Wayverb: A Graphical Tool for Hybrid Modelling Auralisation

A thesis submitted to the University of Huddersfield in partial fulfilment of the requirements for the degree of Master of Arts

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This is the abstract.

Contents

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Introduction

The aim of impulse response synthesis is to simulate the reverberant properties of a space without having to physically build anything. This is useful for a variety of applications: architects need to be able to evaluate the acoustics of a building before construction begins, sound editors for film sometimes need to mix in recordings which were not made on location, electronic musicians like to conjure imaginary or impossible spaces in their music, and virtual-reality experiences must use audio cues to convince the user that they have been transported to a new environment.

Unfortunately, software allowing accurate binaural impulse responses to be synthesised is not currently widely available. Often, software produced for research purposes is never made public. Such software that *is* available generally suffers from one or more of an array of issues.

Most software relies only on fast geometric methods, which are inaccurate, especially at low frequencies. Conversely, programs opting to use more accurate wave-modelling methods require long time periods, on the order of days, or significant computing power to run.

Licensing is also an problem. Most room-acoustics packages are the product of years of combined research by multiple contributors, which is only made viable by releasing the software commercially. However, this inhibits further research, as the code is not freely available. This model also limits users to those able to pay, restricting widespread adoption.

When software is made available freely, often the user experience suffers. Code requires manual compilation, or can only be run from a textual interface, or the project is outdated and unmaintained.

The Wayverb project provides a solution to these problems, by making available a graphical tool for impulse response synthesis. It combines several simulation techniques, providing an adjustable balance between speed and accuracy. It is also free to download, can be run immediately on commodity hardware, and the source code can be used and extended under the terms of the GNU GPL license.

This thesis will begin by examining common methods of room simulation and the software which implements these methods, explaining why particular techniques were chosen for Wayverb. Then, each of the chosen techniques will be explored in depth, along with a description of their implementation. The procedure for producing a single impulse response from the outputs of multiple modelling techniques will be detailed. Two extensions to the basic room acoustics model will be described, namely frequency-dependent reflections at boundaries, and microphone/head-related transfer function (HRTF) simulation. The project will be evaluated, and finally, avenues for future development will be examined.

1 Context

Acoustics Simulation Techniques

Overview

Room acoustics algorithms fall into two main categories: *geometric*, and *wave-based* (A. Southern, Siltanen, & Savioja, 2011). Wave-based methods aim to numerically solve the wave equation, simulating the actual behaviour of sound waves within an enclosure. Geometric methods instead make some simplifying assumptions about the behaviour of sound waves, which result in faster but less accurate simulations. These assumptions generally ignore all wave properties of sound, choosing to model sound as independent *rays*, *particles*, or *phonons*.

The modelling of waves as particles has found great success in the field of computer graphics, where *ray-tracing* is used to simulate the reflections of light in a scene. The technique works well here because of the relatively high frequencies of the modelled waves. The wavelengths of these waves - the wavelengths of the visible spectrum - will generally be many times smaller than any surface in the scene being rendered, so wave phenomena have little or no effect.

The assumption that rays and waves are interchangeable falls down somewhat when modelling sound. Here, the wavelengths range from 17m to 0.017m for the frequency range 20Hz to 20KHz, so while the simulation may be accurate at high frequencies, at low frequencies the wavelength is of the same order as the wall surfaces in the scene. Failure to take wave effects such as interference and diffraction into account at these frequencies therefore results in noticeable approximation error (Savioja & Svensson, 2015).

In many cases, some inaccuracy is an acceptable (or even necessary) trade-off. Wave-modelling is so computationally expensive that using it to simulate a large scene over a broad spectrum could take weeks on consumer hardware. This leaves geometric methods as the only viable alternative. Though wave-modelling been studied for some time (Smith, 1992), and even applied to small acoustic simulations in consumer devices (such as the Yamaha VL1 keyboard), it is only recently, as computers have become more powerful, that these techniques have been seriously considered for room acoustics simulation.

