The WFS system at La Casa del Suono, Parma

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Casa della Musica, Parma

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La Casa del Suono

- A museum dedicated to the history of audio technology.
  * Created by the City of Parma.
  * A collection of vintage audio equipment.
  * A view on current and future technology.

- Two audio installations using Linux:
  * The 'Lampadario Acoustico'
  * The 'Sala Bianca'

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La Sala Bianca – 1

- A room of approx. 7.5. by 4.5m, entirely white.
- 189 small speakers around the full inner perimeter, including the doors.
- All speakers driven individually, together they form a Wave Field Synthesis system.

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La Sala Bianca – 2

- One speaker every 12cm.
  * Constructed in blocks of 10, 15, or 17.
  * Two-way bass-reflex with mixed order crossover.
  * Designed by Audio Link, using components from Ciare.
  * Very good performance for its size.
  * Frequency range is 50Hz to over 20kHz.

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Wave Field Synthesis – 1

- Based on the Kirchoff-Helmholtz integral:

  The wave field inside a source-free volume V delimited by a surface S is completely determined by either the pressure or the volume velocity at all points of the surface S

- Practical realisation requires some compromises:

  * Replacing the infinite number of points by a grid of discrete sources.
  * Reduction from 3D to 2D.

- WFS recreates the sound field of any number of *primary* (virtual) sound sources using an array of *secondary* (real) sources.

- A variation of the technique can be used to create sources *inside* the volume or perimeter.

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Wave Field Synthesis – 2

- The Sala Bianca system will support up to 48 moving primary sources, rendered in real time.
- Source movement is implemented by sample-rate update of rendering parameters, not by crossfading between static source positions. This means that e.g. the Doppler effect is rendered as well.
- The system is used
  - As part of the museum, for public demonstrations of the technology.
  - For scientific research: as a listening room allowing virtual speaker setups, and for further development of WFS algorithms.
  - As an *instrument* for electro-acoustic music concerts.
- Planning started in 2007, and the system is in use since February 2009.

