Open Source Sound Field Synthesis Toolbox

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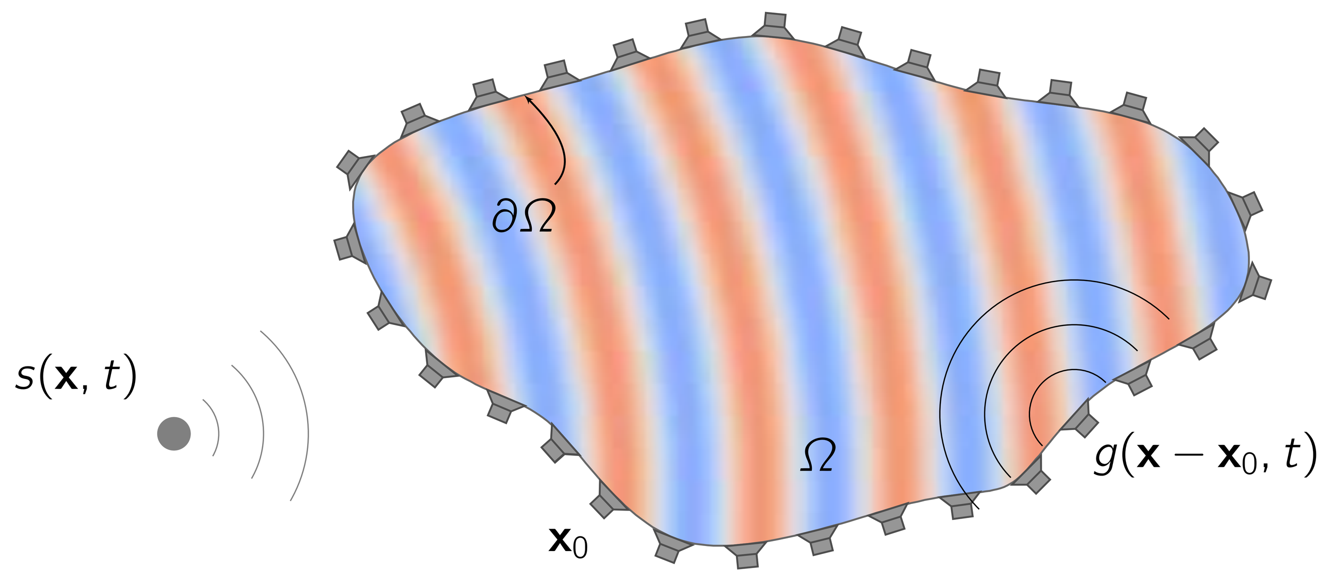
Introduction

Sound Field Synthesis (SFS) aims at production of wave fronts within a large target region enveloped by a massive number of loudspeakers. Nowadays, these techniques are known as Wave Field Synthesis (WFS) as an implicit solution of the SFS problem and as explicit solutions, like Ambisonics in the spherical domain and Spectral Division Method in the cartesian domain. Research and development on Ambisonics and WFS proceeded since the 1970s and the late 1980s, being most lively in the last decade due to DSP power available. This resulted in many SFS systems at research institutes with different rendering methods, thus complicating comparability and reproducibility. In order to pool the outcomes of different SFS approaches the Matlab/Octave based Sound Field Synthesis Toolbox was initiated 2010 as an open source project by the authors. This toolbox was later accompanied by online theoretical documentation giving an overview on the SFS approaches and citing the reference literature. In 2013 porting of the SFS Toolbox to Python was initiated, serving as convenient framework together with Jupyter notebooks. In this contribution we discuss and demonstrate the concepts, workflows and capabilities of the SFS Toolbox and their documentation as fundamental component for open research on SFS.

