// table to fixup Q in order to remain constant for various pole frequencies, from
    - Tim Stilson's code @ CCRMA (also in CLM distribution)

static float gaintable[199] = { 0.999969, 0.990082, 0.980347, 0.970764, 0.961304, 0.951996, 0.94281, 0.933777, 0.924866, 0.916077, 0.90741, 0.898865, 0.890442, 0.882141, 0.873962, 0.865906, 0.857941, 0.850067, 0.842346, 0.834686, 0.827148, 0.819733, 0.812378, 0.805145, 0.798004, 0.790955, 0.783997, 0.77713, 0.770355, 0.763672, 0.75708, 0.75058, 0.744141, 0.737993, 0.731537, 0.725342, 0.719238, 0.713196, 0.707245, 0.701355, 0.695557, 0.689819, 0.684174, 0.678558, 0.673055, 0.667572, 0.66217, 0.65686, 0.651581, 0.646393, 0.641235, 0.636169, 0.631134, 0.62619, 0.621277, 0.616425, 0.611633, 0.606903, 0.602234, 0.597626, 0.593048, 0.588531, 0.584045, 0.579651, 0.575287, 0.570953, 0.566681, 0.562469, 0.558289, 0.554169, 0.550079, 0.546051, 0.542053, 0.538116, 0.53421, 0.530334, 0.52652, 0.522736, 0.518982, 0.515289, 0.511627, 0.507996, 0.504425, 0.500885, 0.497375, 0.493896, 0.490448, 0.487061, 0.483704, 0.480377, 0.477081, 0.4738, 0.470581, 0.467377, 0.464203, 0.46109, 0.457977, 0.454926, 0.451874, 0.448883, 0.445892, 0.442932, 0.440033, 0.437134, 0.434265, 0.431427, 0.428619, 0.425842, 0.423096, 0.42038, 0.417664, 0.415009, 0.412354, 0.409729, 0.407135, 0.404572, 0.402008, 0.399506, 0.397003, 0.394501, 0.392059, 0.389618, 0.387207, 0.384827, 0.382477, 0.380127, 0.377808, 0.375488, 0.37323, 0.370972, 0.368713, 0.366516, 0.364319, 0.362122, 0.359905, 0.357849, 0.355713, 0.353607, 0.351532, 0.349457, 0.347412, 0.345398, 0.343384, 0.34137, 0.339417, 0.337463, 0.33551, 0.33358, 0.331665, 0.329773, 0.327911, 0.32605, 0.324188, 0.322357, 0.320557, 0.318756, 0.316986, 0.315216, 0.313446, 0.311707, 0.309998, 0.308289, 0.30658, 0.304901, 0.303223, 0.301575, 0.299927, 0.298309, 0.296692, 0.295074, 0.293488, 0.291931, 0.290375, 0.288818, 0.287262, 0.285736, 0.284241, 0.282715, 0.28125, 0.279755, 0.27829, 0.276825, 0.275391, 0.273956, 0.272552, 0.271118, 0.26974, 0.268341, 0.266968, 0.265594, 0.264252, 0.262909, 0.261566, 0.260223, 0.258911, 0.257599, 0.256317, 0.255035, 0.25375 };

static inline float saturate( float input ) { //clamp without branching
#define _limit 0.95
    float x1 = fabsf( input + _limit );
    float x2 = fabsf( input - _limit );
    return 0.5 * (x1 - x2);
}

static inline float crossfade( float amount, float a, float b ) {
    return (1-amount)*a + amount*b;
}

//code for setting Q
    float ix, ixfrac;
    int ixint;
    ix = x->p * 99;
    ixint = floor( ix );
    ixfrac = ix - ixint;
    Q = resonance * crossfade( ixfrac, gaintable[ ixint + 99 ], gaintable[ ixint + 100 ] );
```

3.68. Stilson's Moog filter code 371
// code for setting pole coefficient based on frequency
float fc = 2 * frequency / x->srate;
float x2 = fc*fc;
float x3 = fc*x2;
p = -0.69346 * x3 - 0.59515 * x2 + 3.2937 * fc - 1.0072; // cubic fit by DFL, not 100% accurate but better than nothing...
}
}

process loop:
float state[4], output; // should be global scope / preserved between calls
int i,pole;
float temp, input;

for ( i=0; i < numSamples; i++ ) {
    input = *(in++);
    output = 0.25 * ( input - output ); // negative feedback

    for( pole = 0; pole < 4; pole++) {
        temp = state[pole];
        output = saturate( output + p * (output - temp));
        state[pole] = output;
        output = saturate( output + temp );
    }
    lowpass = output;
    highpass = input - output;
    bandpass = 3 * x->state[2] - x->lowpass; // got this one from paul kellet
    *out++ = lowpass;
}

output *= Q; // scale the feedback

3.68.1 Comments

• **Date:** 2004-06-07 08:01:13
  **By:** ku.oc.sdnuosdionamuh@nhoj

What is "x->p" in the code for setting Q?

• **Date:** 2004-06-09 07:19:43
  **By:** DFL

you should set the frequency first, to get the value of p. Then use that value to get the normalized Q value.

• **Date:** 2004-06-09 12:22:00
  **By:** ku.oc.sdnuosdionamuh@nhoj

Ah! That p. Thanks.

• **Date:** 2009-01-06 13:35:18
  **By:** soeren.parton->soerenskleinewelt,de
Hi!

My Output gets stuck at about 1E-7 even when the input is way below. Is that a quantisation problem? Looks as if it's the saturation's fault...

Cheers
Sören

• **Date:** 2010-10-27 15:51:42
• **By:** ten.reknirdaet@cisum

I have not tested, but it looks like gaintable and interpolation can be replaced using approx:

\[
\frac{1}{x \times 1.48 + 0.85} - 0.1765
\]

(range 0 -> 1)

Peace
/Martin

---

### 3.69 Time domain convolution with O(n^\log2(3))

• **Author or source:** Wilfried Welti
• **Created:** 2002-02-10 12:38:01

[Quoted from Wilfrieds mail...]

I found last weekend that it is possible to do convolution in time domain (no complex numbers, 100% exact result with int) with O(n^\log2(3)) (about O(n^1.58)).

Due to smaller overhead compared to FFT-based convolution, it should be the fastest algorithm for medium sized FIR's.
Though, it's slower as FFT-based convolution for large n.

It's pretty easy:

Let's say we have two finite signals of length 2n, which we want convolve: A and B. Now we split both signals into parts of size n, so we get A = A1 + A2, and B = B1 + B2.

Now we can write:

(1) \(A \ast B = (A1+A2) \ast (B1+B2) = A1 \ast B1 + A2 \ast B1 + A1 \ast B2 + A2 \ast B2\)

where \(\ast\) means convolution.

This we knew already: We can split a convolution into four convolutions of halved size.

Things become interesting when we start shifting blocks in time:

Be z a signal which has the value 1 at x=1 and zero elsewhere. Convoluting a signal X with

(continues on next page)
z is equivalent to shifting X by one rightwards. When I define $z^n$ as $n$-fold convolution of z with itself, like: $z^1 = z$, $z^2 = z*z$, $z^0 = z$ shifted leftwards by 1 = impulse at x=0, and so on, I can use it to shift signals:

$X * z^n$ means shifting the signal X by the value n rightwards.

$X * z^{-n}$ means shifting the signal X by the value n leftwards.

Now we look at the following term:

\[(2) (A_1 + A_2 * z^{-n}) * (B_1 + B_2 * z^{-n})\]

This is a convolution of two blocks of size n: We shift $A_2$ by n leftwards so it completely overlaps $A_1$, then we add them. We do the same thing with $B_1$ and $B_2$. Then we convolute the two resulting blocks.

Now let's transform this term:

\[(3) (A_1 + A_2 * z^{-n}) * (B_1 + B_2 * z^{-n}) = A_1*B_1 + A_1*B_2*z^{-n} + A_2*z^{-n}*B_1 + A_2*z^{-n}*B_2*z^{-n} = A_1*B_1 + (A_1*B_2 + A_2*B_1)*z^{-n} + A_2*B_2*z^{-2n}\]

\[(4) (A_1 + A_2 * z^{-n}) * (B_1 + B_2 * z^{-n}) = A_1*B_1 - A_2*B_2*z^{-2n}\]

Now we convolute both sides of the equation (4) by $z^n$:

\[(5) (A_1 + A_2 * z^{-n})*(B_1 + B_2 * z^{-n})*z^n = A_1*B_1*z^n - A_2*B_2*z^{-n}\]

Now we see that the right part of equation (5) appears within equation (1), so we can replace this appearance by the left part of eq (5).

\[(6) A*B = (A_1+A_2)*(B_1+B_2) = A_1*B_1 + A_2*B_1 + A_1*B_2 + A_2*B_2 = A_1*B_1 + (A_1 + A_2 * z^{-n})*(B_1 + B_2 * z^{-n})*z^n - A_1*B_1*z^n - A_2*B_2*z^{-n} + A_2*B_2\]

Voila!

We have constructed the convolution of $A*B$ with only three convolutions of halved size.

(Since the convolutions with $z^n$ and $z^{-n}$ are only shifts of blocks with size n, they of course need only n operations for processing :)

This can be used to construct an easy recursive algorithm of Order $O(n^\log_2(3))$.

---

Listing 114: code

```c
void convolution(value* in1, value* in2, value* out, value* buffer, int size) {
    value* templ = buffer;
```

(continues on next page)
value* temp2 = buffer + size/2;
int i;

// clear output.
for (i=0; i<size/2; i++) out[i] = 0;

// Break condition for recursion: 1x1 convolution is multiplication.
if (size == 1)
{
    out[0] = in1[0] * in2[0];
    return;
}

// first calculate (A1 + A2 * z^-n) * (B1 + B2 * z^-n) * z^n
signal_add(in1, in1+size/2, temp1, size/2);
signal_add(in2, in2+size/2, temp2, size/2);
convolution(temp1, temp2, out+size/2, buffer+size, size/2);

// then add A1*B1 and subtract A1*B1*z^n
convolution(in1, in2, temp1, buffer+size, size/2);
signal_add_to(out, temp1, size);
signal_sub_from(out+size/2, temp1, size);

// then add A2*B2 and subtract A2*B2*z^-n
convolution(in1+size/2, in2+size/2, temp1, buffer+size, size/2);
signal_add_to(out+size/2, temp1, size);
signal_sub_from(out+size/2, temp1, size);
}

"value" may be a suitable type like int or float.
Parameter "size" is the size of the input signals and must be a power of 2. out and buffer must point to arrays of size 2*n.

Just to be complete, the helper functions:

void signal_add(value* in1, value* in2, value* out, int size)
{
    int i;
    for (i=0; i<size; i++) out[i] = in1[i] + in2[i];
}

void signal_sub_from(value* out, value* in, int size)
{
    int i;
    for (i=0; i<size; i++) out[i] -= in[i];
}

void signal_add_to(value* out, value* in, int size)
{
    int i;
    for (i=0; i<size; i++) out[i] += in[i];
}
3.69.1 Comments

- Date: 2003-11-05 11:53:05
- By: ed.luosfosruoivas@nait.sirhC

Here is a delphi translation of the code:

```delphi
// "value" may be a suitable type like int or float.
// Parameter "size" is the size of the input signals and must be a power of 2.
// out and buffer must point to arrays of size 2*n.

procedure signal_add(in1, in2, ou1 :PValue; Size:Integer);
var i : Integer;
begin
  for i:=0 to Size-1 do
  begin
    ou1^[i] := in1^[i] + in2^[i];
  end;
end;

procedure signal_sub_from(in1, ou1 :PValue; Size:Integer);
var i : Integer;
begin
  for i:=0 to Size-1 do
  begin
    ou1^[i] := ou1^[i] - in1^[i];
  end;
end;

procedure signal_add_to(in1, ou1: PValue; Size:Integer);
var i : Integer;
  po, pi1 : PValue;
begin
  po:=ou1;
  pi1:=in1;
  for i:=0 to Size-1 do
  begin
    ou1^[i] := ou1^[i] + in1^[i];
    Inc(po);
    Inc(pi1);
  end;
end;

procedure convolution(in1, in2, ou1, buffer :PValue; Size:Integer);
var tmp1, tmp2 : PValue;
  i : Integer;
begin
  tmp1:=Buffer;
  tmp2:=@(Buffer^[Size div 2]);

  // clear output.
  for i:=0 to Size*2 do ou1^[i]:=0;

  // Break condition for recursion: 1x1 convolution is multiplication.
  if Size = 1 then
  begin
    ou1^[0] := in1^[0] * in2^[0];
  end;
end;
```

(continues on next page)
exit;
end;

// first calculate (A1 + A2 * z^-n)*(B1 + B2 * z^-n)*z^n
signal_add(in1, @(in1^[(Size div 2)]), tmp1, Size div 2);
signal_add(in2, @(in1^[Size 2])), tmp2, Size div 2);
convolution(tmp1, tmp2, @(ou1^[Size div 2])), @(Buffer^[Size]), Size div 2);

// then add A1*B1 and substract A1*B1*z^n
convolution(in1, in2, tmp1, @(Buffer^[Size]), Size div 2);
signal_add_to(ou1, tmp1, size);
signal_sub_from(@(ou1^[Size]), tmp1, size);

// then add A2*B2 and substract A2*B2*z^-n
convolution(@(in1^[Size 2]), @(in2^[Size 2]), tmp1, @(Buffer^[Size]),
→Size div 2);
signal_add_to(@(ou1^[Size]), tmp1, size);
signal_sub_from(@(ou1^[Size]), tmp1, size);
end;

- Date: 2003-11-05 12:19:05
- By: ed.luosfo@nuitsi

Sorry, I forgot the definitions:

type
 Values = Array[0..0] of Single;
PValue = ^Values;

- Date: 2004-04-19 19:47:52
- By: ed.luosfo@nuitsi

I have implemented a Surround-Plugin using this Source-Code.
Basicly a FIR-Filter with 512 Taps, bundled with some HRTF's for sourround panning

http://www.saviourofthesoul.de/Christian/ITA-HRTF.EXE

(Delphi Sourcecode available on request)

### 3.70 Time domain convolution with O(n^log2(3))

- Author or source: Magnus Jonsson
- Created: 2002-09-07 23:23:50

Listing 115: notes
[see other code by Wilfried Welti too!]

Listing 116: code

```c
void mul_brute(float *r, float *a, float *b, int w)
{
```

(continues on next page)
for (int i = 0; i < w+w; i++)
    r[i] = 0;
for (int i = 0; i < w; i++)
{
    float *rr = r+i;
    float ai = a[i];
    for (int j = 0; j < w; j++)
        rr[j] += ai*b[j];
}

// tmp must be of length 2*w
void mul_knuth(float *r, float *a, float *b, int w, float *tmp)
{
    if (w < 30)
    {
        mul_brute(r, a, b, w);
    }
    else
    {
        int m = w>>1;

        for (int i = 0; i < m; i++)
        {
            r[i] = a[m+i]-a[i];
            r[i+m] = b[i]-b[m+i];
        }
        mul_knuth(tmp, r, r+m, m, tmp+w);
        mul_knuth(r, a, b, m, tmp+w);
        mul_knuth(r+w, a+m, b+m, m, tmp+w);

        for (int i = 0; i < m; i++)
        {
            float bla = r[m+i]+r[w+i];
            r[m+i] = bla+r[i]+tmp[i];
            r[w+i] = bla+r[w+m+i]+tmp[i+m];
        }
    }
}

3.71 Type: LPF 24dB/Oct

- **Author or source:** ed.luosfosruoivas@naitsirhC
- **Type:** Bessel Lowpass
- **Created:** 2006-07-28 17:59:18

Listing 117: notes

The filter tends to be unusable for low frequencies in the way, that it seems to flutter, but it never explode. At least here it doesn't.
First calculate the prewarped digital frequency:

\[
K = \tan(\pi \times \text{Frequency} / \text{Samplerate});
\]

\[
K2 = K \times K; \quad // \text{speed improvement}
\]

Then calculate the digital filter coefficients:

\[
A0 = (((105 \times K + 105) \times K + 45) \times K + 10) \times K + 1);
\]

\[
A1 = (-( (420 \times K + 210) \times K2 - 20) \times K - 4) \times t;
\]

\[
A2 = -( (630 \times K2 - 90) \times K2 + 6) \times t;
\]

\[
A3 = -( (420 \times K - 210) \times K2 + 20) \times K - 4) \times t;
\]

\[
A4 = -(((105 \times K - 105) \times K + 45) \times K - 10) \times K + 1) \times t;
\]

\[
B0 = 105 \times K2 \times K2;
\]

\[
B1 = 420 \times K2 \times K2;
\]

\[
B2 = 630 \times K2 \times K2;
\]

\[
B3 = 420 \times K2 \times K2;
\]

\[
B4 = 105 \times K2 \times K2;
\]

Per sample calculate:

\[
\text{Output} = B0 \times \text{Input} + \text{State0};
\]

\[
\text{State0} = B1 \times \text{Input} + A1/A0 \times \text{Output} + \text{State1};
\]

\[
\text{State1} = B2 \times \text{Input} + A2/A0 \times \text{Output} + \text{State2};
\]

\[
\text{State2} = B3 \times \text{Input} + A3/A0 \times \text{Output} + \text{State3};
\]

\[
\text{State3} = B4 \times \text{Input} + A4/A0 \times \text{Output};
\]

For high speed substitute \( A1/A0 \) with \( A1' = A1/A0 \).

### 3.71.1 Comments

- **Date:** 2006-07-28 22:21:29
  - **By:** ed.luosfosruoivas@naitsirhC
  
  It turns out, that the filter is only unstable if the coefficient/state precision isn't high enough. Using double instead of single precision already makes it a lot more stable.

- **Date:** 2006-10-16 00:42:11
  - **By:** ed.luosfosruoivas@naitsirhC
  
  Just found out, that I forgot to remove the temporary variable 't'. It was used in my code for the speedup. You can simply ignore and delete it.

- **Date:** 2009-02-13 14:24:41
  - **By:** kd.oohay@eeffocetarak
  
  Changing the frequency also seems to affect the volume quite a lot. That can't be right? Maybe you should re-post this (and remove the "t" this time)? ;)

- **Date:** 2013-02-13 11:58:19
Your filter does not work! Arise overload in the calculation of coefficients A and B in the cutoff frequency of approximately 10 khz. At low frequencies, the coefficient of the gain increases proportional to the frequency cutoff, which causes congestion. I also noticed that the filter on this basis, the package of ASIO/DSP - DDspBesselFilter.pas does not work, although Butterworth (DDspButterworthFilter.pas) and Chebyshev (DDspChebyshevFilter.pas) work perfectly!

3.72 Various Biquad filters

- **Author or source:** JAES, Vol. 31, No. 11, 1983 November
- **Created:** 2002-01-17 02:08:47
- **Linked files:** filters003.txt

Listing 119: notes

(see linkfile)
Filters included are:

- presence
- shelvelowpass
- 2polebp
- peaknotch
- peaknotch2

3.72.1 Comments

- **Date:** 2008-10-19 23:02:44
- **By:** moc.liamg@321tiloen

I'm kinda stuck trying to figure out the 'pointer' 'structure pointer' loop in the presence EQ.

Can someone explain:

...  

*a0 = a2plus1 + alphan*ma2plus1;
*a1 = 4.0*a;
*a2 = a2plus1 - alphan*ma2plus1;
$b0 = a2plus1 + alphad*ma2plus1;
*b2 = a2plus1 - alphad*ma2plus1;

recipb0 = 1.0/b0;
*a0 *= recipb0;
*a1 *= recipb0;
*a2 *= recipb0;
*b1 = *a1;
*b2 *= recipb0;

....

(continues on next page)
void setfilter_presence(f,freq,boost,bw)
filter *f;
double freq,boost,bw;
{
    presence(freq/(double)SR,boost,bw/(double)SR, 
        &f->cx,&f->cx1,&f->cx2,&f->cy1,&f->cy2);
    f->cy1 = -f->cy1;
    f->cy2 = -f->cy2;
}

How can this be translated into something more easy to understand.

Input = ...
Output = ...

• **Date:** 2008-10-28 12:15:21
• **By:** moc.liamg@321tiloen

Managed to port the presence eq properly. And its sounds great!

Altho I did some changes to some of the code.

changed "d /= mag" to "d = mag"
"bw/srate" to "bw"

There results I got are stable within there parameters:

freq: 3100-18500hz
boost: 0-15db
bw: 0.07-0.40

Really good sound from this filter!

### 3.73 Windowed Sinc FIR Generator

• **Author or source:** Bob Maling
• **Type:** LP, HP, BP, BS
• **Created:** 2005-04-12 20:19:47
• **Linked files:** wsfir.h

Listing 120: notes

This code generates FIR coefficients for lowpass, highpass, bandpass, and bandstop filters by windowing a sinc function.

The purpose of this code is to show how windowed sinc filter coefficients are generated.

Also shown is how highpass, bandpass, and bandstop filters can be made from lowpass
filters.

Included windows are Blackman, Hanning, and Hamming. Other windows can be added by following the structure outlined in the opening comments of the header file.

### 3.73.1 Comments

- **Date:** 2005-04-15 00:02:33
- **By:** ed.losfruosias@naitsirhC

```pascal
// Object Pascal Port...

unit SincFIR;

(* Windowed Sinc FIR Generator
   Bob Maling (BobM.DSP@gmail.com)
   Contributed to musicdsp.org Source Code Archive
   Last Updated: April 12, 2005
   Translated to Object Pascal by Christian-W. Budde

   Usage:
   Lowpass: wsfirLP(H, WindowType, CutOff)
   Highpass: wsfirHP(H, WindowType, CutOff)
   Bandpass: wsfirBP(H, WindowType, LowCutOff, HighCutOff)
   Bandstop: wsfirBS(H, WindowType, LowCutOff, HighCutOff)

   where:
   H (TDoubleArray): empty filter coefficient table (SetLength(H,DesiredLength)!)  
   WindowType (TWindowType): wtBlackman, wtHanning, wtHamming  
   CutOff (double): cutoff (0 < CutOff < 0.5, CutOff = f/fs)  
   --> for fs=48kHz and cutoff f=12kHz, CutOff = 12k/48k => 0.25  
   LowCutOff (double): low cutoff (0 < CutOff < 0.5, CutOff = f/fs)  
   HighCutOff (double): high cutoff (0 < CutOff < 0.5, CutOff = f/fs)

   Windows included here are Blackman, Blackman-Harris, Gaussian, Hanning and Hamming.*)

interface
uses Math;

type TDoubleArray = array of Double;
TWindowType = (wtBlackman, wtHanning, wtHamming, wtBlackmanHarris, wtGaussian); // Window type contstants

// Function prototypes
procedure wsfirLP(var H : TDoubleArray; const WindowType : TWindowType; const CutOff : Double);
procedure wsfirHP(var H : TDoubleArray; const WindowType : TWindowType; const CutOff : Double);
procedure wsfirBP(var H : TDoubleArray; const WindowType : TWindowType; const LowCutOff, HighCutOff : Double);
procedure wsfirBS(var H : TDoubleArray; const WindowType : TWindowType; const LowCutOff, HighCutOff : Double);
```

(continues on next page)
procedure genSinc(var Sinc : TDoubleArray; const CutOff : Double);
procedure wGaussian(var W : TDoubleArray);
procedure wBlackmanHarris(var W : TDoubleArray);
procedure wBlackman(var W : TDoubleArray);
procedure wHanning(var W : TDoubleArray);
procedure wHamming(var W : TDoubleArray);

implementation

// Generate lowpass filter
// This is done by generating a sinc function and then windowing it
procedure wsfirLP(var H : TDoubleArray; const WindowType : TWindowType; const CutOff : Double);
begin
  genSinc(H, CutOff); // 1. Generate Sinc function
case WindowType of
    wtBlackman: wBlackman(H);
    wtHanning: wHanning(H);
    wtHamming: wHamming(H);
    wtGaussian: wGaussian(H);
    wtBlackmanHarris: wBlackmanHarris(H);
  end;
end;

// Generate highpass filter
// This is done by generating a lowpass filter and then spectrally inverting it
procedure wsfirHP(var H : TDoubleArray; const WindowType : TWindowType; const CutOff : Double);
var i : Integer;
begin
  wsfirLP(H, WindowType, CutOff); // 1. Generate lowpass filter
  // 2. Spectrally invert (negate all samples and add 1 to center sample) lowpass filter
  // = delta[n-((N-1)/2)] - h[n], in the time domain
  for i:=0 to Length(H) div 2 do H[i]:=H[i]*-1.0;
  for i:=Length(H) div 2+1 to Length(H)-1 do H[i]:=-H[i];
end;

// Generate bandstop filter
// This is done by generating a lowpass and highpass filter and adding them
procedure wsfirBS(var H : TDoubleArray; const WindowType : TWindowType; const LowCutOff, HighCutOff : Double);
var i : Integer;
begin
  SetLength(H2,Length(H));
  wsfirLP(H, WindowType, LowCutOff); // 1. Generate lowpass filter at first (low) cutoff frequency
  wsfirHP(H2, WindowType, HighCutOff); // 2. Generate highpass filter at second (high) cutoff frequency
  for i:=0 to Length(H)-1 do H[i]:=H[i]+H2[i];
end;
do H[i]:=H[i]+H2[i];
SetLength(H2,0);
end;

// Generate bandpass filter
// This is done by generating a bandstop filter and spectrally inverting it
procedure wsfirBP(var H : TDoubleArray; const WindowType : TWindowType; const
→LowCutOff, HighCutOff : Double);
var i : Integer;
begin
wsfirBS(H, WindowType, LowCutOff, HighCutOff); // 1. Generate bandstop filter

// 2. Spectrally invert (negate all samples and add 1 to center sample) lowpass
→filter
// = delta[n-(N-1)/2] - h[n], in the time domain
for i:=0 to Length(H)-1
do H[i]:=H[i]*-1.0;
H[(Length(H)-1) div 2]:=H[(Length(H)-1) div 2]+1.0;
end;

// Generate sinc function - used for making lowpass filter
procedure genSinc(var Sinc : TDoubleArray; const Cutoff : Double); 
var i,j : Integer;
begin
j:=Length(Sinc)-1;
k:=1/j;
// Generate sinc delayed by (N-1)/2
for i:=0 to j do
if (i=j div 2)
then Sinc[i]:=2.0*Cutoff
else
begin
n:=i-j/2.0;
Sinc[i]:=sin(2.0*PI*Cutoff*n)/(PI*n);
end;
end;

// Generate window function (Gaussian)
procedure wGaussian(var W : TDoubleArray);
var i,j : Integer;
k : Double;
begin
j:=Length(W)-1;
k:=1/j;
for i:=0 to j 
do W[i]:=W[i]*(exp(-5.0/(sqr(j)))*(2*i-j)*(2*i-j)))
end;

// Generate window function (Blackman-Harris)
procedure wBlackmanHarris(var W : TDoubleArray);
var i,j : Integer;
k : Double;
begin
j:=Length(W)-1;
k:=1/j;
(continues on next page)
for i:=0 to j  
  do W[i]:=W[i]*(0.35875-0.48829*cos(2*PI*(i+0.5)*k)+0.14128*cos(4*PI*(i+0.5)*k)-0.˓
→01168*cos(6*PI*(i+0.5)*k));
end;

// Generate window function (Blackman)  
procedure wBlackman(var W : TDoubleArray);  
var i,j : Integer;  
k : Double;  
begin  
j:=Length(W)-1;  
k:=1/j;  
for i:=0 to j  
  do W[i]:=W[i]*(0.42-(0.5*cos(2*PI*i*k))+(0.08*cos(4*PI*i*k)));  
end;

// Generate window function (Hanning)  
procedure wHanning(var W : TDoubleArray);  
var i,j : Integer;  
k : Double;  
begin  
j:=Length(W)-1;  
k:=1/j;  
for i:=0 to j  
  do W[i]:=W[i]*(0.5*(1.0-cos(2*PI*i*k)));  
end;

// Generate window function (Hamming)  
procedure wHamming(var W : TDoubleArray);  
var i,j : Integer;  
k : Double;  
begin  
j:=Length(W)-1;  
k:=1/j;  
for i:=0 to j  
  do W[i]:=W[i]*(0.54-(0.46*cos(2*PI*i*k)));  
end.

• Date: 2007-01-06 04:23:59  
• By: uh.etle.fni@yfoocs

The Hanning window is often incorrectly referred to as 'Hanning', since it was named after a guy called Julius von Hann. So it's more appropriate to call it 'Hann' window.

• Date: 2007-09-02 20:33:31  
• By: Dave in sinc land

I've seen a BASIC version of the same genSinc code. Shouldn't a 'sin(2.0*Cutoff)' be used when the divide by zero check is 0?  
...  
if (i=j div 2)  
then Sinc[i]:=2.0*Cutoff

(continues on next page)
else
  begin
    n:=i-j/2.0;
    Sinc[i]:=sin(2.0*PI*Cutoff*n)/(PI*n);
  end;
...

• Date: 2007-09-02 21:22:35
• By: Dave in sinc land

Scrap that, I've just FFT'd the response, and it appears to be correct as it was. Hey, it just looked wrong o.k. ;)

• Date: 2008-09-08 00:57:52
• By: moc.liamg@olleocisuor

What do I have to do to apply this windowed sinc filter to a signal "Y" for example... what is the code for this?
Imagine signal "Y" is a stereo song which means that I have Y1 from channel 1 and Y2 from channel 2.. help me please as soon as possible because at least i want to know how to apply the filter to any signal...

• Date: 2012-06-10 07:57:12
• By: ten.xoc@53namhsima

Here is a FIR filter that works with up to about 80 coefficients on a Sony PSP running at 280 Megahertz. The multipliers (8191.0 and 32767.0) may need to be incremented by one, or not. You need to call 'fir_filter' with the sample to process in 'sample' and the floating point coefficients in '*coefs' and how long the entire filter is in 'len' and the returned sample is a 16 bit audio (signed short) sample. When it is first run it will normalize the filter.

/* code starts here, remove spaces between the includes */
#include < math.h >
#include < string.h >
#include < stdio.h >
#include < stdlib.h >

  void normalizeCoefs(signed short *firshort, signed short *outfilter, unsigned long len)
  {
    // filter gain at uniform frequency intervals
    double *g=NULL;
    double *dtemp=NULL;
    double theta, s, c, sac, sas;
    double gMax = -100.0;
    double sc = 10.0/log(10.0);
    double t = M_PI / len;
    long i=0;
    long n=len-1;
    double normFactor =0;
    g=(double*)malloc((len+1)*sizeof(double));
    dtemp=(double*)malloc((len+1)*sizeof(double));
    for (i=0; i<len; i++)
    { 
      dtemp[i]=firshort[i]/32768.0;
for (i=0; i<len; i++)
{
    theta = i*t;
    sac = 0.0;
    sas = 0.0;
    long k=0;
    for (k=0; k<len; k++)
    {
        c =cos(k*theta);
        s =sin(k*theta);
        sac += c*(dtemp[k]);
        sas += s*(dtemp[k]);
    }
    g[i] = sc*log(sac*sac + sas*sas);
    if(g[i]>gMax)
    {
        gMax=g[i];
    }
}

// normalise to 0 dB maximum gain
for (i=0; i<len; i++)
{
    g[i] -= gMax;
}

// normalise coefficients
normFactor =0;pow(10.0, -0.05*gMax);
for (i=0; i<len; i++)
{
    dtemp[i] *= normFactor;
}  
n=len-1;
for (i=0; i<len; i++)
{
    outfilter[i]=dtemp[n--]*32767.0;
}
free(dtemp);
free(g);

signed short generalFIR(short input, short *coefs, unsigned long len,unsigned char resetit)
{
  
    static signed short *delay_line=NULL;
    static unsigned int first=1;
    static signed long reacc=0;
    unsigned long filtcnt=0;
    static int consumer=1;
    static int producer=0;
    unsigned long tx=0;
    if(resetit==1)
    {
        first=1;
    }
    if(first==1)
if(delay_line!=NULL)  
    free(delay_line);
producer=0;
consumer=1;
delay_line=(signed short*)malloc(reallen*sizeof(signed short));
    first=0;
}
reacc=0;
delay_line[producer++]=input;
if(producer>len-1)  
{
    producer=len;
}
int filtptr=consumer;
for(tx=0;tx<len;tx++)  
{
    reacc+=(delay_line[filtptr++]*coefs[tx]);
    if(filtptr>len-1)  
    {  
        filtptr=len;
    }
}
consumer++;
if(consumer>len-1)  
{
    consumer=len;
}
reacc = reacc >> 15;
if(reacc<-32768)  
    reacc= -32768;
if(reacc>32767)  
    reacc=32767;
return (signed short)reacc;

signed short fir_filter(signed short sample,double *coefs,unsigned long len)  
{
    static unsigned char first=1;
    static signed short *newfir=NULL;
    if(first==1)  
    {
        unsigned long i=0;
        if(newfir!=NULL)  
        {
            free(newfir);
            newfir=NULL;
        }
        newfir=(signed short*)malloc((filterorder+1) * sizeof(signed short));
        if(newfir==NULL)  
        {
            return 0;
        }
        for(k=0;k<len;k++)  
        {
            newfir[k]=coefs[k] * 8191.0;
        }
    }  
    return (signed short)reacc;
}
3.74 Zoelzer biquad filters

- **Author or source:** Udo Zoelzer: Digital Audio Signal Processing (John Wiley & Sons, ISBN 0 471 97226 6), Chris Townsend
- **Type:** biquad IIR
- **Created:** 2002-01-17 02:13:13

Listing 121: notes

Here’s the formulas for the Low Pass, Peaking, and Low Shelf, which should cover the basics. I tried to convert the formulas so they are little more consistent. Also, the Zolzer low pass/shelf formulas didn’t have adjustable Q, so I added that for consistency with Roberts formulas as well. I think someone may want to check that I did it right.

------------- Chris Townsend
I mistranscribed the low shelf cut formulas. Hopefully this is correct. Thanks to James McCartney for noticing.
------------- Chris Townsend

Listing 122: code

```
omega = 2*PI*frequency/sample_rate
K=tan(omega/2)
Q=Quality Factor
V=gain

LPF:  b0 = K^2
      b1 = 2*K^2
      b2 = K^2
      a0 = 1 + K/Q + K^2
      a1 = 2*(K^2 - 1)
      a2 = 1 - K/Q + K^2

peakingEQ:
      boost:
        b0 = 1 + V*K/Q + K^2
        b1 = 2*(K^2 - 1)
        b2 = 1 - V*K/Q + K^2
        a0 = 1 + K/Q + K^2
        a1 = 2*(K^2 - 1)
        a2 = 1 - K/Q + K^2
```
### 3.74.1 Comments

- **Date:** 2002-04-11 10:33:20
- **By:** moc.oohay@bdorezlangis

I get a different result for the low-shelf boost with parametric control. Zolzer builds his low shelf from a pair of poles and a pair of zeros at:

- **poles:** \( Q(-1 + j) \)
- **zeros:** \( \sqrt{V}Q(-1 + j) \)

Where (in the book) \( Q=1/\sqrt{2} \)

So,

\[
H(s) = \left( s^{2} + 2\sqrt{V}Qs + 2VQ^{2} \right) /
\left( s^{2} + 2Qs + 2Q^{2} \right)
\]

If you analyse this in terms of:

\[ H(s) = \text{LPF}(s) + 1 \]

it sort of falls apart, as we've gained a zero in the LPF. (as does zolzer)

Then, if we bilinear transform that, we get:

\[
a0 = 1 + 2\sqrt{V}QK + 2VQ^{2}K^{2}
\]
\[
a1 = 2(2VQ^{2}K^{2} - 1)
\]
\[
a2 = 1 - 2\sqrt{V}QK + 2VQ^{2}K^{2}
\]
\[
b0 = 1 + 2QK + 2Q^{2}K^{2}
\]
\[
b1 = 2(2Q^{2}K^{2} - 1)
\]
\[
b2 = 1 - 2QK + 2Q^{2}K^{2}
\]
H(z) = \frac{a0z^2 + a1z + a2}{b0z^2 + b1z + b2}

Which, I think, is right...

Dave.

- **Date**: 2002-04-13 08:14:38
  - **By**: moc.oohay@bdorezlangis

Very sorry, I interpreted Zolzer's s-plane poles as z-plane poles. Too much digital stuff.

After getting back to grips with s-plane maths :) and much graphing to test that it's right, I still get slightly different results.

\begin{align*}
b0 &= 1 + \sqrt{V} \cdot K/Q + V \cdot K^2 \\
b1 &= 2 \cdot (V \cdot K^2 - 1) \\
b2 &= 1 - \sqrt{V} \cdot K/Q + V \cdot K^2 \\
a0 &= 1 + K/Q + K^2 \\
a1 &= 2 \cdot (K^2 - 1) \\
a2 &= 1 - K/Q + K^2
\end{align*}

The way the filter works is to have two poles on a unit circle around the origin in the s-plane, and two zeros that start at the poles at V0=1, and move outwards. The above co-efficients represent that. Chris's original results put the poles in the right place, but put the zeros at the location where the poles would be if they were butterworth, and move out from there - yielding some rather strange results...

But I've graphed that extensively, and it works fine now :)

Dave.

- **Date**: 2005-01-17 07:21:21
  - **By**: asynth(at)io(dot)com

Once you divide through by a0, the Zoelzer LPF gives coefficient values that are identical to the RBJ LPF.

This one is a cheaper formulation because there is only one transcendental function - call (tan) instead of two (sin, cos) for RBJ.

-- james mccartney

- **Date**: 2005-01-18 02:33:04
  - **By**: asynth(at)io(dot)com

Actually, sin and cos are pretty cheap when done via taylor series, so I take that last bit back.

-- james mccartney

- **Date**: 2005-05-04 14:23:01
  - **By**: se.arret@htrehgraknu

Anybody know the formulation for Band Pass, High Pass and High shelf ?

- **Date**: 2005-05-04 16:57:08
  - **By**: ed.luofsruoivas@naitsrhC
Have a look at tobybear's Filter Explorer: http://www.tobybear.de/p_filterexp.html

Usually you can derivate a highpass from a lowpass and vice versa.

• **Date:** 2005-05-05 11:15:46  
  **By:** se.arret@htrehgraknu

Thanks Christian, lots of things solved now !!

Unfortunately, Bandpass continues missing. I don't know if it's really possible to obtain a Bandpass filter out of this ( my filters math knowlegde isn't so deep), but i asked for it because would be nice to have the complete set of Zoeltzer filters

I supose thta YOU can derive one from another as you stated, but this is not my case.

Anyway, lots of thanks for your help

• **Date:** 2005-05-20 21:04:10  
  **By:** moc.noitanigamiodua@jbr

>Actually, sin and cos are pretty cheap when done via taylor series, so I take that last bit back
---
also, James, the sin() and cos() are less of a problem for implementing in a fixed-point context. tan() is a bitch.

r b-j

• **Date:** 2006-06-27 17:32:53  
  **By:** uh.etle.fni@yfoocs

<table>
<thead>
<tr>
<th>Highpass version:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HPF:</strong></td>
</tr>
<tr>
<td>( b_0 = 1 - K^2 )</td>
</tr>
<tr>
<td>( b_1 = -2*K^2 )</td>
</tr>
<tr>
<td>( b_2 = 1 - K^2 )</td>
</tr>
<tr>
<td>( a_0 = 1 + K/Q + K^2 )</td>
</tr>
<tr>
<td>( a_1 = 2*(K^2 - 1) )</td>
</tr>
<tr>
<td>( a_2 = 1 - K/Q + K^2 )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bandpass version:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BPF1</strong> (peak gain = Q):</td>
</tr>
<tr>
<td>( b_0 = K )</td>
</tr>
<tr>
<td>( b_1 = 0 )</td>
</tr>
<tr>
<td>( b_2 = -K )</td>
</tr>
<tr>
<td>( a_0 = 1 + K/Q + K^2 )</td>
</tr>
<tr>
<td>( a_1 = 2*(K^2 - 1) )</td>
</tr>
<tr>
<td>( a_2 = 1 - K/Q + K^2 )</td>
</tr>
</tbody>
</table>

| BPF2 (peak gain = zero):           |
| \( b_0 = K/Q \)                    |

(continues on next page)
b1 = 0
b2 = -K/Q
a0 = 1 + K/Q + K^2
a1 = 2*(K^2 - 1)
a2 = 1 - K/Q + K^2

Couldn't figure out the notch coeffs yet...

-- peter schoffhauzer

- **Date:** 2006-06-28 00:07:25
- **By:** uh.etle.fni@yfoocs

Got the notch too finally ;)

Notch

b0 = 1 + K^2
b1 = 2*(K^2 - 1)
b2 = 1 + K^2
a0 = 1 + K/Q + K^2
a1 = 2*(K^2 - 1)
a2 = 1 - K/Q + K^2

The HPF seems to have an error in the previous post. The correct HPF version:

HPF:
b0 = 1 + K/Q
b1 = -2
b2 = 1 - K/Q
a0 = 1 + K/Q + K^2
a1 = 2*(K^2 - 1)
a2 = 1 - K/Q + K^2

Hopefully it works now. Anyone confirms?
The set is complete now. Happy coding :)

-- peter schoffhauzer

- **Date:** 2006-06-28 20:22:23
- **By:** uh.etle.fni@yfoocs

For sake of completeness ;)

Allpass:

b0 = 1 - K/Q + K^2
b1 = 2*(K^2 - 1)
b2 = 1
a0 = 1 + K/Q + K^2
a1 = 2*(K^2 - 1)
a2 = 1 - K/Q + K^2

-- peter schoffhauzer

- **Date:** 2006-06-30 00:59:04
What was wrong with the first version:

HPF:
\[
\begin{align*}
b_0 &= 1 - K^2 \\
b_1 &= -2 (!!) \\
b_2 &= 1 - K^2 \\
a_0 &= 1 + K/Q + K^2 \\
a_1 &= 2(K^2 - 1) \\
a_2 &= 1 - K/Q + K^2
\end{align*}
\]

you only have to delete \( K^2 \). In the other version the cutoff frequency depends on \( Q \)!

Also the Allpass should be symmetrical:

\[
\begin{align*}
b_0 &= 1 - K/Q + K^2 \\
b_1 &= 2(K^2 - 1) \\
b_2 &= 1 + K/Q + K^2 (!!) \\
a_0 &= 1 + K/Q + K^2 \\
a_1 &= 2(K^2 - 1) \\
a_2 &= 1 - K/Q + K^2
\end{align*}
\]

If you divide by \( a_0 \) (to reduce a coefficient) \( b_2 \) will get 1 of course.

Ah, thanks for the allpass correction! I used TobyBear Filter Explorer, where I see only 5 coeffs instead of six, that was the source of confusion.

However, the highpass is still not perfect. In my 2nd version, the cutoff is not dependent of \( Q \), because the cutoff is determined by the pole positions, which are set by \( a_1 \) and \( a_2 \). Instead, as the zero positions change according to \( Q \), the cutoff slope varies. So it has an interesting behaviour, for low \( Q \)s it has a 6dB/Oct slope, for infinite resonance, the slope becomes 12dB/Oct.

However, with your suggested HPF version, I got only a strange highshelf-like filter.

So here is my 3rd version, which I hope works fine:

HPF:
\[
\begin{align*}
b_0 &= 1 \\
b_1 &= -2 \\
b_2 &= 1 \\
a_0 &= 1 + K/Q + K^2 \\
a_1 &= 2(K^2 - 1) \\
a_2 &= 1 - K/Q + K^2
\end{align*}
\]

Quite simple isn't it? ;)

Cheers

Peter
Tan can also be approximated using Taylor series (approx sin and cos with Taylor, \(\tan(x) = \frac{\sin(x)}{\cos(x)}\)) well, there's a heavy division that you can't get rid of.

.. well, that's not true in all cases. The advantage of \(\tan()\) is that you can use \(\tan(x) \approx x\) when \(x\) is small. So you can get coefficients without any transcendental functions for low and middle frequencies.

Peter

I think it is possible to get a Taylor serie of the \(\tan()\) function ? And it is possible to do a polynomial division of the sin & cos series to get rid of the division, you get the same thing...

Yes, there is a Taylor serie for \(\tan(x)\), but near pi/2, it converges very slowly, so high frequencies is a problem again.

Let's suppose you approximate \(\sin(x)\) with \(x - x^3/6 + x^5/120\), and \(\cos(x)\) with \(1 - x^2/2 + x^4/24\).

So \(\tan(x)\) would be

\[
\frac{x - x^3/6 + x^5/120}{1 - x^2/2 + x^4/24}
\]

How do you do a polynomial division for that?

Here's also a highshelf filters for completeness:

\[
K := \tan(fW0*0.5);
t2 := ;
t3 := K*fQ; t6 := (V);
t5 := sqrt(2*V)*K;
t1 := 1/;
\]

\[
b0 = (K*K + \sqrt{2*V})*K + V);
b1 = 2*(K*K - V);
b2 = (K*K - \sqrt{2*V})*K + V);
a0 = (K*K + K*fQ + 1);
a1 = -2*(K*K - 1);
a2 = -(K*K - K*fQ + 1);
\]
4.1 2 Wave shaping things

- **Author or source:** Frederic Petrot
- **Created:** 2002-03-20 01:12:01

Listing 1: notes