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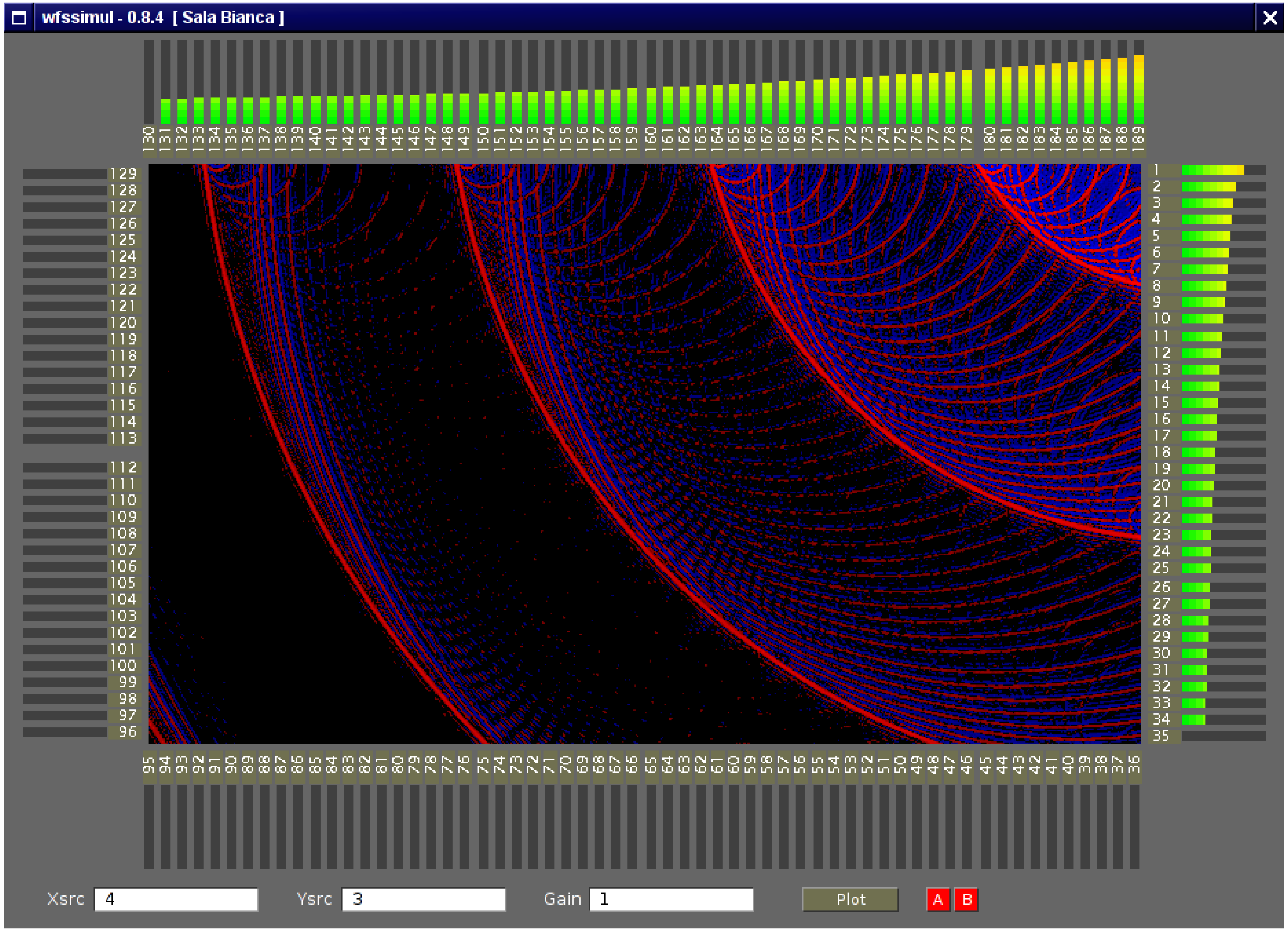
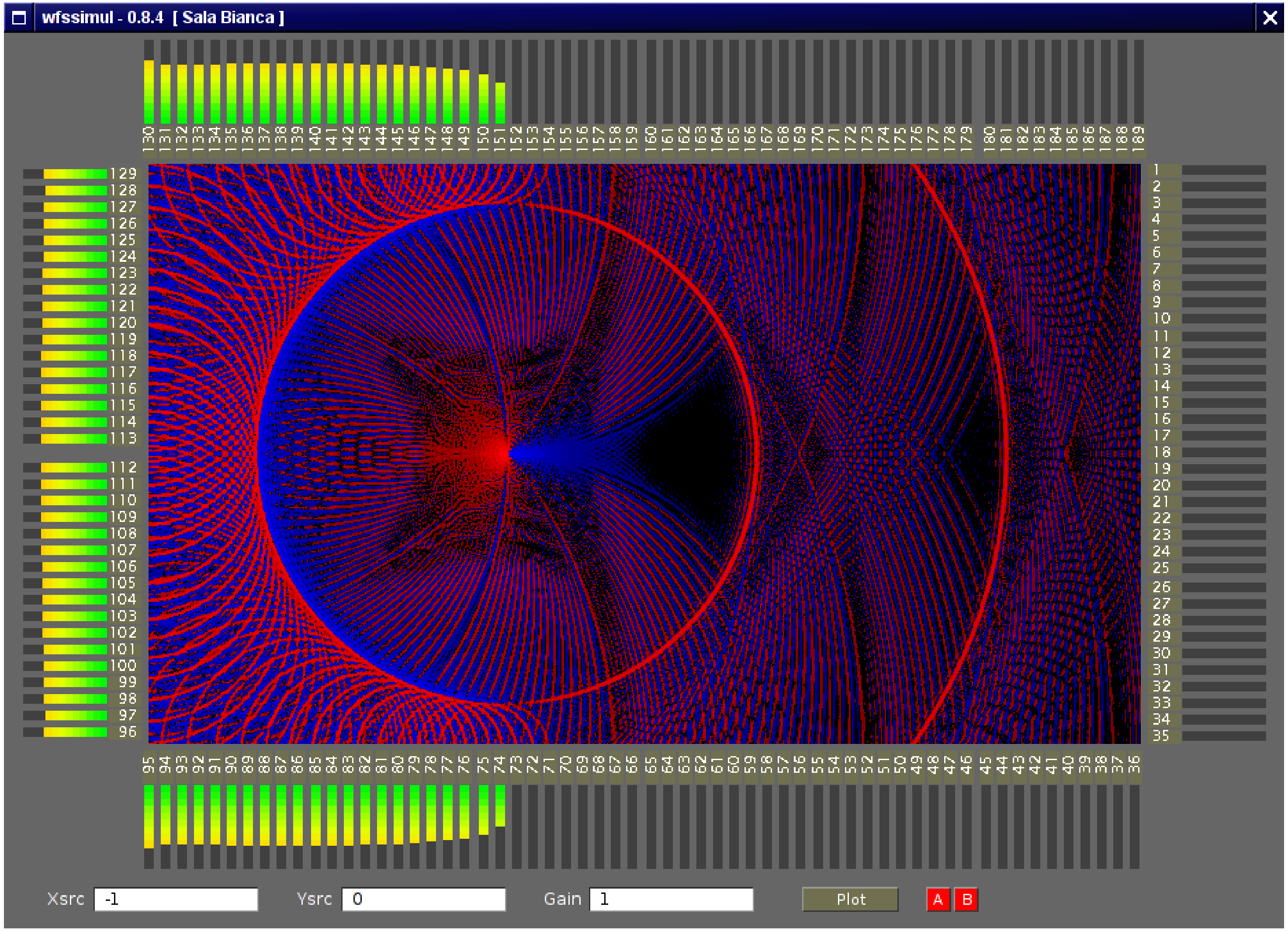
Simulations – 1



A primary source at X = 4, Y = 3.

Simulations – 2



A primary source inside the perimeter.

The audio system – Hardware

- 4 Siemens/Fujitsu PCs running ArchLinux
- RME MADI interfaces, convertors and matrix.
- 192 channels of Aphex DA converters.
- 24 8-channel QSC amplifiers.
- Lots of cables.

