Aeolus

A church organ in your PC

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Overview

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- Organ sound
- Requirements
- Short demo
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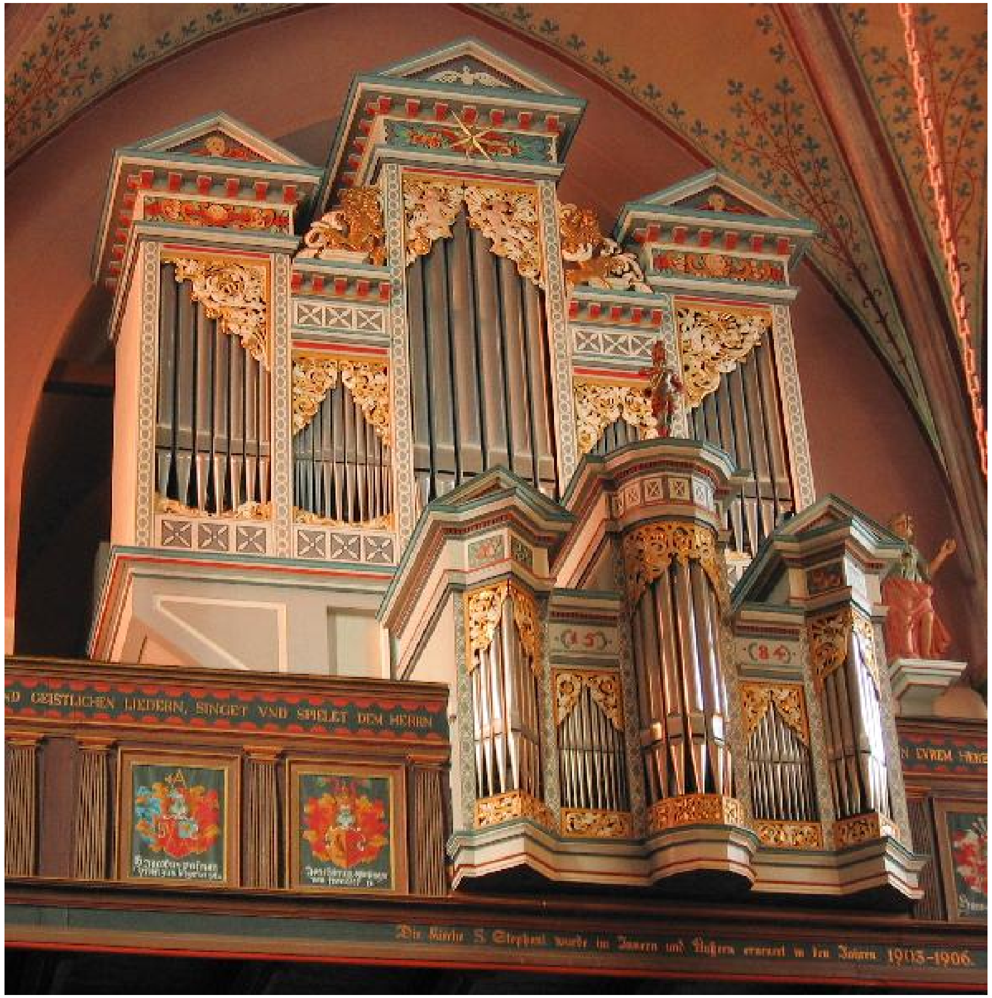
- Demo



Karl Schuke organ at St.Stephani, Helmstedt, Germany
Photo by Matthias Nagorni

A story....

Trinity Church, Wall Street, New York

- September 2001: the organ is destroyed by the corrosive dust of the twin towers.
- Summer 2003: A new instrument is installed. It feautures:
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  - ?

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(*) “Windows was soon rejected for not being up to the task”

Targets

My ambitions for Aeolus ar more modest. . .

- *Not* a 'perfect' imitation or replacement for a real organ.
- A *musical* instrument, that can be enjoyed by musicians.
- Give the user access to all parameters, to
  - modify and adapt the program to his/her own needs,
  - or even define a completey new instrument.
- Have a framework for future research and development.

What is an organ ?

- "A musical instrument producing sound by blowing air through pipes, and played via a keyboard."
- History goes back to Greek and Roman times.
- Disappeared from Western Europe at the end of the Roman Empire, preserved by and re-imported to Europe from the Byzantine culture.
- Oldest existing instruments are from the 15^{th} century.
- A long and complicated history, linked to music history, religion and politics.
- Some important periods:
  - Baroque period in Gemany: Buxtehude, Pachelbel, Bach...
  - Romantic period in France: Franck, Fauré, Vierne, Widor...
  - Second half of 20^{th} century: the authenticity movement.

There is an enormous diversity in organ types, sizes, and sounds.

Some organ jargon

Stop : a set of pipes, one (or more) for each note, all having the same type of sound.

- Each stop can be separately switched on or off.
- Stop names are traditional or refer to other intruments.
- There are *thousands* of different stops.
- Pitch is indicated by the length in feet of the largest pipe:
  - 8 : nominal pitch.
  - $16, 32$: one or two octaves lower.
  - $4, 2, 1$: one, two or three octaves higher.
  - $2\frac{2}{3}$: one octave plus a fifth higher ($F \times 3$).
  - $1\frac{3}{5}$: two octaves plus a third higher ($F \times 5$).