```
Makes nice saturations effects that can be easily computed using cordic
First using a atan function:
y1 using k=16
max is the max value you can reach (32767 would be a good guess)
Harmonics scale down linealy and not that fast

Second using the hyperbolic tangent function:
y2 using k=2
Harmonics scale down linealy very fast
```

Listing 2: code

```
y1 = (max>>1) * atan(k * x/max)
y2 = max * th(x/max)
```

4.1.1 Comments

- **Date:** 2006-06-26 01:12:05
- **By:** ten.labolgcbs@rohtlabi

```
Why are you calling decompiled script code?BALTHOR
```
Yeah, atan & tanh, and really any sigmoid function, can create decent overdrive sound→if oversampled and eq’ed properly. I’ve used them in some of my modelers w/ good results.→For a more realistic sound, two half-wave soft clippers in series will add duty-cycle→modulation and a transfer curve similar to 3/2 tube power curve. Something like: if(x < 0) y = -A * tanh(B * x); followed immediately by: if(y >= 0) y = -A * tanh(B *→-y); Don’t forget to invert each output (-A * tanh). Coefficients A & B are left to the→designer.

I got this technique after reading a paper discussing a hardware implementation of→this type of circuit used in Carvin amps, here: http://www.trueaudio.com/at_eetjlm.htm→(original link at www.simulanalog.org)

4.2 Alien Wah

- **Author or source:** Nasca Octavian Paul (or.liame@acsanluap)
- **Created:** 2002-02-10 12:51:57
- **Linked files:** alienwah.c

**Listing 3: notes**

I found this algorithm by "playing around" with complex numbers. Please email me your opinions about it.

Paul.

4.3 Band Limited PWM Generator

- **Author or source:** rf.liamtoh@57eninres_luap
- **Type:** PWM generator
- **Created:** 2006-05-11 19:09:04

**Listing 4: notes**

This is a commented and deobfuscated version of my 1st April fish. It is based on a tutorial code by Thierry Rochebois. I just translated and added comments.

Regards,

Paul Sernine.
// SelfPMpwm.cpp

// Antialised PWM oscillator

// This program generates a 44100Hz-raw-PCM-mono-wavefile.
// It is based on Tomisawa's self-phase-modulated sinewave generators.
// Rochebois uses a common phase accumulator to feed two half-Tomisawa-
// oscillators. Each half-Tomisawa-oscillator generates a bandlimited
// sawtooth (band limitation depending on the feedback coeff B).
// These half oscillators are phase offseted according to the desired
// pulse width. They are finally combined to obtain the PW signal.
// Note: the anti-"hunting" filter is a critical feature of a good
// implementation of Tomisawa's method.

#include <math.h>
#include <stdio.h>
const float pi=3.14159265359f;

int main()
{
  float freq,dphi;  //\< frequency (Hz) and phase increment(rad/sample)
  float dphif=0;  //\< filtered (anti click) phase increment
  float phi=-pi;  //\< phase
  float Y0=0,Y1=0;  //\< feedback memories
  float PW=pi;  //\< pulse width ]0,2pi[ 
  float B=2.3f;  //\< feedback coef 
  FILE *f=fopen("SelfPMpwm.pcm","wb");
  // sequence ('a'=mi=E)
  // you can edit this if you prefer another melody.
  static char seq[]="aiakahiaihiaiakahiaiakahiafahad";  //\< sequence
  int note=sizeof(seq)-2;  //\< note number in the sequence
  int octave=0;  //\< octave number
  float env,envf=0;  //\< envelopped and filtered envelopped
  for(int ns=0;ns<8*(sizeof(seq)-1)*44100/6;ns++)
  {
    //waveform control --------------------------------------------------
    //Frequency
    //freq=27.5f*powf(2.0f,8*ns/(8*30*44100.0f/6)); //sweep
    freq=27.5f*powf(2.0f,octave+seq[note]-"a"-5)/12.0f;  
    //freq+=1.0f+0.01f*sinf(ns*0.0015f)); //vibrato
    dphi=freq*(pi/22050.0f);  // phase increment
    dphif+=0.1f*(dphi-dphif);  //notes and enveloppe trigger
    if((ns%44100/6)==0)
    {
      note++;
      if(note>=(sizeof(seq)-1))// sequence loop
      {
        note=0;
        octave++;
      }
      env=1;  //env set
      PW=pi*(0.4+0.5f*(rand()%1000)/1000.0f);  //random PW
    }
  }
}
```c
56  
57  env*=0.9998f;       // exp enveloppe
58  envf+=0.1f*(env-envf);    // de-clicked enveloppe
59  B=1.0f;                // feedback coefficient
60  //try this for a nice bass sound:
61  //B*=envf*envf;        // feedback controlled by enveloppe
62  B*=2.3f*(1-0.0001f*freq);  // feedback limitation
63  if(B<0) 
64      B=0;
65
66  //waveform generation -----------------------------------------------
67  //Common phase
68  phi+=dphif;                // phase increment
69  if(phi>=pi) 
70      phi=2*pi;        // phase wrapping
71
72  // "phase"  half Tomisawa generator 0
73  // B*Y0 -> self phase modulation
74  float out0=cosf(phi+B*Y0); // half-output 0
75  Y0=0.5f*(out0+Y0);         // anti "hunting" filter
76
77  // "phase+PW" half Tomisawa generator 1
78  // B*Y1 -> self phase modulation
79  // PW -> phase offset
80  float out1=cosf(phi+B*Y1+PW); // half-output 1
81  Y1=0.5f*(out1+Y1);         // anti "hunting" filter
82
83  // combination, enveloppe and output
84  short s=short(15000.0f*(out0-out1)*envf);
85  fwrite(&s,2,1,f);          // file output
86  }
87  fclose(f);
88  return 0;
89  }

4.3.1 Comments

- **Date:** 2006-05-23 09:31:44
- **By:** —

Did anyone try this?

How is the antialiasing compared to applying phaserror between two oscs in zerocross, one aliasing the other not (but pitcherror).

Best Regards,
Arif Ove Karlsen.

- **Date:** 2010-02-04 08:37:45
- **By:** ude.notecnirp.inmula@esornep
The implementation certainly produces aliased waveforms -- they are glaring on a spectrogram at 

-60dB and faint at -30dB. But it is a remarkably efficient algorithm. The aliasing can be mitigated somewhat by using a smaller feedback coefficient.

### 4.4 Bit quantization/reduction effect

- **Author or source:** Jon Watte
- **Type:** Bit-level noise-generating effect
- **Created:** 2002-04-12 13:53:03

Listing 6: notes

This function, run on each sample, will emulate half the effect of running your signal through a Speak-N-Spell or similar low-bit-depth circuitry.

The other half would come from downsampling with no aliasing control, i.e., replicating every N-th sample N times in the output signal.

Listing 7: code

```c
1 short keep_bits_from_16( short input, int keepBits ) {
    return (input & (-1 << (16-keepBits)));
}
```

### 4.4.1 Comments

- **Date:** 2005-05-30 23:01:56
- **By:** moc.liamg@codlli

//I add some code to prevent offset.

// Code :
```c
short keep_bits_from_16( short input, int keepBits ) {
    short prevent_offset = static_cast<unsigned short>(-1) >> keepBits+1;
    input &= (-1 << (16-keepBits)));
    return input + prevent_offset
}
```

### 4.5 Class for waveguide/delay effects

- **Author or source:** moc.xinortceletrams@urugra
- **Type:** IIR filter
- **Created:** 2002-04-23 06:46:34
Flexible-time, non-sample quantized delay, can be used for stuff like waveguide → synthesis
or time-based (chorus/flanger) fx.

MAX_WG_DELAY is a constant determining MAX buffer size (in samples)

```cpp
class cwaveguide
{
  public:
    cwaveguide() { clear(); }
    virtual ~cwaveguide() {};

    void clear()
    {
      counter = 0;
      for(int s = 0; s < MAX_WG_DELAY; s++)
        buffer[s] = 0;
    }

    inline float feed(float const in, float const feedback, double const delay)
    {
      // calculate delay offset
      double back = (double)counter - delay;

      // clip lookback buffer-bound
      if(back < 0.0)
        back = MAX_WG_DELAY + back;

      // compute interpolation left-floor
      int const index0 = floor_int(back);

      // compute interpolation right-floor
      int index_1 = index0 - 1;
      int index1 = index0 + 1;
      int index2 = index0 + 2;

      // clip interp. buffer-bound
      if(index_1 < 0) index_1 = MAX_WG_DELAY - 1;
      if(index1 >= MAX_WG_DELAY) index1 = 0;
      if(index2 >= MAX_WG_DELAY) index2 = 0;

      // get neighbour samples
      float const y_l = buffer[index_1];
      float const y0 = buffer[index0];
      float const y1 = buffer[index1];
      float const y2 = buffer[index2];

      // compute interpolation x
      float const x = (float)back - (float)index0;

      // calculate
      float const c0 = y0;
      float const c1 = 0.5f * (y1 - y_l);
      (continues on next page)
```
float const c2 = y_1 - 2.5f*y0 + 2.0f*y1 - 0.5f*y2;
float const c3 = 0.5f*(y2-y_1) + 1.5f*(y0-y1);

float const output=(((c3+x+c2)*x+c1)*x+c0);

// add to delay buffer
buffer[counter]=in+output*feedback;

// increment delay counter
counter++;
void compress(
    float* wav_in, // signal
    int n, // N samples
    double threshold, // threshold (percents)
    double slope, // slope angle (percents)
    int sr, // sample rate (smp/sec)
    double tla, // lookahead (ms)
    double twnd, // window time (ms)
    double tatt, // attack time (ms)
    double trel // release time (ms)
) {

typedef float stereodata[2];
stereodata* wav = (stereodata*) wav_in; // our stereo signal
threshold *= 0.01; // threshold to unity (0...1)
slope *= 0.01; // slope to unity
tla *= 1e-3; // lookahead time to seconds
twnd *= 1e-3; // window time to seconds
tatt *= 1e-3; // attack time to seconds
trel *= 1e-3; // release time to seconds

    // attack and release "per sample decay"
double att = (tatt == 0.0) ? (0.0) : exp (-1.0 / (sr * tatt));
double rel = (trel == 0.0) ? (0.0) : exp (-1.0 / (sr * trel));

    // envelope
double env = 0.0;

    // sample offset to lookahead wnd start
    int lhsmp = (int) (sr * tla);

    // samples count in lookahead window
    int nrms = (int) (sr * twnd);

    // for each sample...
    for (int i = 0; i < n; ++i) {
        // now compute RMS
        double summ = 0;

        // for each sample in window
        for (int j = 0; j < nrms; ++j) {
            int lki = i + j + lhsmp;
            double smp;

            // if we in bounds of signal?
            // if so, convert to mono
            if (lki < n)
                smp = 0.5 * wav[lki][0] + 0.5 * wav[lki][1];
            else
                smp = 0.0; // if we out of bounds we just get zero in smp

            summ += smp * smp; // square em..
        }
    }
}(continues on next page)
\begin{verbatim}
  double rms = sqrt (sum / nrms);  // root-mean-square

  // dynamic selection: attack or release?
  double theta = rms > env ? att : rel;

  // smoothing with capacitor, envelope extraction...
  // here be aware of pIV denormal numbers glitch
  env = (1.0 - theta) * rms + theta * env;

  // the very easy hard knee 1:N compressor
  double gain = 1.0;
  if (env > threshold)
    gain = gain - (env - threshold) * slope;

  // result - two hard kneed compressed channels...
  float leftchannel = wav[i][0] * gain;
  float rightchannel = wav[i][1] * gain;
\end{verbatim}

4.6.1 Comments

- **Date:** 2004-06-10 21:31:18
- **By:** moc.regnimmu@psd-cisum

My comments:

A rectangular window is not physical. It would make more physical sense, and be a lot cheaper, to use a 1-pole low pass filter to do the RMS averaging. A 1-pole filter means you can lose the bounds checks in the RMS calculation.

It does not make sense to convert to mono before squaring, you should square each channel separately and then add them together to get the total signal power.

You might also consider whether you even need any filtering other than the attack/release filter. You could modify the attack/release rates appropriately, place the sqrt after the attack/release, and lose the rms averager entirely.

I don't think your compressor actually approaches a linear slope in the decibel domain. You need a gain law more like

\[
  \text{double gain = exp(max(0.0,log(env)-log(thresh))*slope);}
\]

Sincerely,
Frederick Umminger

- **Date:** 2004-07-30 05:31:36
To sum up (and maybe augment) the RMS calculation method, this question and answer may be of use...

***********

music-dsp@shoko.calarts.edu writes:
I am looking at gain processing algorithms. I haven't found much in the way of reference material on this, any pointers? In the level detection code, if one is doing peak detection, how many samples does one generally average over (if at all)? What kind of window size for RMS level detection?
Is the RMS level detection generally the same algo. as peak, but with a bigger window?

The peak detector can be easily implemented as a one-pole low pass, you just have to modify it, so that it tracks the peaks and gently falls down afterwards. RMS detection is done by squaring the input signal, averaging with a lowpass and taking the root afterwards.

Hope this helps.

Kind regards

Steffan Diedrichsen
DSP developer
emagic GmbH

***********

I found the thread by searching old [music-dsp] forum posts. Hope it helps.

How would you use a 1-pole lowpass filter to do RMS averaging? How do you pick a coefficient to use?

Use \( x = \exp(-1/d) \), where \( d \) is the time constant in samples. A 1 pole IIR filter has an infinite impulse response, so instead of window width, this coeff determines the time when the impulse response reaches 36.8% of the original value.

Coeffs:
\[
\begin{align*}
a0 &= 1.0 - x; \\
b1 &= -x;
\end{align*}
\]

Loop:
\[
\text{out} = a0 \times \text{in} - b1 \times \text{tmp};
\]
tmp = out;

-- peter schoffhauzer

- Date: 2008-11-20 08:30:28
- By: moc.361@oatuxt

I am looking at gain processing algorithms.
There are too such sentences:

double att = (tatt == 0.0) ? (0.0) : exp (-1.0 / (sr * tatt));
double rel = (trel == 0.0) ? (0.0) : exp (-1.0 / (sr * trel));

can you tell me something about the exp (-1.0 / (sr * tatt))?  

New day ~

thanks

- Date: 2010-04-28 15:12:47
- By: moc.liamg@enin.kap

This is a useful reference, however the RMS calculations are pretty dodgy. Firstly, there is a bug where is calculates the number of samples to use:

int sr, // sample rate (smp/sec)
...
double twnd, // window time (ms)
...
// samples count in lookahead window
int nrms = (int) (sr * twnd);

The units are mixed when calculating the number of samples in the RMS window. The window time needs to be converted to seconds before multiplying by the sample rate.

As others have mentioned the RMS calculation is also really expensive, and in my tests I found it was pretty inaccurate unless you use a LOT of samples (you basically need a (sample rate)/2 window of samples in your RMS calculation to accurately measure the power of all frequencies).

I ended up using the 1 pole low pass filter approach suggested here, and it is a good cheap approximation of power. I did, however, end up multiplying it by root(2) (the RMS of a sine wave, which seemed like a reasonable normalisation factor) in order to get it between 0 and -1, which is a more useful range.

Another slightly more accurate way to calculate the RMS without iterating over and entire window for each sample is to keep a running total of the squared sums of samples.

for( i = 0; i < NumSamples; ++i )

(continues on next page)
Calculating the power in the signal is definitely the awkward part of this DSP!

4.7 Decimator

- **Author or source:** ed.bcw@raeybot
- **Type:** Bit-reducer and sample&hold unit
- **Created:** 2002-11-25 18:13:49

Listing 12: notes

This is a simple bit and sample rate reduction code, maybe some of you can use it. The parameters are bits (1..32) and rate (0..1, 1 is the original samplerate). Call the function like this:
y=decimate(x);

A VST plugin implementing this algorithm (with full Delphi source code included) can be downloaded from here:
http://tobybear.phreque.com/decimator.zip

Comments/suggestions/improvements are welcome, send them to: tobybear@web.de

Listing 13: code

```pascal
// bits: 1..32
// rate: 0..1 (1 is original samplerate)

********** Pascal source **********
var m:longint;
    y,cnt,rate:single;

// call this at least once before calling
// decimate() the first time
procedure setparams(bits:integer;shrate:single);
begin
    m:=1 shl (bits-1);
    cnt:=1;
    rate:=shrate;
end;
```

(continues on next page)
function decimate(i:single):single;
begin
  cnt:=cnt+rate;
  if (cnt>1) then
  begin
    cnt:=cnt-1;
    y:=round(i*m)/m;
  end;
  result:=y;
end;

Listing 14: code

int bits=16;
float rate=0.5;

long int m=1<<(bits-1);
float y=0,cnt=0;

float decimate(float i)
{
  cnt+=rate;
  if (cnt>=1)
  {
    cnt=1;
    y=(long int)(i*m)/(float)m;
  }
  return y;
}

4.7.1 Comments

  • Date: 2002-12-03 12:44:42
  • By: moc.noicratse@ajelak

Nothing wrong with that, but you can also do fractional-bit-depth decimations, allowing smooth degradation from high bit depth to low and back:

// something like this -- this is completely off the top of my head
// precalculate the quantization level
float bits; // effective bit depth
float quantum = powf( 2.0f, bits );

// per sample
y = floorf( x * quantum ) / quantum;

  • Date: 2003-02-14 20:04:36
  • By: es.yarps@fek.rd

4.7. Decimator
it looks to me like the c-line

long int m=1<<(bits-1);

doesn't give the correct number of quantisation levels if the number of levels is _
→defined as
2^bits. if bits=2 for instance, the above code line returns a bit pattern of 10 (3) _
→and not
11 (2^2) like one would expect.

please, do correct me if im wrong.

/heatrof

4.8 Delay time calculation for reverberation

• Author or source: Andy Mucho

• Created: 2002-01-17 02:19:54

Listing 15: notes

This is from some notes I had scribbled down from a while back on
automatically calculating diffuse delays. Given an intial delay line gain
and time, calculate the times and feedback gain for numlines delay lines..

Listing 16: code

```c
int numlines = 8;
float t1 = 50.0; // d0 time
float g1 = 0.75; // d0 gain
float rev = -3*t1 / log10 (g1);

for (int n = 0; n < numlines; ++n)
{
    float dt = t1 / pow (2, (float) (n) / numlines));
    float g = pow (10, -((3*dt) / rev));
    printf ("d%d t=%.3f g=%.3f
", n, dt, g);
}
```

The above with t1=50.0 and g1=0.75 yields:

d0 t=50.000 g=0.750
d1 t=45.850 g=0.768
d2 t=42.045 g=0.785
d3 t=38.555 g=0.801
d4 t=35.355 g=0.816
d5 t=32.421 g=0.830
d6 t=29.730 g=0.843
d7 t=27.263 g=0.855

To go more diffuse, chuck in dual feedback paths with a one cycle delay
effectively creating a phase-shifter in the feedback path, then things get
more exciting.. Though what the optimum phase shifts would be I couldn't

(continues on next page)
4.9 Dynamic convolution

- **Author or source:** Risto Holopainen
- **Type:** a naive implementation in C++
- **Created:** 2005-06-05 22:05:19

Listing 17: notes

This class illustrates the use of dynamic convolution with a set of IRs consisting of exponentially damped sinusoids with glissando. There's lots of things to improve for efficiency.

Listing 18: code

```cpp
#include <cmath>

class dynaconv

public:
    // sr=sample rate, cf=resonance frequency,
    // dp=frq sweep or nonlinearity amount
    dynaconv(const int sr, float cf, float dp);
    double operator()(double);

private:
    // steps: number of amplitude regions, L: length of impulse response
    enum {steps=258, dv=steps-2, L=200};
    double x[L];
    double h[steps][L];
    int S[L];
    double conv(double *x, int d);
};
dynaconv::dynaconv(const int sr, float cfr, float dp)
{
    for(int i=0; i<L; i++)
        x[i] = S[i] = 0;
    
    double sc = 6.0/L;
    double frq = twopi*cfr/sr;
    // IR's initialised here.
    // h[0] holds the IR for samples with lowest amplitude.
    for(int k=0; k<steps; k++)
        {
            double sum = 0;
            double theta=0;
```
36 double w;
37 for(int i=0; i<L; i++)
{
    // IR of exp. decaying sinusoid with glissando
    h[k][i] = sin(theta)*exp(-sc*i);
    w = (double)i/L;
    theta += frq*(1 + dp*w*(k - 0.4*steps)/steps);
    sum += fabs(h[k][i]);
}

double norm = 1.0/sum;
for(int i=0; i<L; i++)
    h[k][i] *= norm;
}

double dynaconv::operator()(double in)
{
    double A = fabs(in);
    double a, b, w, y;
    int sel = int(dv*A);

    for(int j=L-1; j>0; j--)
    {
        x[j] = x[j-1];
        S[j] = S[j-1];
    }
    x[0] = in;
    S[0] = sel;

    if(sel == 0)
        y = conv(x, 0);
    else if(sel > 0)
    {
        a = conv(x, 0);
        b = conv(x, 1);
        w = dv*A - sel;
        y = w*a + (1-w)*b;
    }

    return y;
}

double dynaconv::conv(double *x, int d)
{
    double y=0;
    for(int i=0; i<L; i++)
        y += x[i] * h[S[i]+d][i];
    return y;
}

4.9.1 Comments

- Date: 2005-06-06 08:26:12
You can speed things up by:

a) rewriting the "double dynaconv::conv(double *x, int d)" function using Assembler, SSE and 3DNow routines.

b) instead of this

"else if(sel > 0)
{
 a = conv(x, 0);
 b = conv(x, 1);
 w = dv*A - sel;
 y = w*a + (1-w)*b;
}"

you can create a temp IR by fading the two impulse responses before convolution. Then you'll only need ONE CPU-expensive-convolution.

c) this one only works with the upper half wave!

d) only nonlinear components can be modeled. For time-variant modeling (compressor/limiter) you'll need more than this.

e) the algo is protected by a patent. But it's easy to find more efficient ways, which aren't protected by the patent.

With my implementation i can fold up to 4000 Samples (IR) in realtime on my machine.

Correction to d:

d) only time invariant nonlinear components can be modeled; and then adequate memory must be used.
Compressors/Limiters can be modelled, but the memory requirements will be somewhat frightening.
Time-variant systems, such as flangers, phasors, and sub-harmonic generators (i.e. anything with an internal clock) will need more than this.

4.10 ECE320 project: Reverberation w/ parameter control from PC

- Author or source: Brahim Hamadicharef (project by Hua Zheng and Shobhit Jain)
- Created: 2002-05-24 13:34:45
- Linked files: rev.txt.
4.11 Early echo’s with image-mirror technique

- **Author or source:** Donald Schulz
- **Created:** 2002-02-11 17:35:48
- **Linked files:** early_echo.c.
- **Linked files:** early_echo_eng.c.

Donald Schulz's code for computing early echoes using the image-mirror method. There's an English and a German version.

4.12 Fold back distortion

- **Author or source:** ed.bpu@eriflleh
- **Type:** distortion
- **Created:** 2005-05-28 19:11:06

A simple fold-back distortion filter. If the signal exceeds the given threshold-level, it mirrors at the positive/negative threshold-border as long as the signal lies in the legal range (-threshold..+threshold).

There is no range limit, so inputs don't need to be in -1..+1 scale. Threshold should be >0 depending on use (low thresholds) it makes sense to rescale the input to full amplitude.

Performs approximately the following code (just without the loop):

```c
while (in>threshold || in<-threshold)
{
    // mirror at positive threshold
    if (in>threshold) in= threshold - (in-threshold);
    // mirror at negative threshold
    if (in<-threshold) in= -threshold + (-threshold-in);
}
```
4.13 Guitar feedback

• Author or source: Sean Costello
• Created: 2002-02-10 20:01:07

It is fairly simple to simulate guitar feedback with a simple Karplus-Strong algorithm (this was described in a CMJ article in the early 90's):

Run the output of the Karplus-Strong delay lines into a nonlinear shaping function for distortion (i.e. 6 parallel delay lines for 6 strings, going into 1 nonlinear shaping function that simulates an overdriven amplifier, fuzzbox, etc.);

Run part of the output into a delay line, to simulate the distance from the amplifier to the "strings";

The delay line feeds back into the Karplus-Strong delay lines. By controlling the amount of the output fed into the delay line, and the length of the delay line, you can control the intensity and pitch of the feedback note.

4.13.1 Comments

• Date: 2016-06-10 19:59:36
• By: moc.liamg@1a7102egroj

'NO esta completo falta algo, no se, si es el filtro biquad

Public Function karplustrong_b1(PNumSamples As Long) As Integer()
Dim x() As Single
Dim y() As Single
Dim n As Long
Dim Num As Long

(continues on next page)
Dim ArrResp() As Integer
Dim C As Single
Dim Fs As Long
Dim fP As Single
Dim amplitud As Long
Dim i As Long
Dim valor As Single
Dim Ind1 As Long
Dim Ind2 As Long
Dim suma As Single
Dim media As Single
Dim valorsigno As Single

Fs = 44100
fP = 400 '400hz pitch frequency

'Num = (Fs / Fp)

ReDim x(PNumSamples)
ReDim y(PNumSamples)

'generar numeros aleatorios rango 0 a 1
'iniciar numeros aleatorios
Randomize
suma = 0
For i = 0 To PNumSamples
    valor = Rnd * 1 - 0.5
    'valorsigno = Rnd * 1
    'If valorsigno > 0.5 Then valor = -valor
    x(i) = valor
    suma = suma + valor
Next

media = suma / PNumSamples
'media = 1

'calcular la media y dividir
For i = 0 To PNumSamples
    valor = x(i)
    x(i) = valor / media
Next

Num = PNumSamples - 1
C = 0.5

For n = 0 To PNumSamples - 1
    'Ind1 = Abs(n - Num)
    'Ind2 = Abs(n - (Num + 1))
\begin{verbatim}
Ind2 = Abs((n))
Ind2 = Abs((n + 1) Mod Num) / 2
y(n) = x(n) + C * (y(Ind1) + y(Ind2))
Next

ReDim ArrResp(NumSamples)
amplitud = 1000
For i = 0 To Num
    ArrResp(i) = RangoInteger(y(i) * amplitud)
Next
karplustrong_b1 = ArrResp
End Function
\end{verbatim}

### 4.14 Lo-Fi Crusher

- **Author or source:** David Lowenfels
- **Type:** Quantizer / Decimator with smooth control
- **Created:** 2003-04-01 15:34:40

**Listing 25: notes**

Yet another bitcrusher algorithm. But this one has smooth parameter control.

Normfreq goes from 0 to 1.0; (freq/samplerate)
Input is assumed to be between 0 and 1.
Output gain is greater than unity when bits < 1.0;

**Listing 26: code**

```plaintext
function output = crusher( input, normfreq, bits );
    step = 1/2^(bits);
    phasor = 0;
    last = 0;
    for i = 1:length(input)
        phasor = phasor + normfreq;
        if (phasor >= 1.0)
            phasor = phasor - 1.0;
            last = step * floor( input(i)/step + 0.5 ); %quantize
        end
        output(i) = last; %sample and hold
    end
end
```

### 4.14.1 Comments

- **Date:** 2004-06-16 21:10:39
- **By:** moc.liamtoh@132197kk
what's the "bits" here? I tried to run the code, it seems it's a dead loop here, can't figure out why

• **Date:** 2005-10-26 23:25:13
• **By:** df

bits goes from 1 to 16

• **Date:** 2016-03-19 02:47:47
• **By:** moc.liamg@tnemniatretnEsneS2

I'm having trouble with the code as well. Is there something I'm missing?

### 4.15 Lookahead Limiter

• **Author or source:** ed.luosfosruoivas@naitsirhC
• **Type:** Limiter
• **Created:** 2009-11-16 08:45:47

Listing 27: notes

I've been thinking about this for a long time and this is the best I came up with so far.

I might be all wrong, but according to some simulations this looks quite nice (as I want it to be).

The below algorithm is written in prosa. It's up to you to transfer it into code.

Listing 28: code

```
1 Ingredients:
2 ------------
3
4 1 circular buffers (size of the look ahead time)
5 2 circular buffers (half the size of the look ahead time)
6 4 parameters ('Lookahead Time [s]', 'Input Gain [dB]', 'Output Gain [dB]' and 'Release Time [s]')
7 a handfull state variables
8
9 Recipe:
10 -------
11
12 0. Make sure all buffers are properly initialized and do not contain any dirt (pure zeros are what we need).
13
14 For each sample do the following procedure:
15
16 1. Store current sample in the lookahead time circular buffer, for later use (and retrieve the value
```
that falls out as the preliminary 'Output')

2. Find maximum within this circular buffer. This can also be implemented efficiently
→ with an hold
algorithm.

3. Gain this maximum by the 'Input Gain [dB]' parameter

4. Calculate necessary gain reduction factor (=1, if no gain reduction takes place
→ and <1 for any
signal above 0 dBFS)

5. Eventually subtract this value from 1 for a better numerical stability. (MUST BE
→ UNDONE LATER!)

6. Add this gain reduction value to the first of the smaller circular buffers to
→ calculate the short
time sum (add this value to a sum and subtract the value that felt out of the
→ circular buffer).

7. Normalize the sum by dividing it by the length of the circular buffer ([samples] / 2)

8. Repeat step 6 & 7 with this sum in the second circular buffer. The reason for
→ these steps is to
transform dirac impulses to a triangle (dirac → rect → triangle)

9. Apply the release time (release time → release slew rate 'factor' → multiply by
→ that factor) to
the 'Maximum Gain Reduction' state variable

10. Check whether the currently calculated gain reduction is higher than the 'Maximum
→ Gain Reduction'.
If so, replace!

11. Eventually remove (1 - x) from step 5 here

12. Calculate effective gain reduction by the above value gained by input and output
→ gain.

13. Apply this gain reduction to the preliminary 'Output' from step 1

Repeat the above procedure (step 1-13) for all samples!

4.16 Most simple and smooth feedback delay

- Author or source: moc.liamtoh@sishehnyosrpitna
- Type: Feedback delay
- Created: 2003-09-03 12:58:52
4.16.1 Comments

- **Date:** 2003-09-03 13:25:47
  - **By:** moc.liamtoh@sisehtnysorpitna

  // This algo didn't seem to work on testing again, just change:
  // -------------------------------------------------------------------
  Output = DlyBuffer[ i++ ] = Input + (DlyBuffer[ j ] * fFeedback);
  // -------------------------------------------------------------------
  // to
  // ---------------------------------------------------------------
  Output = DlyBuffer[ i ] = Input + (DlyBuffer[ j ] * fFeedback);
  i++;
  // ---------------------------------------------------------------
  // and it will work fine.

- **Date:** 2003-09-08 12:07:22
  - **By:** moc.liamtoh@sisehtnysorpitna

  // Here's a more clear source. both BufferSize and MaxDlyTime are amounts of samples.
  // BufferSize
  // should best be 2*MaxDlyTime to have proper sound.
  // -
  if( i >= BufferSize )
    i = 0;
  j = i - (fDlyTime * MaxDlyTime);
  if( j < 0 )
    j += BufferSize;
  Output = DlyBuffer[ i ] = Input + (DlyBuffer[ j ] * fFeedback);
  i++;
4.17 Most simple static delay

- **Author or source:** moc.liamtoh@sisehtnysorpitna
- **Type:** Static delay
- **Created:** 2003-09-02 06:21:15

### Listing 31: notes

This is the most simple static delay (just delays the input sound an amount of \( \rightarrow \) samples).

Very useful for newbies also probably very easy to change in a feedback delay (for, \( \rightarrow \) comb filters for example).

Note: fDlyTime is the delay time parameter (0 to 1)

\[
i = \text{input index} \\
j = \text{output index}
\]

### Listing 32: code

```c
if ( i >= SampleRate )
  i = 0;

DlyBuffer[ i ] = Input;

j = i - (fDlyTime * SampleRate);
i++;

if ( j < 0 )
  j = SampleRate + j;

Output = DlyBuffer[ j ];
```

4.17.1 Comments

- **Date:** 2003-09-02 09:17:47
- **By:** moc.liamtoh@sisehtnysorpitna

Another note: The delay time will be 0 if fDlyTime is 0 or 1.

- **Date:** 2003-09-08 12:21:20
- **By:** gro.ekaf@suomynona

// I think you should be careful with mixing floats and integers that way (error-prone, // slow float-to-int conversions, etc).

// This should also work (haven’t checked, not best way of doing it):

// ... (initializing) ..

(continues on next page)
```c
float numSecondsDelay = 0.3f;
int numSamplesDelay_ = (int)(numSecondsDelay * sampleRate); // maybe want to round to an integer instead of truncating..

float *buffer_ = new float[2*numSamplesDelay];

for (int i = 0; i < numSamplesDelay_; ++i)
{
    buffer_[i] = 0.f;
}

int readPtr_ = 0;
int writePtr_ = numSamplesDelay_;

// ... (processing) ...

for (i = each sample)
{
    buffer_[writePtr_] = input[i];
    output[i] = buffer_[readPtr_];

    ++writePtr_;
    if (writePtr_ >= 2*numSamplesDelay_)
        writePtr_ = 0;

    ++readPtr_;
    if (readPtr_ >= 2*numSamplesDelay_)
        readPtr_ = 0;
}
```

**Date:** 2004-08-24 19:31:45  
**By:** moc.liamg@noteex

I may be missing something, but I think it gets a little simpler than the previous two examples. The difference in result is that actual delay will be 1 if d is 0 or 1.

```
i = input/output index
d = delay (in samples)

Code:

out = buffer[i];
buffer[i] = in;
i++;
if(i >= delay) i = 0;
```

**Date:** 2005-12-18 02:35:00  
**By:** moc.liamg@noteex

or even in three lines...

```
out = buffer[i];
buffer[i++] = in;
if(i >= delay) i = 0;
```
The only problem with this implementation, is that it is not really an audio effect! All this will do is to delay the input signal by a given number of samples! ...why would you ever want to do that? ...this would only ever work if you had a DSP and speakers both connected to the audio source and run them at the same time, so the speakers would be playing the original source and the DSP containing the delayed source connected to another set of speakers! this is not really an audio effect!