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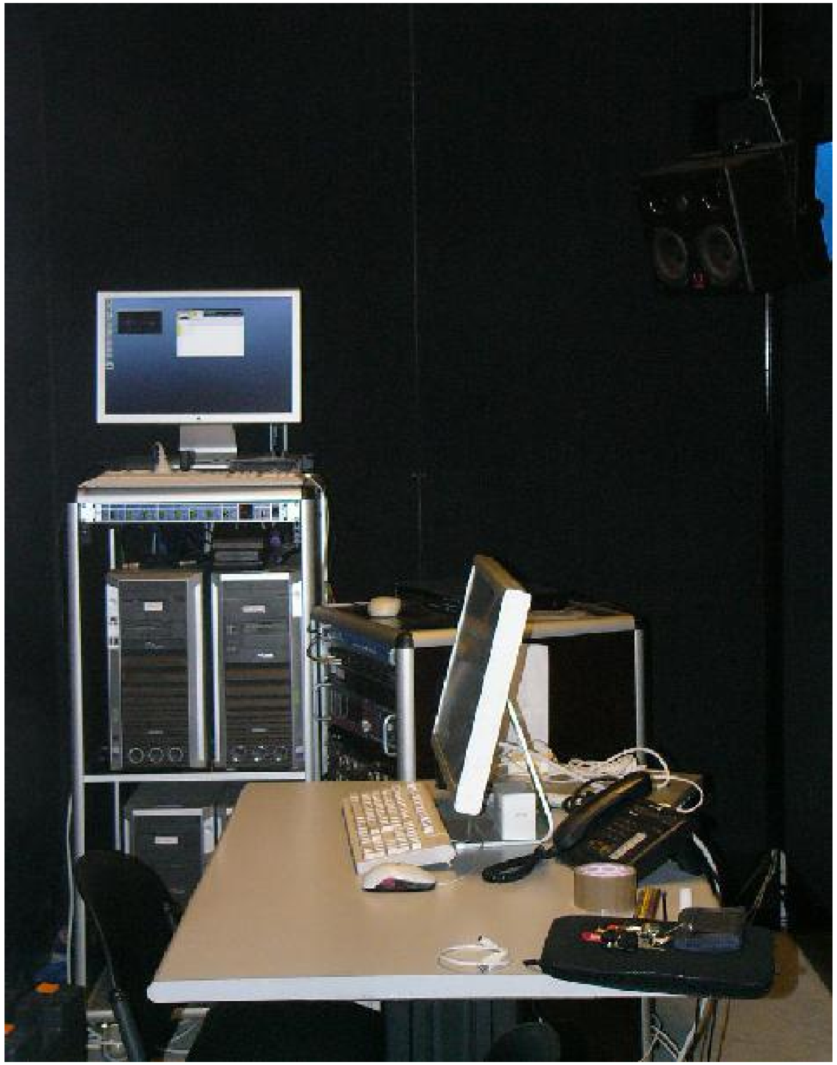
The audio system – The control room

- Originally meant to be an Ambisonics room at double the size.
- Contains all PCs, (also for the Lampadario), network HW,. . .
- Mic preamps and analog audio lines to Sala Bianca, for recording, concerts, etc.



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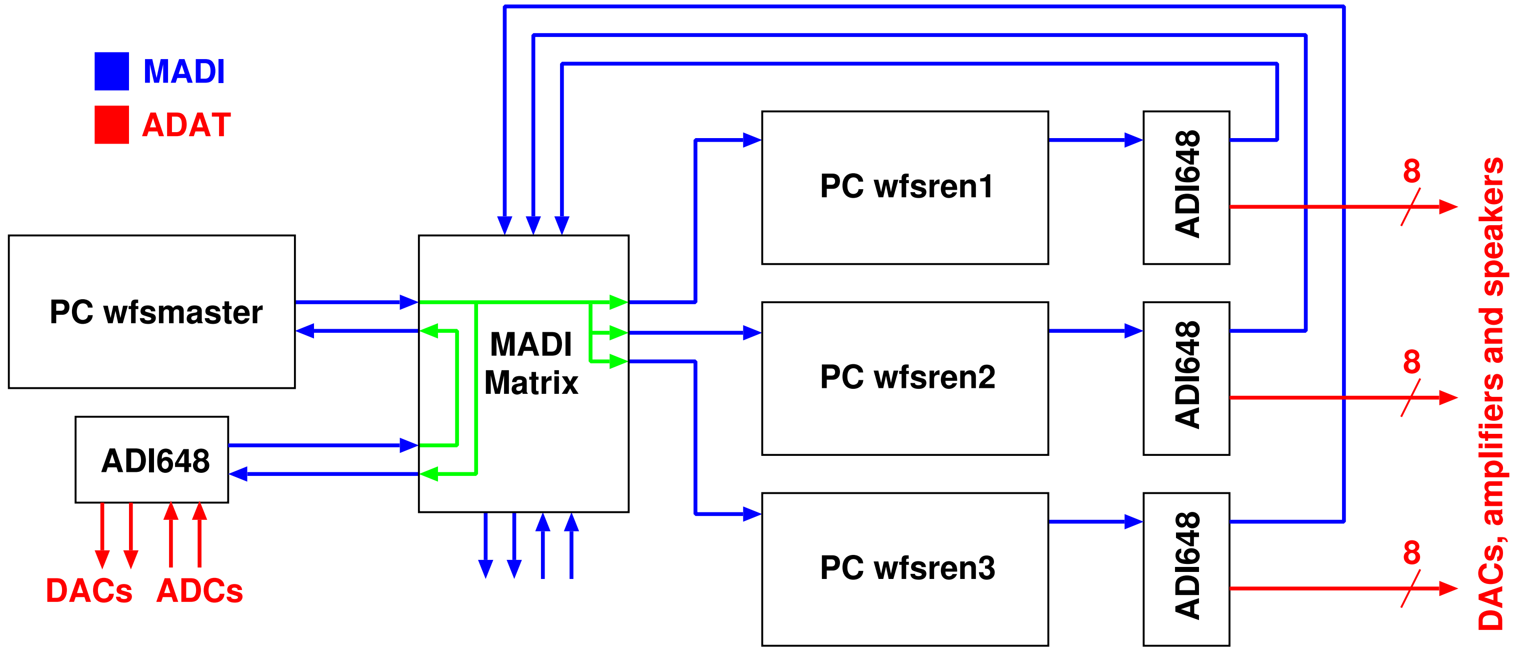
The audio system – Structure



