Geometric Modeling of Sound Propagation in 3D Environments

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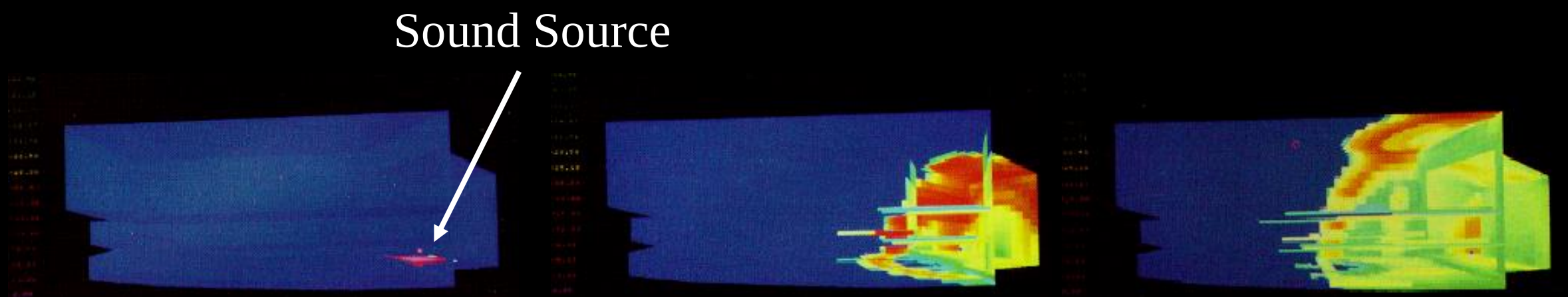
Computer Science Department
Princeton University

Goal

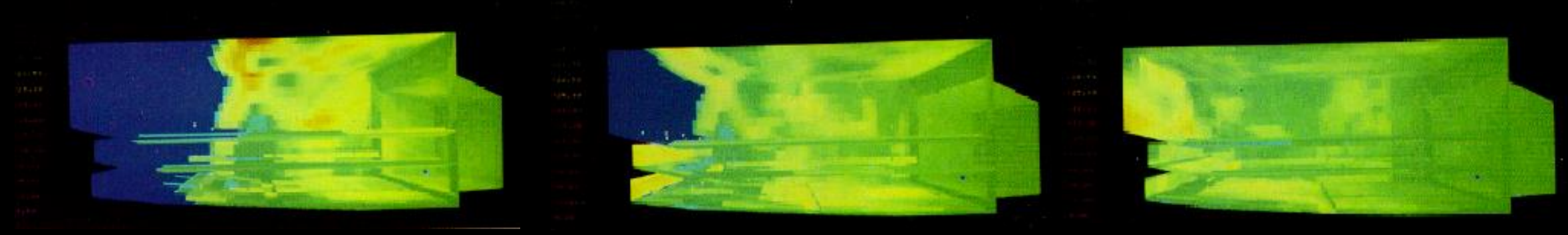
Model propagation of sound in 3D environments



0-10 ms

30-40 ms

60-70 ms



90-100 ms

120-130 ms

150-160 ms

Stettner92

Motivation

Realistic acoustics improve ...

- ➢ Localization of auditory cues
- Comprehension of space
- Sense of presence

Vartek NV

Evans & Sutherland

Motivation

Realistic acoustics improve ...