...Here is a pseudo code example of a delay effect that will mix both the original sound with the delayed sound:

Pseudo Code implementation for simple delay:
- This implementation will put the current audio signal to the left channel and the delayed audio signal to the right channel. this is suitable for any stereo codec!

```plaintext
delay_function {
    left_channel // for stereo left
    right_channel // for stereo right
    mono      // mono representation of stereo input
    delay_time // amount of time to delay input
    counter = 0 // counter

    // setup an array that is the same length as the maximum delay time:
    delay_array[max delay time] // array containing delayed data

    // convert stereo to mono:
    (left_channel + right_channel) / 2

    // initialise time to delay signal - maybe input from user
    delay_time = x

    if (delay_time = 0){
        left_out = mono
        right_out = mono
    }
    else {
        // put current input data to left channel:
        left_out = mono
        // put oldest delayed input data to right channel:
        right_out = delay_array[index]

        // overwrite with newest input:
        delay_array[index] = mono;

        // is index at end of delay buffer? if not increment, else set to zero
        if (index < delay_time) index++
        else index = 0
    }
}
```

(continues on next page)
4.18 Parallel combs delay calculation

- **Author or source:** Juhana Sadeharju (if.tenuf.cin@aihuok)
- **Created:** 2002-05-23 19:49:40

```
Listing 33: notes

This formula can be found from a patent related to parallel combs structure. The formula places the first echoes coming out of parallel combs to uniformly distributed sequence. If \( T_1, \ldots, T_n \) are the delay lines in increasing order, the formula can be derived by setting \( T_{k-1}/T_k = \text{Constant} \) and \( T_n/(2\times T_1) = \text{Constant} \), where \( 2\times T_1 \) is the echo coming just after the echo \( T_n \).

I figured this out myself as it is not told in the patent. The formula is not the best which one can come up. I use a search method to find echo sequences which are uniform enough for long enough time. The formula is uniform for a short time only.

The formula doesn't work good for series allpass and FDN structures, for which a similar formula can be derived with the same idea. The search method works for these structures as well.
```

4.19 Phaser code

- **Author or source:** Ross Bencina
- **Created:** 2002-02-11 17:41:53
- **Linked files:** phaser.cpp

```
Listing 34: notes

(see linked file)
```

4.19.1 Comments

- **Date:** 2005-06-01 22:48:17
- **By:** ed.luosfosruoivas@naitsirhC

```pascal
// Delphi / Object Pascal Translation:
// -------------------------------

unit Phaser;

// Still not efficient, but avoiding denormalisation.
```

(continues on next page)


```delphi
interface

type
  TAllPass = class(TObject)
  private
    fDelay : Single;
    fA1, fZM1 : Single;
    fSampleRate : Single;
    procedure SetDelay(v:Single);
  public
    constructor Create;
    destructor Destroy; override;
    function Process(const x:single):single;
    property SampleRate : Single read fSampleRate write fSampleRate;
    property Delay : Single read fDelay write SetDelay;
  end;

  TPhaser = class(TObject)
  private
    fZM1 : Single;
    fDepth : Single;
    fLFOInc : Single;
    fLFOPhase : Single;
    fRate : Single;
    fMinimum : Single;
    fMaximum : Single;
    fMin : Single;
    fMax : Single;
    fSampleRate : Single;
    fAllpassDelay: array[0..5] of TAllPass;
    procedure SetSampleRate(v:Single);
    procedure SetMinimum(v:Single);
    procedure SetMaximum(v:Single);
    procedure SetRate(v:Single);
    procedure Calculate;
  public
    constructor Create;
    destructor Destroy; override;
    function Process(const x:single):single;
    property SampleRate : Single read fSampleRate write SetSampleRate;
    property Depth : Single read fDepth write fDepth; //0..1
    property Feedback : Single read fFeedback write fFeedback; // 0..<1
    property Minimum : Single read fMin write SetMinimum;
    property Maximum : Single read fMax write SetMaximum;
    property Rate : Single read fRate write SetRate;
  end;

implementation

uses DDSPUtils;

const kDenorm=1E-25;

constructor TAllpass.Create;
begin
  inherited;
end;
```

(continues on next page)
fA1:=0;
fZM1:=0;
end;

destructor TAllpass.Destroy;
begin
  inherited;
end;

function TAllpass.Process(const x: single): single;
begin
  Result:=x*-fA1+fZM1;
fZM1:=Result*fA1+x;
end;

procedure TAllpass.SetDelay(v: Single);
begin
  fDelay:=v;
fA1:=(1-v)/(1+v);
end;

constructor TPhaser.Create;
var
  i: Integer;
begin
  inherited;
fSampleRate:=44100;
  fFeedBack:=0.7;
  fLFOPhase:=0;
  fDepth:=1;
  fZM1:=0;
  Minimum:=440;
  Maximum:=1600;
  Rate:=5;
  for i:=0 to Length(fAllpassDelay)-1
    do fAllpassDelay[i]:=TAllpass.Create;
end;

destructor TPhaser.Destroy;
var
  i: Integer;
begin
  for i:=0 to Length(fAllpassDelay)-1
    do fAllpassDelay[i].Free;
  inherited;
end;

procedure TPhaser.SetRate(v: Single);
begin
  fLFOInc:=2*Pi*(v/SampleRate);
end;

procedure TPhaser.Calculate;
begin
  fMin:= fMinimum / (fSampleRate/2);
  fMax:= fMinimum / (fSampleRate/2);
end;

procedure TPhaser.SetMinimum(v: Single);
begin
  fMinimum:=v;
  Calculate;
end;

procedure TPhaser.SetMaximum(v:Single);
begin
  fMaximum:=v;
  Calculate;
end;

function TPhaser.Process(const x:single):single;
var d: Single;
  i: Integer;
begin
  //calculate and update phaser sweep lfo...
  d := fMin + (fMax-fMin) * ((sin( fLFOPhase )+1)/2);
  flFOPhase := flFOPhase + fLFOInc;
  if flFOPhase>=Pi*2
     then flFOPhase:=flFOPhase-Pi*2;
  //update filter coeffs
  for i:=0 to 5 do fAllpassDelay[i].Delay:=d;
  //calculate output
  Result:= fAllpassDelay[0].Process(
    fAllpassDelay[1].Process(
      fAllpassDelay[2].Process(
        fAllpassDelay[3].Process(
          fAllpassDelay[4].Process(
            fAllpassDelay[5].Process(kDenorm + x + fZM1 * fFeedBack )))
          ));
    fZM1:=tanh2a(Result);
  Result:=tanh2a(1.4*(x + Result * fDepth));
end;

procedure TPhaser.SetSampleRate(v:Single);
begin
  fSampleRate:=v;
end;
end.

• Date: 2005-06-01 22:51:25
  • By: ed.luofosruoivas@naitsirhC

Ups, forgot to remove my special, magic incrediants "tanh2a(1.4*(". It's just
to make the sound even warmer.

The frequency range i used for Minimum and Maximum is 0..22000. But I believe there
is still an error in that formula. The input range doesn't matter (if you remove my...
→special
increment), because it is a linear system.

• Date: 2005-06-05 21:40:35
  • By: moc.yddaht@yddaht

4.19. Phaser code 427
// I thought I already posted this but here's my interpretation for Delphi and KOL.
// The reason I repost this, is that it is rather efficient and has no denormal
→ problems.

unit Phaser;
{

    Unit: Phaser
    purpose: Phaser is a six stage phase shifter, intended to reproduce the
    sound of a traditional analogue phaser effect.
    Author: Thaddy de Koning, based on a musicdsp.pdf C++ Phaser by
    Copyright: This version (c) 2003, Thaddy de Koning
    Copyrighted Freeware

    Remarks: his implementation uses six first order all-pass filters in
    series, with delay time modulated by a sinusoidal.
    This implementation was created to be clear, not efficient.
    Obvious modifications include using a table lookup for the lfo,
    not updating the filter delay times every sample, and not
    tuning all of the filters to the same delay time.

    It sounds sensationally good!
}

interface

uses Kol, AudioUtils, SimpleAllpass;

type
PPhaser = ^TPhaser;
TPhaser = object(Tobj)
    private
        FSamplerate: single;
        FFeedback: single;
        Ff1oPhase: single;
        FDepth: single;
        FOldOutput: single;
        FMinDelta: single;
        FMaxDelta: single;
        FLfoStep: single;
        FAllpDelays: array[0..5] of PAllpassdelay;
        FLowFrequency: single;
        FHighFrequency: single;
    procedure SetRate(TheRate: single); // cps
    procedure SetFeedback(TheFeedback: single); // 0 -> <1.
    procedure SetDepth(TheDepth: single);
    procedure SetHighFrequency(const Value: single);
    procedure SetLowFrequency(const Value: single); // 0 -> 1.
    procedure SetRange(LowFreq, HighFreq: single); // Hz
    public
        destructor Destroy; virtual;
        function Process(inSamp: single): single;
    property Rate: single write Setrate; //In Cycles per second
    property Depth: single read Fdepth write setdepth; //0.. 1
    property Feedback: single read FFeedback write setfeedback; //0..< 1
    property Samplerate: single read FSamplerate write FSamplerate;
(continues on next page)
function NewPhaser: PPhaser;

implementation

{ TPhaser }
function NewPhaser: PPhaser;
var
  i: integer;
begin
  New(Result, Create);
  with Result^ do
  begin
    Fsamplerate := 44100;
    FFeedback := 0.7;
    FlfoPhase := 0;
    Fdepth := 1;
    FOldOutput := 0;
    setrange(440,1720);
    setrate(0.5);
    for i := 0 to 5 do
      FAllpDelays[i] := NewAllpassDelay;
  end;
end;

destructor TPhaser.Destroy;
var
  i: integer;
begin
  for i := 5 downto 0 do FAllpDelays[i].Free;
  inherited;
end;

procedure TPhaser.SetDepth(TheDepth: single); // 0 -> 1.
begin
  Fdepth := TheDepth;
end;

procedure TPhaser.SetFeedback(TheFeedback: single); //0..1;
begin
  FFeedback := TheFeedback;
end;

procedure TPhaser.SetRange(LowFreq, HighFreq: single);
begin
  FMinDelta := LowFreq / (Fsamplerate / 2);
  FMaxDelta := HighFreq / (Fsamplerate / 2);
end;

procedure TPhaser.SetRate(TheRate: single);
begin
  FLfoStep := 2 * _PI * (Therate / Fsamplerate);
end;
end;

const
    _1: single = 1;
    _2: single = 2;

var
    Delaytime, Output: single;
    i: integer;
begin
    //calculate and Process phaser sweep lfo...
    Delaytime := FMinDelta + (FMaxDelta - FMinDelta) * ((sin(FlfoPhase) + 1) / 2);
    FlfoPhase := FlfoPhase + FLfoStep;
    if (FlfoPhase >= _PI * 2) then
        FlfoPhase := FlfoPhase - _PI * 2;
    //Process filter coeffs
    for i := 0 to 5 do
        FAllpDelays[i].setDelay(Delaytime);
    //calculate output
        (FAllpDelays[5].Process(inSamp + FOldOutput * FFeedback))))));
    FOldOutput := Output;
    Result := kDenorm + inSamp + Output * Fdepth;
end;

procedure TPhaser.SetHighFrequency(const Value: single);
begin
    FHighFrequency := Value;
    setRange(FlowFrequency, FHighFrequency);
end;

procedure TPhaser.SetLowFrequency(const Value: single);
begin
    FLowFrequency := Value;
    setRange(FlowFrequency, FHighFrequency);
end;
end.

• Date: 2005-06-05 21:44:47
• By: moc.yddaht@yddaht

// And here the allpass:
unit SimpleAllpass;
/
    Unit: SimpleAllpass
    purpose: Simple allpass delay for creating reverbs and phasing/flanging
    Author:
    Copyright:
    Remarks:
/
interface
uses kol, audioutils;
type
PAllpassDelay = ^TAllpassDelay;
TAllpassdelay = object(Tobj)
protected
   Fa1, Fzm1: single;
public
   procedure SetDelay(delay: single); // sample delay time
   function Process(inSamp: single): single;
end;

function NewAllpassDelay: PAllpassDelay;
implementation
function NewAllpassDelay: PAllpassDelay;
begin
   New(Result, Create);
   with Result^ do
      begin
         Fa1 := 0;
         Fzm1 := 0;
      end;
end;

begin
   Result := kDenorm + inSamp * -Fa1 + Fzm1;
   Fzm1 := Result * Fa1 + inSamp + kDenorm;
end;

procedure TAllpassDelay.SetDelay(delay: single); // In sample time
begin
   Fa1 := (1 - delay) / (1 + delay);
end.

• Date: 2005-06-06 08:15:37
• By: ed.luosfrosuoivas@nait.sirhC

// You'll get a good performance boost by combining the 6 allpasses to one and
   rewriting
// that one to FPU code. Heavy speed increase AND you can make the number of allpasses
// variable as well.

// This would look similar to this:
function TMasterAllpass.Process(const x:single):single;
var a : array[0..1] of Single;
   b : Single;
   i : Integer;
begin
   a[0] := x * Fa1 + FY[0];
   b := a[0] * Fa1;
end.
\[ fY[0] := b - x; \]
\[ i := 0; \]
while \( i < fStages \) do
begin
\[ a[1] := b - fY[i+1]; \]
\[ b := a[1] * fA1; \]
\[ fY[i+1] := a[0] - b; \]
\[ a[0] := b - fY[i+2]; \]
\[ b := a[0] * fA1; \]
\[ fY[i+2] := a[1] - b; \]
\[ Inc(i, 2); \]
end;
\[ a[1] := b - fY[5]; \]
\[ b := a[1] * fA1; \]
\[ fY[5] := a[0] - b; \]
\[ Result := a[1]; \]
end;

Now all you have to do is crawling into the FPU registers...

- **Date:** 2005-06-07 11:31:05
- **By:** moc.yddaht@yddaht

Point taken ;)
Maybe we should combine all the stuff ;)
Btw:
It's lots of fun working from each others code, don't you think?

## 4.20 Polynorninal Waveshaper

- **Author or source:** ed.luofosruoi@naitsirhC
- **Type:** (discrete harmonics)
- **Created:** 2006-07-28 17:58:54

### Listing 35: notes

The following code will describe how to excite discrete harmonics and only these harmonics. A simple polynomial waveshaper for processing the data is included as well.

However the code don't claim to be optimized. Using a horner scheme with precalculated coefficients should be your choice here.

Also remember to oversample the data (optimal in the order of the harmonics) to have them alias free.

### Listing 36: code

1. We assume the input is a sinewave (works for any input signal, but this makes everything more clear).
2. Then we have \( x = \sin(a) \)
the first harmonic is plain simple (using trigonometric identities):

\[
\cos(2a) = \cos^2(a) - \sin^2(a) = 1 - 2\sin^2(a)
\]

using the general trigonometric identities:

\[
\sin(x + y) = \sin(x)\cos(y) + \sin(y)\cos(x)
\]

\[
\cos(x + y) = \cos(x)\cos(y) - \sin(x)\sin(y)
\]

together with some math, you can easily calculate: \(\sin(3x), \cos(4x), \sin(5x)\), and so on...

Here's how the resulting waveshaper may look like:

```c
// o = output, i = input
o = fPhase[1]* i * fGains[0] +
    fPhase[1]*( 2*i*i - 1 ) * fGains[1] +
    fPhase[2]*( 4*i*i - 3*i ) * fGains[2] +
    fPhase[3]*( 8*i*i*i - 8*i*i + 1 ) * fGains[3] -
    fPhase[4]*( 16*i*i*i*i*i*i - 20*i*i*i - 1 ) * fGains[4] +
    fPhase[5]*( 32*i*i*i*i*i*i - 48*i*i*i*i - 7*i ) * fGains[5] -
    fPhase[6]*( 64*i*i*i*i*i*i*i - 112*i*i*i*i - 32*i*i + 1 ) * fGains[6] +
    fPhase[7]*( 128*i*i*i*i*i*i*i*i*i*i*i - 256*i*i*i*i*i*i*i*i - 160*i*i*i*i - 32*i*i + 1 ) * fGains[7];
```

P.S.: I don't want to see a single comment about the fact that the code above is unoptimized. I know that!

### 4.20.1 Comments

- **Date:** 2006-07-28 22:16:36
- **By:** ed.luosfosruoivas@naitsirhC

Here's the more math like version:

```c
// o = output, i = input
o = fPhase[1]* i * fGains[0] +
    fPhase[1]*( 2*i^2 - 1 ) * fGains[1] +
    fPhase[2]*( 4*i^3 - 3*i ) * fGains[2] +
    fPhase[3]*( 8*i^4 - 8*i^2 + 1 ) * fGains[3] -
    fPhase[4]*( 16*i^5 - 20*i^3 + 5*i ) * fGains[4] +
    fPhase[5]*( 32*i^6 - 48*i^4 + 18*i - 1 ) * fGains[5] -
    fPhase[6]*( 64*i^7 - 112*i^5 + 56*i - 7*i ) * fGains[6] +
    fPhase[7]*( 128*i^8 - 256*i^6 + 160*i - 32*i + 1 ) * fGains[7];
```
Actually, this *doesn't* work in the way described on any input, only on single
→sinusoids of
amplitude 1. It's nonlinear - (a+b)^n is not the same thing as a^n+b^n, nor are (a*b)^n
→and a*(b^n). Even just a sum of two sinusoids or a single sinusoid of a different amplitude breaks
→the
chosen-harmonics-only thing.

Do'oh. You're right. Once more I got fooled by the way of my measurement. That...
→explains a
lot of things... Thanks for the clarification!

Btw. the coefficients follow the chebyshev polynomials. Just in case you wonder about
→the
logic behind. Maybe we can call it chebyshev waveshaper from now on...

I played with this idea for a while yesterday to no avail before discovering this...
→post tonight.
I thought I could excite any harmonic I wanted using select Chebyshev Polynomials.
→But you are
totally right - it doesn't work that way. Any complex waveform that can be broken
→down into a
Fourier series is a linear sum of terms. Squaring or cubing the waveform, and
→therefore this sum,
leads to multiple cross terms which introduce additional frequencies. It does only
→work with
normalized single sinusoids ... which is too bad.

Right now, the only way I can see to do this sort of thing where you excite select
→harmonics at will
is to run an FFT and then work from there in the frequency domain.

But my question is, if we are looking to simulate tube saturation, is the Chebyshev
→method good
enough. What, after all, do tubes do? Does a tube amp actually add discrete harmonics
→or is it
introducing all of those cross term frequencies as well?
According to another post, the tube is simply a non linear function, for example a →tan(x).
Actually by saturating any signal you will get harmonics (any but a pure square which →cannot
be more saturated of course...). As tan(x) is not linear, you should get harmonics... →that's all.
Now if you want to pass only the high frequencies, just split the signal into 2 →frequencies using
a lowpass vs highpass = signal - lowpass and process the frequencies you want to.

- **Date:** 2010-09-16 19:17:13
  - **By:** moc.liamg@libojyr

I would like to add that this method could result in an approximated harmonic exciter →using an
array of filters sufficiently narrow and steep to approximately single out individual →frequencies
composing the original signal.

As such, it would be processing intensive because the polynomial would need to be →calculated on
each band.

What you have presented is not completely bad. You only need to take into →consideration that you're
getting frequency terms that are not necessarily harmonics. Steve Harris has a →LADSPA plugin that
uses the chebychev polynomial as a waveshaper...and he calls it a harmonic exciter.

To user physicstrick: Tube emulation is much more than waveshaping. Bias conditions →change with
signal dynamics, and you essentially get signal-power modulated duty cycle. I have →found some good
articles about this and also there is a commercial product that claims to solve the →discretized
system of ODE's in real time. This model eats CPU like you would not imagine.

My simple "trick" is to include the nonlinear function in a 1rst order filter →calculation and
also to modulate the filter time constants with the filter state variable amplitude. →This is not
quite right, but it produces an emulation that is more pleasing than plain →waveshaping.

- **Date:** 2013-01-18 02:31:27
  - **By:** moc.liamtoh@niffumtohrepus

If I'm correct, you're describing the same technique achievable by use of Chebyschev →polynomials,
i.e. generating any integral harmonic of the original signal. I've experimented with →these,
synthesizing only the second, third, fourth, etc. harmonics, but could never get a →realistic
sound, probably because overdriven tubes/transistors don't work this way and there's →no intermodulation
distortion, only the pure harmonics.
4.21 Reverberation Algorithms in Matlab

- **Author or source:** Gautham J. Mysore (moc.oohay@mjmahtuag)
- **Created:** 2003-07-15 08:58:05
- **Linked files:** MATLABReverb.zip.

These M-files implement a few reverberation algorithms (based on Schroeder's and Moorer's algorithms). Each of the M-files include a short description.

There are 5 M-files that implement reverberation. They are:

- schroeder1.m
- schroeder2.m
- schroeder3.m
- moorer.m
- stereoverb.m

The remaining 8 M-files implement filters, delay lines etc. Most of these are used in the above M-files. They can also be used as building blocks for other reverberation algorithms.

4.21.1 Comments

- **Date:** 2003-08-15 04:04:56
- **By:** moc.loa@mnijwerb

StereoVerb is the name of an old car stereo "enhancer" from way back. I was just trying to find it's roots.

- **Date:** 2004-04-02 04:44:46
- **By:** moc.oohay@y_sunave

There is another allpass filter transfer function.

\[ \frac{-g+Z^{-m}}{1-gZ^{-m}} \]

\( g \) is the attenuation
\( m \) is the number of delay (in sampel)

This allpass will give exponential decay impulse response, compare to your allpass that give half sinc decay impulse response.
4.22 Reverberation techniques

- **Author or source:** Sean Costello
- **Created:** 2002-02-10 20:00:11

Listing 38: notes

- Parallel comb filters, followed by series allpass filters. This was the original design by Schroeder, and was extended by Moorer. Has a VERY metallic sound for sharp transients.

- Several allpass filters in series (also proposed by Schroeder). Also suffers from metallic sound.

- 2nd-order comb and allpass filters (described by Moorer). Not supposed to give much of an advantage over first order sections.

- Nested allpass filters, where an allpass filter will replace the delay line in another allpass filter. Pioneered by Gardner. Haven't heard the results.

- Strange allpass amp delay line based structure in Jon Dattorro article (JAES). Four allpass filters are used as an input to a cool "figure-8" feedback loop, where four allpass reverberators are used in series with a few delay lines. Outputs derived from various taps in structure. Supposedly based on a Lexicon reverb design. Modulating delay lines are used in some of the allpass structures to "spread out" the eigentones.

- Feedback Delay Networks. Pioneered by Puckette/Stautner, with Jot conducting extensive recent research. Sound VERY good, based on initial experiments. Modulating delay lines and feedback matrixes used to spread out eigentones.

- Waveguide-based reverbs, where the reverb structure is based upon the junction of many waveguides. Julius Smith developed these. Recently, these have been shown to be essentially equivalent to the feedback delay network reverbs. Also sound very nice. Modulating delay lines and scattering values used to spread out eigentones.

- Convolution-based reverbs, where the sound to be reverbed is convolved with the impulse response of a room, or with exponentially-decaying white noise. Supposedly the best sound, but very computationally expensive, and not very flexible.

- FIR-based reverbs. Essentially the same as convolution. Probably not used, but shorter. FIR filters are probably used in combination with many of the above techniques, to provide early reflections.
4.23 Simple Compressor class (C++)

- **Author or source**: Citizen Chunk
- **Type**: stereo, feed-forward, peak compressor
- **Created**: 2005-05-28 19:11:42
- **Linked files**: simpleSource.zip

Listing 39: notes

Everyone seems to want to make their own compressor plugin these days, but very few know where to start. After replying to so many questions on the KVR Dev Forum, I figured I might as well just post some ready-to-use C++ source code.

This is a C++ implementation of a simple, stereo, peak compressor. It uses a feed-forward topology, detecting the sidechain level pre-gain reduction. The sidechain detects the rectified peak level, with stereo linking to preserve imaging. The attack/release uses the EnvelopeDetector class (posted in the Analysis section).

Notes:
- Make sure to call initRuntime() before processing starts (i.e. call it in resume()).
- The process function takes a stereo input.
- VST params must be mapped to a practical range when setting compressor parameters. Don't try setAttack(0.0f).

(see linked files)

4.23.1 Comments

- **Date**: 2005-11-26 01:56:48
- **By**: moc.liamtoh@361_lt

This code works perfectly, and I have tried a number of sound and each worked correctly. The conversion is linear in logarithm domain.

The code has been written in such a professional style, can not believe it is FREE!! Keep it up. Two super huge thumbs up.

Ting

4.24 Soft saturation

- **Author or source**: Bram de Jong
- **Type**: waveshaper
- **Created**: 2002-01-17 02:18:37
This only works for positive values of $x$. $a$ should be in the range $0..1$

```
Listing 41: code

1 x < a:
2 f(x) = x
3 x > a:
4 f(x) = a + (x-a)/(1+((x-a)/(1-a))^2)
5 x > 1:
6 f(x) = (a+1)/2
```

### 4.24.1 Comments

- **Date:** 2005-09-09 21:17:55  
  **By:** gro.esabnaceo@euarg

This is a most excellent waveshaper.

I have implemented it as an effect for the music tracker Psycle, and so far I am very pleased with the results. Thanks for sharing this knowledge, Bram!

- **Date:** 2006-03-12 02:35:16  
  **By:** moc.erawtfosnetpot@nosniborb

I'm wondering about the $>1$ condition here. If $a$ is 0.8, values $<1$ approach 0.85 but values $>1$ are clamped to 0.9 (there's a gap)

If you substitute $x=1$ to the equation for $x>a$ you get: $a+((1-a)/4)$ not $(a+1)/2$

Have I missed something or is there a reason for this?

(Go easy I'm new to all of this)

- **Date:** 2006-08-24 11:03:04  
  **By:** musicdsp@Nospam dsparsons.co.uk

```
Substituting x=1 into equation 2 (taking many steps)

$f(x) = a + (x-a)/(1+ ((x-a)/(1-a))^2)$
= $a + (1-a)/(1+ ((1-a)/(1-a))^2)$
= $a + (1-a)/(1+ 1^2)$
= $a + (1-a)/2$
= $2a/2 + (1-a)/2$
= $2a + 1 - a) /2$
= $(a+1) / 2$
```
You can normalise the output:
\[ f(x)' = f(x) \times \left(1/((a+1)/2)\right) \]
This gives a nice variable shaper with smooth curve upto clipping at 0dBFS

## 4.25 Stereo Enhancer

- **Author or source:** vl.xobni@ksimruk
- **Created:** 2004-06-27 22:44:16

### Listing 42: notes

Stereo Enhancer

### Listing 43: code

```c
// WideCoeff 0.0 .... 1.5
#define StereoEnhancer(SamplL,SamplR,MonoSign, DeltaLeft,WideCoeff )
    MonoSign = (SamplL + SamplR)/2.0;
    DeltaLeft = SamplL - MonoSign;
    DeltaLeft *= WideCoeff;
    SamplL+=DeltaLeft;
    SamplR-=DeltaRight;
```

### 4.25.1 Comments

- **Date:** 2004-08-20 17:45:38
- **By:** moc.liamg@noteex

```c
#define StereoEnhancer(SamplL,SamplR,MonoSign, DeltaLeft,Deltaright,WideCoeff )
    MonoSign = (SamplL + SamplR)/2.0;
    DeltaLeft = SamplL - MonoSign;
    DeltaLeft *= WideCoeff;
    DeltaRight = SamplR - MonoSign;
    DeltaRight *= WideCoeff;
```

I think this is more along the lines of what you were trying to accomplish. I doubt...

---this is

the correct way of implementing this type of thing however.

- **Date:** 2004-08-24 15:40:31
- **By:** moc.noomyab@grubmah_kram
I believe both pieces of code do the same thing. Since MonoSign is set equal to the average of the two signals, in the second case DeltaRight = -DeltaLeft.

- **Date**: 2005-01-07 10:20:20
- **By**: thaddy@thaddy.com

```delphi
// Here's an implementation of the classic stereo enhancer in Delphi BASM
// Values below 0.1 have a narrowing effect
// Values above 0.1 widens
parameters:
  Buffer = eax
  Amount = edx
  Samples = ecx

const
  Spread: single = 6.5536;

procedure Sound3d32f(Buffer: PSingle; Amount: Single; Samples: integer);
asm
  fld Amount
  fmul spread
  mov ecx, edx
    // move samples to ecx
  shr ecx, 1
    // divide by two, stereo = 2 samples
@Start:
  fld [eax].dword
    // left sample
  fld [eax+4].dword
    // right sample, whole calculation runs on the stack
  fld st(0)
    // copy
  fadd st(0), st(2)
  fmul half
    // average =st(0), right sample = st(1), left = st(2),
    // amount=st(3)
  fld st(0)
    // copy average
  fsubr st(0), st(3)
    // left difference
  fmul st(0), st(4)
    // amount
  fadd st(0), st(1)
    // add average
  fadd st(0), st(3)
    // add original
  fmul half
    // divide by two
  fstp [eax].dword
    // and store
  fld st(0)
  fsubr st(0), st(2)
    // right difference
  fmul st(0), st(4)
    // amount
  faddp
    // add average
  faddp
    // add original
  fmul half
    // divide by 2
  fstp [eax+4].dword;
    // and store
  fxch
    // Dangling average?? remove it later, tdk
 .ffree st(1)
  add eax, 8
    // advance to next stereo pair
loop @Start
  ffree st(0);
    // Cleanup amount
end;
```

- **Date**: 2005-03-24 09:45:09
- **By**: moc.yddaht@yddaht
Note 'half' is defined as const half:single = 0.5;
This is an omission in the above posting.

- **Date:** 2005-04-21 22:04:02
- **By:** moc.liamtoh@gorpketg

This original code makes indeed no sense.

```c
#define StereoEnhance(SamplL, SamplR, MonoSign, DeltaL, WideCoeff)
    MonoSign = (SamplL + SamplR)/2.0;
    DeltaL = SamplL - MonoSign;
    DeltaL = DeltaL * WideCoeff;
    SamplL = SamplL + DeltaL;
    SamplR = SamplR - DeltaL;
```

Deltaleft hold no stereoinformation.
explained: Deltaleft=L-(L+R) = R!!!
So, in this example your stereo image would slide to the right more as you put __widecoeff higher.

A better implementation is the following code.
```c
#define StereoEnhance(SamplL, SamplR, MonoSign, stereo, WideCoeff)
    MonoSign = (SamplL + SamplR)/2.0;
    stereo = SamplL - SamplR;
    stereo = DeltaL * WideCoeff;
    SamplL = SamplR + stereo; // R+Stereo = L
    SamplR = SamplL - stereo; // L-Stereo = R
```

This way of stereoenhancement will lead to exaggerated reverberation effects __-snaredrums__.
This is not the best way to do widening, but it is the easiest.

Gtekprog.
Evert Verduin

- **Date:** 2005-04-21 22:06:51
- **By:** moc.liamtoh@gorpketg

oops,

```c
stereo = SamplL - SamplR;
```
needs ofcourse to be
```c
stereo = SamplL - Sampl1R;
```
and
```c
stereo = DeltaL * WideCoeff;
```
needs to be
```c
stereo = stereo * WideCoeff;
```
Again the correct code:
```c
#define StereoEnhance(SamplL, SamplR, MonoSign, 
```
(continues on next page)
stereo,WideCoeff ) \
MonoSign = (SamplL + SamplR)/2.0; \
stereo = SamplL - SamplR; \
stereo = stereo * WideCoeff; \
SamplL=Samp1R + stereo; // R+Stereo = L
SamplR=Samp1L - stereo; // L-Stereo = R

This will do.

Evert

- **Date:** 2009-04-17 13:16:42
- **By:** moc.liamg@nostohnotyalc

You mean to use MonoSign variable somewhere - as in:

```c
#define StereoEnhancement(SampleL, SampleR, MonoSign, 
    stereo, WideCoeff ) \
MonoSign = (SampleL + SampleR)/2.0; \
stereo = SampleL - SampleR; 
    stereo = stereo * WideCoeff; \
    SampleL = MonoSign + stereo; // R+Stereo = L
    SampleR = MonoSign - stereo; // L-Stereo = R
```

Or some variation?

Clayton

## 4.26 Stereo Field Rotation Via Transformation Matrix

- **Author or source:** Michael Gruhn
- **Type:** Stereo Field Rotation
- **Created:** 2008-03-17 09:40:10

**Listing 44: notes**

This work is hereby placed in the public domain for all purposes, including use in commercial applications.

'angle' is the angle by which you want to rotate your stereo field.

```
// Calculate transformation matrix's coefficients
cos_coef = cos(angle);
sin_coef = sin(angle);

// Do this per sample
out_left = in_left * cos_coef - in_right * sin_coef;
out_right = in_left * sin_coef + in_right * cos_coef;
```
4.26.1 Comments

- **Date:** 2008-10-07 19:56:47
  **By:** moc.liamtoh@iniluigj

This looks like the rotation formula for a point in space. Can you explain how does it work for a sound signal? Let's say that angle is 90 degrees, then you formula gives:

- `out_left = -in_right`
- `out_right = in_left`

How would this be a 90 deg rotation of the sound?

- **Date:** 2008-10-15 12:16:02
  **By:** Foo

It IS the exact formula as rotation for a point in a 2D space (around its origin).

Now this is applied to the stereo field. Imagine it as a left-right plot, so the values of the left and right channel get plotted (just like a goniometer: http://en.wikipedia.org/wiki/Goniometer_(audio)).

So now you can see the stereo image (mono = straight line, stereo = circle, etc...).

Now when you rotate THIS plot and then use the values of the rotated plot for the new left and right sample values, you rotated the stereo image. So just get a goniometer and look at how the signal changes when you run it through the algorithm, it will be pretty obvious.

Hope this helps.

- **Date:** 2008-11-16 02:13:27
  **By:** Bar

Sorry this makes no sense at all. The rotation formula is predicated on the assumption that (x,y) are coordinates of two orthogonal dimensions. Now you can choose to visualize stereo signals anyway you like, including being on a Cartesian plan, or as polar coordinates, what have you... But this visualization has no relationship to the physical location of the sound. The left and right channels are NOT orthogonal dimensions physically. What the formula does is just some weird panning. As the previous comment pointed out, just plug in some easy angles like 90, 180 ... and see if you can make any valid interpretations out of them. You can't.

- **Date:** 2008-11-18 21:22:49
  **By:** Foo

So you want mathematical prove? Even though I consider this childish, because it'd take you <5 minutes to put this in Matlab or any other DSP prototyping bench and hear the rotation effect for...
 yourself. Anyway ...

For 180° the output should be totally inverted. So:
\[
\begin{align*}
\cos(180) &= -1 \\
\sin(180) &= 0 \\
\text{out}\_\text{left} &= -\text{in}\_\text{left} \\
\text{out}\_\text{right} &= -\text{in}\_\text{right}
\end{align*}
\]

at 90° this means for a mono signal that the left channel will be a phase inverse of the right channel, so ... go directly to result, do not calculate:
\[
\begin{align*}
\text{out}\_\text{left} &= -\text{in}\_\text{right} \\
\text{out}\_\text{right} &= \text{in}\_\text{left}
\end{align*}
\]

at 45° is just like hard panning to the right (with a 3dB volume attenuation), so for a mono signal the expected results would be one channel silence and the other would have the signal, so we calculate:
\[
\begin{align*}
\cos(45) &= \sqrt{2}/2 \\
\sin(45) &= \sqrt{2}/2
\end{align*}
\]

for mono signal we assume: mono = in\_left = in\_right ... so it follows:
\[
\begin{align*}
\text{out}\_\text{left} &= \text{mono} \times \sqrt{2}/2 - \text{mono} \times \sqrt{2}/2 = 0 \\
\text{out}\_\text{right} &= \text{mono} \times \sqrt{2}/2 + \text{mono} \times \sqrt{2}/2 = \text{mono} \times \sqrt{2} = \text{mono} \times 3\text{dB}
\end{align*}
\]

and one more, 360° means same output as input, calculate for yourself.

Valid enough?

• Date: 2008-11-20 20:18:24
• By: Bar

Then I'm not sure what you mean by rotation. In my mind, I see two sound sources at arbitrary locations and I'm at the center of rotation. So the effect of a rotation would depend on the angle subtended by the three points to begin with, which doesn't even show up in the formula. Also please explain what does it mean by the two channels being orthogonal dimensions, which is what the formula is based on. (I assume you understand the mathematical basis of how the formula is derived.)

No, a phase inversion on both channels don't sound 180 deg rotated. It sounds exactly the same as before.

• Date: 2008-11-20 21:27:25
• By: Bar

Let's try another experiment. You're in the midpoint of the line joining the two speakers and is the center of rotation. Your signal happens to have all zeros for the left channel. The formula
simplifies to:
\[
\begin{align*}
\text{out}_\text{left} &= -\text{in}_\text{right} \times \sin \\
\text{out}_\text{right} &= \text{in}_\text{right} \times \cos
\end{align*}
\]
As you rotate from 0 to 90, sin goes from 0 to 1, cos goes from 1 to 0. So the formula predicts that the left channel goes from silence to a phase inverted right, and the right channel goes from full sound to silence. Whereas physically the sound should move from my right to directly in front of me. Please explain.

• Date: 2008-11-20 21:36:54
  • By: Bar

Yet another childish thought. If one can treat signals as if they were space locations, then surely translations will work just as well as rotations. So to move a sound source to another location, one just add constants to the signals?

• Date: 2008-11-23 18:10:37
  • By: Foo

If the source would be dead center a 180° rotation would mean the source would be behind you, but since in stereo there is no front or behind (just left and right), behind gets indicated by phase reversal (I know it doesn't reflect the position, but you can't because there is only left and right).

Also the rotation is clockwise, so a positive angles shift the source to the right, which means for your example if you'd rotate from 0° to -90° you'd indeed get the signal one the left channel and the right blank. For a mono signal (both channels identical that is) and a rotation range of -45° to 45° is the same as panning (with a 0dB pan law).

But I'll admit I was totally wrong and this entry in the musicdsp is the most faultiest that there ever was and isn't going to be useful at all, to no one. Anyway if this is not stereo field rotation, how would YOU call it? I'd happily forward the new terminology to the siteadmin, so the entries' description can be changed as soon as possible to whatever you think it is.

I'm just glad that I'm not the only one that is using wrong terminology, e.g. the Waves S1-Imager's "Rotation" does the same as the above posted code, as does Nick Whitehurst's c_superstereo and others ...

So tell me what it is called and I'll see if I can get the name changed, so everyone can be happy.
Though I doubt I can get Waves nor any audio engineers to also adapt the new, correct terminology, that you will proved, for this kind of effect.

BTW if you want to discuss this further please mail to: 1337foo42bar69@trashmail.net because there is no need to waste more comment space about this (I now think or at least hope that it only is a ...) terminology discussion, because there is nothing wrong with the code itself I posted, or is there?

• **Date:** 2009-07-17 11:02:36
  • **By:** null

Waves S1 Rotation, as you said, does exactly this. It is stereo field rotation, but in the same way could be considered panning.

Thanks a lot for the useful code, it will be put to good use. :)

• **Date:** 2014-03-28 12:52:38
  • **By:** moc.liamg@nabihci.nasleinad

I just tried this out but as you rotate the field there are points where the field is flattened to become simply a mono signal rotated. visualize the output on a x/y vectorscope and perform the rotation to see what I mean.

I made a correction. The algorithm should be like this:

\[
\begin{align*}
  r &= \text{rotation\_angle} \\
  \text{out\_left} &= (\text{in\_left} \ast \cos(r)) - (\text{in\_right} \ast \sin(r + \pi)); \\
  \text{out\_right} &= (\text{in\_left} \ast -\sin(r)) - (\text{in\_right} \ast \cos(r + \pi));
\end{align*}
\]

• **Date:** 2014-06-17 22:51:38
  • **By:** moc.liamg@jdcismuff

Why are you adding pi to the sin and cos at the end?

What will adding 3.14 to the rotation do besides move the rotation angle further 3.14? IE if rotation angle is 90, you're just adding 3.14 to it equaling 93.14. Why only to the right channel? Shouldn't that cause problems?

Wouldn't that mean that the reason this wont sound flat is because the calculations are 3.14 off?

4.27 **Stereo Width Control (Obtained Via Transfromation Matrix)**

• **Author or source:** Michael Gruhn
• **Type:** Stereo Widener

• **Created:** 2008-03-17 16:54:42

---

**Listing 46: notes**

(I was quite surprised that this wasn't already in the archive, so here it is.)

This work is hereby placed in the public domain for all purposes, including use in commercial applications.

'width' is the stretch factor of the stereo field:

width < 1: decrease in stereo width
width = 1: no change
width > 1: increase in stereo width
width = 0: mono

---

**Listing 47: code**

```cpp
// calculate scale coefficient
coef_S = width*0.5;

// then do this per sample
m = (in_left + in_right)*0.5;
s = (in_right - in_left)*coef_S;

out_left = m - s;
out_right = m + s;
```

---

### 4.27.1 Comments

• **Date:** 2008-04-06 11:32:43

• **By:** ku.oc.oohay@895rennacs

Nice peace of code. I would add the following code at the end of the source to compensate for the loss/gain of amplitude:

```cpp
out_left /= 0.5 + coef_S;
out_right /= 0.5 + coef_S;
```

---

• **Date:** 2008-04-06 17:40:29

• **By:** -

Scanner, no I wouldn't add that. First off it is unnecessary calculation you can → rescale the MS matrix to your liking already! Plus your methode will cause a boost by 6dBs when you → set the width to 0 = mono. So mono signals get boosted by 6dB which I'm sure isn't what you → intented.

Note: My original code is correct that is, when you'd look at an audio signal on a → goniometer it would scale the audio signal at the S-axis and leaving everything else unaffected.