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Networked audio ?

Using a Gigabit network for audio connections instead of MADI was considered but rejected.

- The synchronisation issues could be solved easily.
- Solutions were emerging, but untested for e.g. 48 channels.
- Performance of the hardware and drivers was not at all guaranteed.
- It would probably result in larger system latency.
- It would not permit major savings for the audio hardware.

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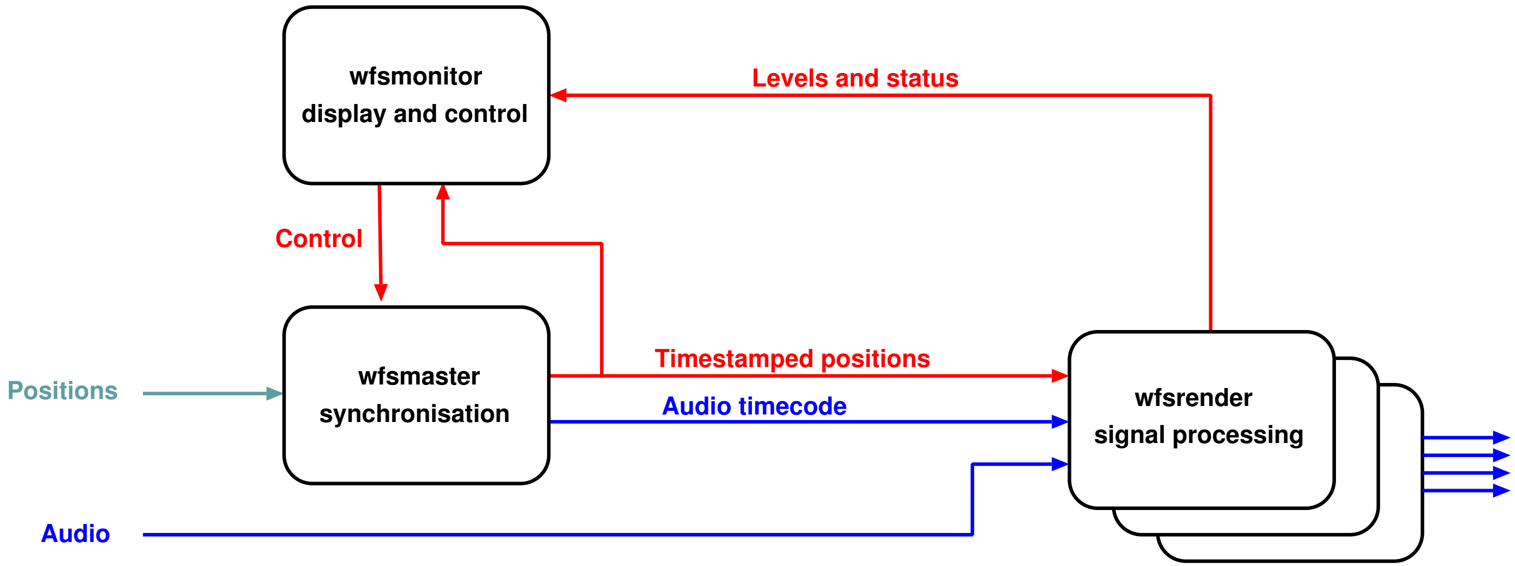
Software architecture



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WFSmaster

- Command line application, controlled via WFSmonitor or Python supervisor.
- Provides a single access point for source position and movement commands.
- Translates these commands into periodic updates sent to the render applications.

- Ensures audio and data synchronisation in the entire system:
  * Source movement data must be applied with sample accuracy on all machines, but
  * jack periods on the render machines are not synchronised, and
  * position updates arrive asynchronously via the network.