Division : a set of stops controlled by the same keyboard.

- Each division is a 'mini' organ, and also has its own character.

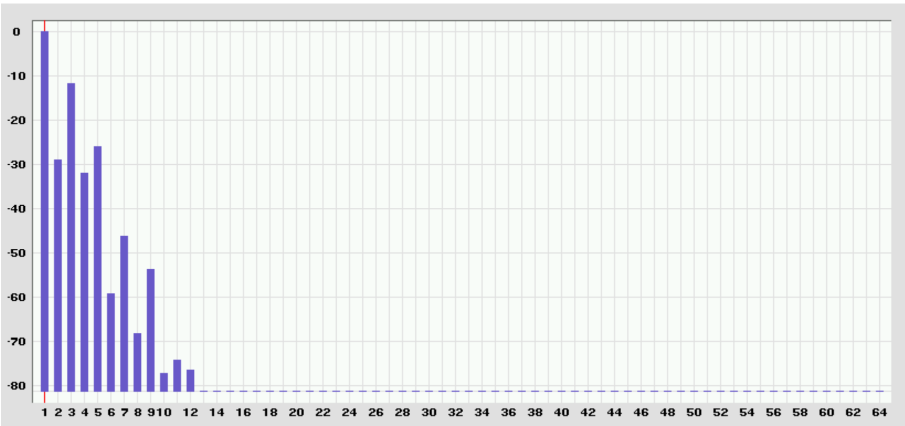
Organ : an instrument consisting of one or more (1...6) divisions.

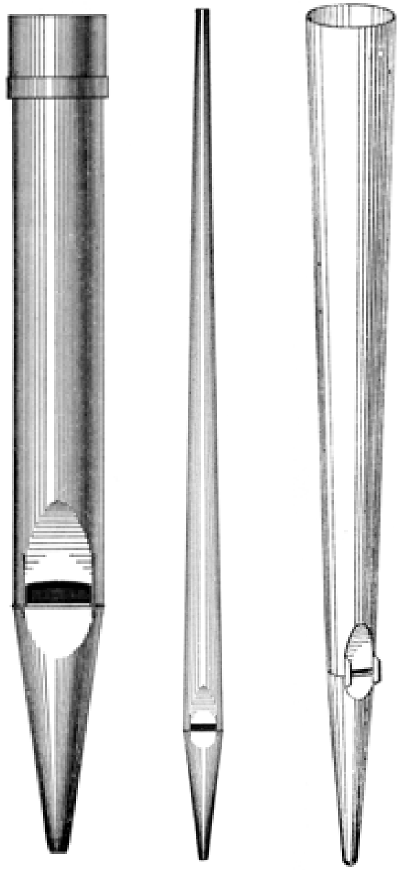
- The church of the Palácio National in Mafra, Portugal, has six large organs...

Stops 1

Labial or flue stops

- No moving parts - vibrating air column
- Pitch determined by pipe lenght
- Pipe also acts as a filter
- Relatively soft sound