(continues on next page)
But as I don't want people that add the additional calculation that scanner requested, (sorry not trying to mock you), an volume adjusted version.

[code]
// calc coefs
tmp = 1/max(1 + width,2);
coef_M = 1 * tmp;
coef_S = width * tmp;

// then do this per sample
m = (in_left + in_right)*coef_M;
s = (in_right - in_left )*coef_S;

out_left = m - s;
out_right = m + s;
[/code]

• Date: 2008-04-06 21:42:16
• By: ku.oc.oohay@895reennacs

Hi Michael,

Thanks for the correction, I have build your solution in PureData and it is better than my suggestion was. B.t.w. there was already a posting on stereo enhancement on this site, you can find it under the effects section.

• Date: 2008-04-07 22:47:14
• By: -

Scanner, no problem and yes I've seen the "Stereo Enhancer" entry, though (even though it seems to try to achieve the same as this here) it is (as far as I can see) broken.

4.28 Time compression-expansion using standard phase vocoder

• Author or source: Cournappe
• Type: vocoder phase time stretching
• Created: 2002-12-01 21:15:54
• Linked files: vocoder.m.

Listing 48: notes

Standard phase vocoder. For imporved techniques (faster), see paper of Laroche: "Improved phase vocoder time-scale modification of audio" Laroche, J.; Dolson, M. Speech and Audio Processing, IEEE Transactions on, Volume: 7 Issue: 3, May 1999 Page(s): 323 -332
4.29 Transistor differential amplifier simulation

• Author or source: ed.luosforsuoivas@naitsirhC
• Type: Waveshaper
• Created: 2004-08-09 07:46:11

Listing 49: notes

Writting an exam about electronic components, i learned several equations about simulating that stuff. One simplified equation was the \( \tanh(x) \) formula for the differential amplifier. It is not exact, but since the amplifiers are driven with only small amplitudes the behaviour is most often even advanced linear.
The fact, that the amp is differential, means, that the 2n order is eliminated, so the sound is also similar to a tube.
For a very fast use, this code is in pure assembly language (not optimized with SSE-Code yet) and performs in VST-Plugins very fast.
The code was written in delphi and if you want to translate the assembly code, you should know, the the parameters passing is done via registers. So pinp=EAX pout=EDX sf=ECX.

Listing 50: code

```plaintext
procedure Transistor(pinp,pout : PSingle; sf:Integer; Faktor: Single);
asm
@Start:
 fld Faktor
 fld [eax].single
 fmul st(0),st(1)
 fldl2e
 fmul
 fld st(0)
 frndint
 fsub st(1),st
 fxch st(1)
 f2xml
 fld1
 fadd
 fscale  { result := z * 2**i }
 fstp st(1)
 fld st(0)
 fmulp
 fld st(0)
 fld1
 faddp
 fld1
 fsin p st(2),st(0)
 fdivp
 fstp [edx].single
```

(continues on next page)
31 add eax, 4
32 add edx, 4
33 loop @Start
34 fstp st(0)
35 end;

4.30 UniVox Univibe Emulator

- **Author or source:** moc.liamg@libojyr
- **Type:** 4 Cascaded all-pass filters and optocoupler approximation
- **Created:** 2010-09-09 07:52:24

Listing 51: notes

This is a class and class member functions for a "Vibe derived by means of bilinear transform of the all-pass filter stages in a UniVibe. Some unique things happen as this filter is modulated, so this has been somewhat involved computation of filter coefficients, and is based on summation of 1rst-order filter stages as algebraically decoupled during circuit analysis. A second part is an approximated model of the Vactrol used to modulate the filters, including its time response to hopefully recapture the modulation shape. It is likely there is a more efficient way to re-create the LFO shape, and perhaps would be best with a lookup table. Keeping the calculation in the code makes it possible for other people to modify and improve the algorithm.

Notice no wet/dry mix is implemented in this code block's "out" function. Originally this was implemented in the calling routine, but if you use it as a stand-alone function you may want to add summation to the input signal as it is an important part of the "chorus" mode on the Vibe. The code as is represents only the Vibrato (warble) mode.

This is a module found in the Rakarrack guitar effects program. It is GPL, so please give credit due and keep it free. You can find any of the omitted parts to see more precisely how it is implemented with JACK on Linux by looking at the original sources at sourceforge.net/projects/rakarrack.

Listing 52: code

/*
 * Copyright (C) 2008-2010 Ryan Billing
 * Author: Ryan Billing

This program is free software; you can redistribute it and/or modify

(continues on next page)
it under the terms of version 2 of the GNU General Public License
as published by the Free Software Foundation.

This program is distributed in the hope that it will be useful,
but WITHOUT ANY WARRANTY; without even the implied warranty of
MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the
GNU General Public License (version 2) for more details.

You should have received a copy of the GNU General Public License
(version 2) along with this program; if not, write to the Free Software
Foundation,
Inc., 59 Temple Place, Suite 330, Boston, MA 02111-1307 USA

*/

class Vibe
{

public:

Vibe (float *efxoutl_, float *efxoutr_);
~Vibe ();
//note some of these functions not pasted below to improve clarity
//and to save space
void out (float *smpsl, float *smpsr);
void setvolume (int value);
void setpanning (int value);
void setpreset (int npreset);
void changepar (int npar, int value);
int getpar (int npar);
void cleanup ();

float outvolume;
float *efxoutl;
float *efxoutr;

private:

int Pwidth;
int Pfz;
int Plrccross;
int Pdepth;
int Ppanning;
int Pvolume;
//all the ints above are the parameters to modify with a proper function.

float fwidth;
float fdepth;
float rpanning, lpanning;
float flrcross, fcross;
float fb;
EffectLFO lfo; //EffectLFO is an object that calculates the next sample from the
→LFO each time it's called

float Ra, Rb, b, dTC, dRCl, dRCr, lampTC, ilampTC, minTC, alphal, alphar, stepl,
→stepr, oldstepl, oldstepr;
float fbr, fbl;
float dalphal, dalphar;
float lstep, rstep;
float cperiod;
float q1, oldq1;
float gr, oldgr;

class fparams {
public:
    float x1;
    float y1;
    //filter coefficients
    float n0;
    float n1;
    float d0;
    float d1;
    } vc[8], vcvo[8], ecvc[8], vevo[8], bootstrap[8];

float vibefilter(float data, fparams *ftype, int stage);
void init_vibes();
void modulate(float ldrl, float ldrr);
float bjt_shape(float data);

float R1;
float Rv;
float C2;
float C1[8];

float beta; //transistor forward gain.
float gain, k;
float oldcvolt[8];
float en1[8], en0[8], ed1[8], ed0[8];
float cn1[8], cn0[8], cd1[8], cd0[8];
float ecn1[8], ecn0[8], ecd1[8], ecd0[8];
float on1[8], on0[8], od1[8], od0[8];

class FPreset *Fpre;

Vibe::Vibe (float * efxoutl_, float * efxoutr_)
{
    efxoutl = efxoutl_;    
    efxoutr = efxoutr_; 

    //Swing was measured on operating device of: 10K to 250k.
    //400K is reported to sound better for the "low end" (high resistance)
    //Because of time response, Rb needs to be driven further.
    //End resistance will max out to around 10k for most LFO freqs.
    //pushing low end a little lower for kicks and giggles
    Ra = 500000.0f; //Cds cell dark resistance.
    Ra = logf(Ra);  //this is done for clarity
    Rb = 600.0f;    //Cds cell full illumination
    b = exp(Ra/logf(Rb)) - CNST_E;
    dTC = 0.085f;
    dRC1 = dTC;    //Right & left channel dynamic time contsants
    dRCr = dTC;    //Right & left channel dynamic time contsants
}
\begin{verbatim}
minTC = logf(0.005f/dTC);
//cSAMPLE_RATE is 1/SAMPLE_RATE
alphal = 1.0f - cSAMPLE_RATE/(dRC1 + cSAMPLE_RATE);
alphar = alphal;
dalphal = dalphar = alphal;
lampTC = cSAMPLE_RATE/(0.02 + cSAMPLE_RATE); //guessing 10ms
ilampTC = 1.0f - lampTC;
lstep = 0.0f;
rstep = 0.0f;
Pdepth = 127;
Ppanning = 64;
lpanning = 1.0f;
rpanning = 1.0f;
fdepth = 1.0f;
oldgl = 0.0f;
oldgr = 0.0f;
gl = 0.0f;
gr = 0.0f;
for (int jj = 0; jj<8; jj++) oldcvolt[jj] = 0.0f;
cperiod = 1.0f/fPERIOD;
\end{verbatim}

\begin{verbatim}
} \}
Vibe::~Vibe ()
{ }
}
\}

void
Vibe::cleanup ()
{
//Yeah, clean up some stuff
}

void
Vibe::out (float *smpsl, float *smpsr)
{ }

int i,j;
float lfol, lfor, xl, xr, fxl, fxr;
float vbe,vin;
float cvolt, ocvolt, evolt, input;
float emitterfb = 0.0f;
float outl, outr;

input = cvolt = ocvolt = evolt = 0.0f;
lfo.effectlfoout (&lfol, &lfor);
lfol = fdepth + lfol*fwidth;
lfor = fdepth + lfor*fwidth;
if (lfol < 1.0f)
\end{verbatim}
176  lfol = 1.0f;
177  else if (lfol < 0.0f)
178      lfol = 0.0f;
179  if (lfor > 1.0f)
180      lfor = 1.0f;
181  else if (lfor < 0.0f)
182      lfor = 0.0f;
183      lfor = 2.0f - 2.0f/(lfor + 1.0f);  //
184      lfol = 2.0f - 2.0f/(lfol + 1.0f);  //emulate lamp turn on/off characteristic by
185                                    //typical curves
186  for (i = 0; i < PERIOD; i++)          
187  {                                     
188    //Left Lamp
189    gl = lfol*lampTC + oldgl*ilampTC;
190    oldgl = gl;
191    //Right Lamp
192    gr = lfor*lampTC + oldgr*ilampTC;
193    oldgr = gr;
194  
195  //Left Cds
196    stepl = gl*alphal + dalphal*oldstepl;
197    oldstepl = stepl;
198    dRCl = dTC*expf(stepl*minTC);
199    alphal = cSAMPLE_RATE/(dRCl + cSAMPLE_RATE);
200    dalphal = 1.0f - cSAMPLE_RATE/(0.5f*dRCl + cSAMPLE_RATE);  //different attack &
201                                    //release character
202    xl = CNST_E + stepl*b;
203    fxl = expf(Ra/logf(xl));
204  
205  //Right Cds
206    stepr = gr+alphar + dalphar*oldstepr;
207    oldstepr = stepr;
208    dRCr = dTC*expf(stepr*minTC);
209    alphar = cSAMPLE_RATE/(dRCr + cSAMPLE_RATE);
210    dalphar = 1.0f - cSAMPLE_RATE/(0.5f*dRCr + cSAMPLE_RATE);  //different attack &
211                                    //release character
212    xr = CNST_E + stepr*b;
213    fxr = expf(Ra/logf(xr));
214  
215  if(i%16 == 0) modulate(fxl, fxr);
216  
217  //Left Channel
218  
219  input = bjt_shape(fbl + smps1[i]);
220  
221  emitterfb = 25.0f/fxl;
222  for(j=0;j<4;j++) //4 stages phasing
223  {             
224    cvolt = vibefilter(input,ecvc,j) + vibefilter(input + emitterfb+oldcvolt[j],vc,j);
225    ocvolt = vibefilter(cvolt,vcvo,j);
226    oldcvolt[j] = ocvolt;
227    evolt = vibefilter(input, vevo,j);
228    input = bjt_shape(ocvolt + evolt);
229  }

4.30. UniVox Univibe Emulator
fbl = fb*ocvolt;
outl = lpanning*input;

//Right channel

input = bjt_shape(fbr + smpsr[i]);
emitterfb = 25.0f/fxr;
for(j=4;j<8;j++) //4 stages phasing
{
cvolt = vibefilter(input,ecvc,j) + vibefilter(input + emitterfb*oldcvolt[j],vc,j);
ocvolt = vibefilter(cvolt,vcvo,j);
oldcvolt[j] = ocvolt;
evolt = vibefilter(input, vevo,j);
input = bjt_shape(ocvolt + evolt);
}

fbr = fb*ocvolt;
outr = rpanning*input;
efxoutl[i] = outl*fcross + outr*flrcross;
efxoutr[i] = outr*fcross + outl*flrcross;

};

float Vibe::vibefilter(float data, fparams *ftype, int stage)
{
float y0 = 0.0f;
y0 = data*ftype[stage].n0 + ftype[stage].x1*ftype[stage].n1 - ftype[stage].
˓→y1*ftype[stage].d1;
ftype[stage].y1 = y0 + DENORMAL_GUARD;
ftype[stage].x1 = data;
return y0;
}

float Vibe::bjt_shape(float data)
{
float vbe, vout;
float vin = 7.5f*(1.0f + data);
if(vin<0.0f) vin = 0.0f;
if(vin>15.0f) vin = 15.0f;
vbe = 0.8f - 0.8f/(vin + 1.0f); //really rough, simplistic bjt turn-on emulator
vout = vin - vbe;
vout = vout*0.1333333333f -0.90588f; //some magic numbers to return gain to unity &
˓→zero the DC
return vout;
}

void Vibe::init_vibes()
285  k = 2.0f*SAMPLE_RATE;
286  float tmpgain = 1.0f;
287  R1 = 4700.0f;
288  Rv = 4700.0f;
289  C2 = 1e-6f;
290  beta = 150.0f; //transistor forward gain.
291  gain = -beta/(beta + 1.0f);
292  
293  //Univibe cap values 0.015uF, 0.22uF, 470pF, and 0.0047uF
294  C1[0] = 0.015e-6f;
295  C1[1] = 0.22e-6f;
296  C1[2] = 470e-12f;
297  C1[3] = 0.0047e-6f;
298  C1[4] = 0.015e-6f;
299  C1[5] = 0.22e-6f;
300  C1[6] = 470e-12f;
301  C1[7] = 0.0047e-6f;
302  
303  for(int i =0; i<8; i++)
304  {
305  //Vo/Ve driven from emitter
306  en1[i] = k*R1*C1[i];
307  en0[i] = 1.0f;
308  ed1[i] = k*(R1 + Rv)*C1[i];
309  ed0[i] = 1.0f + C1[i]/C2;
310  
311  // Vc~=Ve/(Ic*Re*alpha^2) collector voltage from current input.
312  //Output here represents voltage at the collector
313  cn1[i] = k*gain*Rv*C1[i];
314  cn0[i] = gain*(1.0f + C1[i]/C2);
315  cd1[i] = k*(R1 + Rv)*C1[i];
316  cd0[i] = 1.0f + C1[i]/C2;
317  
318  //Contribution from emitter load through passive filter network
319 ecn1[i] = k*gain*R1*(R1 + Rv)*C1[i]*C2/(Rv*(C2 + C1[i]));
320  ecn0[i] = 0.0f;
321  edc1[i] = k*(R1 + Rv)*C1[i]*C2/(C2 + C1[i]);
322  edc0[i] = 1.0f;
323  
324  // %Represents Vo/Vc. Output over collector voltage
325  on1[i] = k*Rv*C2;
326  on0[i] = 1.0f;
327  od1[i] = k*Rv*C2;
328  od0[i] = 1.0f + C2/C1[i];
329  
330  // %Bilinear xform stuff
331  tmpgain = 1.0f/(cd1[i] + cd0[i]);
332  vc[i].n1 = tmpgain*(cn0[i] - cn1[i]);
333  vc[i].n0 = tmpgain*(cn1[i] + cn0[i]);
334  vc[i].d1 = tmpgain*(cd0[i] - cd1[i]);
335  vc[i].d0 = 1.0f;
336  
337  tmpgain = 1.0f/(ecd1[i] + ecd0[i]);
338  ecvc[i].n1 = tmpgain*(ecn0[i] - ecn1[i]);
339  ecvc[i].n0 = tmpgain*(ecn1[i] + ecn0[i]);
340  ecvc[i].d1 = tmpgain*(ecd0[i] - ecd1[i]);
341  ecvc[i].d0 = 1.0f;
```c
ecvc[i].d0 = 1.0f;

tmpgain = 1.0f/(od1[i] + od0[i]);
vcvo[i].n1 = tmpgain*(on0[i] - on1[i]);
vcvo[i].n0 = tmpgain*(on1[i] + on0[i]);
vcvo[i].d1 = tmpgain*(od0[i] - od1[i]);
vcvo[i].d0 = 1.0f;

vevo[i].n1 = tmpgain*(en0[i] - en1[i]);
vevo[i].n0 = tmpgain*(en1[i] + en0[i]);
vevo[i].d1 = tmpgain*(ed0[i] - ed1[i]);
vevo[i].d0 = 1.0f;

// bootstrap[i].n1
// bootstrap[i].n0
// bootstrap[i].d1

// bootstrap

}  

}  

}

void Vibe::modulate(float ldrl, float ldrr)
{
  float tmpgain;
  float R1pRv;
  float C2pC1;
  Rv = 4700.0f + ldrl;
  R1pRv = R1 + Rv;

  for(int i =0; i<8; i++)
  {
    if(i==4) {
      Rv = 4700.0f + ldrr;
      R1pRv = R1 + Rv;
    }
    C2pC1 = C2 + C1[i];
    //Vo/Ve driven from emitter
    ed1[i] = k*(R1pRv)*C1[i];
    //ed1[i] = R1pRv*kC1[i];
    // Vc~=Ve/(Ic*Re*alpha^2) collector voltage from current input.
    //Output here represents voltage at the collector
    cn1[i] = k*gain*Rv*C1[i];
    //cn1[i] = kgainC1[i]*Rv;
    //cd1[i] = (R1pRv)*C1[i];
    cd1[i]=ed1[i];

    //Contribution from emitter load through passive filter network
    ecn1[i] = k*gain*R1+cd1[i]*C2/(Rv*(C2pC1));
    //ecn1[i] = iC2pC1[i]*kgainR1C2*cd1[i]/Rv;
    ecd1[i] = k*cd1[i]*C2/(C2pC1);
    //ecd1[i] = iC2pC1[i]*k*cd1[i]*C2/(C2pC1);
```
399 // %Represents Vo/Vc. Output over collector voltage
400 on1[i] = k*Rv*C2;
401 od1[i] = on1[i];
402
403 // %Bilinear xform stuff
404 tmpgain = 1.0f/(cd1[i] + cd0[i]);
405 vc[i].n1 = tmpgain*(cn0[i] - cn1[i]);
406 vc[i].n0 = tmpgain*(cn1[i] + cn0[i]);
407 vc[i].d1 = tmpgain*(cd0[i] - cd1[i]);
408
409 tmpgain = 1.0f/(ecd1[i] + ecd0[i]);
410 ecvc[i].n1 = tmpgain*(ecn0[i] - ecn1[i]);
411 ecvc[i].n0 = tmpgain*(ecn1[i] + ecn0[i]);
412 ecvc[i].d1 = tmpgain*(ecd0[i] - ecd1[i]);
413 ecvc[i].d0 = 1.0f;
414
415 tmpgain = 1.0f/(od1[i] + od0[i]);
416 vcvo[i].n1 = tmpgain*(on0[i] - on1[i]);
417 vcvo[i].n0 = tmpgain*(on1[i] + on0[i]);
418 vcvo[i].d1 = tmpgain*(od0[i] - od1[i]);
419
420 tmpgain = 1.0f/(ed1[i] + ed0[i]);
421 vevo[i].n1 = tmpgain*(en0[i] - en1[i]);
422 vevo[i].n0 = tmpgain*(en1[i] + en0[i]);
423 vevo[i].d1 = tmpgain*(ed0[i] - ed1[i]);
424
425 }
426 }
427
428}

## 4.31 Variable-hardness clipping function

- **Author or source:** Laurent de Soras (moc.ecrofmho@tnernual)
- **Created:** 2004-04-07 09:36:46
- **Linked files:** laurent.gif

Listing 53: notes

k >= 1 is the "clipping hardness". 1 gives a smooth clipping, and a high value gives hardclipping.

Don't set k too high, because the formula use the pow() function, which use exp() and would overflow easily. 100 seems to be a reasonable value for "hardclipping"

Listing 54: code

\[
f(x) = \text{sign}(x) \times \text{pow}\left(\text{atan}\left(\text{pow}\left(\text{abs}(x), k\right)\right), \frac{1}{k}\right);
\]

### 4.31.1 Comments

- **Date:** 2003-11-15 03:56:35

4.31. Variable-hardness clipping function 459
// Use this function instead of atan and see performance increase drastically :) 

inline double fastatan( double x )
{
    return (x / (1.0 + 0.28 * (x * x)));
}

The greater k becomes the lesser is the change in the form of f(x, k). I recommend using 
f2(x, k2) = sign(x) * pow(atan(pow(abs(x), 1 / k2)), k2) , k2 in [0.01, 1] where k2 is the "clipping softness" (k2 = 0.01 means "hardclipping", k2 = 1 means "softclipping"). This gives better control over the clipping effect.

Don't know if i understood ok , but, how can i clip at diferent levels than -1.0/1.0 using this func? tried several ways but none seems to work

The most straightforward way to adjust the level (x) at which the signal is clipped would be to multiply the signal by 1/x before the clipping function then multiply it again by x afterwards.

Atan is a nice softclipping function, but you can do without pow().

x: input value
a: clipping factor (0 = none, infinity = hard)
ainv: 1/a
y = ainv * atan( x * a );

Even better, you can normalize the output using:

shape = 1..infinity

precalc:
    inv_atan_shape=1.0/atan(shape);
process:
    output = inv_atan_shape * atan(input*shape);
This gives a very soft transition from no distortion to hard clipping.

- **Date**: 2011-01-03 14:07:35
  - **By**: moc.liamg@nalevart

Scoofy,

What do you mean with 'shape'?
Is it a new parameter?

- **Date**: 2013-01-18 02:42:09
  - **By**: moc.liamtoh@niffumtohrepus

\[
\text{sign}(x) \times \text{pow}(\text{atan}(\text{pow}(\text{abs}(x), k)), (1 / k))
\]

OUCH! That's a lot of pow, atan and floating point division - probably kill most CPU's :) My experience has been that any sigmoid function will create decent distortion if oversampled and eq'ed properly. You can adjust the "hardness" of the clipping by simply changing a couple coefficients, or by increasing/decreasing the input gain: like so:

\[
y = A \times \tanh(B \times x)
\]

Cascading a couple/few of these will give you bone-crushing, Megadeth/Slayer style grind while rolling back the gain gives a Fender Twin sound.

Two cascaded half-wave soft clippers gives duty-cycle modulation and a transfer curve similar to the 3/2 power curve of tubes. I came up w/ a model based on that solution after reading this: http://www.trueaudio.com/at_eetjlm.htm (orig. link at www.simulanalog.org)

- **Date**: 2013-06-14 11:42:26
  - **By**: moc.liamtoh@niffumtohrepus

If anyone is interested, I have a working amp modeler and various c/c++ classes that model distortion circuits by numerical solutions to non-linear ODE's like those described by Yeh, Smith, Macak, Pakarinen, et al. in their PhD disertations and DAFX papers. Although static waveshapers/filters can give decent approximations & cool sounds, they lack the dynamic properties of the actual circuits and have poor harmonics. I also have whitepapers on my implementations for those that think math is cool. Drop me a line for more info.

### 4.32 WaveShaper

- **Author or source**: Bram de Jong


- **Type:** waveshaper
- **Created:** 2002-01-17 02:17:49

**Listing 55: notes**

where \( x \) (in \([-1..1]\) will be distorted and \( a \) is a distortion parameter that goes from \(-1\) to \(\infty\). The equation is valid for positive and negative values. If \( a \) is 1, it results in a slight distortion and with bigger \( a \)'s the signal gets more funky.

A good thing about the shaper is that feeding it with bigger-than-one values, doesn't create strange fx. The maximum this function will reach is 1.2 for \( a=1 \).

**Listing 56: code**

\[
\text{f}(x, a) = x \cdot (\text{abs}(x) + a)/(x^2 + (a-1) \cdot \text{abs}(x) + 1)
\]

### 4.33 Waveshaper

- **Author or source:** Jon Watte
- **Type:** waveshaper
- **Created:** 2002-01-17 02:19:17

**Listing 57: notes**

A favourite of mine is using a sin() function instead. This will have the "unfortunate" side effect of removing odd harmonics if you take it to the extreme: a triangle wave gets mapped to a pure sine wave. This will work with a going from .1 or so to \( a = 5 \) and bigger! The mathematical limits for \( a = 0 \) actually turns it into a linear function at that point, but unfortunately FPUs aren't that good with calculus :-) Once a goes above 1, you start getting clipping in addition to the "soft" wave shaping. It starts getting into more of an effect and less of a mastering tool, though :-)

Seeing as this is just various forms of wave shaping, you could do it all with a look-up table, too. In my version, that would get rid of the somewhat-expensive sin() function.

**Listing 58: code**

```
(input: a == "overdrive amount")
z = M_PI * a;
s = 1/sin(z)
b = 1/a
if (x > b)
f(x) = 1
```

(continues on next page)
9 \textbf{else}
10 \hspace{1em} f(x) = \sin(z\cdot x) \cdot s

4.34 Waveshaper

- **Author or source:** Partice Tarrabia and Bram de Jong
- **Created:** 2002-01-17 02:21:49

Listing 59: notes

\textit{amount should be in } [-1..1] \textit{ Plot it and stand back in astonishment! ;)}

Listing 60: code

1 \hspace{1em} x = \text{input in } [-1..1] \hspace{1em}
2 y = \text{output} \hspace{1em}
3 k = 2 \cdot \text{amount} / (1 - \text{amount}); 
4 \hspace{1em}
5 f(x) = (1 + k) \cdot x / (1 + k \cdot \text{abs}(x))

4.34.1 Comments

- **Date:** 2002-06-27 07:15:59
- **By:** moc.noicratse@ajelak

I haven't compared this to the other waveshapers, but its behavior with input outside the [-1..1] range is interesting. With a relatively moderate shaping amounts which don't distort in-range signals severely, it damps extremely out-of-range signals fairly hard, e.g. x = 100, \( k = 0.1 \) yields \( y = 5.26 \); as x goes to infinity, y approaches 5.5. This might come in handy to control nonlinear processes which would otherwise be prone to computational blowup.

4.35 Waveshaper (simple description)

- **Author or source:** Jon Watte
- **Type:** Polynomial; Distortion
- **Created:** 2002-08-15 00:45:22

Listing 61: notes

> The other question; what's a 'waveshaper' algorithm. Is it simply another word for distortion?

A typical "waveshaper" is some function which takes an input sample value \( X \) and transforms it to an output sample \( X' \). A typical implementation would
be a look-up table of some number of points, and some level of interpolation between those points (say, cubic). When people talk about a wave shaper, this is most often what they mean. Note that a wave shaper, as opposed to a filter, does not have any state. The mapping from X -> X' is stateless.

Some wave shapers are implemented as polynomials, or using other math functions. Hard clipping is a wave shaper implemented using the min() and max() functions (or the three-argument clamp() function, which is the same thing). A very mellow and musical-sounding distortion is implemented using a third-degree polynomial; something like X' = (3/2)X - (1/2)X^3. The nice thing with polynomial wave shapers is that you know that the maximum they will expand bandwidth is their order. Thus, you need to oversample 3x to make sure that a third-degree polynomial is aliasing free. With a lookup table based wave shaper, you don't know this (unless you treat an N-point table as an N-point polynomial :-)

```
Listing 62: code
float waveshape_distort( float in ) {
    return 1.5f * in - 0.5f * in * in * in;
}
```

4.35.1 Comments

- **Date:** 2005-06-30 09:41:07
- **By:** ed.luosfosruoivas@naitsirhC

Yes! It's one of the most simple waveshaper and you know the amount of oversampling! Works very nice (and fast).

4.36 Waveshaper :: Gloubi-boulga

- **Author or source:** Laurent de Soras on IRC
- **Created:** 2002-03-17 15:40:13

```
Listing 63: notes
Multiply input by gain before processing
```

```
Listing 64: code
const double x = input * 0.686306;
const double a = 1 + exp (sqrt (fabs (x)) * -0.75);
output = (exp (x) - exp (-x * a)) / (exp (x) + exp (-x));
```

4.36.1 Comments

- **Date:** 2004-09-25 21:42:39
- **By:** ten.etelirt@gnihtliam
you can use a taylor series approximation for the exp, save time by realizing that
exp(-x) = 1/exp(x), use newton's method to calculate the sqrt with less precision...
and if you use SIMD instructions, you can calculate several values in parallel. dunno
what the savings would be like, but it would surely be faster.

• **Date:** 2005-05-25 22:32:21  
  • **By:** ed.luosfosruoivas@naitsirhC

```pascal
// Maybe something like this:

function GloubiBoulga(x:Single):Single;
var a,b:Single;
begin
  x:=x*0.686306;
  a:=1+exp(sqrt(f_abs(x))*-0.75);
  b:=exp(x);
  Result:=(b-exp(-x*a))*b/(b*b+1);
end;
```

still expensive, but...

• **Date:** 2005-05-28 00:49:48  
  • **By:** ed.luosfosruoivas@naitsirhC

A Taylor series doesn't work very well, because the approximation effects the result_—very early due to
a) numerical critical additions & subtractions of approximations
b) approximating approximated "a" makes the result even more worse.
The above version has already been improved, by removing 2 of 5 exp() functions.
You can also try to express the exp(x)+exp(-x) as cosh(x) with its approximation. So:

```
b:=exp(x);
Result:=(b-exp(-x*a))*b/(b*b+1);
```

would be:

```
Result:=(exp(x)-exp(-x*a))*20160/40320+x*x*(20160+ x*x*(1680+x*x*(56+x*x)));
```

but this is again more worse. Anyone else?

• **Date:** 2005-09-13 09:55:55  
  • **By:** llun.ved@regguHwodahS

Use table lookup with interpolation.

• **Date:** 2005-09-22 01:07:58  
  • **By:** ten.baltg@liced

IMHO, you can use

```
x - 0.15 * x^2 - 0.15 * x^3
```

instead of this scary formula.

I try to explain my position with this small graph:

(continues on next page)
This is only first step, if you want to get more correct result you can use interpolation method called method of minimal squares (this is translation from russian, maybe in england it has another name)

- **Date:** 2005-09-22 07:19:07  
  **By:** ku.oc.snosrapsd@psdcisum

That's much better decil - thx for that!

DSP

- **Date:** 2005-09-22 11:05:07  
  **By:** ten.baltg@liced

You are welcome :)

Now I've working under plugin with wapeshapping processing like this. I've put a link to it here, when I've done it.

- **Date:** 2005-09-24 01:15:38  
  **By:** ten.baltg@liced

You can check my version: http://liteprint.com/download/SweetyVST.zip

Please, send comments and suggestions to my email.

Dmitry.

- **Date:** 2005-10-27 09:57:44  
  **By:** moc.liamtoh@12_namyaj

Which formula exactly did you use decil, for your plugin? How do you get different harmonics from this algo. thanx

jay

- **Date:** 2005-11-15 09:09:48  
  **By:** ten.etelirt@liam

wow, blast from the past seeing this turn up on kvraudio.

christian - i'd have thought that an advantage of using a taylor series approximation would be that it limits the order of the polynomial (and the resulting bandwidth) somewhat. it's been ages since i tested, but i thought i got some reasonable sounding results using the taylor series
approximation. maybe not.

decil - isn't that a completely unrelated polynomial (similar to the common and cheap, $-x - a x^3$?).
i'd think you'd have to do something about the dc from the $x^2$ term, too (or do a $-\text{sign}(x) x^2$).

anyway, your plugin sounds to be popular so i look forward to checking it out later at home.
5.1 16-Point Fast Integer Sinc Interpolator.

- Author or source: moc.liamg@tramum

Listing 1: notes
This is designed for fast upsampling with good quality using only a 32-bit accumulator. Sound quality is very good. Conceptually it resamples the input signal 32768x and performs nearest-neighbour to get the requested sample rate. As a result downsampling will result in aliasing.

The provided Sinc table is Blackman-Harris windowed with a slight lowpass. The table entries are 16-bit and are 16x linear-oversampled. It should be pretty easy to figure out how to make your own table for it.

Code provided is in Java. Converting to C/MMX etc. should be pretty trivial.

Remember the interpolator requires a number of samples before and after the sample to be interpolated, so you can't resample the whole of a passed input buffer in one go.

Have fun,
Martin
public class SincResampler {
    private final int FP_SHIFT = 15;
    private final int FP_ONE = 1 << FP_SHIFT;
    private final int FP_MASK = FP_ONE - 1;

    private final int POINT_SHIFT = 4; // 16 points
    private final int OVER_SHIFT = 4; // 16x oversampling

    private final short[] table = {
        0, -7,  27,  -71,  142,  -227,  299,  -227,  142,  -71,   27,  
        0,  0,  -5,   36,  -142,  450,  -1439,  32224,  2302,  -974,  455,  -190,   64, 
        0,  6,  -33,  128,  -391,  1042,  -2894,  31584,  4540,  -1765,  786,  -318,  105, 
        0,  15,  -86,  322,  -936,  2343,  -5800,  25249,  15006,  -4765,  2011,  -802,  269, 
        0,  14,  -83,  319,  -938,  2347,  -5671,  20396,  20396,  -5671,  2347,  -938,  319, 
        0,  12,  -77,  299,  -885,  2215,  -5298,  17738,  22920,  -5849,  2394,  -957,  328, 
        0,  10,  -68,  269,  -802,  2011,  -4765,  15006,  25249,  -5800,  2343,  -936,  322, 
        0,  9,  -58,  232,  -698,  1749,  -4109,  12263,  27328,  -5498,  2185,  -870,  300, 
        0,  7,  -47,  191,  -578,  1448,  -3366,  9568,  29105,  -4922,  1916,  -757,  261, 
        0,  5,  -36,  148,  -449,  1121,  -2573,  6977,  30535,  -4056,  1533,  -597,  204, 
        0,  3,  -25,  105,  -318,  786,  -1765,  4540,  31584,  -2894,  1042,  -391,  128, 
        0,  2,  0,  0,
    };
}
0, 2, -15, 64, -190, 455, -974, 2302, 32224, -1439, 450, -142, 36, → -5, 0, 0, 0, 0, 0, 0, 0, -15, 64, -190, 455, -974, 2302, 32224, -1439, 450, -142, 36, → 27, -7, 0, -7, 27, -71, 142, -227, 299, 32439, 299, -227, 142, -71, → 27, -7, 0

};

private final int POINT_SHIFT = 1; // 2 points
private final int OVER_SHIFT = 0; // 1x oversampling
private final short[] table = {
    32767, 0,
    0, 32767
};

private final int POINTS = 1 << POINT_SHIFT;
private final int INTERP_SHIFT = FP_SHIFT - OVER_SHIFT;
private final int INTERP_BITMASK = (1 << INTERP_SHIFT) - 1;

/*
  input - array of input samples
  inputPos - sample position (must be at least POINTS/2 + 1, ie. 7)
  inputFrac - fractional sample position (0 <= inputFrac < FP_ONE)
  step - number of input samples per output sample * FP_ONE
  lAmp - left output amplitude (1.0 = FP_ONE)
  lBuf - left output buffer
  rAmp - right output amplitude (1.0 = FP_ONE)
  rBuf - right output buffer
  pos - offset into output buffers
  count - number of output samples to produce
*/
public void resample( short[] input, int inputPos, int inputFrac, int step, int lAmp, int[] lBuf, int rAmp, int[] rBuf, int pos, int count ) {
  for( int p = 0; p < count; p++ ) {
    int tabidxl = (inputFrac >> INTERP_SHIFT) << POINT_SHIFT;
    };
*/

5.1. 16-Point Fast Integer Sinc Interpolator.
```c
int tabidx2 = tabidx1 + POINTS;
int bufidx = inputPos - POINTS/2 + 1;
int a1 = 0, a2 = 0;

for( int t = 0; t < POINTS; t++ ) {
    a1 += table[ tabidx1++ ] * input[ bufidx ] >> 15;
    a2 += table[ tabidx2++ ] * input[ bufidx ] >> 15;
    bufidx++;
}

int out = a1 + ( ( a2 - a1 ) * ( inputFrac & INTERP_BITMASK ) >> INTERP_SHIFT );

lBuf[ pos ] += out * lAmp >> FP_SHIFT;
rBuf[ pos ] += out * rAmp >> FP_SHIFT;
pos++;
inputFrac += step;

inputPos += inputFrac >> FP_SHIFT;
inputFrac &= FP_MASK;
}
```

5.2 16-to-8-bit first-order dither

- **Author or source:** Jon Watte
- **Type:** First order error feedforward dithering code
- **Created:** 2002-04-12 13:52:36

Listing 3: notes

This is about as simple a dithering algorithm as you can implement, but it's likely to sound better than just truncating to N bits. Note that you might not want to carry forward the full difference for infinity. It's probably likely that the worst performance hit comes from the saturation conditionals, which can be avoided with appropriate instructions on many DSPs and integer SIMD type instructions, or CMOV.
Last, if sound quality is paramount (such as when going from > 16 bits to 16 bits) you probably want to use a higher-order dither function found elsewhere on this site.

Listing 4: code

```c
// This code will down-convert and dither a 16-bit signed short
// mono signal into an 8-bit unsigned char signal, using a first
// order forward-feeding error term dither.

#define uchar unsigned char

void dither_one_channel_16_to_8( short * input, uchar * output, int count, int *memory )
{
    int m = *memory;
    while( count-- > 0 ) {
        int i = *input++;
        i += m;
        int j = i + 32768 - 128;
        uchar o;
        if( j < 0 ) {
            o = 0;
        } else if( j > 65535 ) {
            o = 255;
        } else {
            o = (uchar)((j>>8)&0xff);
        }
        m = ((j-32768+128)-i);
        *output++ = o;
    }
    *memory = m;
}
```

5.3 3rd order Spline interpolation

- **Author or source:** Dave from Muon Software, originally from Josh Scholar
- **Created:** 2002-01-17 03:14:54

Listing 5: notes

(from Joshua Scholar about Spline interpolation in general...)
According to sampling theory, a perfect interpolation could be found by replacing each sample with a sinc function centered on that sample, ringing at your target nyquest frequency, and at each target point you just sum all of contributions from the sinc functions of every single point in source. The sinc function has ringing that dies away very slowly, so each target sample will have to have contributions from a large neighborhood of source samples. Luckily, by definition the sinc function is bandwidth limited, so once we have a source that is prefiltered for
our target nyquest frequency and reasonably oversampled relative to our nyquest frequency, ordinary interpolation techniques are quite fruitful even though they would be pretty useless if we hadn't oversampled.

We want an interpolation routine that at very least has the following characteristics:

1. Obviously it's continuous. But since finite differencing a signal (I don't really know about true differentiation) is equivalent to a low frequency attenuator that drops only about 6 dB per octave, continuity at the higher derivatives is important too.

2. It has to be stiff enough to find peaks when our oversampling missed them. This is where what I said about the combination the sinc function's limited bandwidth and oversampling making interpolation possible comes into play.

I've read some papers on splines, but most stuff on splines relates to graphics and uses a control point descriptions that is completely irrelevant to our sort of interpolation. In reading this stuff I quickly came to the conclusion that splines:

1. Are just piecewise functions made of polynomials designed to have some higher order continuity at the transition points.

2. Splines are highly arbitrary, because you can choose arbitrary derivatives (to any order) at each transition. Of course the more you specify the higher order the polynomials will be.

3. I already know enough about polynomials to construct any sort of spline. A polynomial through 'n' points with a derivative specified at 'm[1]' points and second derivatives specified at 'm[2]' points etc. will be a polynomial of the order n-1+m[1]+m[2]...

A way to construct third order splines (that admittedly doesn't help you construct higher order splines), is to linear interpolate between two parabolas. At each point (they are called knots) you have a parabola going through that point, the previous and the next point. Between each point you linearly interpolate between the polynomials for each point. This may help you imagine splines.

As a starting point I used a polynomial through 5 points for each knot and used MuPad (a free Mathematica like program) to derive a polynomial going through two points (knots) where at each point it has the same first two derivatives as a 4th order polynomial through the surrounding 5 points. My intuition was that basing it on polynomials through 3 points wouldn't be enough of a neighborhood to get good continuity. When I tested it, I found that not only did basing it on 5 point polynomials do much better than basing it on 3 point ones, but that 7 point ones did nearly as badly as 3 point ones. 5 points seems to
be a sweet spot.