* An audio time code generated by WFSmaster is used as a time reference by the render machines, and

* position updates are timestamped using this code.

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WFSrender

- Command line application running on all rendering machines
- Controlled and monitored via WFSmonitor.
- Receives mono source signals and audio time code via the audio interface.
- Receives source position commands via the network
- Computes signals for up to 64 speakers.
- All instances are equal and read hostname to determine the set of speakers to use.
- Major parts are implemented as plugins:
  - * The layout plugin defines system geometry.
  - * The engine plugin defines the DSP algorithms.

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WFSrender - Layout plugin

- Defines the geometry of the speaker array.
- Provides functions to read or calculate:
  * Speaker coordinates,
  * Vectors orthogonal to the line of speakers,
  * Distance of a point to the line of speakers,
  * Inside or outside determination of source locations,
  * Calibration data and parameters.
- Also allows linear (non-closed) arrays.

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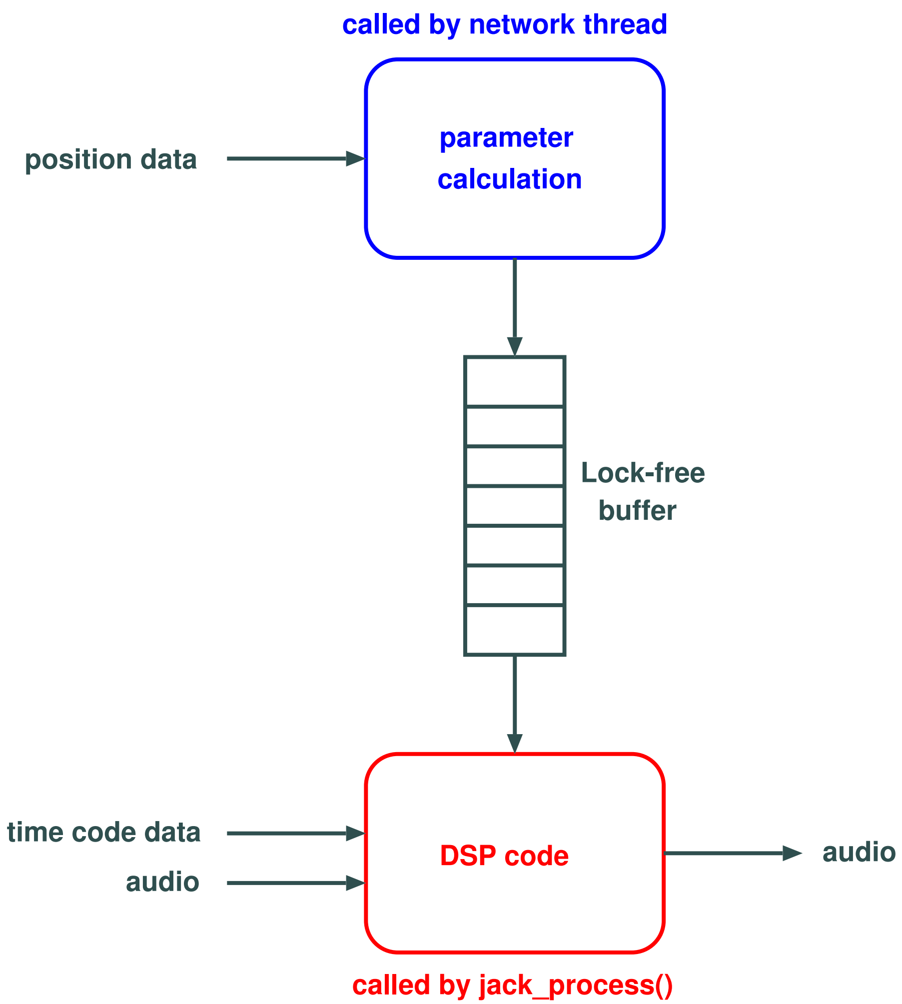
WFSrender - Engine plugin



- Contains two main routines:
  - Parameter calculation called by the network receiver thread.
  - DSP code called by jack_process().
- A lock-free buffer is required between the two.

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The DSP code

- Control rate calculation of rendering parameters.
  - Each combination of (primary, secondary) source depends on a specific delay and filter.
  - The filter can be decomposed into two fixed filters combined with variable gain factors.
  - This results in a delay value and two gain factors for each combination of (input, output).
  - Control rate is variable, but normally set to 1024 samples (around 25ms or 40 updates per second).

- Audio rate calculation:
  - Two filters for each input.
  - Implementation of the sample-accurate synchronisation.
  - Linear interpolation of the the three rendering parameters.
  - Calculation of the speaker driving signals.
  - An optional correction filter for each output.
  - Calculations can be optimised for stationary sources.