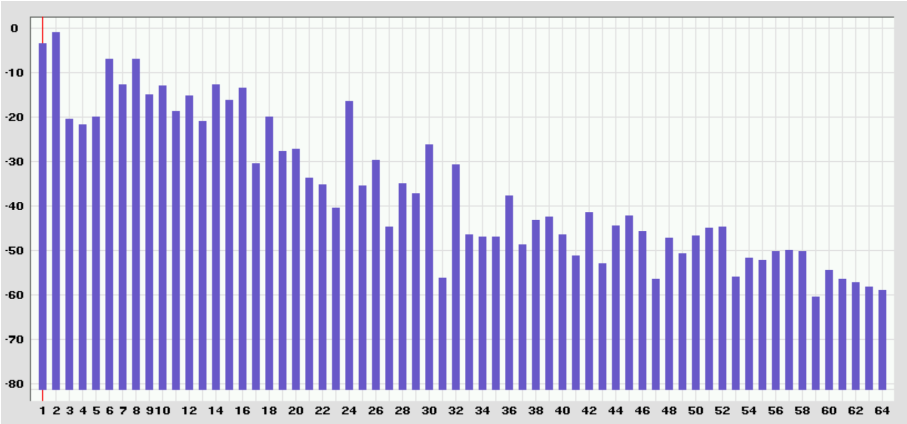


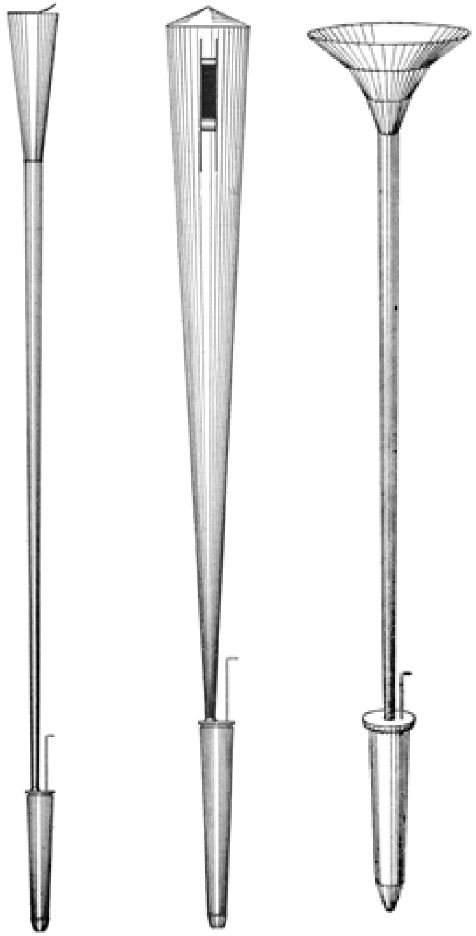


Stops 2

Reed stops

- Sound produced by vibrating metal spring
- Pipe mainly acts as a filter
- All sorts of weird pipe shapes
- Very bright sound

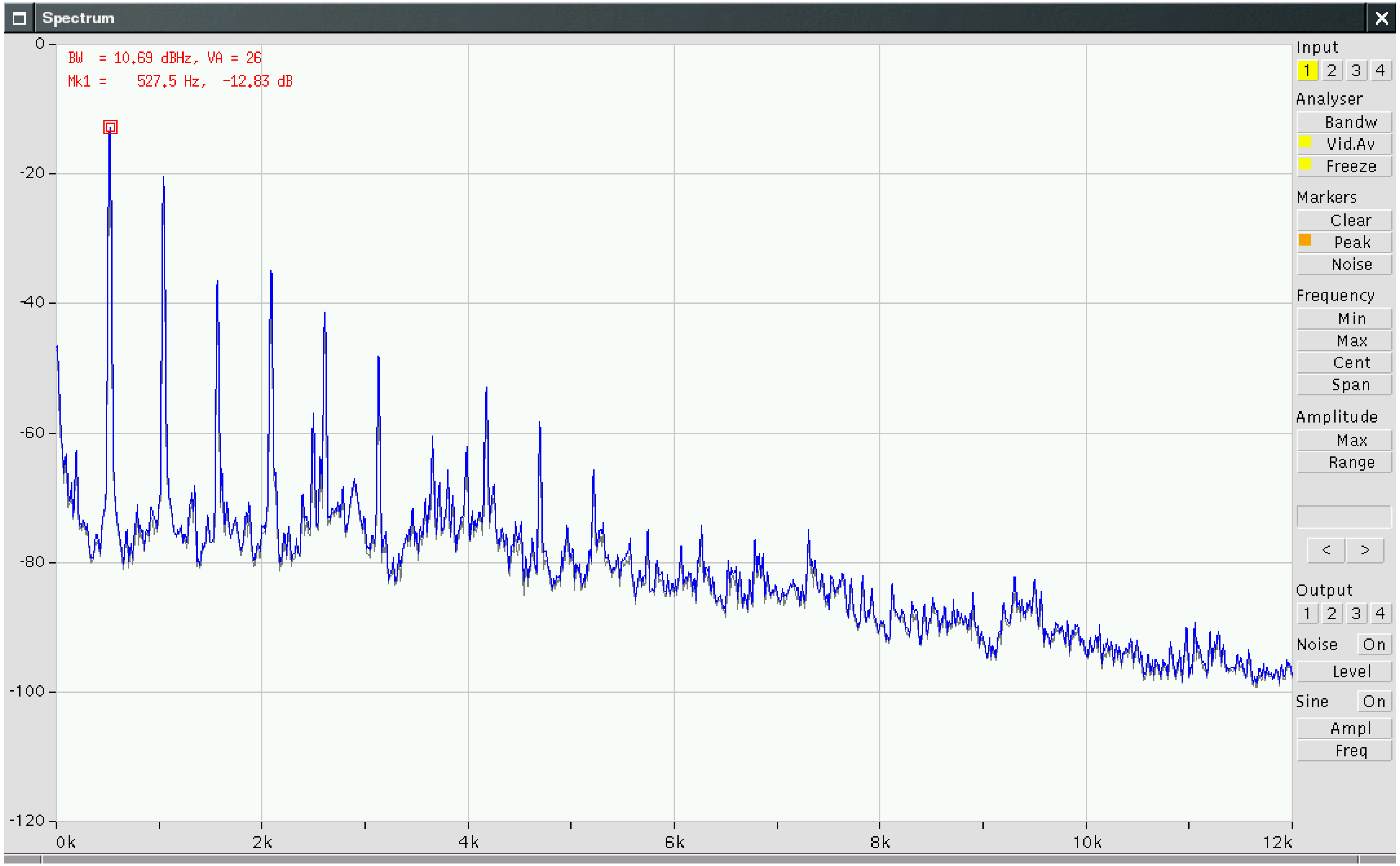




Organ sound 1

- The sound of a single pipe starts with an 'attack' phase, normally less than 0.5 seconds.
  - Each harmonic has its own attack profile.
  - Some harmonics 'overshoot' the steady state level.
  - Others only build up after a delay.
- The attack is followed by a 'steady state' phase, showing only minimal variation over time, caused by air turbulence and complex interactions with other parts.
- Many pipes also produce chiff - filtered noise.
  - Noise can be quite prominent during the attack.
  - There is no simple relation between the harmonic and noise spectra.
  - Noise spectrum is typical for a lattice (waveguide) filter.