However, I could have set the derivatives to a nearly arbitrary values - basing the values on those of polynomials through the surrounding points was just a guess.

I've read that the math of sampling theory has different interpretation to the sinc function one where you could upsample by making a polynomial through every point at the same order as the number of points and this would give you the same answer as sinc function interpolation (but this only converges perfectly when there are an infinite number of points). Your head is probably spinning right now - the only point of mentioning that is to point out that perfect interpolation is exactly as stiff as a polynomial through the target points of the same order as the number of target points.

Listing 6: code

```c
//interpolates between L0 and H0 taking the previous (L1) and next (H1) points into account
inline float ThirdInterp(const float x, const float L1, const float L0, const float H0, const float H1)
{
    return L0 +
    .5f*x*(H0 - L1 +
    x*(H0 + L0)*(-2) + L1 +
    x*( (H0 - L0)*9 + (L1 - H1)*3 +
    x*((L0 - H0)*15 + (H1 - L1)*5 +
    x*((H0 - L0)*6 + (L1 - H1)*2 ))));
}
```

5.3.1 Comments

- **Date:** 2002-05-21 06:14:20  
  - **By:** moc.a@a

**What is x ?**

- **Date:** 2002-06-09 19:45:59  
  - **By:** yahoo.co.uk@sewar_ekim

The samples being interpolated represent the wave amplitude at a particular instant of time, T - an impulse train. So each sample is the amplitude at T=0,1,2,3 etc.

The purpose of interpolation is to determine the amplitude, a, for an arbitrary t, where t is any real number:
x = \text{t} - T(p0) - myk

\checkmark Date: 2002-06-09 19:53:03
\checkmark By: yahoo.co.uk@sewar_ekim

Dang! My nice diagram had its spacing stolen, and it now makes no sense!

p1, p0, n0, n1 are supposed to line up with 0,1,2,3 respectively. a is supposed to line up with the t. And finally, \text{-x-> spans between 1 and t.}

\checkmark Date: 2002-09-16 02:34:30
\checkmark By: lc.arret@assenacf

1.- What is 5f ?
2.- How I can test this procedure?.

Thank you

\checkmark Date: 2003-04-15 10:59:26
\checkmark By: moc.oohay@SIHT_EVOMER_ralohcshsoj

This is years later. but just in case anyone has the same problem as fcanessa... In C or C++ you can append an 'f' to a number to make it single precision, so .5f is the same as .5

\checkmark Date: 2012-07-10 13:51:17
\checkmark By: ac.cisum-mutnaug@noicd

About that thing you've said "5 point seems to be the sweet spot". Well, it might depends on the sampling rate.

### 5.4 5-point spline interpolation

\checkmark Author or source: Joshua Scholar, David Waugh
\checkmark Type: interpolation
\checkmark Created: 2002-01-17 03:12:34
Listing 7: code

```c
// nMask = sizeof(wavetable)-1 where sizeof(wavetable is a power of two.
double interpolate(double* wavetable, int nMask, double location)
{
    /* 5-point spline*/

    int nearest_sample = (int) location;
    double x = location - (double) nearest_sample;

    double p0=wavetable[(nearest_sample-2)&nMask];
    double p1=wavetable[(nearest_sample-1)&nMask];
    double p2=wavetable[nearest_sample];
    double p3=wavetable[(nearest_sample+1)&nMask];
    double p4=wavetable[(nearest_sample+2)&nMask];
    double p5=wavetable[(nearest_sample+3)&nMask];

    return p2 + 0.041666666666666666666666*x*x*((p3-p1)*16.0+(p0-p4)*2.0
    + x*x*(p3+66.0-p2+70.0-p4+33.0+p1+39.0+p5+7.0-p0+9.0
    + x*x*(p2+126.0-p3+124.0+p4+61.0-p1+64.0-p5+12.0+p0+13.0
    + x*x((p3-p2)*50.0+(p1-p4)*25.0+(p5-p0)*5.0))));
}
```

5.4.1 Comments

• Date: 2003-05-27 12:20:46
  • By: moc.oohay@SIHTEVOMERralohcshsoj

The code works much better if you oversample before interpolating. If you oversample enough (maybe 4 to 6 times oversampling) then the results are audiophile quality.

• Date: 2010-08-26 20:55:45
  • By: moc.oohay@xofirgomsnart

This looks old...but if anybody reads this:
What do you mean by oversample first? That is practically what you are doing with interpolation. For example, if you want to oversample 6x, you would interpolate 5 evenly spaced points in between p2 and p3 using 5 points at base frequency centered around p2. The 5-point spline interpolation seems like a lower CPU algorithm than a good sinc interpolation, and as a bonus it does not have much of a transient response (only 5 samples worth).

My main target application for something like this is delay line interpolation where there is a concern regarding high frequency notch depth...5th order interpolation is certainly an improvement over linear interpolation :)

• Date: 2012-10-04 08:00:31
  • By: Josh Scholar

By oversample I meant do a windowed sinc doubling oversample a couple times.

The point is that a 4 times oversample can be based on table values and only gives you points exactly 1/4, 1/2 and 3/4 between the samples.

(continues on next page)
Then the spline can be used to interpolate totally arbitrary points between those, say speeding up and slowing down as needed, at very high quality.

If you don’t oversample first, you’ll get an audible amount of aliasing, though not as much as a linear interpolation. Unless the source has a lot of roll off (which is equivalent to it being oversampled anyway).

Can any explain the derivation of this?

### 5.5 Allocating aligned memory

- **Author or source:** Benno Senoner
- **Type:** memory allocation
- **Created:** 2002-01-17 03:08:46

Listing 8: notes

We waste up to align_size + sizeof(int) bytes when we alloc a memory area.

We store the aligned_ptr - unaligned_ptr delta in an int located before the aligned area.

This is needed for the free() routine since we need to free all the memory not only the aligned area.

You have to use aligned_free() to free the memory allocated with aligned_malloc()!

Listing 9: code

```c
/* align_size has to be a power of two !! */

void *aligned_malloc(size_t size, size_t align_size) {
  char *ptr,*ptr2,*aligned_ptr;
  int align_mask = align_size - 1;
  ptr=(char *)malloc(size + align_size + sizeof(int));
  if(ptr==NULL) return(NULL);
  ptr2 = ptr + sizeof(int);
  aligned_ptr = ptr2 + (align_size - ((size_t)ptr2 & align_mask));
  ptr2 = aligned_ptr - sizeof(int);
  *((int *)&ptr2)=((int)(aligned_ptr - ptr));
  return(aligned_ptr);
}

void aligned_free(void *ptr) {
```

(continues on next page)
5.6 Antialiased Lines

- **Author or source:** moc.xinortceletrams@urugra
- **Type:** A slow, ugly, and unoptimized but short method to perform antialiased lines in a framebuffer
- **Created:** 2004-04-07 09:38:53

Listing 10: notes

Simple code to perform antialiased lines in a 32-bit RGBA (1 byte/component) framebuffer.

pframebuffer <- unsigned char* to framebuffer bytes (important: Y flipped line order! [like in the way Win32 CreateDIBSection works...])

client_height=framebuffer height in lines
client_width=framebuffer width in pixels (not in bytes)

This doesn't perform any clip check so it fails if coordinates are set out of bounds.
sorry for the english

Listing 11: code

```c
void PutTransPixel(int const x, int const y, UCHAR const r, UCHAR const g, UCHAR const b, UCHAR const a) {
    unsigned char *ppix=pframebuffer+(x+(client_height-(y+1))*client_width)*4;
    ppix[0]=((a*b)+(255-a)*ppix[0])/256;
    ppix[1]=((a*g)+(255-a)*ppix[1])/256;
    ppix[2]=((a*r)+(255-a)*ppix[2])/256;
}

void LineAntialiased(int const x1, int const y1, int const x2, int const y2, UCHAR const r, UCHAR const g, UCHAR const b) {
    // some useful constants first
    double const dw=x2-x1;
    double const dh=y2-y1;
    double const slx=dh/dw;
    double const sly=dw/dh;

    // determine whichever raster scanning behaviour to use
    if(fabs(slx)<1.0) {
        // (continues on next page)
    }
```

(continues on next page)
// x scan
int tx1=x1;
int tx2=x2;
double raster=y1;

if(x1>x2)
{
    tx1=x2;
    tx2=x1;
    raster=y2;
}

for(int x=tx1;x<=tx2;x++)
{
    int const ri=int(raster);
    double const in_y0=1.0-(raster-ri);
    double const in_y1=1.0-(ri+1-raster);
    PutTransPixel(x,ri+0,r,g,b,in_y0*255.0);
    PutTransPixel(x,ri+1,r,g,b,in_y1*255.0);
    raster+=slx;
}
else
{
    // y scan
    int ty1=y1;
    int ty2=y2;
    double raster=x1;
    if(y1>y2)
    {
        ty1=y2;
        ty2=y1;
        raster=x2;
    }

    for(int y=ty1;y<=ty2;y++)
    {
        int const ri=int(raster);
        double const in_x0=1.0-(raster-ri);
        double const in_x1=1.0-(ri+1-raster);
        PutTransPixel(ri+0,y,r,g,b,in_x0*255.0);
        PutTransPixel(ri+1,y,r,g,b,in_x1*255.0);
        raster+=sly;
    }
}
5.6.1 Comments

- Date: 2004-02-11 12:53:12  
  By: Gog

Sorry, but what does this have to do with music DSP ??

- Date: 2004-02-14 17:39:38  
  By: moc.liamtoh@101_vap

well, for drawing envelopes, waveforms, etc on screen in your DSP app....

- Date: 2004-02-15 11:59:04  
  By: Gog

But... there are TONS of graphic toolkits to do just that. No reason to "roll your own ...". One f.i. is GDI+ (works darn well to be honest), or if you want non-M$ (and better!) go with AGG at (http://www.antigrain.com). And there are even open-source cross-platform toolkits (if you want to do Unix and Mac without coding). Graphics and GUIs is a very time-consuming task to do from scratch, therefore I think using libraries such as the above is the way to go, liberating energy to do the DSP stuff... ;-)

- Date: 2004-03-11 02:56:19  
  By: Rich

I don't want a toolkit, I want antialiased line drawing and nothing more. Everything else is fine.

- Date: 2004-03-11 17:32:09  
  By: Justin

Anyone know how to get the pointer to the framebuffer? Perhaps there is a different answer for different platforms?

- Date: 2004-09-12 07:39:28  
  By: ed.stratnemesab@kcaahcs.leinad

you can also draw everything in a 2x (vertically and horizontally) higher resolution, and then reduce the size again by always taking the average of 4 pixels. that works well.

- Date: 2008-11-20 18:07:21  
  By: moc.liamg@okolila

I think it can be useful to those designing graphical synths.

But the Wu line algorithm is considerably more fast and works only with integers.

http://en.wikipedia.org/wiki/Xiaolin_Wu's_line_algorithm

5.6. Antialiased Lines

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5.7 Automatic PDC system

- **Author or source:** Tebello Thejane
- **Type:** the type that actually works, completely
- **Created:** 2006-07-16 11:39:56
- **Linked files:** pdc.pdf

Listing 12: notes

No, people, implementing PDC is actually not as difficult as you might think it is.

This paper presents a solution to the problem of latency inherent in audio effects processors, and the two appendices give examples of the method being applied on Cubase SX (with an example which its native half-baked PDC fails to solve properly) as well as a convoluted example in FL Studio (taking advantage of the flexible routing capabilities introduced in version 6 of the software). All that's necessary to understand it is a grasp of basic algebra and an intermediate understanding of how music production software works (no need to understand the Laplace transform, linear processes, sigma and integral notation... YAY!).

Please do send me any feedback (kudos, errata, flames, job offers, questions, comments) you might have - my email address is included in the paper - or simply use musicdsp.org's own commenting system.

Tebello Thejane.

Listing 13: code

(I have sent the PDF to Bram as he suggested)

5.7.1 Comments

- **Date:** 2006-07-18 08:12:00
  - **By:** moc.liamg@saoxyz

Oops! RBJ's first name is Robert, not Richard! Man, that's a bad one...

- **Date:** 2006-07-21 10:24:53
  - **By:** moc.liamg@saoxyz

Okay, I've sent a fixed version to Bram. It should be uploaded shortly. Bigger diagrams, too, so there's less aliasing in Adobe Acrobat Reader. Hopefully no more embarisingly bad errors (like misspelling my own name, or something...).

- **Date:** 2006-10-09 15:27:24
  - **By:** moc.liamg@saoxyz
5.8 Base-2 exp

- **Author or source:** Laurent de Soras
- **Created:** 2002-01-17 03:06:08

Listing 14: notes

Linear approx. between 2 integer values of val. Uses 32-bit integers. Not very efficient but fastest than exp().

This code was designed for x86 (little endian), but could be adapted for big endian processors.

Laurent thinks you just have to change the (*(1 + (int *) &ret)) expressions and replace it by (*(int *) &ret). However, He didn't test it.

Listing 15: code

```c
inline double fast_exp2 (const double val)
{
    int e;
    double ret;

    if (val >= 0)
    {
        e = int (val);
        ret = val - (e - 1);
        (*((1 + (int *) &ret)) &= ~(2047 << 20)) += (e + 1023) << 20;
    }
    else
    {
        e = int (val + 1023);
        ret = val - (e - 1024);
        (*((1 + (int *) &ret)) &= ~(2047 << 20)) += e << 20;
    }
    return (ret);
}
```

5.8.1 Comments

- **Date:** 2002-04-10 02:48:33
- **By:** gro.ecruosrv@cimotabus

Here is the code to detect little endian processor:

```c
union
{

```
I've tested the `fast_exp2()` on both little and big endian (intel, AMD, and motorola) processors, and the comment is correct.

Here is the completed function that works on all endian systems:

```c
inline double fast_exp2( const double val )
{
    union
    {
        short val;
        char ch[sizeof( short )];
    } un;
    un.val = 256; // 0x10;
    if (un.ch[1] == 1)
    {
        // then we're little
    }

    // return 2 to the power of val (exp base2)
    int e;
    double ret;
    if (val >= 0)
    {
        e = int (val);
        ret = val - (e - 1);
        if (un.ch[1] == 1)
            (*((1 + (int *) &ret)) &= ~(2047 << 20)) += (e + 1023) << 20;
        else
            (*((int *) &ret)) &= ~(2047 << 20)) += (e + 1023) << 20;
    }
    else
    {
        e = int (val + 1023);
        ret = val - (e - 1024);
        if (un.ch[1] == 1)
            (*((1 + (int *) &ret)) &= ~(2047 << 20)) += e << 20;
        else
            (*((int *) &ret)) &= ~(2047 << 20)) += e << 20;
    }
    return ret;
}
```
5.9 Bit-Reversed Counting

- **Author or source**: moc.oohay@ljbliam
- **Created**: 2004-06-19 10:10:39

**Listing 16: notes**

Bit-reversed ordering comes up frequently in FFT implementations. Here is a non-branching algorithm (given in C) that increments the variable "s" bit-reversedly from 0 to N-1, where N is a power of 2.

**Listing 17: code**

```c
int r = 0; // counter
int s = 0; // bit-reversal of r/2
int N = 256; // N can be any power of 2
int N2 = N << 1; // N<<1 == N*2

do {
    printf("%u ", s);
    r += 2;
    s ^= N - (N / (r&-r));
} while (r < N2);
```

5.9.1 Comments

- **Date**: 2005-08-10 07:20:50
  - **By**: moc.oohay@r_adihaw

This will give the bit reversal of N number of elements (where N is a power of 2). If we want reversal of a particular number out of N, is there any optimised way other than doing bit wise operations?

- **Date**: 2006-03-30 23:17:55
  - **By**: moc.oohay@ljbliam

There's a better way that doesn't require counting, branching, or division. It's probably the fastest way of doing bit reversal without a special instruction. I got this from Jörg's FXT book:

```c
unsigned r; // value to be bit-reversed

// Assume r is 32 bits
r = ((r & 0x55555555) << 1) | ((r & 0xaaaaaaaa) >> 1);
r = ((r & 0x33333333) << 2) | ((r & 0xcccccccc) >> 2);
r = ((r & 0x0f0f0f0f) << 4) | ((r & 0xf0f0f0f0) >> 4);
r = ((r & 0x00ff00ff) << 8) | ((r & 0xff00ff00) >> 8);
r = ((r & 0x0000ffff) << 16) | ((r & 0xffff0000) >> 16);
```

- **Date**: 2010-09-20 15:22:09
  - **By**: ed.bew@mfyknarf
The way mentioned in the comment might be faster but is fixed to 32 bits. If you do a FFT with 1024 points you need 10 bits bit-reversal. Thus the originally mentioned algorithm is more flexible because it works for any bit width. If you use it for FFT (that's actually the only case you normally use bit-reversal) you either need to calculate the bit-reversal for each array index, so counting upwards in bit-reversal order is not such a bad way. I'm not sure whether the second algorithm is really faster than the counter if you consider the whole array. (There are 5 instructions per line making 25 instructions in sum for each calculated index with the second algorithm compared to 7 instructions in the counting algorithm)

5.10 Block/Loop Benchmarking

- **Author or source:** moc.xinortceletrams@urugra
- **Type:** Benchmarking Tool
- **Created:** 2003-06-24 07:30:43

**Listing 18: notes**

Requires CPU with RDTSC support

**Listing 19: code**

```
// Block-Process Benchmarking Code using rdtsc
// useful for measure DSP block stuff
// (based on Intel papers)
// 64-bit precision
// VeryUglyCode(tm) by Arguru

// globals
UINT time,time_low,time_high;

// call this just before enter your loop or whatever
void bpb_start()
{
    // read time stamp to EAX
    __asm rdtsc;
    __asm mov time_low,eax;
    __asm mov time_high,edx;
}

// call the following function just after your loop
// returns average cycles wasted per sample
UINT bpb_finish(UINT const num_samples)
{
    __asm rdtsc
    __asm sub eax,time_low;
    __asm sub edx,time_high;
    __asm div num_samples;
    __asm mov time,eax;
    return time;
}
```
5.10.1 Comments

- **Date:** 2004-05-16 18:20:13
- **By:** moc.sulp.52retsinnab@etep

If running windows on a mutliprocessor system, apparently it is worth calling:

SetThreadAffinityMask(GetCurrentThread(), 1);

to reduce artefacts.

 dv_vstechart/html/optimization.asp)

- **Date:** 2004-08-26 00:33:18
- **By:** rf.eerf@uerum.emualliug

__asm sub eax,time_low;
__asm sub edx,time_high;

should be

__asm sub eax,time_low
__asm SBB edx,time_high // substract with borrow

5.11 Branchless Clipping

- **Author or source:** ku.oc.snosrapsd@psdcisum
- **Type:** Clipping at 0dB, with none of the usual ‘if..then..’
- **Created:** 2005-10-30 10:33:19

Listing 20: notes

I was working on something that I wanted to ensure that the signal never went above 0dB,
and a branchless solution occurred to me.

It works by playing with the structure of a single type, shifting the sign bit down to
make a new multtiplicand.

calling MaxZerodB(mydBSample) will ensure that it will never stray over 0dB.
By playing with signs or adding/removing offsets, this offers a complete branchless
limiting solution, no matter whether dB or not (after all, they’re all just numbers...
→).

eq:
Limit to <=0 : sample:=MaxZerodB(sample);
Limit to <=3 : sample:=MaxZerodB(sample-3)+3;
Limit to <=-4 : sample:=MaxZerodB(sample+4)-4;

Limit to >=0 : sample:=-MaxZerodB(-sample);
Limit to >=2 : sample:=-MaxZerodB(-sample+2)+2;
Limit to >=-1.5: sample:=-MaxZerodB(-sample-1.5)-1.5;

(continues on next page)
Whether it actually saves any CPU cycles remains to be seen, but it was an interesting diversion for half an hour :)

[Translating from pascal to other languages shouldn't be too hard, and for doubles, you'll need to fiddle it abit :)]

Listing 21: code

```pascal
function MaxZerodB(dBin:single):single;
var tmp:longint;
begin
  // given that leftmost bit of a longint indicates the negative,
  // if we shift that down to bit0, and multiply dBin by that
  // it will return dBin, or zero :
  tmp:=(longint((@dBin)^) and $80000000) shr 31;
  result:=dBin*tmp;
end;
```

5.11.1 Comments

- **Date**: 2005-11-29 18:33:09
  - **By**: hotpop.com@blargg
  
  Since most processors include a sign-preserving right shift, you can right shift by 31 to end up with either -1 (all bits set) or 0, then mask the original value with it:

  ```pascal
  out = (in >> 31) & in;
  ```

- **Date**: 2005-12-01 20:33:28
  - **By**: moc.liamg@tarmum
  
  I prefer this method, using a sign-preserving shift, as it can clip a signal to arbitrary bounds:

  ```pascal
  over = upper_limit - samp
  mask = over >> 31
  over = over & mask
  samp = samp + over
  over = samp - lower_limit
  mask = over >> 31
  over = over & mask
  samp = samp - over
  ```

  Is it faster? Maybe on modern machines with 20-plus-stage pipelines and if the signal is clipped often, as the branches are not predictable.

- **Date**: 2006-03-22 17:53:44
  - **By**: ku.oc.snorspsd@psdcisum
hmm.. Did some looking into the sign preserving thing. My laptop has an P3 which didn't preserve as mentioned, and my work PC (P4HT) didn't either. Maybe its an AMD or motorola thing :)  

unless it's how delphi interprets the shr.. what does a C++ compiler generate for '>>_' ?

**Date:** 2006-03-28 14:42:44  
**By:** moc.liamg@tramum

C and C++ have sign-preserving shifts. If the value is negative, a right shift will add ones onto the left hand side (thus -2 becomes -1 etc).

Java also has a non-sign-preserving right shift operator (>>>).

I tried googling for information on how Delphi handles shifts, but nothing turned up. Looks like you might need to use in-line assembly :/

**Date:** 2006-03-30 02:47:35  
**By:** ed.ko0@oreb

Here my SAR function for Delphi+FreePascal

```pascal
FUNCTION SAR(Value,Shift:INTEGER):INTEGER; {$IFDEF CPU386}ASSEMBLER; REGISTER;{$ELSE}{$IFDEF FPC}INLINE;{$ELSE}REGISTER;{$ENDIF}{$ENDIF}{IFDEF CPU386}
ASM
    MOV ECX,EDX
    SAR EAX,CL
END;
{$ELSE}
BEGIN
    RESULT:=(Value SHR Shift) OR (($FFFFFFFF+(1-((Value AND (1 SHL 31)) SHR 31) AND _ORD(Shift<>0))) SHL (32-Shift));
END;
{$ENDIF}
```

**Date:** 2006-03-30 03:19:59  
**By:** ed.ko0@oreb

My branchless clipping functions (the first is faster than the second)

```pascal
FUNCTION Clip(Value,Min,Max:SINGLE):SINGLE; ASSEMBLER; STDCALL;
CONST Constant0Dot5:SINGLE=0.5;
ASM
    FLD DWORD PTR Value
    FLD DWORD PTR Min
    FLD DWORD PTR Max
    FLD ST(2)
    FSUB ST(0),ST(2)
    FABS
    FADD ST(0),ST(2)
    FADD ST(0),ST(1)
```

(continues on next page)
```assembly
FLD ST(3)
FSUB ST(0),ST(2)
FABS
FSUBP ST(1),ST(0)
FMUL DWORD PTR Constant0Dot5

FFREE ST(4)
FFREE ST(3)
FFREE ST(2)
FFREE ST(1)
END;

FUNCTION ClipDSP(Value:SINGLE):SINGLE; {$IFDEF CPU386 ASSEMBLER; REGISTER; ASM
MOV EAX,DWORD PTR Value
AND EAX,$80000000
AND DWORD PTR Value,$7FFFFFFF
FLD DWORD PTR Value
FLD1
FSUBP ST(1),ST(0)
FSTP DWORD PTR Value

MOV EDX,DWORD PTR Value
AND EDX,$80000000
SHR EDX,31
NEG EDX
AND DWORD PTR Value,EDX
FLD DWORD PTR Value
FLD1
FADDP ST(1),ST(0)
FSTP DWORD PTR Value
OR DWORD PTR Value,EAX

FLD DWORD PTR Value
END;
{$ELSE}
VAR ValueCasted:LONGWORD ABSOLUTE Value;
Sign:LONGWORD;
BEGIN
Sign:=ValueCasted AND $80000000;
ValueCasted:=ValueCasted AND $7FFFFFFF;
Value:=Value-1;
ValueCasted:=ValueCasted AND (-LONGWORD((ValueCasted AND $80000000) SHR 31));
Value:=Value+1;
ValueCasted:=ValueCasted OR Sign;
RESULT:=Value;
END;
{$ENDIF}
```
5.12 Calculate notes (java)

- **Author or source:** gro.kale@ybsral
- **Type:** Java class for calculating notes with different in params
- **Created:** 2002-06-21 02:33:13
- **Linked files:** Frequency.java

Listing 22: notes

Converts between string notes and frequencies and back. I vaguely remember writing bits of it, and I got it off the net somewhere so don't ask me

- Larsby

5.13 Center separation in a stereo mixdown

- **Author or source:** Thiburce BELAVENTURE
- **Created:** 2004-02-11 14:00:08

Listing 23: notes

One year ago, I found a little trick to isolate or remove the center in a stereo mixdown.

My method uses the time-frequency representation (FFT). I use a min function between left and right channels (for each bin) to create the pseudo center. I apply a phase correction, and subtract this signal from the left and right signals.

Then, we can remix them after treatments (or without) to produce a stereo signal in output.

This algorithm (I called it "TBIsolator") is not perfect, but the result is very nice, better than the phase technic (L subtract R...). I know that it is not mathematically correct, but as an estimation of the center, the exact match is very hard to obtain. So, it is not so bad (just listen the result and see).

My implementation uses a 4096 FFT size, with overlap-add method (factor 2). With a lower FFT size, the sound will be more dirty, and with a 16384 FFT size, the center will have too much high frequency (I don't explore why this thing appears).

I just post the TBIsolator code (see FFTReal in this site for implement the FFT engine).

pIns and pOuts buffers use the representation of the FFTReal class (0 to N/2-1: real parts, N/2 to N-1: imaginary parts).
Have fun with the TBIIsolator algorithm! I hope you enjoy it and if you enhance it, contact me (it's my baby...).

P.S.: the following function is not optimized.

Listing 24: code

```c
/* ============================================================== */
/* nFFTSize must be a power of 2 */
/* ============================================================== */
/* Usage examples: */
/* - suppress the center: fAmpL = 1.f, fAmpC = 0.f, fAmpR = 1.f */
/* - keep only the center: fAmpL = 0.f, fAmpC = 1.f, fAmpR = 0.f */
/* ============================================================== */

void processTBIIsolator(float *pIns[2], float *pOuts[2], long nFFTSize, float fAmpL, float fAmpC, float fAmpR)
{
    float fModL, fModR;
    float fRealL, fRealC, fRealR;
    float fImagL, fImagC, fImagR;
    double u;

    for (long i = 0, j = nFFTSize / 2; i < nFFTSize / 2; i++)
    {
        fModL = pIns[0][i] * pIns[0][i] + pIns[0][j] * pIns[0][j];
        fModR = pIns[1][i] * pIns[1][i] + pIns[1][j] * pIns[1][j];

        // min on complex numbers
        if (fModL > fModR)
        {
            fRealC = fRealR;
            fImagC = fImagR;
        }
        else
        {
            fRealC = fRealL;
            fImagC = fImagL;
        }

        // phase correction...
        u = fabs(atan2(pIns[0][j], pIns[0][i]) - atan2(pIns[1][j], pIns[1][i])) / 3.141592653589;
        if (u >= 1) u = 1.;
        u = pow(1 - u*u*u, 24);
        fRealC *= (float) u;
        fImagC *= (float) u;

        // center extraction...
        fRealL = pIns[0][i] - fRealC;
        fImagL = pIns[0][j] - fImagC;
        fRealR = pIns[1][i] - fRealC;
    }
}
```

(continues on next page)
5.13.1 Comments

- **Date:** 2004-02-11 18:40:30
- **By:** moc.ecrubiht@cehcnamf

I am sorry, my source code is not totally correct.

1 - the for is:

```
for ( long i = 0, j = nFFTSize / 2; i < nFFTSize / 2; i++, j++ )
```

2 - the correct min is:

```
if ( fModL > fModR )
{
    fRealC = pIns[1][i];
    fImagC = pIns[1][j];
}
else
{
    fRealC = pIns[0][i];
    fImagC = pIns[0][j];
}
```

3 - in the phase correction:

```
if ( u >= 1 ) u -= 1.;
```

must be replaced by:

```
if ( u >= 1 ) u = 2 - u;
```

Thiburce 'TB' BELAVENTURE

5.14 Center separation in a stereo mixdown

- **Author or source:** Thiburce BELAVENTURE
- **Created:** 2004-02-14 15:14:09
One year ago, I found a little trick to isolate or remove the center in a stereo mixdown.

My method uses the time-frequency representation (FFT). I use a min function between left and right channels (for each bin) to create the pseudo center. I apply a phase correction, and I subtract this signal to the left and right signals.

Then, we can remix them after treatments (or without) to produce a stereo signal in output.

This algorithm (I called it "TBIsolator") is not perfect, but the result is very nice, better than the phase technic (L subtract R...). I know that it is not mathematically correct, but as an estimation of the center, the exact match is very hard to obtain. So, it is not so bad (just listen the result and see).

My implementation uses a 4096 FFT size, with overlap-add method (factor 2). With a lower FFT size, the sound will be more dirty, and with a 16384 FFT size, the center will have too much high frequency (I don't explore why this thing appears).

I just post the TBIsolator code (see FFTReal in this site for implement the FFT engine).

pIns and pOuts buffers use the representation of the FFTReal class (0 to N/2-1: real parts, N/2 to N-1: imaginary parts).

Have fun with the TBIsolator algorithm! I hope you enjoy it and if you enhance it, contact me (it's my baby...).

P.S.: the following function is not optimized.

```c
/* ============================================================== */
/* nFFTSize must be a power of 2 */
/* ============================================================== */
/* Usage examples: */
/* - suppress the center: fAmpL = 1.f, fAmpC = 0.f, fAmpR = 1.f */
/* - keep only the center: fAmpL = 0.f, fAmpC = 1.f, fAmpR = 0.f */
/* ============================================================== */
void processTBIsolator(float *pIns[2], float *pOuts[2], long nFFTSize, float fAmpL, float fAmpC, float fAmpR)
{
    float fModL, fModR;
    float fRealL, fRealC, fRealR;
    float fImagL, fImagC, fImagR;
    double u;

    for ( long i = 0, j = nFFTSize / 2; i < nFFTSize / 2; i++ )
    {
        (continues on next page)
```


```
18 fModL = pIns[0][i] * pIns[0][i] + pIns[0][j] * pIns[0][j];
19 fModR = pIns[1][i] * pIns[1][i] + pIns[1][j] * pIns[1][j];
20
21 // min on complex numbers
22 if ( fModL > fModR )
23 {
24     fRealC = fRealR;
25     fImagC = fImagR;
26 }
27 else
28 {
29     fRealC = fRealL;
30     fImagC = fImagL;
31 }
32
33 // phase correction...
34 u = fabs(atan2(pIns[0][j], pIns[0][i]) - atan2(pIns[1][j], pIns[1][i])) / 3.141592653589;
35
36 if ( u >= 1 ) u -= 1.;
37 u = pow(1 - u*u*u, 24);
38 fRealC *= (float) u;
39 fImagC *= (float) u;
40
41 // center extraction...
42 fRealL = pIns[0][i] - fRealC;
43 fImagL = pIns[0][j] - fImagC;
44 fRealR = pIns[1][i] - fRealC;
45 fImagR = pIns[1][j] - fImagC;
46
47 // You can do some treatments here...
48 pOuts[0][i] = fRealL * fAmpL + fRealC * fAmpC;
49 pOuts[0][j] = fImagL * fAmpL + fImagC * fAmpC;
50 pOuts[1][i] = fRealR * fAmpR + fRealC * fAmpC;
51 pOuts[1][j] = fImagR * fAmpR + fImagC * fAmpC;
52 }
53 }
```

5.15 Cheap pseudo-sinusoidal lfo

- Author or source: moc.regnimmu@regnimmuf
- Created: 2004-04-07 09:39:28

Listing 27: notes

Although the code is written in standard C++, this algorithm is really better suited for dsps where one can take advantage of multiply-accumulate instructions and where the

(continues on next page)
required phase accumulator can be easily implemented by masking a counter. It provides a pretty cheap roughly sinusoidal waveform that is good enough for an lfo.

Listing 28: code

```cpp
// x should be between -1.0 and 1.0
inline double pseudo_sine(double x) {
    // Compute 2*(x^2-1.0)^2-1.0
    x *= x;
    x -= 1.0;
    x *= x;
    // The following lines modify the range to lie between -1.0 and 1.0.
    // If a range of between 0.0 and 1.0 is acceptable or preferable
    // (as in a modulated delay line) then you can save some cycles.
    x *= 2.0;
    x -= 1.0;
}
```

5.15.1 Comments

- **Date:** 2004-03-31 09:08:57
  - **By:** ed.bew@hakkeb
    
    You forgot a
    return x;

- **Date:** 2004-04-05 19:43:15
  - **By:** moc.regnimmu@regnimmuf
    
    Doh! You're right.
    ~Frederick

5.16 Clipping without branching

- **Author or source:** Laurent de Soras (moc.ecrofmho@tnerual)
- **Type:** Min, max and clip
- **Created:** 2004-04-07 09:35:57

Listing 29: notes

It may reduce accuracy for small numbers. I.e. if you clip to [-1; 1], fractional part of the result will be quantized to 23 bits (or more, depending on the bit depth of the
(continued from previous page)

temporary results). Thus, 1e-20 will be rounded to 0. The other (positive) side effect is the denormal number elimination.

Listing 30: code

```c
float max (float x, float a)
{
    x -= a;
    x += fabs (x);
    x *= 0.5;
    x += a;
    return (x);
}

float min (float x, float b)
{
    x = b - x;
    x += fabs (x)
    x *= 0.5;
    x = b - x;
    return (x);
}

float clip (float x, float a, float b)
{
    x1 = fabs (x-a);
    x2 = fabs (x-b);
    x = x1 + (a+b);
    x -= x2;
    x *= 0.5;
    return (x);
}
```

5.16.1 Comments

- **Date:** 2002-04-15 04:05:45
- **By:** ten.xfer@spelk

AFAIK, the fabs() is using if()...

- **Date:** 2002-05-27 11:48:41
- **By:** moc.tecollev@ydna

fabs/fabsf do not use if and are quicker than:
if (x<0) x = -x;
Do the speed tests yourself if you don’t believe me!

- **Date:** 2002-06-26 09:55:50
- **By:** moc.noicratse@ajelak

Depends on CPU and optimization options, but yes, Visual C++/x86/full optimization uses intrinsic fabs, which is very cool.

5.16. Clipping without branching
And of course you could always use one of those nifty bit-tricks for fabs :) (Handy when you don't want to link with the math-library, like when coding a softsynth for a 4Kb-executable demo :))

according to my benchmarks (using the cpu clock cycle counter), fabs and the 'nifty bit tricks' have identical performance characteristics, EXCEPT that with the nifty bit trick, sometimes it has a -horrible- penalty, which depends on the context... maybe it does not optimize consistently? I use libmath fabs now. (i'm using gcc-3.3-linux on a P3)

Precision can be a major problem with these. In particular, if you have an algorithm that blows up with negative input, don't guard via clip( in, 0.0, 1.0 ) - it will occasionally go negative.

5.17 Constant-time exponent of 2 detector

Author or source: Brent Lehman (moc.oohay@ljbliam)

Created: 2002-02-10 12:53:15

In your common FFT program, you want to make sure that the frame you're working with has a size that is a power of 2. This tells you in just a few operations. Granted, you won't be using this algorithm inside a loop, so the savings aren't that great, but every little hack helps ;)

Listing 31: notes

Listing 32: code

5.17.1 Comments

Date: 2002-02-12 03:20:11
I think I prefer:

```c
if (! (size & (size - 1))) return;
```

I'm not positive this is fewer instructions than the above, but I think it's easier to see why it works (n and n-1 will share bits unless n is a power of two), and it doesn't require two's-complement.

- Tom 7

## 5.18 Conversion and normalization of 16-bit sample to a floating point number

- **Author or source:** George Yohng
- **Created:** 2007-05-02 13:34:21

Listing 33: code

```c
float out;
signed short in;

// This code does the same as
// out = ((float)in)*(1.0f/32768.0f);
// Depending on the architecture and conversion settings,
// it might be more optimal, though it is always advisable to check its speed against genuine
// algorithms.
((unsigned &)out)=0x43818000^in;
out-=259.0f;
```

### 5.18.1 Comments

- **Date:** 2007-05-15 06:09:54
- **By:** moc.mot@lx_iruy

Hi George Yohng

I tried it... but it's create the heavy noise!!

- **Date:** 2007-09-20 17:51:12
- **By:** George Yohng

Correction:

```c
((unsigned &)out)=0x43818000^((unsigned short)in);
out-=259.0f;
```

(needs to have a cast to 'unsigned short')
5.19 Conversions on a PowerPC

- **Author or source:** James McCartney
- **Type:** motorola ASM conversions
- **Created:** 2002-01-17 03:07:18

Listing 34: code

```c
double ftod(float x) { return (double)x;
00000000: 4E800020   blr
// blr == return from subroutine, i.e. this function is a noop
5    float dtof(double x) { return (float)x;
6    00000000: FC200818   frsp   fp1,fp1
7    00000004: 4E800020   blr
8    int ftoi(float x) { return (int)x;
9    00000000: FC00081E   fctiwz   fp0,fp1
10   00000004: D801FFF0   stfd   fp0,-16(SP)
11   00000008: 8061FFF4   lwz   r3,-12(SP)
12   0000000C: 4E800020   blr
13   int dtoi(double x) { return (int)x;
14   00000000: FC00081E   fctiwz   fp0,fp1
15   00000004: D801FFF0   stfd   fp0,-16(SP)
16   00000008: 8061FFF4   lwz   r3,-12(SP)
17   0000000C: 4E800020   blr
18   double itod(int x) { return (double)x;
19   00000000: C8220000   lfd   fp1,@1558(RTOC)
20   00000004: 6C608000   xoris   r0,r3,58000
21   00000008: 9001FFF4   stw   r0,-12(SP)
22   0000000C: 3C004330   lis   r0,17200
23   00000010: 9001FFF0   stw   r0,-16(SP)
24   00000014: C801FFF0   lfd   fp0,-16(SP)
25   00000018: FC200828   fsub   fp1,fp0,fp1
26   0000001C: 4E800020   blr
27   float itof(int x) { return (float)x;
28   00000000: C8220000   lfd   fp1,@1558(RTOC)
29   00000004: 6C608000   xoris   r0,r3,58000
30   00000008: 9001FFF4   stw   r0,-12(SP)
31   0000000C: 3C004330   lis   r0,17200
32   00000010: 9001FFF0   stw   r0,-16(SP)
33   00000014: C801FFF0   lfd   fp0,-16(SP)
34   00000018: EC200828   fsubs   fp1,fp0,fp1
35   0000001C: 4E800020   blr
```

5.20 Cubic interpolation

- **Author or source:** Olli Niemitalo
- **Type:** interpolation
- **Created:** 2002-01-17 03:05:33
Listing 35: notes

(see linkfile)
finpos is the fractional, inpos the integer part.

Listing 36: code

```c
1 xm1 = x [inpos - 1];
2 x0 = x [inpos + 0];
3 x1 = x [inpos + 1];
4 x2 = x [inpos + 2];
5 a = (3 * (x0-x1) - xm1 + x2) / 2;
6 b = 2*x1 + xm1 - (5*x0 + x2) / 2;
7 c = (x1 - xm1) / 2;
8 y [outpos] = (((a * finpos) + b) * finpos + c) * finpos + x0;
```

5.21 Cure for malicious samples

- **Author or source:** moc.eh-u@sru
- **Type:** Filters Denormals, NaNs, Infinities
- **Created:** 2005-03-24 00:32:54

Listing 37: notes

A lot of incidents can happen during processing samples. A nasty one is → denormalization, which makes cpus consume insanely many cycles for easiest instructions.