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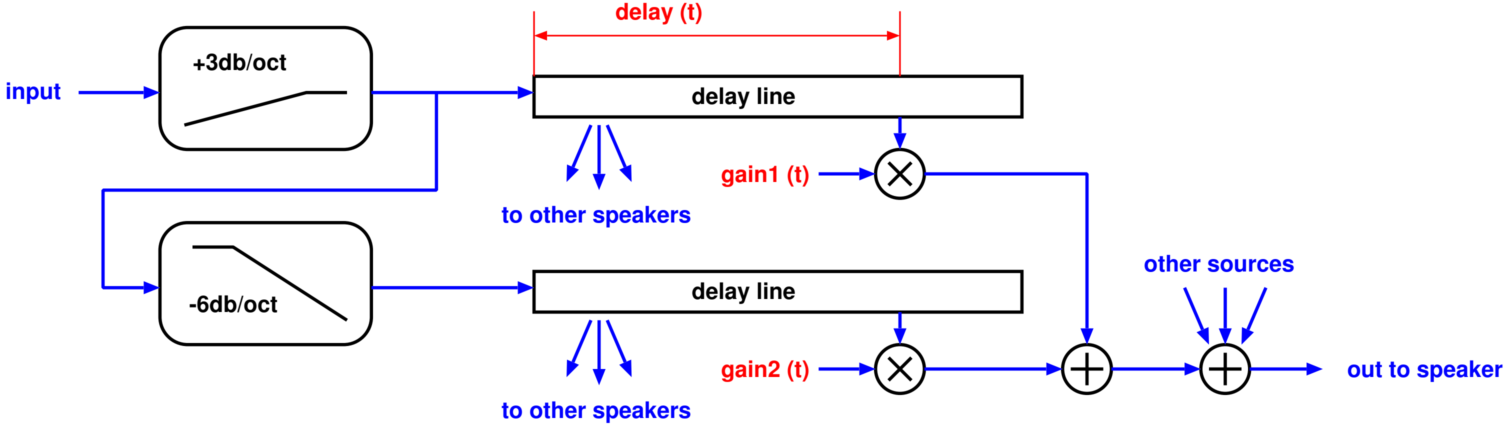
The basic algorithm

Three parameters for each (input, output) pair, updated at sample rate: $delay, gain1, gain2.$



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External interfaces – 1

- Primary source position can be controlled via two interfaces:
- Shared memory interface.
  - Available only on the *wfsctl* computer.
  - Allows sample-accurate synchronisation of audio and control data.
  - Used by LAPSPA plugins, WFSmixer and Python code.
- OSC interface.
  - Available anywhere on the network.
  - Used by major composition and synthesis tools.
  - Basic commands allows controlled-velocity movement.
- Available audio interfaces are analog, ADAT and MADI.

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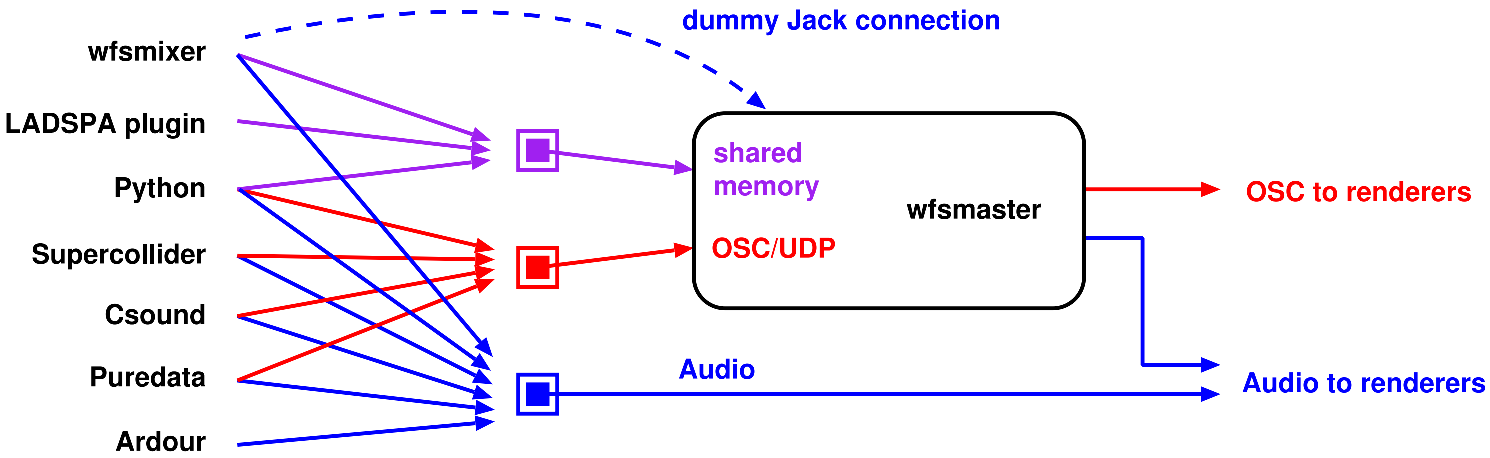
External interfaces – 2