Organ sound 2



Typical labial pipe spectrum

(Recording by Reiner Janke).

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Organ sound 3

- The spectrum of a stop changes significantly over the range of five octaves. Notes that are close together are similar but never identical.
- Some stop combinations blend together, in others each stop remains a separate sound. This depends on the spectra, and on psycho-acoustics. Sounds are separated by
  - small differences in frequency or delay,
  - different attack profiles,
  - different direction or apparent distance.

  Human hearing is very apt at picking up these hints.
- Even for a small organ, the sound is modified by reflections in the cabinet. For larger organs these can have significant delays.
- Every real organ is designed for a particular environment. A large organ needs the acoustics of a large space such as a church in order to sound good.
- The sound of a real organ is defined by the *voicing* process: each individual pipe is adjusted to arrive at a balanced sound.

Organ sound 4 : Tuning

- Pitch : frequency of a_1 : 400...480 Hz.
- Temperament : relative tuning of the 12 notes of an octave. This poses a fundamental problem - it is impossible to get all the intervals right.
  - 12 musical fifths are equal to 7 octaves, but $(3/2)^{12}$ is not exactly equal to 2^7.
  - 3 musical thirds are equal to 1 octave, but $(5/4)^3$ is not exactly equal to 2.
- Every temperament is a compromise.
  - Optimise for a few keys only (meantone temperaments - modal music).
  - Allow all keys, but keep different character (circulating temperaments - baroque music)
  - Distribute the errors evenly (equal temperament - romantic music)
- Temperament has significant influence on the 'character' of stops that have a prominent 3^{rd} or 5^{th} harmonic.

Requirements

- Generators flexible enough to allow for all types of stops.
- Correct modelling of the complex attack phase of a pipe sound.
- All parameters that define a stop are a function of the note number.
- Programmable variations in delay time, frequency, spectrum, attack profile. . .
- Flexibility in tuning and temperament.
- Correct emulation of the acoustic environment.
- One to four divisions, up to 32 stops per division.
- The end user must be allowed to define the instrument.
- As much parameters as possible should be accessible.
- The program should run on a medium performance PC.

First demo

- General features.
- A guided tour.
- A short musical example.

Choice of algorithm 1

- Recorded samples
  + Realism and quality
  – Lots of work in recording and preparation
  – Also picks up reverb : less flexible
  – Copyright issues
- Additive synthesis
  + Very flexible
  + Intuitive mapping between parameter set and sound
  + Parameter sets can be obtained by analysis
  – Lots of parameters

Choice of algorithm 2

- Waveguide filters
  - \+ Close to physical reality
  - – Requires specialist knowledge and tools
- Physical modelling
  - \+ High quality results
  - – Complex
  - – Requires specialist knowledge and tools
- Subtractive and FM synthesis
  - – No systematic approach - results are found more or less by accident.

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Additive synthesis was chosen for the first release.

Choice of algorithm 3

- Up to a few hundreds of pipes can sound at the same time.

  $\longrightarrow$ Wavetables are the only solution.

  $\longrightarrow$ Separation of generation and rendering.

  $\longrightarrow$ Allows re-use of rendering engine.

- Wavetables need to be recalculated if pitch, temperament or sample frequency are modified.

- Each wavetable consist of an attack part, and a loop.

- Loop length is determined by required frequency accuracy:

  Maximum absolute error < 0.1 Hz.

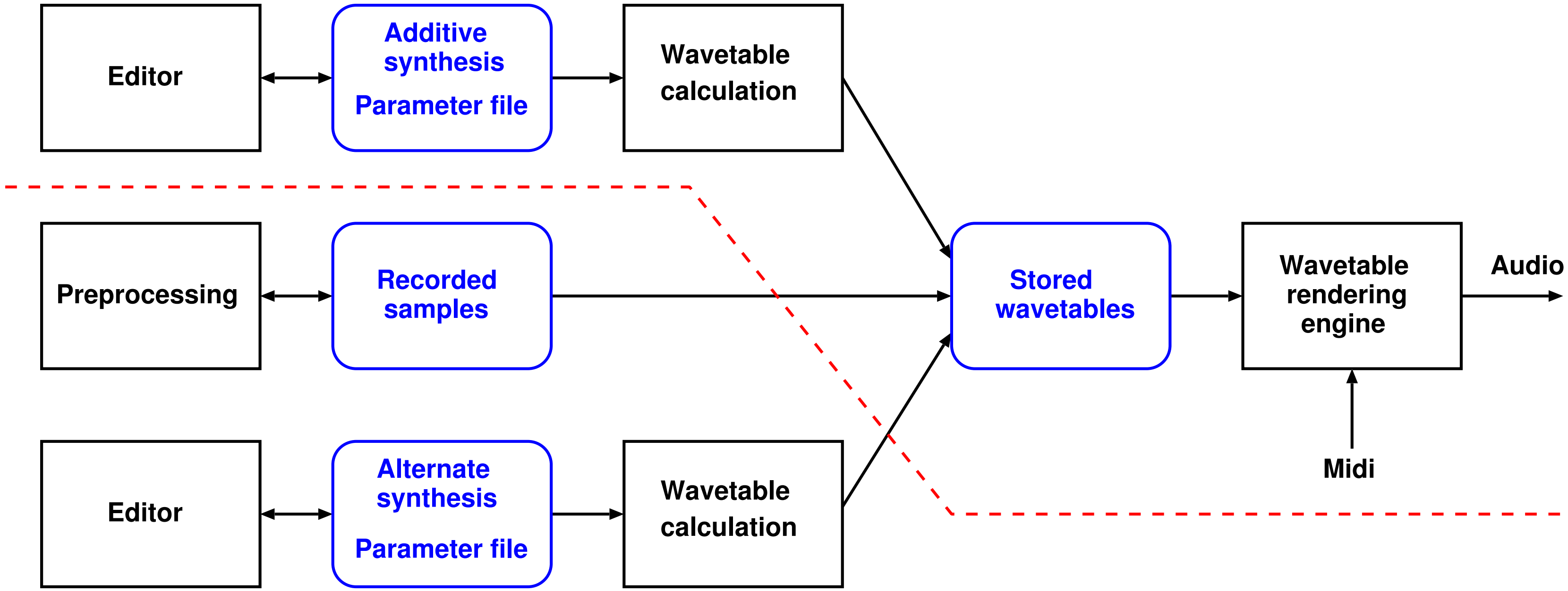
  Maximum relative error < 0.1 %.