- Localization of auditory cues
- ➢ Comprehension of space
- Sense of presence

Unreal Tournament,
Epic / GT Interactive 1999

Large stone hall

Alone in the Dark 4,
Darkworks/Infogrames, 2000

Small wood corridor

Unreal Tournament,
Epic / GT Interactive 1999

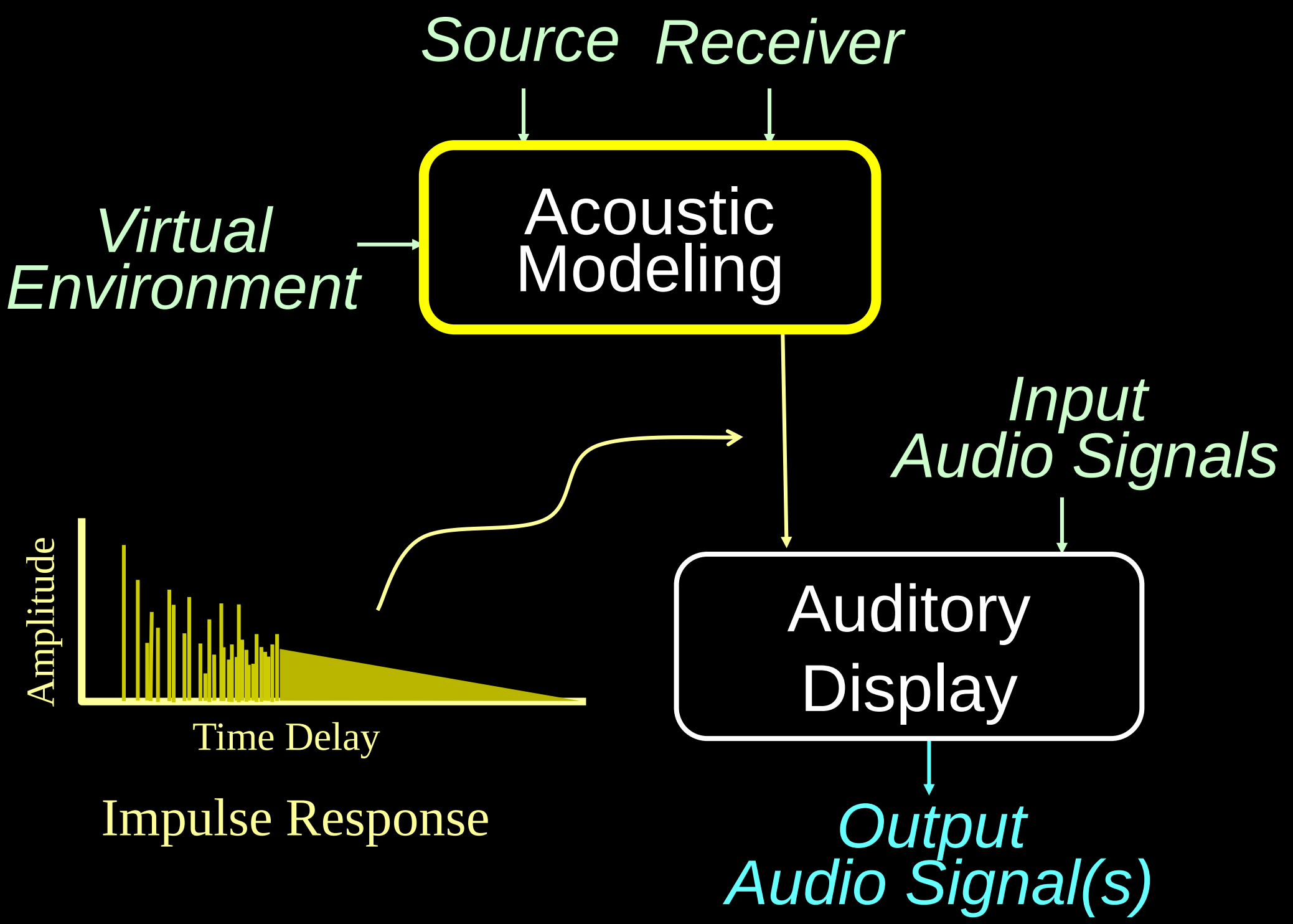
Small metal room

Motivation

Realistic acoustics improve ...

