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Simulating Room Acoustics Using Ray Tracing

Angefertigt an der Fakultät für Informatik und Wirtschaftsinformatik der Technischen Hochschule Würzburg-Schweinfurt

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Übersicht

TEXT DEUTSCH

Abstract

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Kapitel 1

Einleitung

Zitat: [1, 8].

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$$\boldsymbol{v} = \boldsymbol{f}(\boldsymbol{A}) = |\mathcal{C}| \cdot \operatorname*{argmax}_{\boldsymbol{A}} \sum_i \boldsymbol{A}\boldsymbol{A}_i \quad \forall \boldsymbol{A} \in \mathcal{C} \tag{1.1}$$

Check math[1]:

$$a, A, \boldsymbol{a}, \boldsymbol{A}, \alpha, \Sigma, \boldsymbol{\alpha}, \boldsymbol{\Sigma} \tag{1.2}$$

[1] In einer technischen Arbeit braucht man sehr sehr wenige Fußnoten; meistens gar keine in der ganzen Arbeit

Sed ut perspiciatis unde omnis iste natus error sit voluptatem accusantium doloremque laudantium, totam rem aperiam, eaque ipsa quae ab illo inventore veritatis et quasi architecto beatae vitae dicta sunt explicabo. Nemo enim ipsam voluptatem quia voluptas sit aspernatur aut odit aut fugit, sed quia consequuntur magni dolores eos qui ratione voluptatem sequi nesciunt. Neque porro quisquam est, qui dolorem ipsum quia dolor sit amet, consectetur, adipisci velit, sed quia non numquam eius modi tempora incidunt ut labore et dolore magnam aliquam quaerat voluptatem. Ut enim ad minima veniam, quis nostrum exercitationem ullam corporis suscipit laboriosam, nisi ut aliquid ex ea commodi consequatur? Quis autem vel eum iure reprehenderit qui in ea voluptate velit esse quam nihil molestiae consequatur, vel illum qui dolorem eum fugiat quo voluptas nulla pariatur? At vero eos et accusamus et iusto odio dignissimos ducimus qui blanditiis praesentium voluptatum deleniti atque corrupti quos dolores et quas molestias excepturi sint occaecati cupiditate non provident, similique sunt in culpa qui officia deserunt mollitia animi, id est laborum et dolorum fuga. Et harum quidem rerum facilis est et expedita distinctio. Nam libero tempore, cum soluta nobis est eligendi optio cumque nihil impedit quo minus id quod maxime placeat facere

Li Europan lingues es membres del sam familie. Lor separat existentie es un myth. Por scientie, musica, sport etc, litot Europa usa li sam vocabular. Li lingues differe solmen in li grammatica, li pronunciation e li plu commun vocabules. Omnicos directe al desirabilite de un nov lingua franca: On refusa continuar payar custosi traductores. At solmen va esser necessi far uniform grammatica, pronunciation e plu sommun paroles. Ma quande lingues coalesce, li grammatica del resultant lingue es plu simplic e regulari quam ti del coalescent lingues. Li nov lingua franca va esser plu simplic e regulari quam li existent Europan lingues. It va esser tam simplic quam Occidental in fact, it va esser Occidental. A un Angleso it va semblar un simplificat Angles, quam un skeptic Cambridge amico dit me que Occidental es. Li Europan lingues es membres del sam familie. Lor separat existentie es un myth. Por scientie, musica, sport etc, litot Europa usa li sam vocabular. Li lingues differe solmen in li grammatica, li pronunciation e li plu commun vocabules. Omnicos directe al desirabilite de un nov lingua franca: On refusa continuar payar custosi traductores. At solmen va esser necessi far uniform grammatica, pronunciation e plu sommun paroles.

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Kapitel 2

Introduction

2.1 Motivation

While there has been plenty of research into simulating sound propagation using both geometric and numerical methods, nearly all of it only concerns itself with static scenes, where neither objects within the scene nor the sound emitter nor receiver move with time.
Simulation of dynamic or moving scenes is mostly unexplored: Raghuvanshi et al. [7] explore a numerical approach to handle dynamically moving emitters and receivers and Chandak et al. [3] attempt to simulate dynamic scenes in real-time, with support for dynamically moving scenes but sacrificing accuracy. Besides the AD-Frustum described in [3] being prone to minor visibility issues, it also fails to consider that as sound does not travel instantly, objects and receivers can still move while a sound wave is traversing the scene. This same issue also occurs in EAR, a simulation tool that supports blender's keyframe system for moving scenes.
This is because of the approach both Chandak [3] and EAR use, which will be called the snapshot method in this thesis: At the time rays are emitted to create an impulse response, a snapshot of the scene in its current state is taken, then rays are bounced through this snapshot. This approach comes with a few advantages: As the snapshot is essentially just a static scene, the same bouncing logic used for static scenes can be copied without changes. Also, crucially, knowledge of how the scene will move over the time the ray spends bouncing around it is not required. All data necessary to simulate the bouncing is available at the time the ray is emitted, without a need for information on how the scene will continue to move. This is especially helpful for real-time simulation of dynamic scenes, as data about how the scene will continue to move is not fully known at runtime.
The downside of this snapshot approach is that it tends to introduce errors when objects or receivers move at high speeds. As a simple example case, take the scene described in (IMAGE):

A receiver starts 343 meters away from an emitter and moves towards it at 1/9th the speed of sound, roughly 38 meters per second (137.2 kilometers per hour, a speed most modern cars can reach without problems). Using the snapshot approach, a ray traveling directly from emitter to receiver would arrive after travelling the full 343 meters, taking 1 second for it to arrive at the receiver. In actuality, in the time the ray takes to travel the first 90% of that distance, the receiver has already travelled the remaining 10%, making for a response time of 0.9 seconds rather than 1 second.
While Bilibashi et al. [2] have attempted to solve this issue, they only aimed to simulate waves bouncing between a few set points, namely cars, rather than simulating full room acoustics.