  Find integers n, k so that $n/k \sim f/F_{samp}$

  Continued fraction algorithm provides short average loop length.
  $\longrightarrow$ Wavetable length is dominated by attack phase.

- Wavetables can not be used easily to generate noise.
  $\longrightarrow$ Separate solution required - not yet implemented.

Aeolus structure



Aeolus logical structure

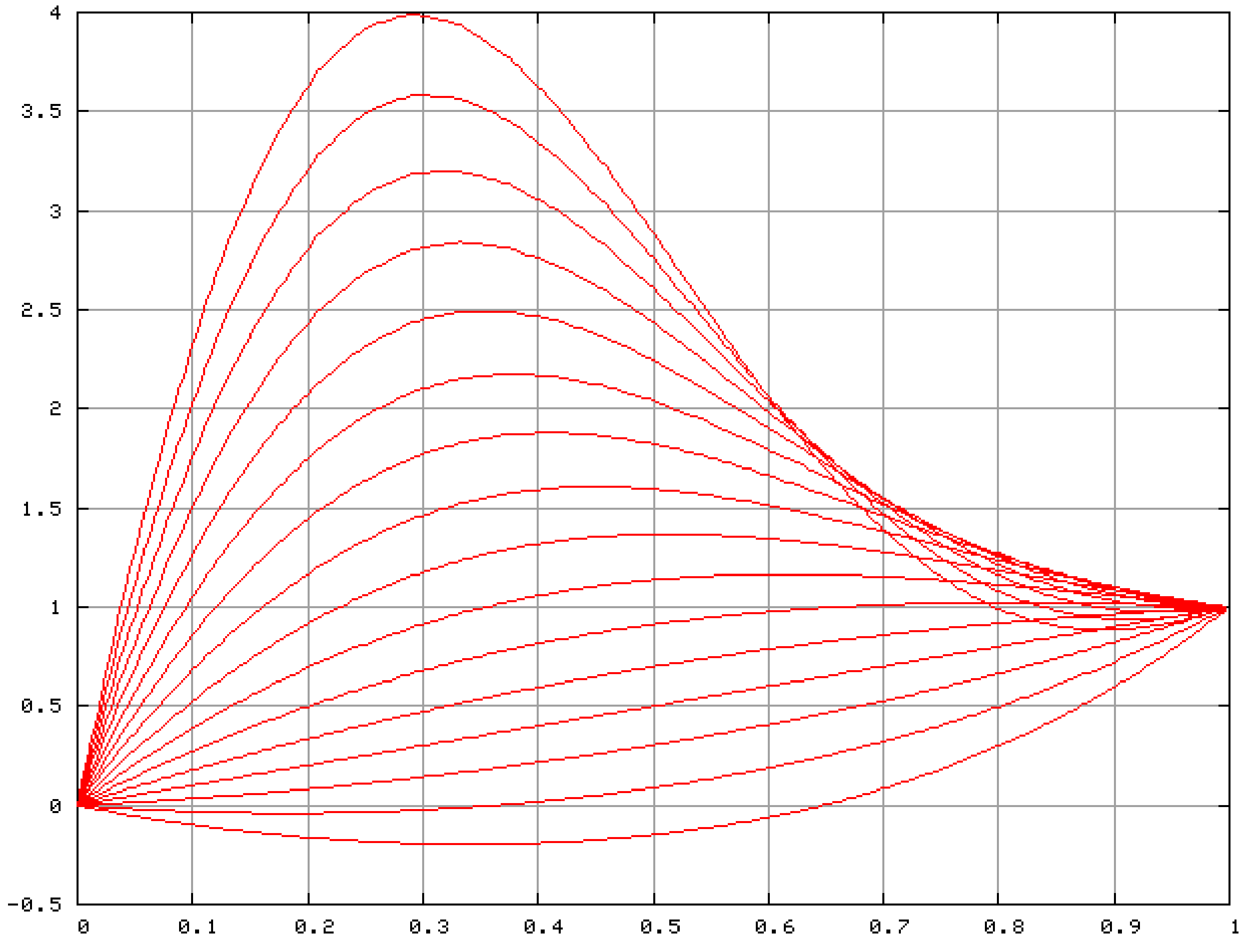
Additive synthesis parameters 1

- At least three parameters are a function of both note number n and harmonic number h:
  - harmonic level,
  - attack time,
  - attack type.
- With 61 notes and 64 harmonics, this gives 11712 values for a single stop.
- First reduction:
  - Define only every 6^{th} note, and interpolate.
  - Requires fourth parameter: random variation of level.