But even worse, if you have NaNs or Infinities inside recursive structures, maybe due → to division by zero, all subsequent samples that are multiplied with these values will → get "infected" and become NaN or Infinity. Your sound makes BLIPPP and that was it, → silence from the speakers.

Thus I've written a small function that sets all of these cases to 0.0f.

You'll notice that I treat a buffer of floats as unsigned integers. And I avoid → branches by using comparison results as 0 or 1.

When compiled with GCC, this function should not create any "hidden" branches, but you should verify the assembly code anyway. Sometimes some parenthesis do the trick...

```c
);) Urs
```

Listing 38: code

```c
1 #ifndef UInt32
2 #define UInt32 unsigned int
```

(continues on next page)
void erase_All_NaNs_Infinities_And_Denormals( float* inSamples, int& inNumberOfSamples )
{
    UInt32* inArrayOfFloats = (UInt32*) inSamples;

    for ( int i = 0; i < inNumberOfSamples; i++ )
    {
        UInt32 sample = *inArrayOfFloats;
        UInt32 exponent = sample & 0x7F800000;

        // exponent < 0x7F800000 is 0 if NaN or Infinity, otherwise 1
        // exponent > 0 is 0 if denormalized, otherwise 1

        int aNaN = exponent < 0x7F800000;
        int aDen = exponent > 0;

        *inArrayOfFloats++ = sample * ( aNaN & aDen );
    }
}

5.21.1 Comments

- **Date:** 2005-05-14 17:18:12
  - **By:** dont-email-me

#include <inttypes.h>
and use std::uint32_t
or typedef (not #define)

int const & inNumberOfSamples

- **Date:** 2005-10-14 18:36:07
  - **By:** DevilishHabib

Isn't it bad to declare variables within for loop?
If someone has VC++ standard (no optimizer included, thanks Bill :-( ) , the cycles,
—gained by removing denormals, will be eaten by declaring 4 variables per loop cycle,
—so watch out !

- **Date:** 2007-05-11 05:51:36
  - **By:** if.iki@xemxet

DevilishHabib, that’s rubbish. It doesn't matter where the declaration is as long as
—the code works. Declaring outside the loop is the same thing (you can verify this).

Urs, nice code but you don't get rid of branches just like that. Comparision is,
—comparision no matter what. Your code is equal to "int aNaN = exponent < 0x7F800000;
—? 1 : 0;" which is equal to "int aNaN = 0; if (exponent < 0x7F800000) aNaN = 1;" If,
—we are talking about x86 asm here, there is no instruction that would do the,
—conditional assignment needed. MMX/SSE has it, though.
5.22 Denormal DOUBLE variables, macro

- **Author or source:** Jon Watte
- **Created:** 2002-03-17 15:44:31

Listing 39: notes

Use this macro if you want to find denormal numbers and you're using doubles...

```c
#include PLATFORM_IS_BIG_ENDIAN
#define INDEX 0
#else
#define INDEX 1
#endif
inline bool is_denormal(double const & d ) {
    assert( sizeof( d ) == 2*sizeof( int ) );
    int l = ((int *)&d)[INDEX];
    return (l&0x7fe00000) != 0;
}
```

5.22.1 Comments

- **Date:** 2005-05-14 17:19:48
- **By:** dont-email-me

put the #if inside the function itself

5.23 Denormal numbers

- **Author or source:** Compiled by Merlijn Blaauw
- **Created:** 2002-01-17 03:06:39
- **Linked files:** other001.txt.

Listing 41: notes

this text describes some ways to avoid denormalisation. Denormalisation happens when FPU's go mad processing very small numbers
5.23.1 Comments

- **Date:** 2004-01-31 05:20:38
- **By:** moc.dh2a@ydna

See also the entry about 'branchless min, max and clip' by Laurent Soras in this section,

Using the following function,

```c
float clip (float x, float a, float b) {
    x1 = fabs (x-a);
    x2 = fabs (x-b);
    x = x1 + (a+b);
    x -= x2;
    x *= 0.5;
    return (x);
}
```

If you apply clipping from -1.0 to 1.0 will have a side effect of squashing denormal numbers to zero due to loss of precision on the order of ~1.0.e-20. The upside is that it is branchless, but possibly more expensive than adding noise and certainly more so than adding a DC offset.

5.24 Denormal numbers, the meta-text

- **Author or source:** Laurent de Soras
- **Created:** 2002-02-15 00:16:30
- **Linked files:** denormal.pdf.

Listing 42: notes

This very interesting paper, written by Laurent de Soras (www.ohmforce.com) has everything you ever wanted to know about denormal numbers! And it obviously describes how you can get rid of them too!

(see linked file)

5.25 Denormalization preventer

- **Author or source:** gol
- **Created:** 2005-03-31 16:57:07
A fast tiny numbers sweeper using integer math. Only for 32bit floats. Den_Thres is your 32bit (normalized) float threshold, something small enough but big enough to prevent future denormalizations.

EAX=input buffer
EDX=length
(adapt to your compiler)

Listing 44: code

MOV ECX,EDX
LEA EDI,[EAX+4*ECX]
NEG ECX
MOV EDX,Den_Thres
SHL EDX,1
XOR ESI,ESI

@Loop:
MOV EAX,[EDI+4*ECX]
LEA EBX,[EAX*2]
CMP EBX,EDX
CMOVB EAX,ESI
MOV [EDI+4*ECX],EAX
INC ECX
JNZ @Loop

5.26 Denormalization preventer

• Author or source: eb.tenyks@didid
• Created: 2006-08-05 16:37:20

Because I still see people adding noise or offset to their signal to avoid slow denormalization, here’s a piece of code to zero out (near) tiny numbers instead.

Why zeroing out is better? Because a fully silent signal is better than a little —offset, or noise. A host or effect can detect silent signals and choose not to process them in a safe way. Plus, adding an offset or noise reduces huge packets of denormalization, but still leaves some behind. Also, truncating is what the DAZ (Denormals Are Zero) SSE flag does.

This code uses integer comparison, and a CMOV, so you need a Pentium Pro or higher. There’s no need for an SSE version, as if you have SSE code you’re probably already using the DAZ flag instead (but I advise plugins not to mess with the SSE flags, as the host is... (continues on next page)
likely to have DAZ switched on already). This is for FPU code. Should work much faster than crap FPU comparison.

Den_Thres is your threshold, it cannot be denormalized (would be pointless). The
→ function is Delphi, if you want to adapt, just make sure EAX is the buffer and EDX is length (Delphi register calling convention - it's not the same in C++).

### Listing 46: code

```pascal
const Den_Thres:Single=1/$1000000;

procedure PrevFPUDen_Buffer(Buffer:Pointer;Length:Integer);
asm
PUSH ESI
PUSH EDI
PUSH EBX

MOV ECX,EDX
LEA EDI,[EAX+4*ECX]
NEG ECX
MOV EDX,Den_Thres
SHL EDX,1
XOR ESI,ESI

@Loop:
MOV EAX,[EDI+4*ECX]
LEA EBX,[EAX*2]
CMP EBX,EDX
CMOVB EAX,ESI
MOV [EDI+4*ECX],EAX
INC ECX
JNZ @Loop

POP EBX
POP EDI
POP ESI
End;
```

### 5.26.1 Comments

- **Date:** 2006-08-14 05:36:29
- **By:** uh.etle.fni@yfoocs

You can zero out denormals by adding and subtracting a small number.

```c
void kill_denormal_by_quantization(float &val)
{
    static const float anti_denormal = 1e-18;
    val += anti_denormal;
    val -= anti_denormal;
}
```

(continues on next page)
Reference: Laurent de Soras' great article on denormal numbers:
ldesoras.free.fr/doc/articles/denormal-en.pdf

I tend to add DC because it is faster than quantization. A slight DC offset (0.000000000000000001) won't hurt. That's ~360 decibels...

• Date: 2006-08-14 09:20:43
  • By: gol

>>You can zero out denormals by adding and subtracting a small number

But with drawbacks as explained in his paper.

As for the speed, not sure which is the faster. Especially since the FPU speed is too
manufacturer-dependant (read: it's crap in pentiums), and mine is using integer.

>>A slight DC offset (0.000000000000000001) won't hurt

As I wrote, it really does.. hurt the sequencer, that can't detect pure silence and
optimize things accordingly. A host can detect near-silence, but it can't know
which offset value YOU chose, so may use a lower threshold.

• Date: 2006-08-14 09:33:35
  • By: gol

Btw, I happen to see I had already posted this code, probably years ago, doh!

Anyway this version gives more explanation.

And here's more:
The LEA EBX,[EAX*2] is to get rid of the sign bit.
And the integer comparison of float values can be done providing both are the same
sign (I'm not quite sure it works on denormals, but we don't care, since they're
the ones we want to zero out, so our threshold won't be denormalized).

• Date: 2010-03-10 13:29:06
  • By: moc.liamg@sisehtnysorpitna

You could also add input noise and assure output samples are reset to 0 if they're
below a certain treshold, slightly higher than your noise volume. That ensures
hosts can do proper tail detection and it's cheap.

5.27 Dither code

• Author or source: Paul Kellett
• Type: Dither with noise-shaping
• Created: 2002-01-17 03:13:20
Listing 47: notes

This is a simple implementation of highpass triangular-PDF dither (a good general-purpose dither) with optional 2nd-order noise shaping (which lowers the noise floor by 11dB below 0.1 Fs). The code assumes input data is in the range +1 to -1 and doesn't check for overloads!

To save time when generating dither for multiple channels you can re-use lower bits of a previous random number instead of calling rand() again. e.g. r3=(r1 & 0x7F)<<8;

Listing 48: code

```c
int r1, r2; //rectangular-PDF random numbers
float s1, s2; //error feedback buffers
float s = 0.5f; //set to 0.0f for no noise shaping
float w = pow(2.0, bits-1); //word length (usually bits=16)
float wi= 1.0f/w;
float d = wi / RAND_MAX; //dither amplitude (2 lsb)
float o = wi * 0.5f; //remove dc offset
float in, tmp;
int out;

//for each sample...

r2=r1; //can make HP-TRI dither by r1=rand(); //subtracting previous rand()

in += s * (s1 + s1 - s2); //error feedback
tmp = in + o + d * (float)(r1 - r2); //dc offset and dither

out = (int)(w * tmp); //truncate downwards
if(tmp<0.0f) out--; //this is faster than floor()

s2 = s1;
s1 = in - wi * (float)out; //error
```

5.28 Dithering

- **Author or source:** Paul Kellett
- **Created:** 2002-02-11 17:41:21
- **Linked files:** nsdither.txt
5.29 Double to Int

- **Author or source:** many people, implementation by Andy M00cho
- **Type:** pointer cast (round to zero, or ‘truncate’)
- **Created:** 2002-01-17 03:04:41

Listing 50: notes

- Platform independent, literally. You have IEEE FP numbers, this will work, as long as
  your not expecting a signed integer back larger than 16bits :)
- Will only work correctly for FP numbers within the range of [-32768.0,32767.0]
- The FPU must be in Double-Precision mode

Listing 51: code

```c
typedef double lreal;
typedef float real;
typedef unsigned long uint32;
typedef long int32;

// 2^36 * 1.5, (52-_shiftamt=36) uses limited precision to floor
// 16.16 fixed point representation
const lreal _double2fixmagic = 68719476736.0*1.5;
const int32 _shiftamt = 16;

#if BigEndian_
    #define iexp_ 0
    #define iman_ 1
#else
    #define iexp_ 1
    #define iman_ 0
#endif //BigEndian_

// Real2Int
inline int32 Real2Int(lreal val)
{
    val = val + _double2fixmagic;
    return ((int32*)&val)[iman_] >> _shiftamt;
}

// Real2Int
inline int32 Real2Int(real val)
{
    return Real2Int ((lreal)val);
}

For the x86 assembler freaks here’s the assembler equivalent:
```

(continues on next page)
5.29.1 Comments

- Date: 2007-01-28 20:13:49
  - By: ude.odu@grebnesie.nitram

www.stereopsis.com/FPU.html credits one Sree Kotay for this code.

- Date: 2007-07-11 06:17:12
  - By: kd.sgnik3@sumsar

On PC this may be faster/easier:

```c
int ftoi(float x)
{
    int res;
    __asm
    {
        fld x
        fistp res
    }
    return res;
}
```

```c
int dtoi(double x)
{
    return ftoi((float)x);
}
```

5.30 Envelope Follower

- Author or source: ers
- Created: 2003-03-12 04:08:16

Listing 52: code

```c
#define V_ENVELOPE_FOLLOWER_NUM_POINTS 2000
class vEnvelopeFollower :
{
    public:
        vEnvelopeFollower();
        virtual ~vEnvelopeFollower();
        inline void Calculate(float *b)
        {
```
envelopeVal -= *buff;
if (*b < 0)
    envelopeVal += *buff = -*b;
else
    envelopeVal += *buff = *b;
if (buff++ == bufferEnd)
    buff = buffer;

void SetBufferSize(float value);
void GetControlValue(){return envelopeVal / (float)bufferSize;}

private:
    float buffer[V_ENVELOPE_FOLLOWER_NUM_POINTS];
    float *bufferEnd, *buff, envelopeVal;
    int bufferSize;
    float val;
};

evEnvelopeFollower::evEnvelopeFollower()
{
    bufferEnd = buffer + V_ENVELOPE_FOLLOWER_NUM_POINTS-1;
    buff = buffer;
    val = 0;
    float *b = buffer;
    do
    {
        *b++ = 0;
    }while (b <= bufferEnd);
    bufferSize = V_ENVELOPE_FOLLOWER_NUM_POINTS;
    envelopeVal= 0;
}

evEnvelopeFollower::~vEnvelopeFollower()
{

}

void evEnvelopeFollower::SetBufferSize(float value)
{
    bufferEnd = buffer + (bufferSize = 100 + (int)(value * ((float)V_ENVELOPE_FOLLOWER_NUM_POINTS-102)));
    buff = buffer;
    float val = envelopeVal / bufferSize;
    do
    {
        *buff++ = val;
    }while (buff <= bufferEnd);
    buff = buffer;
}

5.30.1 Comments

• Date: 2007-01-17 13:46:04
• By: gro.akeeb@evets

5.30. Envelope Follower
Nice contribution, but I have a couple of questions...

Looks like there is a typo on GetControlValue... should return a float. Also, I am not clear on the reason for it taking a pointer to a float.

Is there any noticeable speed improvement with the "if (*b < 0)" code, as opposed to using fabs? I would hope that a decent compiler library would inline this (but haven't cracked open the disassembler to find out).

5.31 Exponential curve for

- **Author or source:** moc.liamg@321tiloen
- **Type:** Exponential curve
- **Created:** 2008-10-29 17:29:03

Listing 53: notes

When you design a frequency control for your filters you may need an exponential curve to give the lower frequencies more resolution.

F=20-20000hz
x=0-100%

Case (control middle point):
x=50%
F=1135hz

Ploted diagram with 5 points:
http://img151.imageshack.us/img151/9938/expplotur3.jpg

Listing 54: code

```c
//tweak - 14.15005 to change middle point and F(max)
F = 19+floor(pow(4,x/14.15005))+x*20;
```

5.31.1 Comments

- **Date:** 2008-10-30 13:47:16
  - **By:** moc.liamg@321tiloen

same function with the more friendly exp(x)

```c
y = 19+floor(exp(x/10.2071))+x*20;
```

middle point (x=50) is still at 1135hz

- **Date:** 2008-10-31 01:14:13
  - **By:** moc.liamg@321tiloen
Here is another function:
This one is much more expensive but should sound more linear.

```c
//t - offset
//x - 0-100%
//y - 20-20000hz

t = 64.925;
y = floor(exp(x*log(1.059))*t - t/1.45);
```

Comparison between the two:

• **Date:** 2008-11-01 14:58:20
  • **By:** moc.liamg@321tiloen

Yet another one! :)
This is one should be the most linear one out of the 3. The 50% appears to be exactly the same as Voxengo span midpoint.

```c
//x - 0-100%
//y - 20-20k
y = floor(exp((16+x*1.20103)*log(1.059))*8.17742);
```

//x=0, y=20
//x=50, y=639
//x=100, y=20000

## 5.32 Exponential parameter mapping

• **Author or source:** Russell Borogove
  • **Created:** 2002-03-17 15:42:33

### Listing 55: notes

Use this if you want to do an exponential map of a parameter (mParam) to a range (mMin - mMax).
Output is in mData...

### Listing 56: code

```
float logmax = log10f( mMax );
float logmin = log10f( mMin );
float logdata = (mParam * (logmax-logmin)) + logmin;

mData = powf( 10.0f, logdata );
if (mData < mMin)
{
    mData = mMin;
}
if (mData > mMax)
```

(continues on next page)
```

{  
    mData = mMax;
}
```

### 5.32.1 Comments

- **Date:** 2002-03-26 00:28:53  
  **By:** moc.nsm@seivadrer

> No point in using heavy functions when lighter-weight functions work just as well. Use ln instead of log10f, and exp instead of pow(10,x). Log-linear is the same, no matter which base you're using, and base e is way more efficient than base 10.

- **Date:** 2002-12-06 01:31:55  
  **By:** moc.noicratse@ajelak

> Thanks for the tip. A set of VST param wrapper classes which offers linear float, exponential float, integer selection, and text selection controls, using this technique for the exponential response, can be found in the VST source code archive -- finally.

- **Date:** 2003-08-21 16:01:01  
  **By:** moc.oohay@noi_tca

> Just made my day!  
pretty useful :) cheers Aktion

- **Date:** 2006-09-08 18:27:33  
  **By:** agillesp@gmail

> You can trade an (expensive) ln for a (cheaper) divide here because of the logarithmic identity:  
\[ \ln(x) - \ln(y) = \ln\left(\frac{x}{y}\right) \]

### 5.33 Fast Float Random Numbers

- **Author or source:** moc.liamg@seir.kinimod  
- **Created:** 2009-10-29 13:39:29

Listing 57: notes

A small and fast implementation for random float numbers in the range \([-1,1]\), usable as white noise oscillator.

Compared to the naive usage of the rand() function it gives a speedup factor of 9-10. Compared to a direct implementation of the rand() function (visual studio implementation)
it still gives a speedup by a factor of 2-3.

apart from being faster it also provides more precision for the resulting floats, since its base values use full 32bit precision.

Listing 58: code

```c
// set the initial seed to whatever you like
static int RandSeed = 1;

// using rand() (16bit precision)
// takes about 110 seconds for 2 billion calls
float RandFloat1()
{
    return ((float)rand()/RAND_MAX) * 2.0f - 1.0f;
}

// direct implementation of rand() (16 bit precision)
// takes about 32 seconds for 2 billion calls
float RandFloat2()
{
    return ((float)(((RandSeed = RandSeed * 214013L + 2531011L) >> 16) & 0x7fff)/RAND_MAX) * 2.0f - 1.0f;
}

// fast rand float, using full 32bit precision
// takes about 12 seconds for 2 billion calls
float Fast_RandFloat()
{
    RandSeed *= 16807;
    return (float)(RandSeed = RandSeed * 214013L + 2531011L) / 0x7FFFFFFF * 2.0f * amp - amp;
}
```

5.33.1 Comments

- **Date:** 2009-11-20 23:40:37
  - **By:** judahmenter@geemail.com

There is no doubt that implementation 3 is fast, but the problem I had with it is that there's no obvious way to limit the amplitude of the generated signal.

So instead I tried implementation 2 and ran into a different problem. The code is written such that it assumes that RAND_MAX is equal to 0x7FFF, which was not true on my system (it was 0x7FFFFFFF). Fortunately, this was easy to fix. I simply removed the >> 16 and worked fine for me. My final implementation was:

return (float)(RandSeed = RandSeed * 214013L + 2531011L) / 0x7FFFFFFF * 2.0f * amp - amp;

where "amp" is the desired amplitude.

- **Date:** 2009-12-29 22:53:23
  - **By:** earlevel [] earlevel [] com

5.33. Fast Float Random Numbers
It should be noted in the code that for method #3, you must initialize the seed to non-zero before using it.

- **Date:** 2010-01-24 16:36:03
- **By:** moc.boohay@bob

I don't understand Judahmenter's comment about 3 not limiting the amplitude. As it stands it returns a value -1 to 1, so just multiply by your 'amp' value. This turns into a handy 0-1 random number if you take off the sign bit:

\[(\text{float})(\text{RandSeed} \& 0x7FFFFFFF) \times 4.6566129e-010f;\]

### 5.34 Fast abs/neg/sign for 32bit floats

- **Author or source:** ed.bew@raemybot
- **Type:** floating point functions
- **Created:** 2002-12-18 20:27:04

Listing 59: notes

Haven't seen this elsewhere, probably because it is too obvious? Anyway, these functions are intended for 32-bit floating point numbers only and should work a bit faster than the regular ones.

fastabs() gives you the absolute value of a float
fastneg() gives you the negative number (faster than multiplying with -1)
fastsgn() gives back +1 for 0 or positive numbers, -1 for negative numbers

Comments are welcome (tobybear[AT]web[DOT]de)

Cheers

Toby (www.tobybear.de)

Listing 60: code

```c
// C/C++ code:
float fastabs(float f)
{int i=((*(int*)&f)&0x7fffffff);return (*(float*)&i);}

float fastneg(float f)
{int i=((*(int*)&f)^0x80000000);return (*(float*)&i);}

int fastsgn(float f)
{return 1+(((*(int*)&f)>>31)<<1);}

//Delphi/Pascal code:
function fastabs(f:single):single;
begin i:=longint((@f)^) and $7FFFFFFF;result:=single((@i)^) end;

function fastneg(f:single):single;
```
begin i:=longint((@f)^) xor $80000000;result:=single((@i)^) end;

function fastsgn(f:single):longint;
begin result:=1+((longint((@f)^) shr 31)shl 1) end;

5.34.1 Comments

- **Date:** 2003-01-05 05:01:59
  - **By:** ed.bew@raebybot

Matthias (bekkah[AT]web[DOT]de) wrote me a mail with the following further improvements for the C++ parts of the code:

// C++ code:
inline float fastabs(const float f)
{int i=((*(int*)&f)&0x7fffffff);return (*(float*)&i);}

inline float fastneg(const float f)
{int i=((*(int*)&f)^0x80000000);return (*(float*)&i);}

inline int fastsgn(const float f)
{return 1+(((*(int*)&f)>>31)<<1);}

Thanks!

- **Date:** 2003-01-11 15:53:56
  - **By:** ur.liam@redocip

Too bad these 'tricks' need two additional FWAITs to work in a raw FPU code. Maybe standard fabs and fneg are better? Although, that fastsgn() could be useful since there's no FPU equivalent for it.

Cheers,
Aleksey.

- **Date:** 2003-01-11 15:55:35
  - **By:** ur.liam@redocip

I meant 'fchs' in place of 'fneg'.

- **Date:** 2003-05-05 20:49:34
  - **By:** ten.llavnnarb@divad

I don't know if this is any faster, but atleast you can avoid some typecasting.

function fastabs(f: Single): Single; var i: Integer absolute f;
begin i := i and $7fffffff; Result := f; end;

- **Date:** 2003-07-29 04:55:55
  - **By:** moc.oidua-m@sirhc

5.34. Fast abs/neg/sign for 32bit floats
Note that a reasonable compiler should be able to perform these optimizations for you.
I seem to recall that GCC in particular has the capability to replace calls to
[f]abs() with instructions optimized for the platform.

• Date: 2005-05-25 20:22:59
• By: moc.noicratse@ajelak

On MS compilers for x86, just do:
#pragma intrinsic(fabs)

...and then use fabs() for doubles, fabsf() for floats. The compiler will generate
the FABS instruction, which is generally 1 cycle on modern x86 FPUs. (Internally,
the FPU just masks the bit.)

5.35 Fast binary log approximations

• Author or source: gro.lortnocdnim@gro.pscisum
• Type: C code
• Created: 2002-04-04 17:00:05

Listing 61: notes
This code uses IEEE 32-bit floating point representation knowledge to quickly compute
approximations to the log2 of a value. Both functions return under-estimates of the
value, although the second flavour is less of an under-estimate than the first (and
might be sufficient for using in, say, a dBV/FS level meter).

Running the test program, here's the output:

<table>
<thead>
<tr>
<th>Value</th>
<th>Floor</th>
<th>Approx</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>-4</td>
<td>-3.400000</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0.000000</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1.000000</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>2.250000</td>
</tr>
<tr>
<td>100</td>
<td>6</td>
<td>6.562500</td>
</tr>
</tbody>
</table>

Listing 62: code

// Fast logarithm (2-based) approximation
// by Jon Watte

#include <assert.h>

int floorOfLn2( float f ) {
    assert( f > 0. );
    assert( sizeof(f) == sizeof(int) );
    assert( sizeof(f) == 4 );
    return ( ( (*(int *)&f) & 0x7f800000 ) >> 23 ) - 0x7f;
}

float approxLn2( float f ) {
assert( f > 0. );
assert( sizeof(f) == sizeof(int) );
assert( sizeof(f) == 4 );
int i = (*((int *)&f));

return (((i&0x7f800000)>>23)-0x7f)+(i&0x007fffff)/(float)0x800000;

// Here's a test program:
#include <stdio.h>

// insert code from above here

int main()
{
  printf( "0.1: %d %f \n", floorOfLn2( 0.1 ), approxLn2( 0.1 ) );
  printf( "1: %d %f \n", floorOfLn2( 1. ), approxLn2( 1. ) );
  printf( "2: %d %f \n", floorOfLn2( 2. ), approxLn2( 2. ) );
  printf( "5: %d %f \n", floorOfLn2( 5. ), approxLn2( 5. ) );
  printf( "100: %d %f \n", floorOfLn2( 100. ), approxLn2( 100. ) );
  return 0;
}

5.35.1 Comments

• Date: 2002-12-18 20:08:06
• By: ed.bew@raebybot

Here is some code to do this in Delphi/Pascal:

function approxLn2(f:single):single;
begin
  result:=(((longint((@f)^) and $7f800000) shr 23)-$7f)+(longint((@f)^) and $007fffff)/(longint((@f)^) and $7f800000)-$800000;
end;

function floorOfLn2(f:single):longint;
begin
  result:=((longint((@f)^) and $7f800000) shr 23)-$7f;
end;

Cheers,
Tobybear
www.tobybear.de

5.36 Fast cube root, square root, and reciprocal for x86/SSE CPUs.

• Author or source: moc.noicratse@ajelak
• Created: 2005-05-29 18:36:40

5.36. Fast cube root, square root, and reciprocal for x86/SSE CPUs.
All of these methods use SSE instructions or bit twiddling tricks to get a rough approximation to cube root, square root, or reciprocal, which is then refined with one or more Newton-Raphson approximation steps.

Each is named to indicate its approximate level of accuracy and a comment describes its performance relative to the conventional versions.

Listing 64: code

```c
// These functions approximate reciprocal, square root, and cube root to varying degrees of precision substantially faster than the straightforward methods 1/x, sqrtf(x), and powf(x, 1.0f/3.0f). All require SSE-enabled CPU & OS.
// Unlike the powf() solution, the cube roots also correctly handle negative inputs.

#define REALLY_INLINE __forceinline

// ~34 clocks on Pentium M vs. ~360 for powf
REALLY_INLINE float cuberoot_sse_8bits(float x) {
  float z;
  static const float three = 3.0f;
  _asm {
    mov eax, x                  // x as bits
    movss xmm2, x               // x2: x
    movss xmm1, three            // x1: 3
    // Magic floating point cube root done with integer math.
    // The exponent is divided by three in such a way that remainder bits get shoved into the top of the normalized mantissa.
    mov ecx, eax                 // copy of x
    and eax, 0x7FFFFFFF          // exponent & mantissa of x in biased-127 form
    sub eax, 0x3F800000           // exponent & mantissa of x in 2's comp
    sar eax, 10                  //
    imul eax, 341                // 341/1024 = ~ .333
    add eax, 0x3F800000           // back to biased-127
    and eax, 0x7FFFFFFFFFFF       // remask
    and ecx, 0x80000000           // original sign and mantissa
    or eax, ecx                   // masked new exponent, old sign
    //and mantissa
    mov z, eax                    //
    // use SSE to refine the first approximation
    movss xmm0, z                 // x0: z
    movss xmm3, xmm0              // x3: z
    mulss xmm3, xmm0              // x3: z*z
    movss xmm4, xmm3              // x4: z*z
    mulss xmm3, xmm1              // x3: 3*z*z
    rcpss xmm3, xmm3              // x3: ~ 1/(3*z*z)
    mulss xmm4, xmm0              // x4: z*z*z
  }
  return z;
}
```

(continues on next page)
subss xmm4, xmm2 ; // x4: z*z*z-x
mulss xmm4, xmm3 ; // x4: (z*z*z-x) / (3*z*z)
subss xmm0, xmm4 ; // x0: z' accurate to within about 0.3%
movss z, xmm0

return z;

// ~60 clocks on Pentium M vs. ~360 for powf

REALLY_INLINE float cuberoot_sse_16bits( float x )
{
    float z;
    static const float three = 3.0f;

    _asm
    {
        mov eax, x  // x as bits
        movss xmm2, x  // x2: x
        movss xmm1, three  // x1: 3
        // Magic floating point cube root done with integer math.
        // The exponent is divided by three in such a way that
        // remainder bits get shoved into the top of the normalized
        // mantissa.
        mov ecx, eax  // copy of x
        and eax, 0x7FFFFFFF  // exponent & mantissa of x in biased-127
        sar eax, 10  // 341/1024 ~= .333
        add eax, 0x3F800000  // back to biased-127
        and eax, 0x7FFFFFFF  // remask
        or eax, ecx  // original sign and mantissa
        and mantissa
        mov z, eax  // use SSE to refine the first approximation
        movss xmm0, z  // x0: z
        movss xmm3, xmm0  // x3: z
        mulss xmm3, xmm0  // x3: z*z
        movss xmm4, xmm3  // x4: z*z
        mulss xmm4, xmm1  // x4: 3*z*z
        rcpss xmm3, xmm3  // x3: ~ 1/(3*z*z)
        mulss xmm4, xmm0  // x4: z*z*z
        subss xmm4, xmm2  // x4: z*z*z-x
        mulss xmm4, xmm3  // x4: (z*z*z-x) / (3*z*z)
        subss xmm0, xmm4  // x0: z' accurate to within about 0.3%
    }
}
mulss xmm4, xmm3
    ; // x4: (z*z*z-x) / (3*z*z)
subss xmm0, xmm4
    ; // x0: z' accurate to within

movss z, xmm0
}

return z;
}

// ~77 clocks on Pentium M vs. ~360 for powf
REALLY_INLINE float cuberoot_sse_22bits( float x )
{
    float z;
    static const float three = 3.0f;
    _asm
        {
            mov    eax, x       // x as bits
            movss xmm2, x      // x2: x
            movss xmm1, three  // x1: 3
            // Magic floating point cube root done with integer math.
            // The exponent is divided by three in such a way that
            // remainder bits get shoved into the top of the normalized
            // mantissa.
            mov ecx, eax        // copy of x
            and eax, 0x7FFFFFFF // exponent & mantissa of x in
            // biased-127
            sub eax, 0x3F800000 // exponent & mantissa of x in 2's comp
            sar eax, 10         //
            imul eax, 341       // 341/1024 =~ .333
            add eax, 0x3F800000 // back to biased-127
            and eax, 0x7FFFFFFF // remask
            or eax, ecx         // original sign and mantissa
            and mantissa
            mov    z, eax       //
            // use SSE to refine the first approximation
            movss xmm0, z       // x0: z
            movss xmm3, xmm0    // x3: z
            mulss xmm3, xmm0    // x3: z*z
            movss xmm4, xmm3    // x4: z*z
            mulss xmm3, xmm1    // x3: 3*z*z
            rcpss xmm3, xmm3    // x3: ~ 1/(3*z*z)
            mulss xmm4, xmm0    // x4: z*z*z
            subss xmm4, xmm2    // x4: z*z*z-x
            mulss xmm4, xmm3    // x4: (z*z*z-x) / (3*z*z)
            subss xmm0, xmm4    // x0: z' accurate to within
            about 0.3%
            movss xmm3, xmm0    // x3: z
            mulss xmm3, xmm0    // x3: z*z
            movss xmm4, xmm3    // x4: z*z
            mulss xmm3, xmm1    // x3: 3*z*z
            rcpss xmm3, xmm3    // x3: ~ 1/(3*z*z)
            mulss xmm4, xmm0    // x4: z*z*z
            subss xmm4, xmm2    // x4: z*z*z-x
            "(continues on next page)"}
mulss xmm4, xmm3 // x4: (z*z*z-x) / (3*z*z)
subss xmm0, xmm4 // x0: z''' accurate to within 0.001%

movss xmm3, xmm0
mulss xmm3, xmm0 // x3: z
movss xmm4, xmm3 // x4: z*z
mulss xmm3, xmm1 // x3: 3*z*z
rcpss xmm3, xmm3 // x3: ~ 1/(3*z*z)
mulss xmm4, xmm0 // x4: z*z*z
subss xmm4, xmm2 // x4: z*z*z-x
mulss xmm4, xmm3 // x4: (z*z*z-x) / (3*z*z)
subss xmm0, xmm4 // x0: z'''' accurate to within 0.000012%

movss z, xmm0

return z;

// ~6 clocks on Pentium M vs. ~24 for single precision sqrtf
REALLY_INLINE float squareroot_sse_11bits( float x )
{
    float z;
    _asm
    {
        rsqrtss xmm0, x
        rcpss xmm0, xmm0 // z ~= sqrt(x) to 0.038%
        movss z, xmm0
    }
    return z;
}

// ~19 clocks on Pentium M vs. ~24 for single precision sqrtf
REALLY_INLINE float squareroot_sse_22bits( float x )
{
    static float half = 0.5f;
    float z;
    _asm
    {
        movss xmm1, x // x1: x
        rsqrtss xmm2, xmm1 // x2: -1/sqrt(x) = 1/z
        rcpss xmm0, xmm2 // x0: z == ~sqrt(x) to 0.05%
        movss xmm4, xmm0 // x4: z
        movss xmm3, half
        mulss xmm4, xmm4 // x4: z*z
        mulss xmm2, xmm3 // x2: 1 / 2z
        subss xmm4, xmm1 // x4: z*z-x
        mulss xmm4, xmm2 // x4: (z*z-x)/2z
        subss xmm0, xmm4 // x0: z' to 0.000015%
        movss z, xmm0
    }
    return z;
}
I needed a fast exp() approximation in the -3.14..3.14 range, so I made some approximations based on the tanh() code posted in the archive by Fuzzpilz. Should be pretty straightforward, but someone may find this useful.

The increasing numbers in the name of the function means increasing precision. Maximum error in the -1..1 range:
fastexp3: 0.05 (1.8%)
fastexp4: 0.01 (0.36%)
fastexp5: 0.0016152 (0.59%)
fastexp6: 0.0002263 (0.0083%)
fastexp7: 0.0000279 (0.001%)
fastexp8: 0.0000031 (0.000011%)
fastexp9: 0.0000003 (0.00000011%)

Maximum error in the -3.14..3.14 range:
fastexp3: 8.8742 (38.4%)
fastexp4: 4.8237 (20.8%)
fastexp5: 2.28 (9.8%)
fastexp6: 0.9488 (4.1%)
fastexp7: 0.3516 (1.5%)
fastexp8: 0.1172 (0.5%)
fastexp9: 0.0355 (0.15%)

These were done using the Taylor series, for example I got fastexp4 by using:
\[ \exp(x) = 1 + x + x^2/2 + x^3/6 + x^4/24 + \ldots \]
= (24 + 24x + x^2*12 + x^3*4 + x^4) / 24
(using Horner-scheme:)
= (24 + x * (24 + x * (12 + x * (4 + x)))) * 0.041666666f

Listing 66: code

```c
inline float fastexp3(float x) {
    return (6+x*(6+x*(3+x)))*0.16666666f;
}
inline float fastexp4(float x) {
    return (24+x*(24+x*(12+x*(4+x))))*0.041666666f;
}
inline float fastexp5(float x) {
    return (120+x*(120+x*(60+x*(20+x*(5+x)))))*0.0083333333f;
}
inline float fastexp6(float x) {
    return 720+x*(720+x*(360+x*(120+x*(6+x))))*0.0013888888f;
}
inline float fastexp7(float x) {
    return (5040+x*(5040+x*(2520+x*(840+x*(210+x*(7+x)))))))*0.00019841269f;
}
inline float fastexp8(float x) {
    return (40320+x*(40320+x*(20160+x*(6720+x*(1680+x*(8+x))))))*2.4801587301e-5;
}
inline float fastexp9(float x) {
    return (362880+x*(362880+x*(181440+x*(60480+x*(15120+x*(3024+x*(72+x*(9+x)))))))))*2.75573192e-6;
}
```

### 5.37.1 Comments

- **Date**: 2006-07-03 00:40:15
- **By**: uh.etle.fni@yfoocs

These series converge fast only near zero. But there is an identity:

\[
\exp(x) = \exp(a) \times \exp(x-a)
\]

So, if you want a relatively fast polynomial approximation for \(\exp(x)\) for 0 to ~7.5, you can use:

```c
// max error in the 0 .. 7.5 range: ~0.45%
inline float fastexp(float const &x) {
    if (x<2.5)
        return 2.7182818f * fastexp5(x-1.f);
    return ...
```

(continues on next page)
else if (x<5)
    return 33.115452f * fastexp5(x-3.5f);
else
    return 403.42879f * fastexp5(x-6.f);
}

where 2.7182.. = exp(1), 33.1154.. = exp(3.5) and 403.428.. = exp(6). I chose these values because fastexp5 has a maximum error of 0.45% between -1 - 1.5 (using fastexp6, the maximum error is 0.09%).

Using the identity

\[
\text{pow}(a,x) = \exp(x \times \log(a))
\]

you can use any base, for example to get 2^x:

// max error in the 0-10.58 range: ~0.45%
inline float fastpow2(float const &x)
{
    float const log_two = 0.6931472f;
    return fastexp(x * log_two);
}

These functions are about 3x faster than exp().

-- Peter Schoffhauzer

### 5.38 Fast exp2 approximation

- **Author or source:** Laurent de Soras (moc.ecrofmho@tnerual)
- **Created:** 2002-07-29 18:42:23

Listing 67: notes

Partial approximation of exp2 in fixed-point arithmetic. It is exactly:

\[
[0 ; 1[ \rightarrow [0.5 ; 1[
\]

f : x |-> 2^(x-1)

To get the full exp2 function, you have to separate the integer and fractionnal part of the number. The integer part may be processed by bitshifting. Process the fractionnal part with the function, and multiply the two results.

Maximum error is only 0.3 % which is pretty good for two mul ! You get also the continuity of the first derivate.

-- Laurent

Listing 68: code

```c
// val is a 16-bit fixed-point value in 0x0 - 0xFFFF ([0 ; 1[)
// Returns a 32-bit fixed-point value in 0x80000000 - 0xFFFFFFFF ([0.5 ; 1[)
unsigned int fast_partial_exp2 (int val)
```

(continues on next page)
5.39 Fast log2

- **Author or source:** Laurent de Soras
- **Created:** 2002-02-10 12:31:20

Listing 69: code

```c
inline float fast_log2 (float val)
{
    assert (val > 0);
    int * const exp_ptr = reinterpret_cast<int *> (&val);
    int x = *exp_ptr;
    const int log_2 = ((x >> 23) & 255) - 128;
    x |= ~(255 << 23);
    x += 127 << 23;
    *exp_ptr = x;
    return (val + log_2);
}
```

### 5.39.1 Comments

- **Date:** 2002-12-18 20:13:06
- **By:** ed.bew@raebybot

And here is some native Delphi/Pascal code that does the same thing:

```delphi
function fast_log2(val: single): single;
var
    log2, x: longint;
begin
    begin
        (continues on next page)
```
\texttt{x:=longint((@val)^);\\ log2:=((x \text{ shr } 23) \text{ and } 255)-128;\\ x:=x \text{ and } (\text{not}(255 \text{ shr } 23));\\ x:=x+127 \text{ shr } 23;\\ result:=single((@x)^)+log2;\\ end;\\}

Cheers
Toby

www.tobybear.de

- **Date:** 2003-02-07 23:54:32
- **By:** ed.sulydroc@yrneh

instead of using this pointer casting expressions one can also use a enum like this:

\begin{verbatim}
enum FloatInt
{
    float f;
}
\end{verbatim}

- **Date:** 2003-02-07 23:55:27
- **By:** ed.sulydroc@yrneh

instead of using this pointer casting expressions one can also use a enum like this:

\begin{verbatim}
enum FloatInt
{
    float f;
    int l;
} p;
\end{verbatim}

and then access the data with:

\begin{verbatim}
p.f = x;
p.l >>= 23;
\end{verbatim}

Greetings, Henry

- **Date:** 2003-02-07 23:56:11
- **By:** ed.sulydroc@yrneh

Sorry :

didn't mean enum, ment UNION !!!