Given that wave-based methods are accurate, but become more expensive at higher frequencies, and that geometric methods are inexpensive, but become less accurate at lower frequencies, it is natural to combine the two models in a way that takes advantage of the desirable characteristics of each. That is, by using wave-modelling for low-frequency content, and geometric methods for high-frequency content, simulations may be produced which are accurate across the entire spectrum, without incurring massive computational costs.

Characteristics of Simulation Methods

A short review of simulation methods will be given here. For a detailed survey of methods used in room acoustics, see P. Svensson & Kristiansen (2002).

TODO a diagram giving a nice overview.

Geometric

Geometric methods can largely be grouped into two categories: *stochastic* and *deterministic*.

Stochastic methods are generally based on statistical approximation via some kind of Monte Carlo algorithm. They may be based directly on reflection paths, using *ray tracing* or *beam tracing*, in which rays or beams are considered to transport acoustic energy around the scene. Alternatively, they may use a surface-based technique, such as *acoustic radiance transfer*, in which surfaces are used as intermediate stores of acoustic energy.

These techniques are inherently approximate. They aim to randomly probe the problem space repeatedly, combining the results from several samples so that they converge upon the impulse response for a scene. They can be tuned easily, as quality can be traded-off against speed simply by adjusting the number of samples taken. Surface-based methods, especially, are suited to real-time, as the calculation occurs in several passes, only the last of which involves the receiver object. This means that early passes can be computed and cached, and only the final pass must be recomputed if the receiver position changes.

The main deterministic method is the *image source* method, which is designed to calculate the exact reflection paths between a source and a receiver. For shoebox-shaped rooms, and perfectly rigid surfaces, it is able to produce an exact solution to the wave equation. However, by its nature, it can only model specular (perfect) reflections, ignoring diffuse and diffracted components. For this reason, it is inexact for arbitrary enclosures, and unsuitable for calculating reverb tails, which are predominantly diffuse. The technique also becomes very expensive beyond low orders of reflection. The naive implementation reflects the sound source against all surfaces in the scene, resulting in a set of *image sources*. Then, each of these image sources is itself reflected against all surfaces. For high orders of reflection, the required number of calculations quickly becomes impractical. For these reasons, the image source method is only suitable for early reflections, and is generally combined with a stochastic method to find the late part of an impulse response.

For a thorough exploration of geometric methods please refer to Savioja & Svensson (2015).

Wave-based

Wave-based methods may be derived from the *Finite Element Method* (FEM), *Boundary Element Method* (BEM) or *Finite-Difference Time-Domain* (FDTD) method. Of these, the FEM and BEM operate in the frequency domain, while the FDTD operates directly in the time domain, as its name suggests.

Existing Software

Room acoustics simulation is not a new topic of research. The first documented method for estimating a room impulse response was put forward in (Krokstad, Strom, & Sørsdal, 1968), which describes a geometric method based on ray tracing.

TODO Since then…

Searching online uncovers a handful of programs for acoustic simulation:

Name	Type	Availability
Odeon ("Odeon," 2016)	Geometric	Commercial
CATT-Acoustic ("CATT-Acoustic," 2016)	Geometric	Commercial
Olive Tree Lab ("OTL," 2016)	Geometric	Commercial
EASE ("EASE," 2016)	Geometric	Commercial
Auratorium ("Audioborn – Auratorium," 2016)	Geometric	Commercial
RAVEN (Schröder & Vorländer, 2011)	Geometric	None
RoomWeaver (M. J. Beeson & Murphy, 2004)	Waveguide	None
EAR ("Ear," 2016)	Geometric	Free
PachydermAcoustic ("Pachyderm Acoustic," 2016)	Geometric	Free
Parallel FDTD ("ParallelFDTD," 2016)	Waveguide	Free
i-Simpa ("I-Simpa," 2016)	Geometric, extensible	Free

2 Image-source

Coming soon.

3 Ray Tracer

Coming soon.

4 Waveguide

Coming soon.

5 Microphone Modelling

Coming soon.

6 Boundary Modelling

Coming soon.

7 Evaluation

Coming soon.

8 The Future

Coming soon.

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This list contains all items cited in the text. It also contains some items not directly mentioned, but which nonetheless guided the development of the project, or might shape its future.

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