

Room Impulse Response Estimation using Signed Distance Functions

A Proof of Concept with real time applications in mind

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State of the Art

Current Technologies for RIR estimation:

- Raytracing
- wave-based methods
- images-source method
- hybrid approaches
- A.I. based or supported approaches



Sphere tracing and SDFs

What are *signed distance functions (SDFs)*, what is *sphere tracing* and why is it interesting?



Sphere tracing and SDFs

For decades, the so-called *demo scene* used these techniques in real time graphics. For a long time, in graphics, the only way to get Reflections, Refraction and other complex phenomena (like soft shadows) in real time was by using this technique.¹

Surprisingly, there seems to be no documented attempt for using this advantage for RIR estimation.

¹This is still true today, although Raytracing on the GPU, A.I. supported de-noising and other approaches are catching up

What is an SDF?

Implicit Surfaces can be described by a function f that takes a position in 3D (p_x, p_y, p_z) and returns the distance to the surface. f is a so-called signed distance function.

$$f(p_x, p_y, p_z) = \sqrt{p_x^2 + p_y^2 + p_z^2} - r \quad (1)$$

These functions can be used to create geometry. f describes a sphere in 3D with radius r . The geometry is *not* split up to triangles or quads and therefore potentially infinitely accurate.

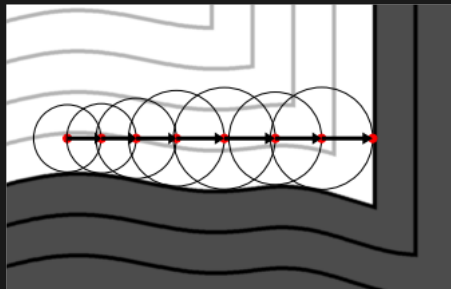


Visualisation of the sphere SDF



What is Sphere tracing?

Sphere tracing is the technique of exploiting the fact that f returns the *distance to the closest surface* to speed up the process of finding surfaces in rendering. At each iteration the maximum distance can be marched.



Advantages and Disadvantages

Disadvantages

- SDF construction can be tedious
- RIR estimation usage not mature
- geometry based (same disadvantages as ray tracing)

Advantages

- Conceptually very different, very different opportunities
- fast
- much research from the field of graphics



Special Opportunities of Sphere Tracing

- Infinite repetition of geometry is just a modulo operation
- There is no rasterization of geometry
- arbitrary dimensions (4D Reverb?)
- SDFs are mathematically easier to analyze than a collection of triangles/quads
- smoothing of geometry is just a single subtraction operation (not adding a lot of triangles). There might be opportunities to efficiently generate geometry for low-frequency passes.
- fractal geometries are easy to implement (Fractal Room Reverb?)



Special Merits of Sphere Tracing - Rounding/Smoothing



Special Merits of Sphere Tracing - Infinite Repetition



Special Merits of Sphere Tracing - Reflection/Refraction



Special Merits of Sphere Tracing - Fractals



The complete simulation runs in a Compute Shader written in GLSL.
Sphere Tracing is used to compute attenuation and delays of rays. For each ray that eventually hits the sound source a delayed, attenuated and filtered unit impulse is inserted in the total RIR.



Frequency Dependent Absorption

For efficiency reasons, every reflection assumes to apply the same filter. This gives the possibility to make use of *binomial filters*.

Assuming at every reflection, a filter $G(z)$ has to be applied, the total filtering that has to be done before adding the delayed attenuated unit impulse is $G(z)^K$, if K reflections occurred.



Frequency Dependent Absorption

A binomial filter's impulse response converges to a Gaussian bell curve [1], which can be approximated as:

$$G(n, K) \approx \frac{1}{\sigma \cdot \sqrt{2\pi}} \cdot e^{-\frac{1}{2}(\frac{n-\mu}{\sigma})^2} \quad (2)$$

with

$$\sigma = \sqrt{K0.231 + 0.562} \quad (3)$$

and

$$\mu = \frac{K}{2} + \frac{1}{2} \quad (4)$$



This paper made *many* simplifications due to its proof-of-concept nature. Nevertheless, results are compared to [2], who did a comparison of different RIR estimation algorithms and an acoustical ground truth[3].



Demo



Demo



Recommended Sources for Beginners in Sphere Tracing

- iquilezles.org, Articles by Inigo Quilez
- Inigo Quilez on Youtube
- thebookofshaders.com, the book of Shaders
- shadertoy.com, shadertoy.com



Source

Find the source code at:

`github.com/hrtlacek/rayMarchReverb`