- **Date:** 2005-10-18 10:03:47
- **By:** Laurent de Soras

More precision can be obtained by adding the following line just before the return() :

\begin{verbatim}
val = map_lin_2_exp (val, 1.0f / 2);
\end{verbatim}
Below is the function (everything is constant, so most operations should be done at compile time):

```c
inline float map_lin_2_exp (float val, float k)
{
    const float a = (k - 1) / (k + 1);
    const float b = (4 - 2*k) / (k + 1); // 1 - 3*a
    const float c = 2*a;
    val = (a * val + b) * val + c;
    return (val);
}
```

You can do the mapping you want for the range [1;2] -> [1;2] to approximate the function log(x)/log(2).

- **Date**: 2005-10-18 10:05:48
- **By**: Laurent de Soras

Sorry I meant log(x)/log(2) + 1

### 5.40 Fast power and root estimates for 32bit floats

- **Author or source**: ed.bew@raebobot
- **Type**: floating point functions
- **Created**: 2002-12-18 21:07:27

**Listing 70: notes**

Original code by Stefan Stenzel (also in this archive, see "pow(x,4) approximation") - extended for more flexibility.

fastpow(f,n) gives a rather *rough* estimate of a float number f to the power of an integer number n (y=f^n). It is fast but result can be quite a bit off, since we directly mess with the floating point exponent. Use it only for getting rough estimates of the values and where precision is not that important.

fastroot(f,n) gives the n-th root of f. Same thing concerning precision applies here.

Cheers
Toby (www.tobybear.de)

**Listing 71: code**

```c
//C/C++ source code:
float fastpower(float f, int n)
{
    long *lp,1;
    lp=(long*)((float*)f); (continues on next page)
```
5.41 Fast rounding functions in pascal

- **Author or source:** moc.liamtoh@abuob
- **Type:** round/ceil/floor/trunc
- **Created:** 2008-03-09 13:09:44

Listing 72: notes

Original documentation with cpp samples:
http://ldesoras.free.fr/prod.html#doc_rounding

Listing 73: code

//Delphi/Pascal source code:
function fastpower(i:single;n:integer):single;
var l:longint;
begin
l:=longint((@i)^);
l:=l-$3F800000;l:=l shl (n-1);l:=l+$3F800000;
result:=single((@l)^);
end;

function fastroot(i:single;n:integer):single;
var l:longint;
begin
l:=longint((@i)^);
l:=l-$3F800000;l:=l shr (n-1);l:=l+$3F800000;
result:=single((@l)^);
end;
function fceil(f:double):integer;
var
  i:integer;
  t : double;
begin
  t := -0.5;
  asm
    fld f
    fadd st, st(0)
    fabs
    fadd t
    fistp i
    sar i, 1
  end;
  result := -i
end;

function ftrunc(f:double):integer;
var
  i:integer;
  t : double;
begin
  t := -0.5;
  asm
    fld f
    fadd st, st(0)
    fabs
    fadd t
    fistp i
    sar i, 1
  end;
  if f<0 then i := -i;
  result := i
end;

function fround(f:double):integer;
var
  i:integer;
  t : double;
begin
  t := 0.5;
  asm
    fld f
    fadd st, st(0)
    fadd t
    fistp i
    sar i, 1
  end;
end;

5.41. Fast rounding functions in pascal
5.41.1 Comments

- Date: 2008-04-23 11:46:58
- By: eb.mapstenyksen@didid

The `fround` doesn't make much sense in Pascal, as in Pascal (well, Delphi & I'm pretty sure FreePascal too), the default rounding is already a fast rounding. The default being FPU rounding to nearest mode, the compiler doesn't change it back & forth. & since it's inlined (well, compiler magic), it's very fast.

5.42 Fast sign for 32 bit floats

- Author or source: Peter Schoffhauser
- Created: 2007-05-14 10:15:43

Listing 74: notes

Fast functions which give the sign of a 32 bit floating point number by checking the sign bit. There are two versions, one which gives the value as a float, and the other gives an int.

The _nozero versions are faster, but they give incorrect 1 or -1 for zero (depending on the sign bit set in the number). The int version should be faster than the Tobybear one in the archive, since this one doesn't have an addition, just bit operations.

Listing 75: code

```c
/*------------------------------------------------------------------------------------
// returns 1.0f for positive floats, -1.0f for negative floats
// for zero it does not work (may gives 1.0f or -1.0f), but it's faster
inline float fast_sign_nozero(float f) {
    float r = 1.0f;
    (int&)(r) |= ((int&)(f & 0x80000000)); // mask sign bit in f, set it in r if necessary
    return r;
}

// returns 1.0f for positive floats, -1.0f for negative floats, 0.0f for zero
inline float fast_sign(float f) {
    if (((int&)(f & 0x7FFFFF))==0) return 0.f; // test exponent & mantissa bits: is input zero?
    else {
        
```

float r = 1.0f;
(int&)r |= ((int&)f & 0x80000000); // mask sign bit in f, set it in r if necessary
return r;
}

// fast sign, returns int
/*-----------------------------------------------------------------------------------
// returns 1 for positive floats, -1 for negative floats
// for 0.0f input it does not work (may give 1 or -1), but it’s faster
inline int fast_sign_int_nozero(float f) {
    return (signed((int&)f & 0x80000000) >> 31 ) | 1;
}

// returns 1 for positive floats, -1 for negative floats, 0 for 0.0f
inline int fast_sign_int(float f) {
    if (((int&)f & 0x7FFFFFFF)==0) return 0; // test exponent & mantissa bits: is input zero?
    return (signed((int&)f & 0x80000000) >> 31 } | 1;
}

5.42.1 Comments

- Date: 2007-05-15 16:49:02
- By: uh.etle.fn1@yfoocs

Now consider when you want to multiply a number by the sign of another:

    if (a>0.f) b = b;
    else b = -b;

This involves 1) a comparison, 2) a branch, 3) an inversion (multiply or bit flip) in one branch. Another method for calculating the same:

    b *= fast_sign_nozero_(a);

This involves 1) a bitwise and, 2) a bitwise or 3) a multiply. Using only bit operations, the branch and/or multiply can be totally eliminated:

    // equivalent to dest *= sgn(source)
inline void mul_sign(float &dest, float &source) {
    (int&)dest &= 0x7FFFFFFF; // clear sign bit
    (int&)dest |= ((int&)dest ^ (int&)source) & 0x80000000f; // set sign bit if necessary
}

This function has only three bitwise operations, which should be very fast. Usage:

    mul_sign(b,a); // b = b*sign(a)

The speed increase with all these functions greatly depends on the predictability of the branches. If the branch is highly predictable (a lot of positive numbers, then also a lot of negative numbers, without mixing them), then an if/else solution is pretty fast. If the branch is unpredictable (random numbers, or audio similar to white noise) bit operations should perform significantly better on today’s most CPUs with multi-level pipelines.

5.42. Fast sign for 32 bit floats

(continues on next page)
Sorry, there is a bug in the above code. Correctly:

```c
// equivalent to dest *= sgn(source)
inline void mul_sign_nozero(float &dest, float const &source) {
    int sign_mask = ((int&)dest ^ (int&)source) & 0x80000000; // XOR and mask
    (int&)dest &= 0x7FFFFFFF; // clear sign bit
    (int&)dest |= sign_mask; // set sign bit if necessary
}
```

### 5.43 Float to int

**Author or source:** Ross Bencina  
**Created:** 2002-01-17 03:15:14

#### Listing 76: notes

```c
// Listing 76: notes

int truncate(float flt) {
    int i;
    static const double half = 0.5f;
    _asm
        { fild flt
        fsub half
        fistp i
    }
    return i
}
```

#### 5.43.1 Comments

**Date:** 2002-06-11 20:12:11  
**By:** moc.xinortelemans@ahaj

Note: Round nearest doesn’t work, because the Intel FPU uses Even-Odd rounding in order to conform to the IEEE floating-point standard: when the FPU is set to use the round-nearest rule, values whose fractional part is exactly 0.5 round toward the nearest *even* integer. Thus, 1.5 rounds to 2, 2.5 rounds to 2, 3.5 rounds to 4. This is quite disastrous for the FLOOR/CEIL functions if you use the strategy you describe.
This version below seems to be more accurate on my Win32/P4. Doesn't deal with the Intel FPU issue. A faster solution than c-style casts though. But you're not always going to get the most accurate conversion. Like the previous comment; 2.5 will convert to 2, but 2.501 will convert to 3.

```c
int truncate(float flt)
{
    int i;
    _asm
    {
        fld flt
        fistp i
    }
    return i
}
```

If you use msvc, just use the /QIfist compile-switch

### 5.44 Float to int (more intel asm)

- **Author or source:** Laurent de Soras (via flipcode)
- **Created:** 2004-06-14 14:51:47

Listing 78: notes

[Found this on flipcode, seemed worth posting here too, hopefully Laurent will approve :)]
-- Ross]

Here is the code I often use. It is not a _ftol replacement, but it provides useful functions. The current processor rounding mode should be "to nearest" ; it is the default setting for most of the compilers.

The [fadd st, st (0) / sar i,1] trick fixes the "round to nearest even number" behaviour.
Thus, round_int (N+0.5) always returns N+1 and floor_int function is appropriate to convert floating point numbers into fixed point numbers.

---------------------
Laurent de Soras
Audio DSP engineer & software designer
Ohm Force - Digital audio software
http://www.ohmforce.com
Listing 79: code

```c
inline int round_int (double x) {
    int i;
    static const float round_to_nearest = 0.5f;
    __asm {
        fld x
        fadd st, st (0)
        fadd round_to_nearest
        fistp i
        sar i, 1
    }
    return (i);
}

inline int floor_int (double x) {
    int i;
    static const float round_toward_m_i = -0.5f;
    __asm {
        fld x
        fadd st, st (0)
        fadd round_toward_m_i
        fistp i
        sar i, 1
    }
    return (i);
}

inline int ceil_int (double x) {
    int i;
    static const float round_toward_p_i = -0.5f;
    __asm {
        fld x
        fadd st, st (0)
        fsubr round_toward_p_i
        fistp i
        sar i, 1
    }
    return (-i);
}
```

5.44.1 Comments

- **Date:** 2004-06-15 07:29:25
- **By:** daniel.schaack[-dot-]basementarts.de
cool trick, but using round to zero FPU mode is still the best method (2 lines):

```asm
__asm
{
  fld x
  fistp y
}
```

- **Date:** 2004-06-18 01:28:41  
  - **By:** moc.krod@dje

If anyone is using NASM, here is how I implemented the first function, if anyone is interested. I did this after sitting down for a while with the Intel manuals. I've not done any x86-FPU stuff before, so this may not be the *best* code. The other functions are easily implemented by modifying this one.

```assembly
bits 32
global dsp_round

HALF dq 0.5
align 4
dsp_round:
  fld qword[HALF]
  fld qword[esp+4]

  fadd st0
  fadd st1

  fistp qword[eax]
  mov eax, [eax]
  sar eax, 1
ret
```

- **Date:** 2004-06-18 13:48:09  
  - **By:** moc.krod@dje

Whoops. I've really gone and embarrassed myself this time. The code I posted is actually broken -- I don't know what I was thinking. I'll post the fixed version a bit later today. My apologies.

- **Date:** 2004-08-10 10:29:44  
  - **By:** pj.krowtenctu@remmah

Will this method also work for other processor types like AMD and CELERON?

- **Date:** 2007-02-19 11:13:19  
  - **By:** uh.etle.fni@yfoocs

It works with AMD and Celeron too (and as I know, probably with all x87 FPUs)

---

5.44. Float to int (more intel asm)
5.45 Float to integer conversion

- **Author or source:** Peter Schoffhauzer
- **Created:** 2007-02-19 10:03:07

Listing 80: notes

The `fld x/fistp i` instructions can be used for fast conversion of floating point numbers to integers. By default, the number is rounded to the nearest integer. However, that's not what we need.

Bits 12 and 11 if the FPU control word determine the way the FPU rounds numbers. The four rounding states are:

- 00 = round to nearest (this is the default)
- 01 = round down (towards -infinity)
- 10 = round up (towards +infinity)
- 11 = truncate up (towards zero)

The status word is loaded/stored using the `fldcw/fstcw` instructions. After setting the rounding mode as desired, the `float2int()` function will use that rounding mode until the control mode is reset. The `ceil()` and `floor()` functions set the rounding mode for every instruction, which is very slow. Therefore, it is a lot faster to set the rounding mode (down or up) before processing a block, and use `float2int()` instead.

References: SIMPLY FPU by Raymond Filiatreault

MSVC (and probably other compilers too) has functions defined in `<float.h>` for changing the FPU control word: `_control87/_controlfp`. The equivalent instructions are:

- `_controlfp(_RC_CHOP, _MCW_RC);` // set rounding mode to truncate
- `_controlfp(_RC_UP _MCW_RC);` // set rounding mode to up (ceil)
- `_controlfp(_RC_DOWN, _MCW_RC);` // set rounding mode to down (floor)
- `_controlfp(_RC_NEAR, _MCW_RC);` // set rounding mode to near (default)

Note that the FPU rounding mode affects other calculations too, so the same code may give different results.

Alternatively, single precision floating point numbers can be truncated or rounded to integers by using SSE instructions `cvtss2si`, `cvttss2si`, `cvtps2pi` or `cvttps2pi`, where SSE instructions are available (which means probably on all modern CPUs). These are not discussed here in detail, but I provided the function `truncateSSE` which always truncates a single precision floating point number to integer, regardless of the current rounding mode.

(continues on next page)
Also I think the SSE rounding mode can differ from the rounding mode set in the FPU control word, but I haven't tested it so far.

Listing 81: code

```c
#ifndef __FPU_ROUNDING_H_
#define __FPU_ROUNDING_H_

static short control_word;
static short control_word2;

// round a float to int using the actual rounding mode
inline int float2int(float x) {
    int i;
    __asm {
        fld x
        fistp i
    }
    return i;
}

// set rounding mode to nearest
inline void set_round2near() {
    __asm {
        fstcw control_word // store fpu control word
        mov dx, word ptr [control_word]
        and dx, 0xf9ff // round towards nearest (default)
        mov control_word2, dx
        fldcw control_word2 // load modified control word
    }
}

// set rounding mode to round down
inline void set_round_down() {
    __asm {
        fstcw control_word // store fpu control word
        mov dx, word ptr [control_word]
        or dx, 0x0400 // round towards -inf
        and dx, 0x07ff
        mov control_word2, dx
        fldcw control_word2 // load modified control word
    }
}

// set rounding mode to round up
inline void set_round_up() {
    __asm {
        fstcw control_word // store fpu control word
        mov dx, word ptr [control_word]
        or dx, 0x0800 // round towards +inf
        and dx, 0xfbff
        mov control_word2, dx
        fldcw control_word2 // load modified control word
    }
}
```

(continues on next page)
// set rounding mode to truncate
inline void set_truncate() {
  __asm {
    fstcw control_word  // store fpu control word
    mov dx, word ptr [control_word]
    or dx, 0x0c00       // rounding: truncate
    mov control_word2, dx
    fldcw control_word2  // load modified control word
  }
}

// restore original rounding mode
inline void restore_cw() {
  __asm fldcw control_word
}

// truncate to integer using SSE
inline long truncateSSE(float x) {
  __asm cvttss2si eax,x
}
#endif

5.45.1 Comments

- **Date:** 2007-12-30 02:01:18
- **By:** moc.liamtoh@kuncorj

I've seen a lot of talk about using the function lrintf() when converting from float → int, regarding bypassing some 'slow' opcodes in what standard compilers put in → for something like:

```c
int myint = (int) myfloat;
```

in otherwords the following code would be faster:

```c
int myint = lrintf(myfloat);
```

This lrintf function is available on GNU C/C++

5.46 Float-to-int, converting an array of floats

- **Author or source:** Stefan Stenzel
- **Created:** 2002-01-17 03:10:32

Listing 82: notes

intel only
Listing 83: code

```c
void f2short(float *fptr, short *iptr, int n)
{
    _asm {
        mov ebx, n
        mov esi, fptr
        mov edi, iptr
        lea ebx, [esi+ebx*4] ; ptr after last
        mov edx, 0x80008000 ; damn endianess confuses...
        mov ecx, 0x4b004b00 ; damn endianess confuses...
        mov eax, [ebx] ; get last value
        push eax
        mov eax, 0x4b014B01
        mov [ebx], eax ; mark end
        mov ax, [esi+2]
        jmp startf2slp
    }

    ; Pad with nops to make loop start at address divisible
    ; by 16 + 2, e.g. 0x01408062, don't ask why, but this
    ; gives best performance. Unfortunately "align 16" does
    ; not seem to work with my VC.
    ; below I noted the measured execution times for different
    ; nop-paddings on my Pentium Pro, 100 conversions.
    ; saturation: off pos neg

    nop ; 355 546 563 <- seems to be best
    nop ; 951 547 544
    nop ; 444 646 643
    nop ; 444 646 643
    nop ; 944 951 950
    nop ; 358 447 644
    nop ; 358 447 643
    nop ; 358 544 643
    nop ; 543 447 643
    nop ; 643 447 643
    nop ; 1047 546 746
    nop ; 545 954 1253
    nop ; 545 547 661
    nop ; 544 547 746
    nop ; 444 947 1147
    nop ; 444 548 545
    in_range:
        mov eax, [esi]
        xor eax, edx
    saturate:
        lea esi, [esi+4]
        mov [edi], ax
        mov ax, [esi+2]
        add edi, 2
    startf2slp:
        cmp ax, cx
        je in_range
        js saturate ; saturate neg -> 0x8000
        mov eax, edx
        dec eax ; saturate pos -> 0x7FFF
    }
}
```

5.46. Float-to-int, converting an array of floats
5.46.1 Comments

- Date: 2003-01-22 20:20:20
- By: moc.xinorteletrams@sungam

```assembly
_asm {
  mov ebx,n
  mov esi,fptr
  mov edi,iptr
  lea ebx,[esi+ebx*4] ; ptr after last
  mov edx,0x80008000 ; damn endianess confuses...
  mov ecx,0x4b004b00 ; damn endianess confuses...
  mov eax,[ebx] ; get last value

  I think the last line here reads outside the buffer.
}
```

5.47 Gaussian dithering

- Author or source: Aleksey Vaneev (ur.liam@redocip)
- Type: Dithering
- Created: 2002-09-29 23:02:52

Listing 84: notes

It is a more sophisticated dithering than simple RND. It gives the most low noise for the whole spectrum even without noise-shaping. You can use as big N as you can afford (it will not hurt), but 4 or 5 is generally enough.

Listing 85: code

```plaintext
Basicly, next value is calculated this way (for RND going from -0.5 to 0.5):

\dither = (RND+RND+...+RND) / N.
\/       \_________
\       N times

If your RND goes from 0 to 1, then this code is applicable:

\dither = (RND+RND+...+RND - 0.5*N) / N.
```
5.48 Gaussian random numbers

- **Author or source:** ed.bew@raebaybot
- **Type:** random number generation
- **Created:** 2002-12-16 19:01:01

```pascal
Listing 86: notes
// Gaussian random numbers
// This algorithm (adapted from "Natur als fraktale Grafik" by
// Reinhard Scholl) implements a generation method for gaussian
// distributed random numbers with mean=0 and variance=1
// (standard gaussian distribution) mapped to the range of
// -1 to +1 with the maximum at 0.
// For only positive results you might abs() the return value.
// The q variable defines the precision, with q=15 the smallest
// distance between two numbers will be 1/(2^q div 3)=1/10922
// which usually gives good results.
// Note: the random() function used is the standard random
// function from Delphi/Pascal that produces *linear*
// distributed numbers from 0 to parameter-1, the equivalent
// C function is probably rand().
```

```pascal
Listing 87: code
const q=15;
c1=(1 shl q)-1;
c2=(c1 div 3)+1;
c3=1/c1;

function GRandom: single;
begin
  result := (2*(random(c2)+random(c2)+random(c2))-3*(c2-1))*c3;
end;
```

5.49 Hermite Interpolator (x86 ASM)

- **Author or source:** moc.oiduacbr@kileib.trebor
- **Type:** Hermite interpolator in x86 assembly (for MS VC++)
- **Created:** 2004-04-07 09:38:32

```pascal
Listing 88: notes
An "assemblified" variant of Laurent de Soras hermite interpolator. I tried to do
calculations as parallell as I could muster, but there is almost certainly room for
improvements. Right now, it works about 5.3 times (!) faster, not bad to start with...

Parameter explanation:
frac_pos: fractional value [0.0f - 1.0f] to interpolator
pntr: pointer to float array where:
  pntr[0] = previous sample (idx = -1)
```

(continues on next page)
pntr[1] = current sample (idx = 0)
pntr[2] = next sample (idx = +1)
pntr[3] = after next sample (idx = +2)

The interpolation takes place between pntr[1] and pntr[2].

Regards,
/Robert Bielik
RBC Audio

Listing 89: code

```c
const float c_half = 0.5f;
__declspec(naked) float __hermite(float frac_pos, const float* pntr)
{
    __asm
    {
        push ecx;
        mov ecx, dword ptr[esp + 12]; // 0x04

        // ST(0)
        add ecx, 0x04;
        ST(1) ST(2) ST(3) ST(4) ST(5) ST(6) ST(7)

        // x1
        fld dword ptr [ecx+4]; // x1
        fsub dword ptr [ecx-4]; // x1-xm1
        fld dword ptr [ecx]; // x0
        fsub dword ptr [ecx+4]; // v
        fld dword ptr [ecx+8]; // x2
        fsub dword ptr [ecx+4]; // x2-x0
        fxch st(2); // x1-xm1
        fmul c_half; // c
        fxch st(2); // x2-x0
        fmul c_half; // 0.5*(x2-x0)
        fxch st(2); // c
        fadd st(0), st(1); // w
        fmul 0.5*(x2-x0) c
        fxch st(2); // 0.5*(x2-x0)
        fadd st(0), st(1); // a
        fadd st(0), st(1); // a
        fadd st(0), st(1); // a
        fadd st(0), st(1); // a
        fadd st(0), st(1); // a
        fadd st(0), st(1); // a
        fadd st(0), st(1); // a
        fmul dword ptr [esp+8]; // a*frac
        fsubp st(1), st(0); // a*f-b
    }
}```
5.49.1 Comments

- **Date:** 2003-11-27 04:53:16  
  **By:** dmi@smartelectronix

This code produces a nasty buzzing sound. I think there might be a bug somewhere but
→ I haven't found it yet.

- **Date:** 2003-11-29 16:41:41  
  **By:** gro.lortnocdnim@psdcisum-sulph

I agree; the output, when plotted, looks like it has overlaid rectangular shapes on it.

- **Date:** 2003-12-02 21:18:57  
  **By:** moc.oiduacbr@kileib.trebor

AHH! True! A bug has sneaked in! Change the row that says:
→ fsubp st(1), st(0); // a*f-b c
to:
→ fsubrp st(1), st(0); // a*f-b c

and it should be much better. Although I noticed that a good optimization by the
→ compiler generates nearly as fast a code, but only nearly. This is still about 10% faster.

- **Date:** 2004-09-07 02:24:34  
  **By:** moc.enecslatnemirepxe@renrewd

I have tested the four hermite interpolation algorithms posted to musicdsp.org plus
→ the assemblified version of

Laurent de Soras’ code by Robert Bielik and found that on a Pentium 4 with full
→ optimization (targeting the

Pentium 4 and above, but not using code that won't work on older processors) with MS
→ VC++ 7 that the second

function is the fastest.

### Function Percent Total Time Return Value
5.50 Hermite interpolation

• Author or source: various
• Created: 2002-04-09 16:55:35

These are all different ways to do the same thing: Hermite interpolation. Try 'em all and benchmark.

Listing 91: code

```
// original
inline float hermite1(float x, float y0, float y1, float y2, float y3)
{
    // 4-point, 3rd-order Hermite (x-form)
    float c0 = y1;
    float c1 = 0.5f * (y2 - y0);
    float c2 = y0 - 2.5f * y1 + 2.f * y2 - 0.5f * y3;
    float c3 = 1.5f * (y1 - y2) + 0.5f * (y3 - y0);
    return ((c3 * x + c2) * x + c1) * x + c0;
}

// james mccartney
inline float hermite2(float x, float y0, float y1, float y2, float y3)
{
    // 4-point, 3rd-order Hermite (x-form)
    float c0 = y1;
    float c1 = 0.5f * (y2 - y0);
    float c3 = 1.5f * (y1 - y2) + 0.5f * (y3 - y0);
    float c2 = y0 - y1 + c1 - c3;
    return ((c3 * x + c2) * x + c1) * x + c0;
}

// james mccartney
inline float hermite3(float x, float y0, float y1, float y2, float y3)
{
    // 4-point, 3rd-order Hermite (x-form)
    float c0 = y1;
    float c1 = 0.5f * (y2 - y0);
    float y0my1 = y0 - y1;
    ```


```c
float c3 = (y1 - y2) + 0.5f * (y3 - y0my1 - y2);
float c2 = y0my1 + c1 - c3;
return ((c3 * x + c2) * x + c1) * x + c0;
}

// laurent de soras
inline float hermite4(float frac_pos, float x0, float x1, float x2)
{
  const float c = (x1 - x0) * 0.5f;
  const float v = x0 - x1;
  const float w = c + v;
  const float a = w + v + (x2 - x0) * 0.5f;
  const float b_neg = w + a;
  return (((a * frac_pos) - b_neg) * frac_pos + c) * frac_pos + x0);
}
```

### 5.50.1 Comments

- **Date:** 2002-05-25 13:37:32  
  **By:** theguylle

> great sources but what is Hermite ?

if you don't describe what is your code made for, you will made a great sources but I

---
don't know why?

cheers Paul

- **Date:** 2002-08-15 00:48:25  
  **By:** gro.psdcisum@marb

hermite is interpolation.

have a look around the archive, you'll see that the word 'hermite' is in more than

---
one item ;-)

-bram

- **Date:** 2003-07-29 10:46:40  
  **By:** rb.moc.rapenas@fwodlanor

Please, would like to know of hermite code it exists in delphi.

thankful

Ronaldo
Cascavel/Paraná/Brasil

- **Date:** 2003-10-10 08:36:06  
  **By:** moc.roctes-dabMAPSON@inirgam.m

---
Please, add, at least, the meaning of each parameter (I mean x, y0, y1, y2, y3)....

Ronaldo, it doesn't take much to translate these to Delphi - for float, either use single or double to your preference!

Looking at the codes, it seems quite clear that the parameters follow a pattern of: Sample Position between middle two samples, then the sample before current, current, current sample +1, current sample +2.

HTH
DSP

What are all these variables standing for? Not very clear :|

parameters are allright.

xm1 ---> x[n-1]
x0 ---> x[n]
x1 ---> x[n+1]
x2 ---> x[n+2]

fractional position stands for a fraction between 0 and 1 to interpolate

Couldn't #2 be sped up a hair by commenting out float c0 = y1;

and then replacing c0 with y1 in the return line? Or do the compilers do that kind of thing automatically when they optimize?
5.51 Linear interpolation

- **Author or source:** uh.etle.fni@yfoocs
- **Type:** Linear interpolators for oversampled audio
- **Created:** 2007-02-19 10:02:41

Listing 92: notes

Simple, fast linear interpolators for upsampling a signal by a factor of 2, 4, 8, 16 or 32.
Not very usable on their own since they introduce aliasing (but still better than zero order hold). These are best used with already oversampled signals.

-- Peter Schoffhauzer

Listing 93: code

```c
#ifndef __LIN_INTERPOLATOR_H_
#define __LIN_INTERPOLATOR_H_

/************************************************************************
* Linear interpolator class
************************************************************************/

class interpolator_linear
{
  public:
    interpolator_linear() {
      reset_hist();
    }

    // reset history
    void reset_hist() {
      dl = 0.f;
    }

    // 2x interpolator
    // out: pointer to float[2]
    inline void process2x(float const in, float *out) {
      out[0] = d1 + 0.5f*(in-d1);  // interpolate
      out[1] = in;
      d1 = in; // store delay
    }

    // 4x interpolator
    // out: pointer to float[4]
    inline void process4x(float const in, float *out) {
      float y = in-d1;
      out[0] = d1 + 0.25f*y;  // interpolate
      out[1] = d1 + 0.5f*y;
      out[2] = d1 + 0.75f*y;
      out[3] = in;
      d1 = in; // store delay
    }

}
```

(continues on next page)
// 8x interpolator
// out: pointer to float[8]
inline void process8x(float const in, float *out) {
    float y = in-d1;
    out[0] = d1 + 0.125f*y;  // interpolate
    out[1] = d1 + 0.25f*y;
    out[2] = d1 + 0.375f*y;
    out[3] = d1 + 0.5f*y;
    out[4] = d1 + 0.625f*y;
    out[5] = d1 + 0.75f*y;
    out[6] = d1 + 0.875f*y;
    out[7] = in;
    d1 = in;  // store delay
}

// 16x interpolator
// out: pointer to float[16]
inline void process16x(float const in, float *out) {
    float y = in-d1;
    out[0] = d1 + (1.0f/16.0f)*y;  // interpolate
    out[1] = d1 + (2.0f/16.0f)*y;
    out[2] = d1 + (3.0f/16.0f)*y;
    out[3] = d1 + (4.0f/16.0f)*y;
    out[4] = d1 + (5.0f/16.0f)*y;
    out[5] = d1 + (6.0f/16.0f)*y;
    out[6] = d1 + (7.0f/16.0f)*y;
    out[7] = d1 + (8.0f/16.0f)*y;
    out[8] = d1 + (9.0f/16.0f)*y;
    out[9] = d1 + (10.0f/16.0f)*y;
    out[10] = d1 + (11.0f/16.0f)*y;
    out[11] = d1 + (12.0f/16.0f)*y;
    out[12] = d1 + (13.0f/16.0f)*y;
    out[13] = d1 + (14.0f/16.0f)*y;
    out[14] = d1 + (15.0f/16.0f)*y;
    out[15] = in;
    d1 = in;  // store delay
}

// 32x interpolator
// out: pointer to float[32]
inline void process32x(float const in, float *out) {
    float y = in-d1;
    out[0] = d1 + (1.0f/32.0f)*y;  // interpolate
    out[1] = d1 + (2.0f/32.0f)*y;
    out[2] = d1 + (3.0f/32.0f)*y;
    out[3] = d1 + (4.0f/32.0f)*y;
    out[4] = d1 + (5.0f/32.0f)*y;
    out[5] = d1 + (6.0f/32.0f)*y;
    out[6] = d1 + (7.0f/32.0f)*y;
    out[7] = d1 + (8.0f/32.0f)*y;
    out[8] = d1 + (9.0f/32.0f)*y;
    out[9] = d1 + (10.0f/32.0f)*y;
    out[10] = d1 + (11.0f/32.0f)*y;
    out[11] = d1 + (12.0f/32.0f)*y;
    out[12] = d1 + (13.0f/32.0f)*y;
    out[13] = d1 + (14.0f/32.0f)*y;
    out[14] = d1 + (15.0f/32.0f)*y;
    out[15] = in;
    d1 = in;  // store delay
}
95 out[14] = d1 + (15.0f/32.0f)*y;
96 out[15] = d1 + (16.0f/32.0f)*y;
97 out[16] = d1 + (17.0f/32.0f)*y;
98 out[17] = d1 + (18.0f/32.0f)*y;
99 out[18] = d1 + (19.0f/32.0f)*y;
100 out[19] = d1 + (20.0f/32.0f)*y;
101 out[20] = d1 + (21.0f/32.0f)*y;
102 out[21] = d1 + (22.0f/32.0f)*y;
103 out[22] = d1 + (23.0f/32.0f)*y;
104 out[23] = d1 + (24.0f/32.0f)*y;
105 out[24] = d1 + (25.0f/32.0f)*y;
106 out[25] = d1 + (26.0f/32.0f)*y;
107 out[26] = d1 + (27.0f/32.0f)*y;
108 out[27] = d1 + (28.0f/32.0f)*y;
109 out[28] = d1 + (29.0f/32.0f)*y;
110 out[29] = d1 + (30.0f/32.0f)*y;
111 out[30] = d1 + (31.0f/32.0f)*y;
112 out[31] = in;
113 } // store delay
114
private:
115
default d1; // previous input
116
};
117
#endif

5.51.1 Comments

- **Date:** 2013-03-31 20:45:21
- **By:** moc.liamg@jdcisumff

I incorporated the 32x interpolator with something along this

```c
void process32x(float const in_l, float const in_r, float *out_l, float *out_r) {
    float y_l = in_l-f_d1_l;
    out_l[0] = f_d1_l + (1.0f/32.0f)*y_l; // interpolate
    out_l[1] = f_d1_l + (2.0f/32.0f)*y_l;
    out_l[2] = f_d1_l + (3.0f/32.0f)*y_l;
    out_l[3] = f_d1_l + (4.0f/32.0f)*y_l;
    out_l[4] = f_d1_l + (5.0f/32.0f)*y_l;
    out_l[5] = f_d1_l + (6.0f/32.0f)*y_l;
    out_l[6] = f_d1_l + (7.0f/32.0f)*y_l;
    out_l[7] = f_d1_l + (8.0f/32.0f)*y_l;
    out_l[8] = f_d1_l + (9.0f/32.0f)*y_l;
    out_l[9] = f_d1_l + (10.0f/32.0f)*y_l;
    out_l[10] = f_d1_l + (11.0f/32.0f)*y_l;
    out_l[11] = f_d1_l + (12.0f/32.0f)*y_l;
    out_l[12] = f_d1_l + (13.0f/32.0f)*y_l;
    out_l[13] = f_d1_l + (14.0f/32.0f)*y_l;
    out_l[14] = f_d1_l + (15.0f/32.0f)*y_l;
    out_l[15] = f_d1_l + (16.0f/32.0f)*y_l;
    out_l[16] = f_d1_l + (17.0f/32.0f)*y_l;
    (continues on next page)
```
out_l[17] = f_d1_l + (18.0f/32.0f)*y_l;
out_l[18] = f_d1_l + (19.0f/32.0f)*y_l;
out_l[19] = f_d1_l + (20.0f/32.0f)*y_l;
out_l[20] = f_d1_l + (21.0f/32.0f)*y_l;
out_l[21] = f_d1_l + (22.0f/32.0f)*y_l;
out_l[22] = f_d1_l + (23.0f/32.0f)*y_l;
out_l[23] = f_d1_l + (24.0f/32.0f)*y_l;
out_l[24] = f_d1_l + (25.0f/32.0f)*y_l;
out_l[25] = f_d1_l + (26.0f/32.0f)*y_l;
out_l[26] = f_d1_l + (27.0f/32.0f)*y_l;
out_l[27] = f_d1_l + (28.0f/32.0f)*y_l;
out_l[28] = f_d1_l + (29.0f/32.0f)*y_l;
out_l[29] = f_d1_l + (30.0f/32.0f)*y_l;
out_l[30] = f_d1_l + (31.0f/32.0f)*y_l;
out_l[31] = in_l;
f_d1_l = in_l; // store delay_l

float y_r = in_r-f_d1_r;

out_r[0] = f_d1_r + (1.0f/32.0f)*y_r; // interpolate
out_r[1] = f_d1_r + (2.0f/32.0f)*y_r;
out_r[2] = f_d1_r + (3.0f/32.0f)*y_r;
out_r[3] = f_d1_r + (4.0f/32.0f)*y_r;
out_r[4] = f_d1_r + (5.0f/32.0f)*y_r;
out_r[5] = f_d1_r + (6.0f/32.0f)*y_r;
out_r[6] = f_d1_r + (7.0f/32.0f)*y_r;
out_r[7] = f_d1_r + (8.0f/32.0f)*y_r;
out_r[8] = f_d1_r + (9.0f/32.0f)*y_r;
out_r[9] = f_d1_r + (10.0f/32.0f)*y_r;
out_r[10] = f_d1_r + (11.0f/32.0f)*y_r;
out_r[11] = f_d1_r + (12.0f/32.0f)*y_r;
out_r[12] = f_d1_r + (13.0f/32.0f)*y_r;
out_r[13] = f_d1_r + (14.0f/32.0f)*y_r;
out_r[14] = f_d1_r + (15.0f/32.0f)*y_r;
out_r[15] = f_d1_r + (16.0f/32.0f)*y_r;
out_r[16] = f_d1_r + (17.0f/32.0f)*y_r;
out_r[17] = f_d1_r + (18.0f/32.0f)*y_r;
out_r[18] = f_d1_r + (19.0f/32.0f)*y_r;
out_r[19] = f_d1_r + (20.0f/32.0f)*y_r;
out_r[20] = f_d1_r + (21.0f/32.0f)*y_r;
out_r[21] = f_d1_r + (22.0f/32.0f)*y_r;
out_r[22] = f_d1_r + (23.0f/32.0f)*y_r;
out_r[23] = f_d1_r + (24.0f/32.0f)*y_r;
out_r[24] = f_d1_r + (25.0f/32.0f)*y_r;
out_r[25] = f_d1_r + (26.0f/32.0f)*y_r;
out_r[26] = f_d1_r + (27.0f/32.0f)*y_r;
out_r[27] = f_d1_r + (28.0f/32.0f)*y_r;
out_r[28] = f_d1_r + (29.0f/32.0f)*y_r;
out_r[29] = f_d1_r + (30.0f/32.0f)*y_r;
out_r[30] = f_d1_r + (31.0f/32.0f)*y_r;
out_r[31] = in_r;
f_d1_r = in_r; // store delay_r

Unfortunately, I am doing something crazy wrong. When I close my plug-in, my DAW freezes. I'm fairly new to programming and am not sure what I'm doing wrong.

I'm using your function to write to an audio buffer which is being set to a delay. This is what the call looks like.
process32x((fLeftAudioBuffer[i] * decay), (fRightAudioBuffer[i] * decay),
   &fCircularLeftAudioBuffer[(fCircularBufferPosition + delayFrames)
   →%kCircularBufferSize],
   &fCircularRightAudioBuffer[(fCircularBufferPosition + delayFrames)
   →%kCircularBufferSize]);

I would love to use this function because it's one line less than how I usually do it.
   It works great with no problems.
fCircularLeftAudioBuffer[(fCircularBufferPosition + delayFrames)%kCircularBufferSize]
   = fLeftAudioBuffer[jh] * decay;
fCircularRightAudioBuffer[(fCircularBufferPosition + delayFrames)
   →%kCircularBufferSize] = fRightAudioBuffer[jh] * decay;

Everything seems simple, but I'm puzzled as to what may be wrong. Thanks.

• Date: 2013-03-31 22:18:36
  • By: moc.liang@jdcisumff

Never mind. I was calling the function from the wrong place. Works like a charm.

Thank you.

5.52 Lock free fifo

• Author or source: Timo
• Created: 2002-09-13 16:21:59
• Linked files: LockFreeFifo.h.

Listing 94: notes

Simple implementation of a lock free FIFO.

5.52.1 Comments

• Date: 2003-04-15 11:17:31
  • By: moc.oohay@SIHTEVOMER_ralohcshsoj

There is a good algorithm for a lock free (but multiprocessor safe) FIFO. But the given implementation is flawed in a number of ways. This code is not reliable.
  Two problems on the surface of it:
  1. I can easily see that it's possible for two threads/processors to return the same item from the head if the timing is right.
  2. there's no interlocked instructions to make sure that changes to the shared variables are globally visible
  3. there's not attempt in the code to make sure that data is read in an atomic way, let alone changed in one...

The code is VERY naive

(continues on next page)
I do have code that works, but it's not so short that will post it in a comment. If anyone needs it they can email me.

- **Date:** 2003-05-15 19:16:24
- **By:** Timo

This is only supposed to work on uniprocessor machines with _one_ reading and _one_ writing thread assuming that the assignments to read and write idx are simple mov instructions (i.e. atomic). To be sure you'd need to write the update parts in hand-coded asm; never know what the compiler comes up with. The context of this code was omitted (i.e. Bram posted my written in 1 min sketch in a discussion on IRC on a lock-free fifo, not production code).