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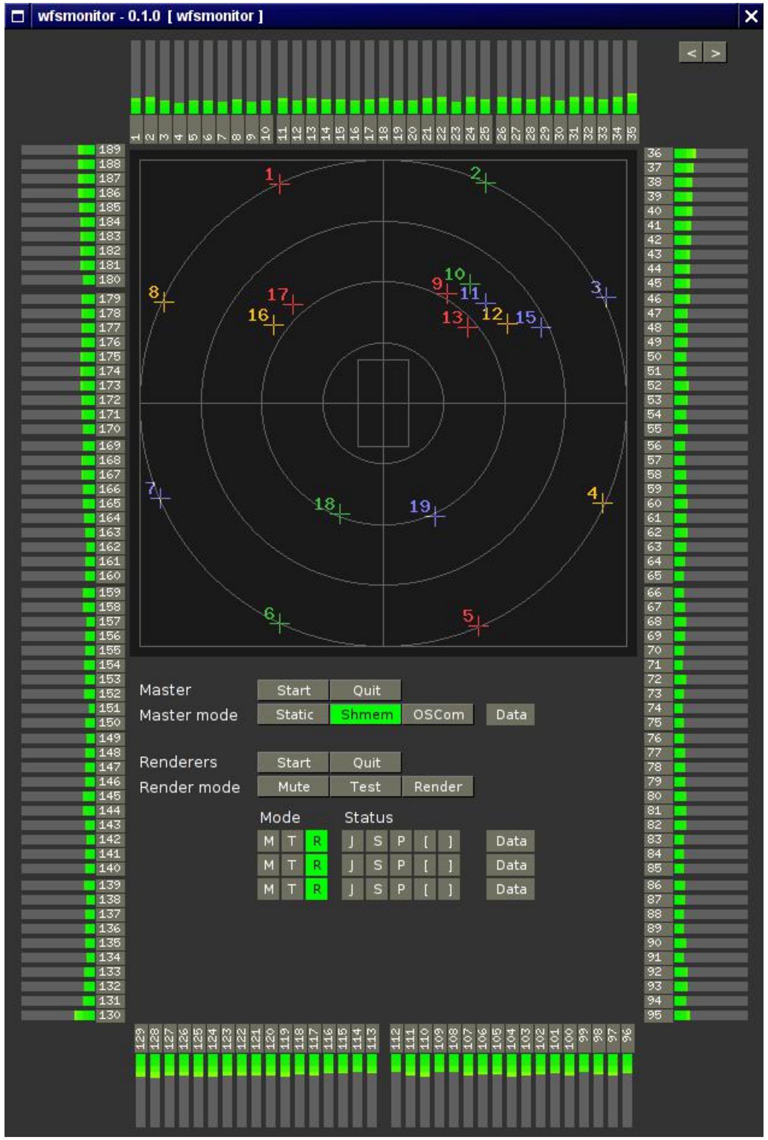
WFSmonitor

- Start, stop and monitoring of the master and render applications.
- Monitoring includes:
  - Program, network and timecode status.
  - Timing of rendering commands.
  - Primary source positions.
  - Speaker levels.
- Also provides test facilities, solo,. . .



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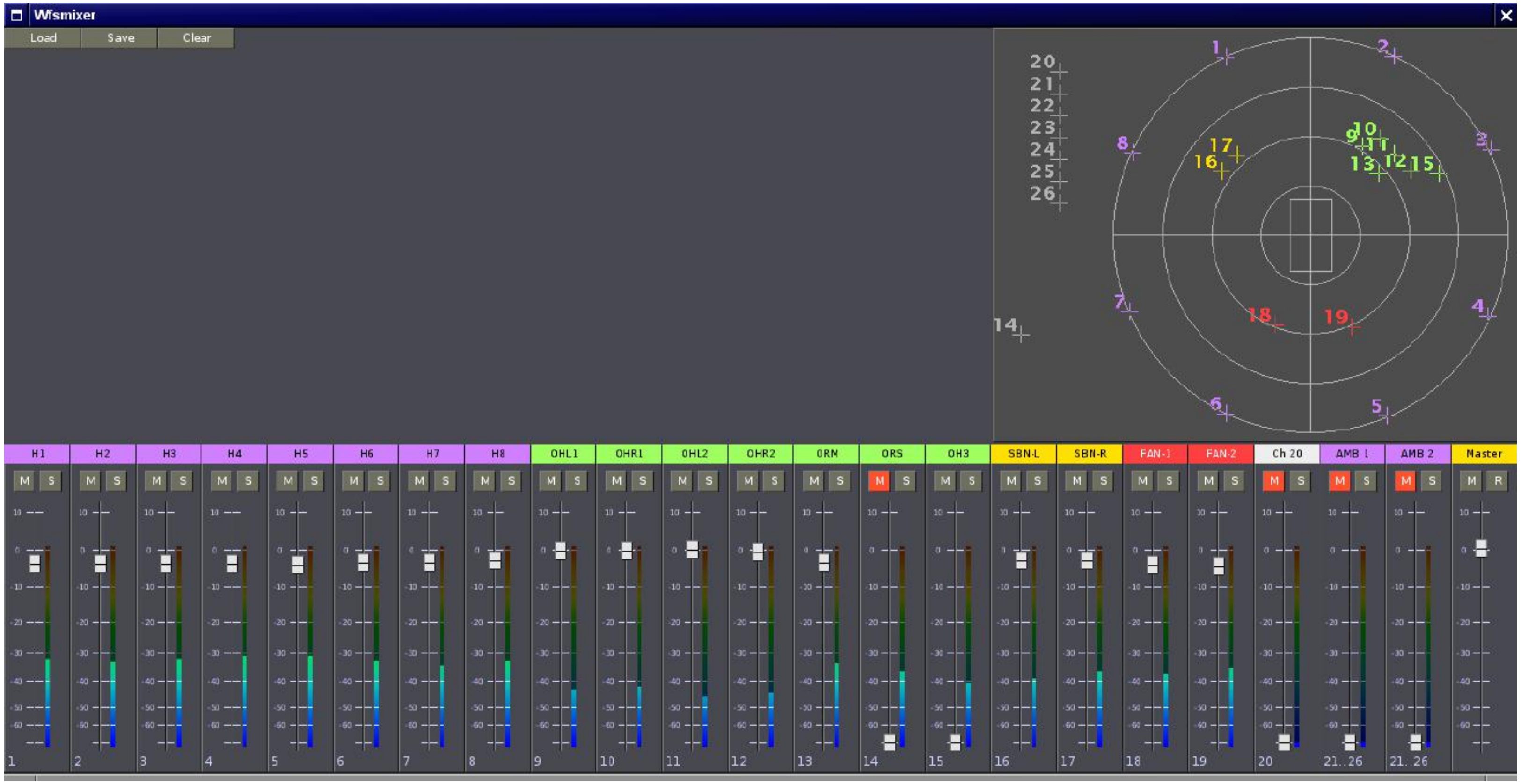
WFSmixer