Fundamental Concept



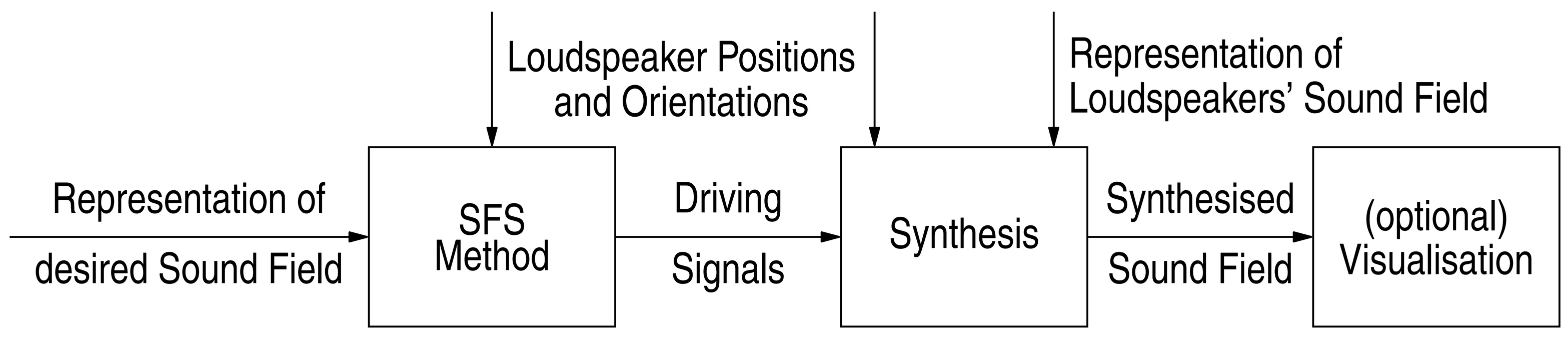
- **Goal**: Accurate synthesis of desired sound field $s(\mathbf{x}, t)$ inside the target region Ω using a loudspeaker distribution along the boundary $\partial\Omega$ (loudspeaker symbols)
- **Solution**: Determine driving signals $d(\mathbf{x}_0, t)$ for each loudspeaker such that

$$\underbrace{s(\mathbf{x}, t)}_{\text{desired sound field}} \overset{!}{=} \underbrace{p(\mathbf{x}, t)}_{\text{synthesised sound field}} = \sum_{\mathbf{x}_0} \underbrace{d(\mathbf{x}_0, t)}_{\text{driving signal}} *_t \underbrace{g(\mathbf{x}-\mathbf{x}_0, t)}_{\text{sound field emitted by loudspeaker at } \mathbf{x}_0} \qquad \forall \mathbf{x} \in \Omega \,.$$

- Equivalent formulation for the temporal frequency domain reads

$$S(\mathbf{x}, \omega) \overset{!}{=} P(\mathbf{x}, \omega) = \sum_{\mathbf{x}_0} D(\mathbf{x}_0, \omega) \cdot G(\mathbf{x}-\mathbf{x}_0, \omega) \qquad \forall \mathbf{x} \in \Omega \,.$$

- Structure of the SFS Toolbox directly maps to the mathematical formulation



- Individual processing chains for time and temporal frequency domain are implemented

Sound Field Representations

Analytic Representations
- Point Source
- Dipole Source
- Line Source
- Plane Wave

→ parameters →

Spatio-Spectral Representations
- Circular Harmonics Domain ↔ Spherical Harmonics Domain
- Plane Wave Domain ↔ Wavenumber Domain
- coefficients

- Fundamental sound fields are parametrised by e.g. position (point/line/dipole source), orientation (dipole source), or propagation direction (plane wave).
- Analytic expression for the spatio-spectral representation of fundamental sound fields exist.
- Conversion between different representations is possible.

Legend
- implemented in Python
- implemented in MATLAB/Octave
- implemented in both Toolboxes
- planned

Open and Free

Both Implementations of the toolbox are free software in terms of the MIT license. Documentation and additional information can be found at

`https://sfs.readthedocs.io`

Driving Signals

Implicit Solutions
- Wave Field Synthesis
- Local Wave Field Synthesis using Virtual Secondary Sources
- Local Wave Field Synthesis using Spatial Bandwidth Limitation

Explicit Solutions
- Near-Field-Compensated Higher-Order Ambisonics (Sphere and Circle)
- Spectral Division Method (Line)
- Equivalent Scattering Approach for Infinite Edge (Rectangle)

Panning
- Vector Base Panning e.g. Intensity (VBIP) Amplitude (VBAP)
- Higher-Order Ambisonics Panning (HOA)

- Implicit solutions are derived as high-frequency approximations of the Helmholtz-Integral Equation. They are not restricted to a particular array geometry.
- Explicit solution of the synthesis problem by deconvolution in the modal domain. Analytic descriptions exist for simple loudspeaker geometries, e.g. lines, circles or spheres.
- Panning techniques typically drive loudspeakers only by level to create a phantom source along the loudspeaker contour rather than a wavefront. So called All-Round Ambisonic Panning and Decoding are prominent techniques that combine VBAP and HOA.