### 5.53 MATLAB-Tools for SNDAN

- **Author or source:** Markus Sapp
- **Created:** 2002-01-17 03:11:05
- **Linked files:** other001.zip

Listing 95: notes

### 5.54 MIDI note/frequency conversion

- **Author or source:** ed.bew@raebbybot
- **Type:** -
- **Created:** 2002-11-25 18:14:17

Listing 96: notes

I get often asked about simple things like MIDI note/frequency conversion, so I thought I could as well post some source code about this. The following is Pascal/Delphi syntax, but it shouldn't be a problem to convert it to almost any language in no time.

Uses for this code are mainly for initializing oscillators to the right frequency based upon a given MIDI note, but you might also check what MIDI note is closest to a given frequency for pitch detection etc. In realtime applications it might be a good idea to get rid of the power and log2 calculations and generate a lookup table on initialization.

A full Pascal/Delphi unit with these functions (including lookup table generation) and a
simple demo application can be downloaded here:
http://tobybear.phreque.com/dsp_conv.zip

If you have any comments/suggestions, please send them to: tobybear@web.de

Listing 97: code

// MIDI NOTE/FREQUENCY CONVERSIONS

const notes:array[0..11] of string= ('C ','C#','D ','D#','E ','F ','F#','G ','G#','A →','A#','B ');

const base_a4=440; // set A4=440Hz

// converts from MIDI note number to frequency
// example: NoteToFrequency(12)=32.703
function NoteToFrequency(n:integer):double;
begin
if (n>=0)and(n<=119) then
result:=base_a4*power(2,(n-57)/12)
else result:=-1;
end;

// converts from MIDI note number to string
// example: NoteToName(12)='C 1'
function NoteToName(n:integer):string;
begin
if (n>=0)and(n<=119) then
result:=notes[n mod 12]+inttostr(n div 12)
else result:='---';
end;

// converts from frequency to closest MIDI note
// example: FrequencyToNote(443)=57 (A 4)
function FrequencyToNote(f:double):integer;
begin
result:=round(12*log2(f/base_a4))+57;
end;

// converts from string to MIDI note
// example: NameToNote('A4')=57
function NameToNote(s:string):integer;
var c,i:integer;
begin
if length(s)=2 then s:=s[1]+s[2];
if length(s)<3 then begin result:=-1;exit end;
s:=toupper(s);
c:=-1;
for i:=0 to 11 do
if notes[i]=copy(s,1,2) then
begin
c:=i;
break
end;
try
i:=strtoint(s[3]);
result:=i*12+c;
end;

(continues on next page)
except
    result:=-1;
end;
if c<0 then result:=-1;
end;

5.54.1 Comments

• Date: 2002-11-29 17:34:28
  • By: ed.bew@raebybot

For the sake of completeness, here is octave fraction notation and pitch class notation:

// converts from MIDI note to octave fraction notation
// the integer part of the result is the octave number, where
// 8 is the octave starting with middle C. The fractional part
// is the note within the octave, where 1/12 represents a semitone.
// example: NoteToOct(57)=7.75
function NoteToOct(i:integer):double;
begin
    result:=3+(i div 12)+(i mod 12)/12;
end;

// converts from MIDI note to pitch class notation
// the integer part of the number is the octave number, where
// 8 is the octave starting with middle C. The fractional part
// is the note within the octave, where a 0.01 increment is a
// semitone.
// example: NoteToPch(57)=7.09
function NoteToPch(i:integer):double;
begin
    result:=3+(i div 12)+(i mod 12)*0.01;
end;

• Date: 2002-12-03 12:36:05
  • By: moc.noicratse@ajelak

I thought most sources gave A-440Hz = MIDI note 69. MIDI 60 = middle C = ~262Hz, A-440 = "A above middle C". Not so?

• Date: 2003-05-14 03:24:58
  • By: DFL

Kaleja is correct. Here is some C code:

double MIDItoFreq( char keynum ) {
    return 440.0 * pow( 2.0, ((double)keynum - 69.0) / 12.0 );
}

you can double-check the table here:
http://tomscarff.tripod.com/midi_analyser/midi_note_frequency.htm
Matlab code for time domain inversion of an impulse response or the division of two of them (transfer function.) The main `teoplitz` function is given both as a `.m` file and as a `.c` file for Matlab’s MEX compilation. The latter is much faster.

```
function inv=invimplms(den,n,d)
% syntax inv=invimplms(den,n,d)
%   den - denominator impulse
%   n   - length of result
%   d   - delay of result
%   inv - inverse impulse response of length n with delay d
%
% Levinson-Durbin algorithm from Proakis and Manolakis p.865
% Author: Bob Cain, May 1, 2001 arcane@arcanemethods.com

m=xcorr(den,n-1);
m=m(n:end);
b=[den(d+1:-1:1);zeros(n-d-1,1)];
inv=toepsolve(m,b);

function quo=divimplms(num,den,n,d)
%Syntax quo=divimplms(num,den,n,d)
%   num - numerator impulse
%   den - denominator impulse
%   n   - length of result
%   d   - delay of result
%   quo - quotient impulse response of length n delayed by d
%
% Levinson-Durbin algorithm from Proakis and Manolakis p.865
% Author: Bob Cain, May 1, 2001 arcane@arcanemethods.com

m=xcorr(den,n-1);
m=m(n:end);
b=xcorr([zeros(d,1);num],den,n-1);
b=b(n:-1:1);
quo=toepsolve(m,b);

function hinv=toepsolve(r,q)
% Solve Toeplitz system of equations.
% Solves R*hinv = q, where R is the symmetric Toeplitz matrix
% who's first column is r
% Assumes all inputs are real
```

(continues on next page)
% Inputs:
%   r - first column of Toeplitz matrix, length n
%   q - rhs vector, length n
% Outputs:
%   hinv - length n solution
% Algorithm from Roberts & Mullis, p.233
% Author: T. Krauss, Sept 10, 1997
% Modified: R. Cain, Dec 16, 2004 to remove a pair of transposes
% that caused errors.

n=length(q);
a=zeros(n+1,2);
a(1,1)=1;

hinv=zeros(n,1);

alpha=r(1);
c=1;
d=2;

for k=1:n-1,
a(k+1,c)=0;
a(1,d)=1;
beta=0;
j=1:k;
beta=sum(r(k+2-j).*a(j,c))/alpha;
a(j+1,d)=a(j+1,c)-beta*a(k+1-j,c);
alpha=alpha*(1-beta^2);
hinv(k+1,1)=(q(k+1)-sum(r(k+2-j).*hinv(j,1)))/alpha;
hinv(j)=hinv(j)+a(k+2-j,d)*hinv(k+1);
temp=c;
c=d;
d=temp;
end

-----What follows is the .c version of toepsolve--------

#include <math.h>
#include "mex.h"

/* function hinv = toepsolve(r,q);
  * TOEPSOLVE  Solve Toeplitz system of equations.
  * Solves R*hinv = q, where R is the symmetric Toeplitz matrix
  * whos first column is r
  * Assumes all inputs are real
  * Inputs:
  *   r - first column of Toeplitz matrix, length n
  *   q - rhs vector, length n
  * Outputs:
  *   hinv - length n solution
  *   Algorithm from Roberts & Mullis, p.233 */
void mexFunction(
  int nlhs,
  mxArray *plhs[],
  int nrhs,
  const mxArray *prhs[
  ]
)
{
  double (*a)[2], *hinv, alpha, beta;
  int c, d, temp, j, k;

  double eps = mxGetEps();
  int n = (mxGetN(prhs[0]) >= mxGetM(prhs[0])) ? mxGetN(prhs[0]) : mxGetM(prhs[0]);
  double *r = mxGetPr(prhs[0]);
  double *q = mxGetPr(prhs[1]);

  a = (double (*)[2])mxCalloc((n+1)*2,sizeof(double));
  if (a == NULL) {
    mexErrMsgTxt("Sorry, failed to allocate buffer.");
  }
  a[0][0] = 1.0;

  plhs[0] = mxCreateDoubleMatrix(n,1,0);
  hinv = mxGetPr(plhs[0]);
  hinv[0] = q[0]/r[0];

  alpha = r[0];
  c = 0;
  d = 1;

  for (k = 1; k < n; k++) {
    a[k][c] = 0;
    a[0][d] = 1.0;
    beta = 0.0;
    for (j = 1; j <= k; j++) {
      beta += r[k+1-j]*a[j-1][c];
    }
    beta /= alpha;
    for (j = 1; j <= k; j++) {
      a[j][d] = a[j][c] - beta*a[k-j][c];
    }
    alpha *= (1 - beta*beta);
    hinv[k] = q[k];
    for (j = 1; j <= k; j++) {
      hinv[k] -= r[k+1-j]*hinv[j-1];
    }
    hinv[k] /= alpha;
    for (j = 1; j <= k; j++) {
      hinv[j-1] += a[k+1-j][d]*hinv[k];
    }
    temp = c;
  }
}
(continues on next page)
These two functions reproduce a traditional professional mixer fader taper.

`MMtoDB` converts millimeters of fader travel from the bottom of the fader for a 100 millimeter fader into decibels. `DBtoMM` is the inverse.

The taper is as follows from the top:
The top of the fader is +10 dB
100 mm to 52 mm : -5 dB per 12 mm
52 mm to 16 mm : -10 dB per 12 mm
16 mm to 4 mm : -20 dB per 12 mm
4 mm to 0 mm : fade to zero. (in these functions I go to -200dB which is effectively zero for up to 32 bit audio.)

```c
float MMtoDB(float mm)
{
    float db;
    mm = 100. - mm;
    if (mm <= 0.) {
        db = 10.;
    } else if (mm < 48.) {
        db = 10. - 5./12. * mm;
    } else if (mm < 84.) {
        db = -10. - 10./12. * (mm - 48.);
    } else if (mm < 96.) {
        db = -40. - 20./12. * (mm - 84.);
    } else if (mm < 100.) {
        db = -60. - 35. * (mm - 96.);
    } else db = -200.;
    return db;
}
```

function MMtoDB(Millimeter:Single):Single;
var mm: Single;
begin
  mm:=100-Millimeter;
  if mm = 0 then Result:=10
  else if mm < 48 then Result:=10-5/12*mm;
  else if mm < 84 then Result:=-10-10/12*(mm-48);
  else if mm < 96 then Result:=-40-20./12*(mm-84);
  else if mm < 100 then Result:=-60-35*(mm-96);
  else Result:=-200.;
end;

function DBtoMM(db:Single):Single;
begin
  if db>=10 then result:=0;
  else if db>-10 then result:=-12/5*(db-10);
  else if db>-40 then result:=48-12/10*(db+10);
  else if db>-60 then result:=84-12/20*(db+40);
  else if db>-200 then result:=96-1/35*(db+60);
  else result:=100.;
  Result:=100-Result;
end;
Flash ActionScript translation:

```actionscript
public function normalizedToDecibel(value : Number) : Number
{
    value = (1 - value) * 100;
    if(value <= 0.0) var db : Number = 10.0;
    else if(value < 48.0) db = 10.0 - 5.0 / 12.0 * value;
    else if(value < 84.0) db = -10.0 - 10.0 / 12.0 * (value - 48.0);
    else if(value < 96.0) db = -40.0 - 20.0 / 12.0 * (value - 84.0);
    else if(value < 100.0) db = -60.0 - 35.0 * (value - 96.0);
    else db = -200.0;
    return db;
}
```

```actionscript
public function decibelToNormalized(decibel : Number) : Number
{
    if(decibel >= 10.0) var normalizedValue : Number = 0.0;
    else if (decibel > -10.0) normalizedValue = -12.0 / 5.0 * (decibel - 10.0);
    else if (decibel > -40.0) normalizedValue = 48.0 - 12.0 / 10.0 * (decibel + 10.0);
    else if (decibel > -60.0) normalizedValue = 84.0 - 12.0 / 20.0 * (decibel + 40.0);
    else if (decibel > -200.0) normalizedValue = 96.0 - 1.0 / 35.0 * (decibel + 60.0);
    else normalizedValue = 100.0;
    return (100.0 - normalizedValue) / 100.0;
}
```

### 5.57 Motorola 56300 Disassembler

- **Author or source:** moc.ngisedigid@dnesnot_sirhc
- **Type:** disassembler
- **Created:** 2005-05-24 07:08:07
- **Linked files:** Disassemble56k.zip.

Listing 102: notes

This code contains functions to disassemble Motorola 56k opcodes. The code was originally created by Stephen Davis at Stanford. I made minor modifications to support many 56300 opcodes, although it would nice to add them all at some point. Specifically, I added (continues on next page)
5.57.1 Comments

- Date: 2005-05-24 20:33:25
  - By: jawoll
  nice! let's disassemble virus c, nord lead 3, ...

- Date: 2005-09-29 19:51:55
  - By: moc.liamg@rhajile
  Very nice. How would one get ahold of the OS for one of these synths, to disassemble it? I've got a Nord Micro, with a single 56303... question is.... how to get the OS from the flash?

- Date: 2011-07-11 08:58:10
  - By: ach nö
  After a first look inside the c file i found out that the header file 'Utility56k.h' is missing which is included in the code file...

5.58 Noise Shaping Class

- Author or source: ude.anaidni@iehsc
- Type: Dithering with 9th order noise shaping
- Created: 2002-04-23 06:49:06
- Linked files: NS9dither16.h.

Listing 103: notes
This is an implementatation of a 9th order noise shaping & dithering class, that runs quite fast (it has one function that uses Intel x86 assembly, but you can replace it with a different rounding function if you are running on a non-Intel platform). _aligned_malloc and _aligned_free require the MSVC++ Processor Pack, available from www.microsoft.com. You can replace them with "new" and "delete," but allocating aligned memory seems to make it run faster. Also, you can replace ZeroMemory with a memset that sets the memory to 0 if you aren't using Win32. Input should be floats from -32768 to 32767 (processS will clip at these points for you, but clipping is bad when you are trying to convert floats to shorts). Note to reviewer - (continues on next page)
it would probably be better if you put the code in a file such as NSDither.h and have a link to it - it's rather long.

(see linked file)

5.58.1 Comments

- Date: 2003-05-14 14:01:22
- By: mail[ns]@mutagene.net

I haven't tried this class out, but it looks like there's a typo in the unrolled loop — shouldn't it read "c[2]*EH[HistPos+2]"? This might this also account for the 3 clock cycle improvement on a P-III.

// This arrangement seems to execute 3 clock cycles faster on a P-III

- Date: 2005-02-15 15:18:55
- By: moc.tnemarkas@vokiahc

Great class! But I found one more mistake: function my_mod(9, 9) gives 9 instead of 0 — (9 % 9 = 0).

HistPos = my_mod((HistPos+8), order);
EH[HistPos+9] = EH[HistPos] = output - samp;

-> HistPos + 9 = 18 (max EH index is 17) which leads to out of array boundary and crash.

So my_mod should look like:

__inline my_mod(int x, int n)
{
    if(x >= n) x-=n;
    return x;
}

5.59 Nonblocking multiprocessor/multithread algorithms in C++

- Author or source: moc.oohay@ralohcshsoj
- Type: queue, stack, garbage collection, memory allocation, templates for atomic algorithms and types
- Created: 2004-04-07 09:38:12
- Linked files: ATOMIC.H.
5.59.1 Comments

- Date: 2008-01-10 17:01:39
- By: ten.xliannahx@xmagie

This code has a problem with operation exceeding 4G times. If you do more then 4G of...
Put and Get with the MPQueue, "AtomicUInt & Index(int i) { return data[i & (len-1)];...
will cause BUG.
Modular operation with length of 2^n is OK, but not for other numbers.
My email does not have any "x" letters.

- Date: 2011-05-23 22:22:21
- By: ude.fcu.sc@awajuk

In MPCountStack::PopElement, what's to prevent another thread from deleting was...
Value().ptr between assigning was and reading was.Value().ptr->next?

5.60 Piecewise quadratic approximate exponential function

- Author or source: Johannes M.-R.
- Type: Approximation of base-2 exponential function
- Created: 2007-06-18 08:09:58

Listing 105: notes

The code assumes round-to-zero mode, and ieee 754 float.
To achieve other bases, multiply the input by the logarithmus dualis of the base.

Listing 106: code

```c
inline float fpow2(const float y) {
  union {
    float f;
    int i;
  } c;

  int integer = (int)y;
  if(y < 0)
    integer = integer-1;
  float frac = y - (float)integer;
  c.i = (integer+127) << 23;
  c.f *= 0.33977f*frac*frac + (1.0f-0.33977f)*frac + 1.0f;
}
```

(continues on next page)
5.61 Pow(x,4) approximation

- **Author or source:** Stefan Stenzel
- **Created:** 2002-01-17 03:09:20

**Listing 107: notes**

Very hacked, but it gives a rough estimate of $x^4$ by modifying exponent and mantissa.

**Listing 108: code**

```c
float p4fast (float in)  
{
   long *lp, l;
   lp=(long *)(&in);  
   l=*lp;
   l-=0x3F800000l;  /* un-bias */
   l<<=2;  /* **4 */
   l+=0x3F800000l;  /* bias */
   *lp=l;
   /* compiler will read this from memory since & operator had been used */
   return in;
}
```

5.62 Rational tanh approximation

- **Author or source:** cschueler
- **Type:** saturation
- **Created:** 2006-11-15 17:29:12

**Listing 109: notes**

This is a rational function to approximate a tanh-like soft clipper. It is based on the pade-approximation of the tanh function with tweaked coefficients.

The function is in the range $x=-3..3$ and outputs the range $y=-1..1$. Beyond this range, the output must be clamped to $-1..1$.

The first to derivatives of the function vanish at $-3$ and $3$, so the transition to the hard clipped region is C2-continuous.
Listing 110: code

```c
float rational_tanh(x)
{
    if ( x < -3 )
        return -1;
    else if ( x > 3 )
        return 1;
    else
        return x * ( 27 + x * x ) / ( 27 + 9 * x * x );
}
```

5.62.1 Comments

- **Date:** 2006-11-24 16:24:54
  - **By:** uh.etle.fnI@yfoocs

Works fine. If you want only a little overdrive, you don't even need the clipping, just the last line for faster processing.

```c
float rational_tanh_noclip(x)
{
    return x * ( 27 + x * x ) / ( 27 + 9 * x * x );
}
```

The maximum error of this function in the -4.5 .. 4.5 range is about 2.6%.

- **Date:** 2006-11-30 15:59:33
  - **By:** uh.etle.fnI@yfoocs

By the way this is the fastest tanh() approximation in the archive so far.

- **Date:** 2006-12-08 21:21:02
  - **By:** cschueler

Yep, I thought so.
That's why I thought it would be worth sharing.

Especially fast when using SSE you can do a 4-way parallel implementation, with MIN/ MAX and the RCP instruction.

- **Date:** 2007-01-26 12:13:50
  - **By:** mdsp

nice one

BTW if you google about "pade-approximation" you'll find a nice page with many solutions for common functions.

there's exp, log, sin, cos, tan, gaussian...

- **Date:** 2007-02-18 03:35:13
  - **By:** uh.etle.fnI@yfoocs

5.62. Rational tanh approximation

567
Yep, but the RCP increases the noise floor somewhat, giving a quantized sound, so I'd refrain from using it for high quality audio.

## 5.63 Reading the compressed WA! parts in gigasampler files

- **Author or source:** Paul Kellett
- **Created:** 2002-02-18 00:51:08
- **Linked files:** gigxpand.zip

Listing 111: notes

(see linkfile)

Code to read the .WA! (compressed .WAV) parts of GigaSampler .GIG files.

For related info on reading .GIG files see http://www.linuxdj.com/evo

## 5.64 Really fast x86 floating point sin/cos

- **Author or source:** moc.nsm@seivadre
- **Created:** 2003-11-25 17:43:28
- **Linked files:** sincos.zip

Listing 112: notes

Frightful code from the Intel Performance optimization front. Not for the squeamish.

The following code calculates sin and cos of a floating point value on x86 platforms to 20 bits precision with 2 multiplies and two adds. The basic principle is to use sin(x+y) and cos(x+y) identities to generate the result from lookup tables. Each lookup table takes care of 10 bits of precision in the input. The same principle can be used to generate sin/cos to full (! Really. Full!) 24-bit float precision using two 8-bit tables, and one 10 bit table (to provide guard bits), for a net speed gain of about 4x over fsin/fcos, and 8x if you want both sin and cos. Note that microsoft compilers have trouble keeping doubles aligned properly on the stack (they must be 8-byte aligned in order not to incur a massive alignment penalty). As a result, this class should NOT be allocated on the stack. Add it as a member variable to any class that uses it.

e.g.

```cpp
class CSomeClass {
    CQuickTrig m_QuickTrig;
    ...
    mQuickTrig.QuickSinCos(dAngle,fSin,fCos);
    ...
}
```
5.65 Reasonably accurate/fastish tanh approximation

- **Author or source:** Fuzzpilz
- **Created:** 2004-08-17 22:56:29

Listing 114: notes

Fairly obvious, but maybe not obvious enough, since I've seen calls to tanh() in code snippets here.

It's this, basically:

\[
\tanh(x) = \frac{\sinh(x)}{\cosh(x)} = \frac{\exp(x) - \exp(-x)}{\exp(x) + \exp(-x)} = \frac{\exp(2x) - 1}{\exp(2x) + 1}
\]

Combine this with a somewhat less accurate approximation for \(\exp\) than usual (I use a third-order Taylor approximation below), and you're set. Useful for waveshaping.

Notes on the \(\exp\) approximation:

It only works properly for input values above \(x\), but since \(\tanh\) is odd, that isn't a problem.

\[
\exp(x) = 1 + x + x^2/(2!) + x^3/(3!) + ...\]

Breaking the Taylor series off after the third term, I get

\[1 + x + x^2/2 + x^3/6.\]

I can save some multiplications by using

\[6 + x * (6 + x * (3 + x))\]

instead; a division by 6 becomes necessary, but is lumped into the additions in the \(\tanh\) part:

\[(a/6 - 1)/(a/6 + 1) = (a - 6)/(a + 6).\]

**Accuracy:**

I haven't looked at this in very great detail, but it's always \(<=\) the real \(\tanh\) (\(>=\) for \(x<0\)), and the greatest deviation occurs at about +/- 1.46, where the result is ca. .95 times the correct value.

This is still faster than \(\tanh\) if you use a better approximation for the exponential, even

(continues on next page)
if you simply call exp.
There are probably additional ways of improving parts of this, and naturally if you're
going to use it you'll want to figure out whether your particular application offers
additional ways of simplifying it, but it's a good start.

Listing 115: code

```c
/* single precision absolute value, a lot faster than fabsf() (if you use MSVC++ 6
Standard - others’ implementations might be less slow) */
float sabs(float a)
{
    int b=(*(int *)(&a))&0x7FFFFFFF;
    return *((float *)(&b));
}

/* approximates tanh(x/2) rather than tanh(x) - depending on how you’re using this;
fixing that could well be wasting a multiplication (though that isn’t much, and it
could be done with an integer addition in sabs instead) */
float tanh2(float x)
{
    float a=sabs(x);
    a=6+a*(6+a*(3+a));
    return ((x<0)?-1:1)*(a-6)/(a+6);
    // instead of using <, you can also check directly
    // whether the sign bit is set (*((int *)(&x)))&0x80000000, but it’s not really
    // worth it */
}
```

5.65.1 Comments

- **Date:** 2004-09-19 03:08:02
  - **By:** ten.xmg@zlipzzuf

Not sure why this didn't occur to me earlier, but you can easily save another two
adds as follows:

```c
a*=6+a*(3+a));
return ((x<0)?-1:1)*a/(a+12);
```

- **Date:** 2004-10-06 22:46:23
  - **By:** moc.noicratse@ajelak

You shouldn't need the sabs() on VC6 - you just need to add:

```c
#pragma intrinsic( fabs )
```

before calling fabsf(), and it should go optimally fast.

- **Date:** 2004-10-07 10:56:45
  - **By:** Laurent de Soras

You can optimise it a bit more by using the fact that tanh (x) = 1 - 2 / (exp (2*x) + 1)
AFAIK intrinsics aren't supported by VC6 Standard, but limited to Professional and Enterprise. Might be wrong, though, in which case I am a silly person. (no time to check now)

Delphi Code:

```delphi
// approximates tanh(x/2) rather than tanh(x) - depending on how you're using
// this, fixing that could well be wasting a multiplication
function tanh2(x:single):Single;
var a : single;
begin
  a:=f_abs(x);
  a:=a*(12+a*(6+a*(3+a)));
  if (x<0)
    then result:= -a/(a+24)
    else result:= a/(a+24);
end;
```

 Laurent de Soras wrote:
"You can optimise it a bit more by using the fact that tanh (x) = 1 - 2 / (exp (2*x) -1)"

It's not faster, because you'll need 3 more cycles. The routine would then look like:

```delphi
function tanh2(x:single):Single;
var a : single;
begin
  a:=f_abs(x);
  a:=24+a*(12+a*(6+a*(3+a)));
  if (x<0)
    then result:= (-1+24/a)
    else result:= (1-24/a);
end;
```

I must have missed this one..
but why is the comparison needed?

a simpler version would be:

```delphi
a:=Abs(x)
Result:=x*(6+a*(3+a))/(a+12)
```

(continues on next page)
So in asm:

```asm
function Tanh2(x:Single):Single;
const c3 :Single=3;
c6 :Single=6;
c12:Single=12;
Asm
    FLD    x
    FLD    ST(0)
    FABS
    FLD    c3
    FADD   ST(0),ST(1)
    FMUL   ST(0),ST(1)
    FADD   c6
    FMULP  ST(2),ST(0)
    FADD   c12
    FDIVP  ST(2),ST(0)
End;
```

..but almost all the CPU is wasted by the division anyway

- **Date:** 2005-05-09 03:11:16
- **By:** eb.tenyks@didid

wait.. has anyone tested this function?

Here's a test plot:
http://www.flstudio.com/gol/tanh.gif

Red=TanH

Green=the approximation suggested in this thread

Blue=another approximation that does:

```pascal
function TanH3(x:Single):Single;
Begin
Result:=x - x*x*x/3 + 2*x*x*x*x*x*x/15;
end;
```

If I didn't do anything wrong, the green one is VERY far from TanH. Blue is both → closer & computationally more efficient.

But ok, this plot is for a normalized 0..1. When you go above, the blue like goes → crazy.
But now considering that -1..1 is what matters the most for what we do, the input → could still be clipped.

- **Date:** 2005-05-09 03:23:10
- **By:** eb.tenyks@didid

forget all this :)

it's all embarrassing bullshit and I obviously need some sleep :)}
Ok ignore my above crap that I can't delete, I swear that this one does work :)  

First I hadn’t seen that this function was assuming x*2, so my graph was scaled by 2..  

Second, the other algo (blue line) is still not to be neglected (because no FDIV) when the input is in the -1..1 range, and it does work.  

Third, I'm suggesting here a version without the comparison/branching, but still, the CPU difference is neglectable because of the FDIV.  

Here it is (this one does NOT assume a premultiplied x)...

plain code:

```pascal
function Tanh2(x:Single):Single;
var a,b:Single;
begin
  x:=x*2;
  a:=abs(x);
  b:=(6+a*(3+a));
  Result:=(x*b)/(a*b+12);
end;
```

asm:

```pascal
function Tanh22(x:Single):Single;
const c3 :Single=3;
c6 :Single=6;
c12 :Single=12;
Mul2:Single=2;
asm
  FLD x
  FMUL Mul2
  FLD ST(0)
  FABS       // a
  FLD c3
  FADD ST(0),ST(1)
  FMUL ST(0),ST(1)
  FADD c6       // b
  FMUL ST(2),ST(0)    // x*b
  FMULP ST(1),ST(0)   // a*b
  FADD c12
  FDIVP ST(1),ST(0)
End;
```

Any suggestions about improving the 3DNow Divide-Operation??? I simply hate my code...

```pascal
procedure Transistor2_3DNow(pinp,pout : PSingle; Samples:Integer;Scalar:Single);
const ng : Array [0..1] of Integer = ($7FFFFFFF,$7FFFFFFF);
```

(continues on next page)
pg : Array [0..1] of Integer = ($80000000,$80000000);
c2 : Array [0..1] of Single = (2,2);
c3 : Array [0..1] of Single = (3,3);
c6 : Array [0..1] of Single = (6,6);
c12 : Array [0..1] of Single = (12,12);
c24 : Array [0..1] of Single = (24,24);
as
shr ecx,1
femms
punpckldq mm1, mm1
movd mm1, Scalar.Single
movq mm0, c2
pfmul mm0, mm1
movq mm3, c3
movq mm4, c6
movq mm5, c12
movq mm6, c24
@Start:
movq mm1, [eax] //mm1=input
pfmul mm1, mm0 //mm1=a
movq mm2, mm1 //mm1=a, mm2=a
pand mm2, ng //mm1=a, mm2=|a|
pfadd mm3, c3 //mm1=a, mm2=|a|, mm3=|a|+3
pfmul mm3, mm2 //mm1=a, mm2=|a|, mm3=|a|*(|a|+3)
pfadd mm3, c6 //mm1=a, mm2=|a|, mm3=6+|a|*(3+|a|)
pfmul mm3, mm2 //mm1=a, mm2=|a|, mm3=|a|*(6+|a|*(3+|a|))
pfadd mm3, c12 //mm1=a, mm2=|a|, mm3=|a|(6+|a|*(3+|a|))
pfmul mm1, mm3 //mm1=a*b, mm2=|a|, mm3=a*(12+|a|*(6+|a|*(3+|a|)))
pfadd mm2, mm3 //mm1=a*b, mm2=|a|*b, mm3=|a|*b+24
movq mm3, mm2
pfrcp mm4, mm3
punpckldq mm3, mm3
pfrcpit1 mm3, mm4
pfrcpit2 mm3, mm4
movq mm4, mm2
punpckhdq mm4, mm4
pfrcp mm5, mm4
pfrcpit1 mm4, mm5
pfrcpit2 mm4, mm5
punpckldq mm4, mm5
pfmul mm1, mm4
movq [edx],mm1
add eax,8
add edx,8
loop @Start
femms
end;

• Date: 2005-05-10 02:26:36
• By: eb.tenyks@didid
mmh why the loop? You can't process more than 2 Tanh in parallel in this filter, can you? What CPU gain did you get btw?

Anyway, sucks that 3Dnow doesn't provide division.. SSE does, though.. DIVPS (or DIVPD to get a double accuracy in this case) would work here. Only problem is that on an AMD I usually get better performances out of 3DNow than SSE/SSE2.

The loop works perfectly well, but it's of course for Tanh() processing of a whole block instead of inside the moog filter.

The thing, that 3DNow doesn't provide division really sucks. Anyway, this way i will save a small amount of performance, but it's not huge. But i believe one can optimize the 12 lines of division further more. Also data prefetching might help a little. Or restructuring, because on AMD the order does matter!

I'll SSE/SSE2 the code tonight. I think SSE gives a good performance boost, but SSE2 precision would be needed, if the thing is inside the moog filter (IIR Filter coefficients should allways stay 64bit to avoid digital artifacts).

Cheers,

Christian

Here's the Analog Devices "Sharc" DSP translation of the tanh function (inline processing of register f0):

```
f11 = 2.;
f0 = f0 * f11;
f11 = abs f0;
f3 = 3.;
f12 = f11+f3;
f12 = f11*f2;
f3 = 6.;
f12 = f12+f3;
f0 = f0*f12;
f12 = f11*f12;
f7 = 12.;
f12 = f12+f3;
f11 = 2.;
f0 = recips f12, f7=f0;
f12=f0*f12;
f7=f0*f7, f0=f11-f12;
f12=f0*f12;
```

(continues on next page)
it can be optimized further more, but hey...

• Date: 2006-02-25 09:57:21
• By: Gene

\[
tanh(x/2) \approx \frac{x}{(\text{abs}(x) + 3/(2 + x \times x))}
\]

better...

• Date: 2006-02-25 11:53:34
• By: Gene

\[
tanh(x/2) \approx \frac{x}{(\text{abs}(x) + 2/(2.12 - 1.44 \times \text{abs}(x) + x \times x))}
\]

Maximum normalized difference 0.0063 from real \( \tanh(x/2) \) — good enough now.

### 5.66 Resampling

• Author or source: ed.corm@liam
• Type: linear interpolated aliased resampling of a wave file
• Created: 2004-04-07 09:39:12

Listing 116: notes

some resampling stuff. the code is heavily used in MSynth, but do not laugh about ;-) perhaps, prefiltering would reduce aliasing.

Listing 117: code

```c
signed short* pSample = ...;
unsigned int sampleLength = ...;

// stretch sample to length of one bar...
float playPosDelta = sampleLength / ( ( 240.0f / bpm ) * samplingRate );

// requires for position calculation...
float playpos1 = 0.0f;
unsigned int iter = 0;

// required for interpolation...
unsigned int i1, i2;

float* pDest = ....;
float* pDestStop = pDest + len;
for( float* pt=pDest; pt<pDestStop; ++pt )
{
    // linear interpolation...
    i1 = (unsigned int)playpos;
    i2 = i1 + 1;
    (*pt) = ((pSample[i2]-pSample[i1]) * (playpos - i1) + pSample[i1]);
}
```

(continues on next page)
// position calculation preventing float sumation error...
playpos1 = (++iter) * playposIncrement;

...
when the input is below a certain threshold (t) these functions return the input, if it goes over that threshold, they return a soft shaped saturation. Neither claims to be fast ;-

Listing 119: code

```c
float saturate(float x, float t)
{
    if(fabs(x)<t)
        return x
    else
    {
        if(x > 0.f);
            return t + (1.f-t)*tanh((x-t)/(1-t));
        else
            return -(t + (1.f-t)*tanh((-x-t)/(1-t)));
    }
}
or

float sigmoid(x)
{
    if(fabs(x)<1)
        return x*(1.5f - 0.5f*x*x);
    else
        return x > 0.f ? 1.f : -1.f;
}
float saturate(float x, float t)
{
    if(abs(x)<t)
        return x
    else
    {
        if(x > 0.f);
            return t + (1.f-t)*sigmoid((x-t)/(1-t)*1.5f));
        else
            return -(t + (1.f-t)*sigmoid((-x-t)/(1-t)*1.5f));
    }
}
```

5.67.1 Comments

- **Date:** 2002-10-15 17:22:22
- **By:** moc.oohay@yrret

But My question is
BUT HAVE YOU TRIED YOUR CODE!!!!!!!!!!!!!!!!?????
I think no, 'cos give a compiling error.
the right (for sintax) version is this:

(continues on next page)
float sigmoid(float x)  
{  
    if(fabs(x)<1)  
        return x*(1.5f - 0.5f*x*x);  
    else  
        return x > 0.f ? 1.f : -1.f;  
}  

float saturate(float x, float t)  
{  
    if(abs(x)<t)  
        return x;  
    else  
    {  
        if(x > 0.f)  
            return t + (1.f-t)*sigmoid((x-t)/((1-t)*1.5f));  
        else  
            return -(t + (1.f-t)*sigmoid((-x-t)/((1-t)*1.5f)));  
    }  
}  

• Date: 2003-11-18 10:16:14  
• By: moc.liamtoh@tnuhcaebmi

except for the missing parenthesis of course =)  
the first line of saturate should be either  

if(fabs(x)) return x;  

or  

if(abs(x)) return x;  

depending on whether you're looking at the first or second saturate function (in the_  
→orig post)

5.68 Sin(x) Aproximation (with SSE code)

• Author or source: moc.kisuw@kmailliw  
• Created: 2004-07-14 10:13:26

Listing 120: notes

Sin Aproximation: sin(x) = x + ( x * (-x * x / 6));  

This is very handy and fast, but not precise. Below you will find a simple SSE code.  

Remember that all movaps command requires 16 bit aligned variables.
Listing 121: code

SSE code for computing only ONE value (scalar)

Replace all "ss" with "ps" if you want to calculate 4 values. And instead of "movps" use "movaps".

```
movss xmm1, xmm0 ; xmm0 = x
mulss xmm1, Filter_GenVal[k_n1] ; * -1
mulss xmm1, xmm0 ; -x * x
divss xmm1, Filter_GenVal[k_6] ; / 6
mulss xmm1, xmm0
addss xmm0, xmm1
```

5.68.1 Comments

- Date: 2004-10-06 22:47:58
- By: moc.noicratse@ajelak

Divides hurt. Change your constant 6 to a constant (1.0/6.0) and change divss to mulss.

- Date: 2005-05-31 05:04:05
- By: little%moc.loa@ykee02

error about 7.5% by +/- pi/2
you can improve this considerably by
fitting cubic at points -pi/2, 0, pi/2 i.e:
sin(x) = x - x^3 / 6.7901358

5.69 Sin, Cos, Tan approximation

- Author or source: http://www.wild-magic.com
- Created: 2003-04-26 00:17:56
- Linked files: approx.h

Listing 122: notes

Code for approximation of cos, sin, tan and inv sin, etc.
Surprisingly accurate and very usable.

[edit by bram]
this code is taken literally from
http://www.wild-magic.com/SourceCode.html
Go have a look at the MgcMath.h and MgcMath.cpp files in their library...
[/edit]

5.69.1 Comments

- Date: 2002-09-01 00:06:40
It'd be nice to have a note on the domain of these functions. I assume Sin0 is meant to be used about zero and Sin1 about 1. But a note to that effect would be good.

Thanks,

james mccartney

Sin0 is faster but less accurate than Sin1, same for the other pairs. The domains are:

- Sin/Cos [0, pi/2]
- Tan [0, pi/4]
- InvSin/Cos [0, 1]
- InvTan [-1, 1]

This comes from the original header file.

5.70 VST SDK GUI Switch without

- **Author or source:** ti.oohay@odrasotniuq
- **Created:** 2004-09-08 12:49:11

Listing 123: notes

In VST GUI an on-value is represented by 1.0 and off by 0.0.

Listing 124: code

```c
Say you have two signals you want to switch between when the user changes a switch.
You could do:

```c
\begin{verbatim}
    if(fSwitch == 0.f) //fSwitch is either 0.0 or 1.0
        output = input1
    else
        output = input2
\end{verbatim}
```

However, you can avoid the branch by doing:

```c
\begin{verbatim}
    output = input1 * (1.f - fSwitch) + input2 * fSwitch
\end{verbatim}
```

Which would be like a quick mix. You could make the change clickless by adding a simple one-pole filter:

```c
\begin{verbatim}
    smooth = filter(fSwitch)
    output = input1 * (1.f - smooth) + input2 * smooth
\end{verbatim}
```

5.70.1 Comments

- **Date:** 2004-09-17 04:12:08
Not trying to be incredulous, but ... Is this really worth it? Assuming that you pre-calc the \((1-f_{\text{Switch}})\), you still have 2 multiplies and 1 add, instead of just an assignment. Are branches really bad enough to justify spending those cycles?

Also, does it matter where in the signal flow the branch is? For instance, if it were at the output, the branch wouldn't be such a problem. But at the input, with many calculations downstream, would it matter more?

Also, what if your branches are much more complicated—i.e. multiple lines per case?

I use it when I have to compute the \((1-f_{\text{Switch}})\) signal anyway. Example: apply a LFO to amplitude and not to frequency. I compute LFO anyway, then I apply \((1-f_{\text{Switch}})\) to frequency and \(f_{\text{Switch}}\) to amplitude.

Yes, branches are really bad!:-) This is because you "break" your cache waiting for a decision. Even if the branch is at the end of your routine, you are leaving a branch to successive code (i.e. to host)

Anyway, this is not ever worth to use, just consider single cases...

Kids, kids, you're both wrong!

chunk: Two multiplies and an add are really cheap on modern hardware - P2/P3 take about 2 clocks for fmul and 1 clock for fadd.

quintosardo: Modern hardware also has good branch prediction, so if the switch is, e.g., a VST parameter that only changes once per process() block, it will branch the same way on the order of 100 times in a row. Correctly predicted branches are basically free; mispredicted branches blow the instruction pipeline, which is a penalty of about 20 cycles or so. If you spread the cost of a single missed prediction over 100 samples, it's cheap enough to not worry about. So yes, use this "predicate transform" to optimize away branches which are unpredictable, but don't worry about branches which are predictable.

And today it is even more ridiculous to think about cycles!
CHAPTER 6

Indices and tables

- genindex
- search