  - Still requires up to $4 \times 11 \times 64 = 2816$ values
- Second reduction:
  - Not all 11 notes need to be defined if not necessary.
  - Manageable solution, but requires dedicated GUI.

Additive synthesis parameters 2

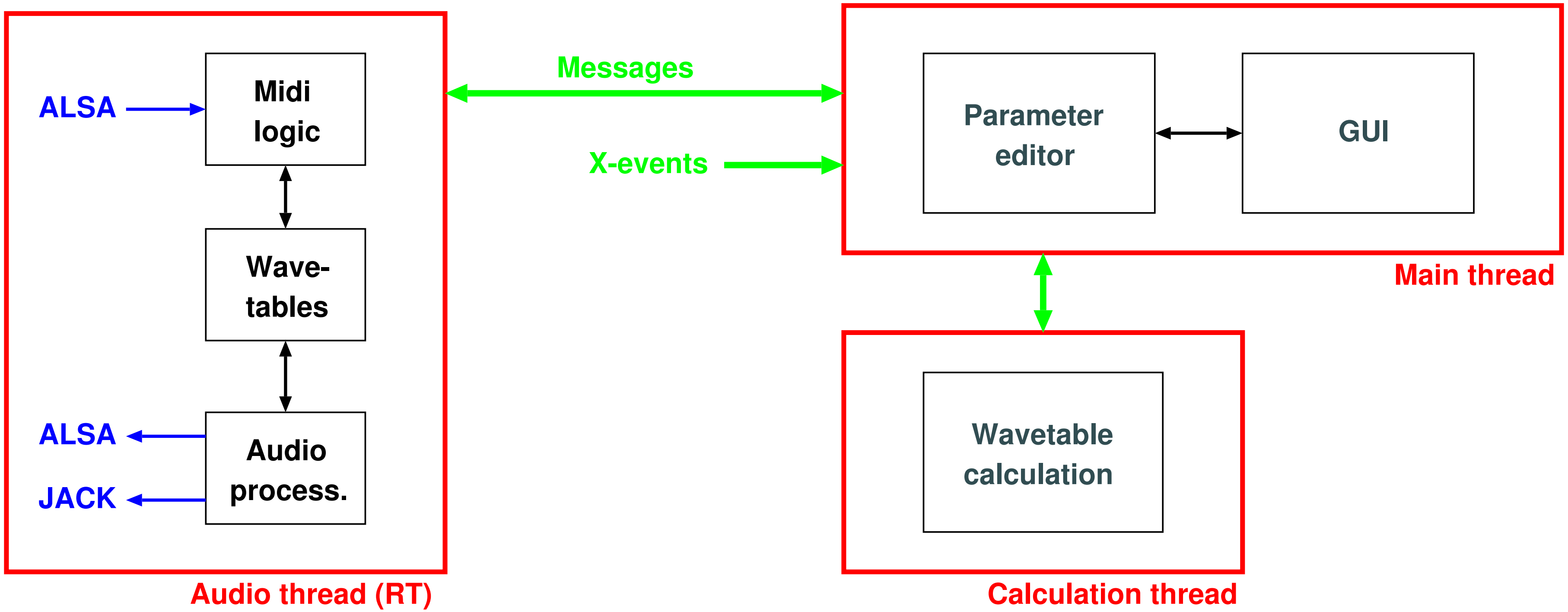
- Other parameters are function of note number only, and defined at up to 11 points, with interpolation:
  - volume,
  - systematic detune,
  - random detune.
- Remaining parameters are:
  - pipe lenght (pitch),
  - stop name,
  - filename,
  - comments and copyright.
- Parameters for each stop are stored in separate files.
- Set of stops for each division and some options are defined in a configuration text file.

Additive synthesis parameters 3



Attack phase profiles.