Synthesis

Sound Propagation Models for Loudspeakers

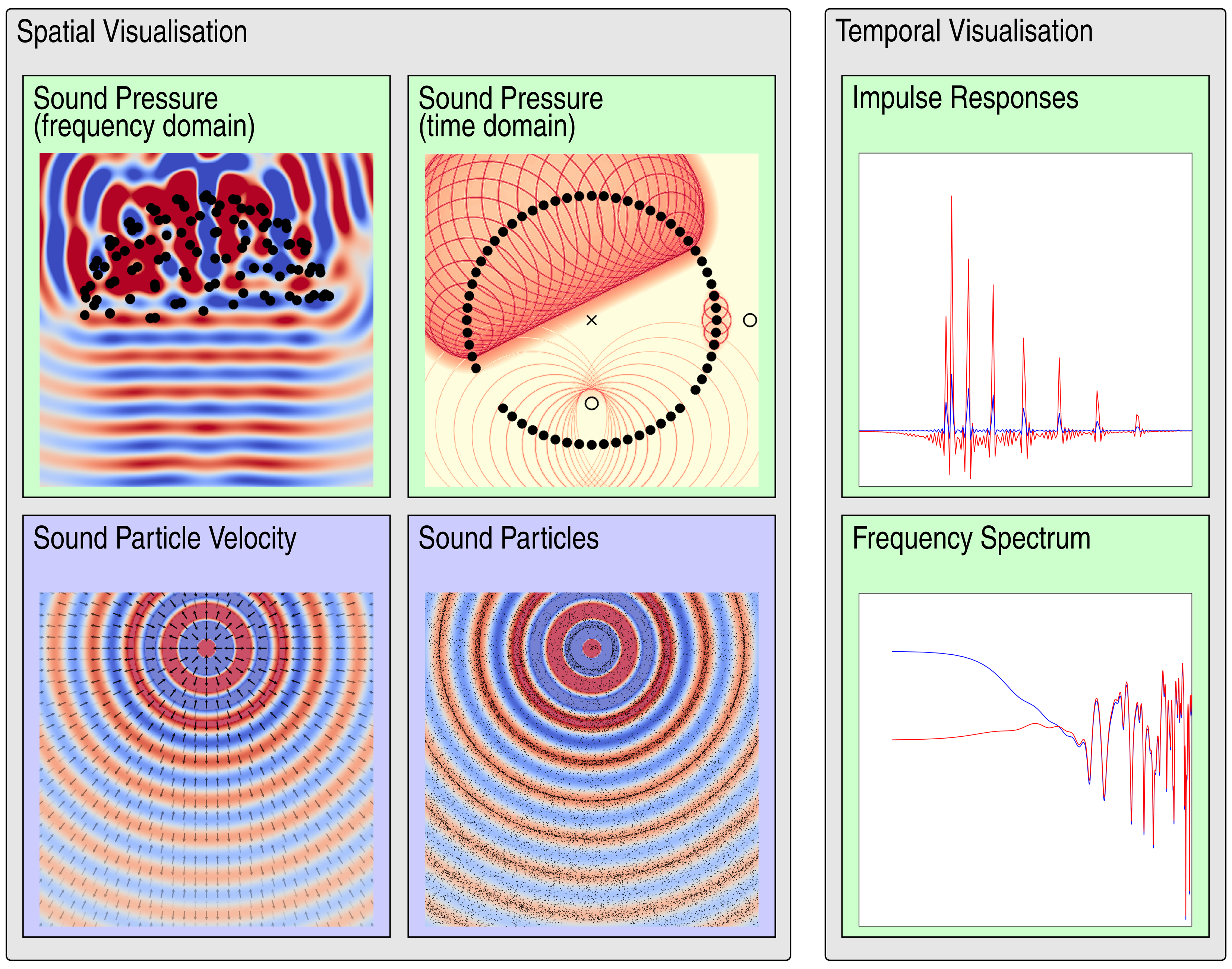
Anechoic Environment
- Point Source
- Dipole Source
- Line Source
- Plane Wave
- Head Related Impulse Response (Binaural Synthesis)

Echoic Environment
- Image Source Model for Point Source in Rectangular Room
- Modal Model for Point Source in Rectangular Room
- Binaural Room Impulse Response (Binaural Synthesis)

Simulated Quantity of Synthesised Sound Field
- Sound Pressure
- Particle Velocity
- Particle Displacement

- Sound propagation models in echoic environments are used to study the effect of the playback room which is generally not considered by the synthesis methods.
- For binaural synthesis, methods for the selection and interpolation of the impulse responses are provided. The toolbox supports the Spatially Oriented Format for Acoustics (SOFA).

Visualisation



- For the sound pressure in frequency and time domain, harmonic and broadband excitations are considered, respectively.
- Sound particle plots can be used to illustrate the particle displacement caused by the deterministic pressure variations of the sound source.

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