2.2 Scope

This thesis proposes a method to simulate rays bouncing through arbitrary scenes with moving receivers and/or objects, assuming all movement within the scene is known at time of calculation. An improved way of checking for intersections between rays and objects is developed, accommodating for this new requirement. Additionally, a method is developed to to losslessly and efficiently store the multiple impulse responses created by re-calculating the impulse responses for different points in time. The goal of this research is to simulate effects such as the situation described in (IMAGE) without errors introduced by the snapshot method as well as accurately recreate the acoustics of a hypothetical, rapidly rotating room. Three test cases are developed for this and compared to an implementation of the snapshot method: An empty scene with the sound receiver approaching the sound emitter at 1/3 the speed of sound, a square room rapidly rotating and a large, L-shaped room also rapidly rotating around one of its ends, with the receiver and emitter both sitting in said end.
Side effects of moving scenes, such as sounds emitted by moving objects, are discarded as they are irrelevant to the changed intersection logic. A note-worthy side effect that gets ignored is mass inertia: The example case where this would become relevant is the inside of a linearly moving enclosed room, such as a driving car. Due to inertia, the acoustics inside this moving room are the same as if the car stood still. Since this effect is only relevant in a niche scenario and it can be simulated using a method that ignores movement entirely, it can be ignored for this research.
Real-time applications cannot use this proposed method as it requires knowledge of the scene's further development ahead of time. Further research is required to develop an alternative method for real-time or dynamic simulations.

Kapitel 3

Interpolating Intersection Checks

3.1 Intersection Checks for Spheres

3.2 Intersection Checks for Surfaces

Kapitel 4

Time-Based Chunks

4.1 Chunks vs. Bounding Volumes

One common optimisation for ray tracing systems is to limit the amount of intersection calculations by eliminating objects the ray cannot intersect with in a simpler way. There are two general sets of methods used for this: Bounding Volume Hierarchies (BVHs, first proposed by Clarke [4]) and Chunks (first proposed by Fujimoto and Iwata). BVHs work by enclosing each object within a volume, intersections with which can easily be calculated. Then, these volumes are combined in a hierarchical tree structure. If a ray doesn't intersect with a bounding volume high up in the hierarchy, all intersection checks with bounding volumes encapsulated by it and their respective objects can be skipped. Chunking instead segments the scene into separate chunks, each of which then keeps track of which objects are inside it. Rays can simply traverse from chunk to chunk and only do intersection checks for objects contained within those chunks. Since objects can move around the scene, using one of these methods without changes becomes inefficient. If, for example, a receiver moves from one end of the scene to the other over the course of ten seconds, its bounding volume would extend over all of that distance for the entirety for the scene, despite it not touching the majority of it for the most part. Similarly, it would be kept in its starting position's chunk for the entirety of the scene, despite leaving that area very early.
For this use case, chunks become a lot more efficient than BVHs: When taking time into account, each object would need separate bounding volumes for separate points in time, forcing a ray to not just check one bounding volume, but multiple per object. This also means that in order to be able to create meaningful bounding volume hierarchies, each object's bounding volumes would need to be separated at the same points in time, which can lead to redundancies if objects move at different times.

The amount of chunks, in turn, does not change: They can be adapted simply by changing how they store which objects are inside them at which time.

4.2 Data Structure

In a simple system, a chunk stores a list where each entry represents an object inside it. To accommodate for objects moving in and out of chunks, entries can instead contain three fields: One containing the index of the object in question, one containing the time at which the object enters the chunk and one containing the time at which the object leaves the chunk. Since the latter two fields might both be optional if the scene starts/ends with the object inside the scene, this can be nicely represented using an additive type such as Rust's Enumerators with different states:

```
// Object stays within chunk for the whole scene
// only store the index
Static(object)
// Object enters and exits chunk at the given times
Dynamic(object, time_entry, time_exit)
// Object enters chunk at the given time
// and stays until the end
Final(object, time_entry)
```

As the scene's start time is known and the state of objects before it is irrelevant, a state containing only an exit time is not necessary as it can be modelled using the `Dynamic` state with a `time_entry` of 0. In a more common multiplicative type, chunk entries can instead be represented as a struct or class where the entry and exit times are optional fields.
A ray traversing this scene can now simply check when it enters and exits a chunk and pick out the objects to check for intersections with accordingly.

4.3 Calculating Chunks

4.4 Traversing Chunks

Kapitel 5

Time-Based Impulse Responses

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Abbildungsverzeichnis

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