Program architecture

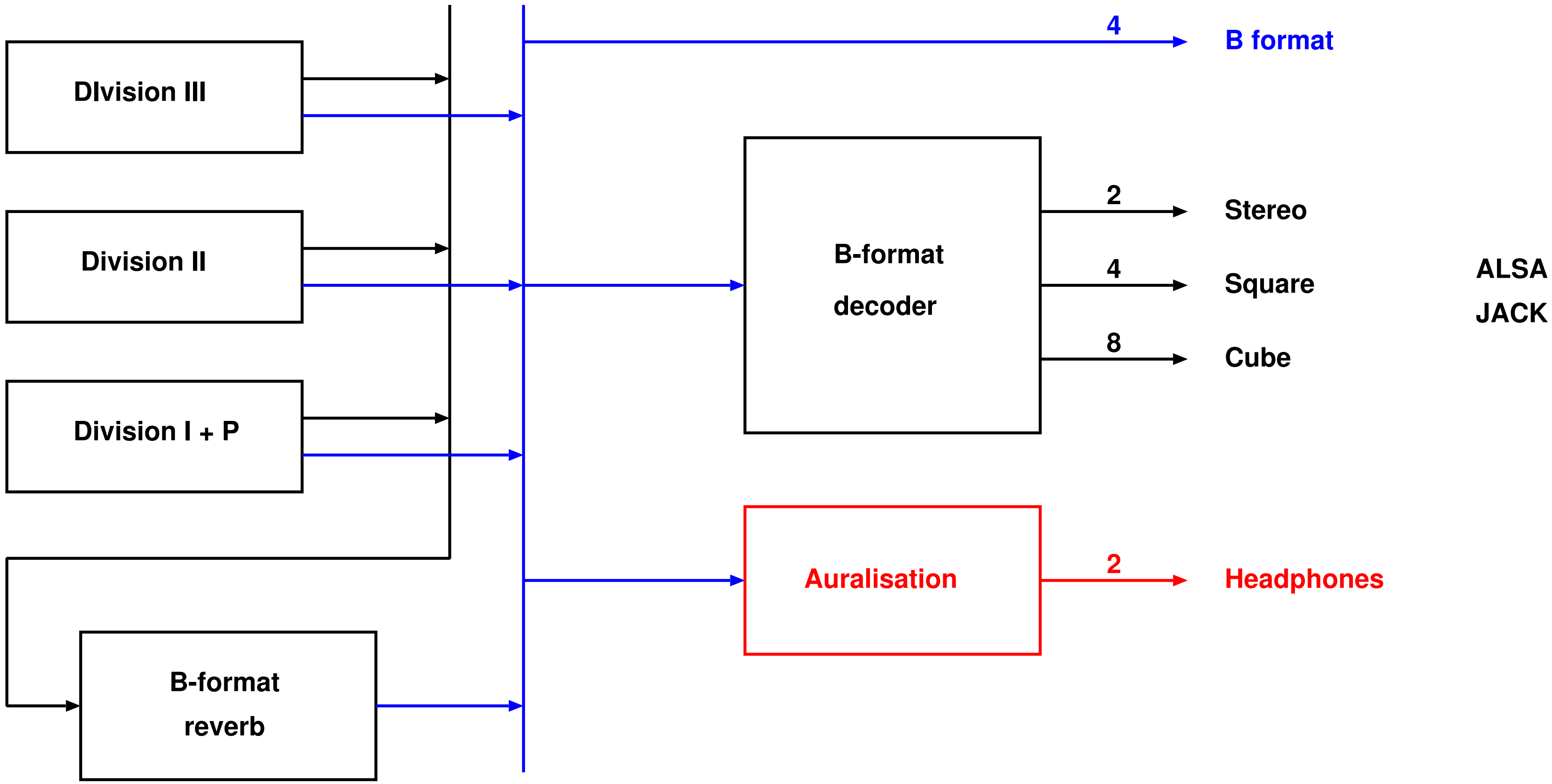


- Only the audio thread runs in real-time mode.
- Relation between audio thread and main thread is MCV.
- Some shared memory for efficient implentation.