- Original version (shown) provided level control, panning and simple movements.
- New version has also in-line panning, EQ, Aux sends and stereo monitor.
- ‘Total recall’ and OSC remote controlled.

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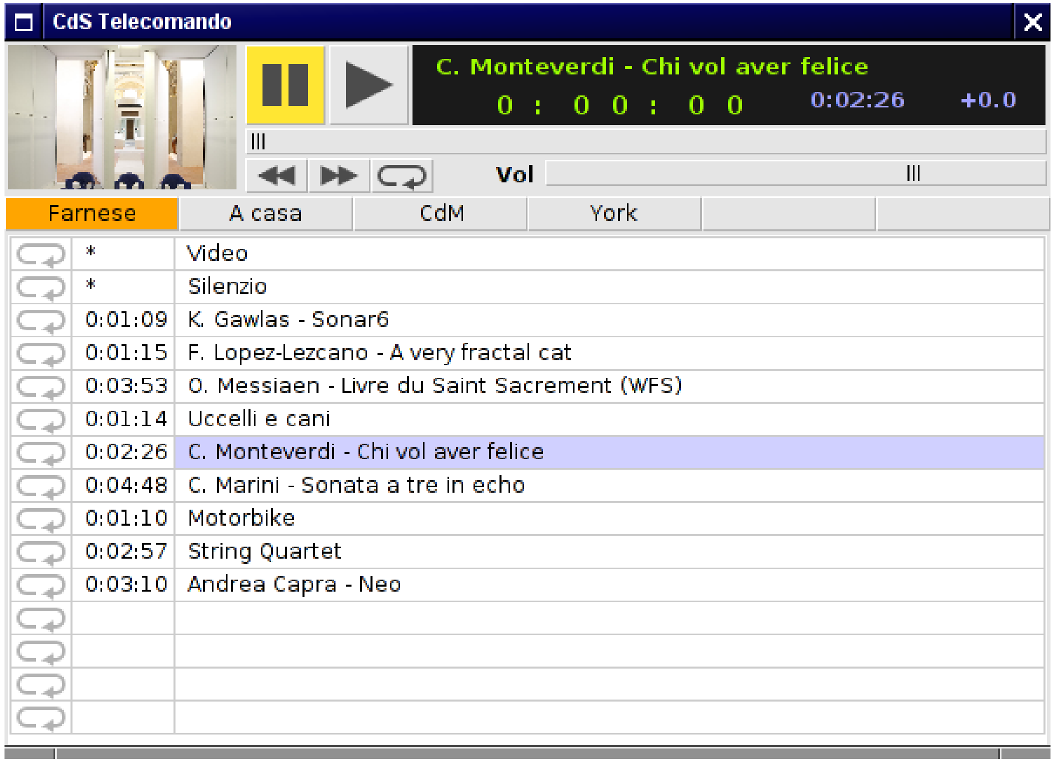
Automatic operation



- Fully automatic operation under control of a Python supervisor program.
- Audio playback via PyJackPlayer, a multichannel player app implemented as a Python class.
- Most other components are Python classes as well.
- The supervisor program also acts as a server to one or more remote control clients running on EEE-PCs.

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The End

Many thanks to all who made it possible to realise this project:

- Prof. A. Farina, University of Parma.
- The president and direction of La Casa della Musica.
- My former colleagues at Audio Link.
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- All members of the LAD list who have provided help and hints.

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