Audio processing - Ambisonics

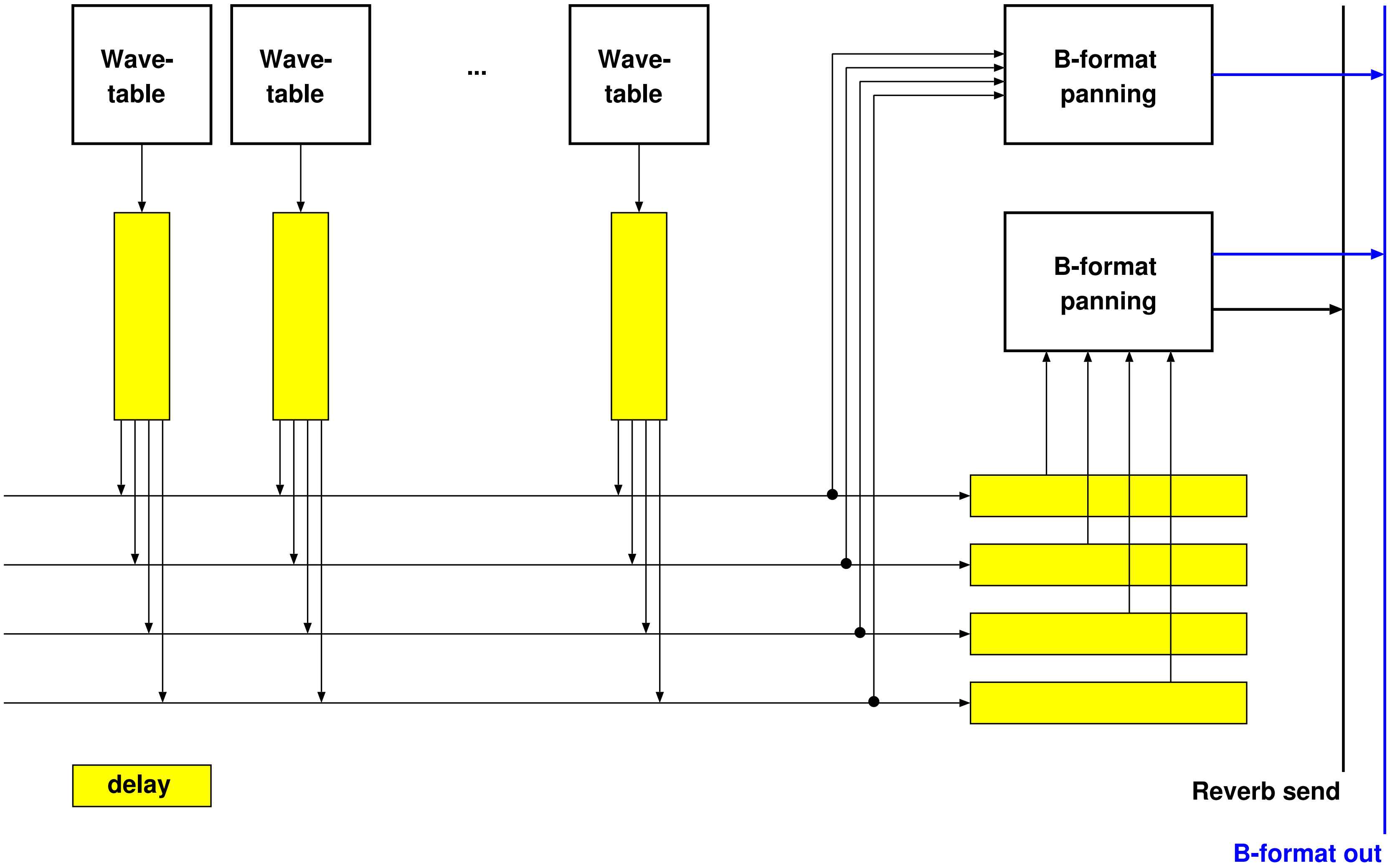
- Surround sound technology developed more than 20 years ago by UK mathematician Michael Gerzon.
  - Originally developed for military applications (SONAR).
  - Aims at accurate sound field reproduction rather than 'surround effects'.
  - The only solution for high quality 2-D or 3-D surround sound.
- First order Ambisonics B-format consist of four signals:
  - A mono signal W,
  - Three difference signals, one for each axis of 3-D space, X, Y, Z.
  - X, Y, Z correspond to the *gradient* of the sound field, and hence to the perceived direction of the sound.
- B-format is used internally in Aeolus and is also one of the output options.

Audio processing - Top level



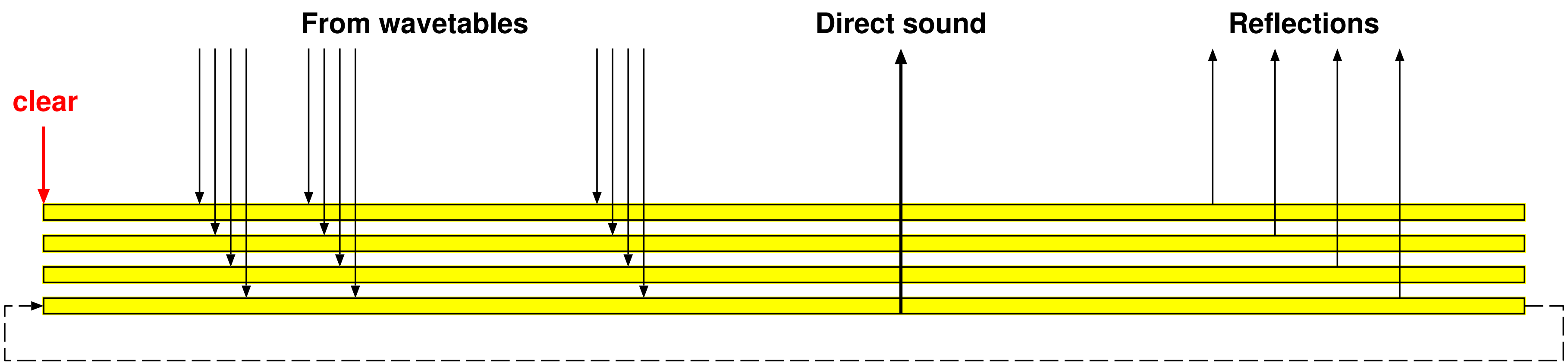
Top level audio processing

Audio processing - Division



Audio processing for one division

Audio processing - Division



Audio processing for one division - implementation

- Per-pipe delay lines replaced by shared circular buffers.
- Audio data never moves, the pointers do.
- Process fragment size is always 64 samples.

The future - things to do

- Clean up the code
- Manual and documentation
- Adding ’chiff’ generators
- More detailed control over attack phase
- Improved reverb, maybe via BruteFIR
- Add auralised headphone output
- New stops and instruments (e.g. French Romantic)
- Other synthesis algorithms

Acknowledgements

I wish to thank the following people for their contributions:

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Reiner Janke

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Aeolus - Demo

- The parameter editor.
- Question time.
- More music.