- Localization of auditory cues
- Comprehension of space
- ➢ Sense of presence

Audio Rendering



Talk Outline

Introduction

Acoustic modeling overview

Beam tracing method

- Stationary sources
- Moving sources

Conclusion

Future work

Acoustic Modeling Overview

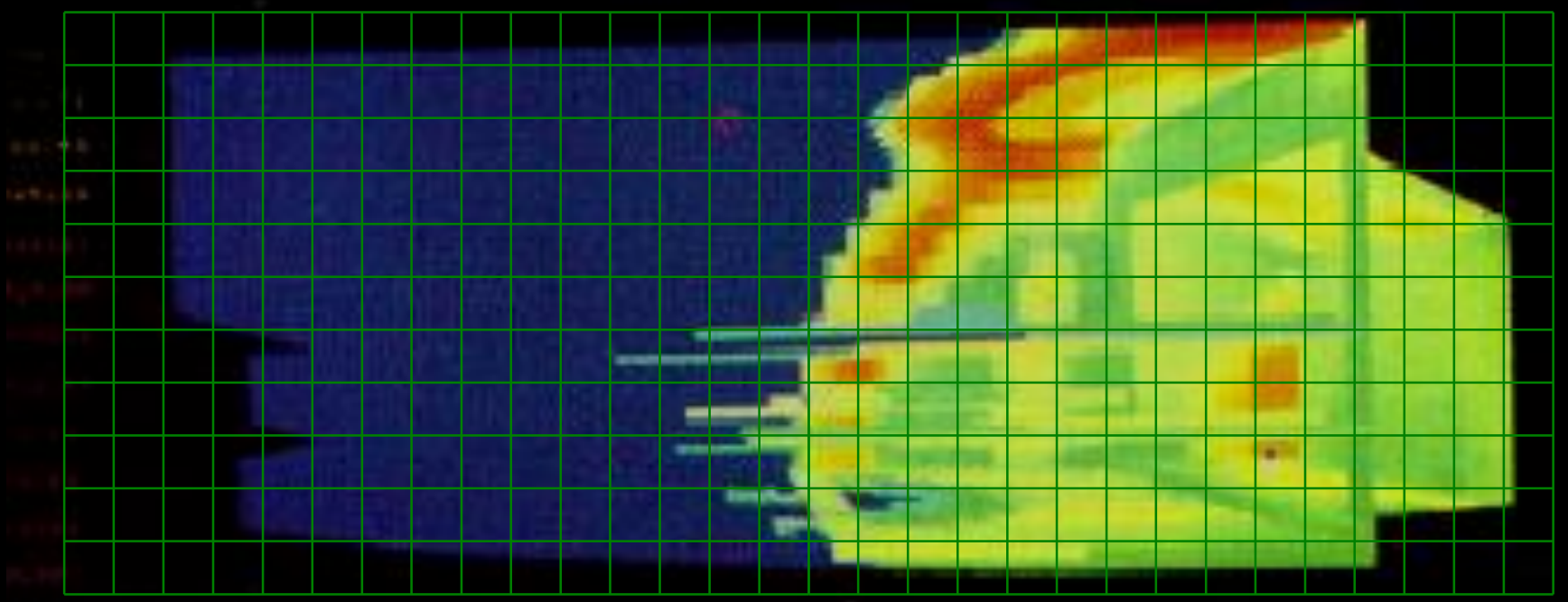
Computational methods

- Finite element methods
- Geometric path tracing
- Artificial reverberation

Acoustic Modeling Overview

Computational methods

- ➢ Finite element methods = wave theory approximation
- Geometric path tracing
- Artificial reverberation

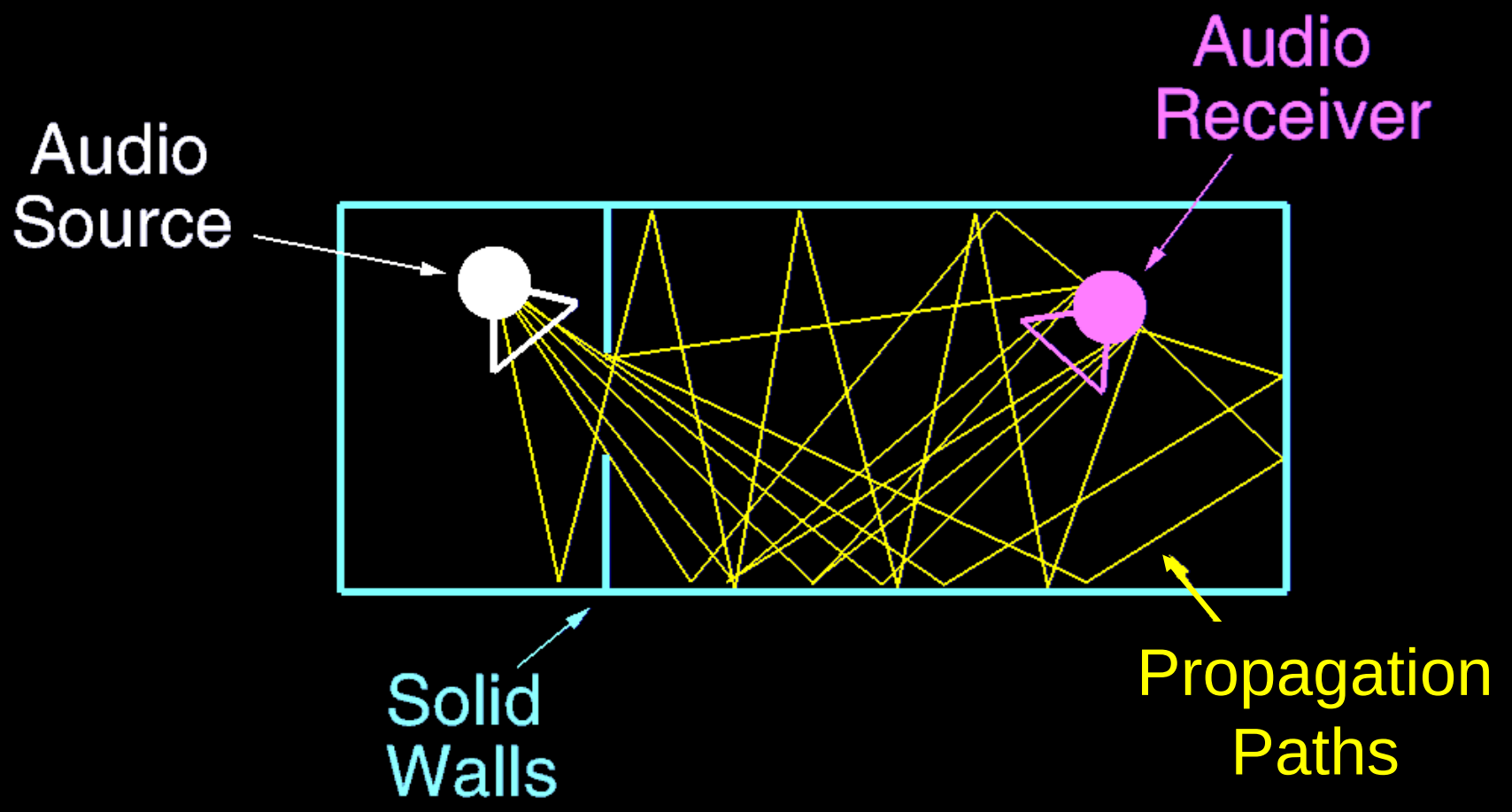


Stettner92

Acoustic Modeling Overview

Computational methods

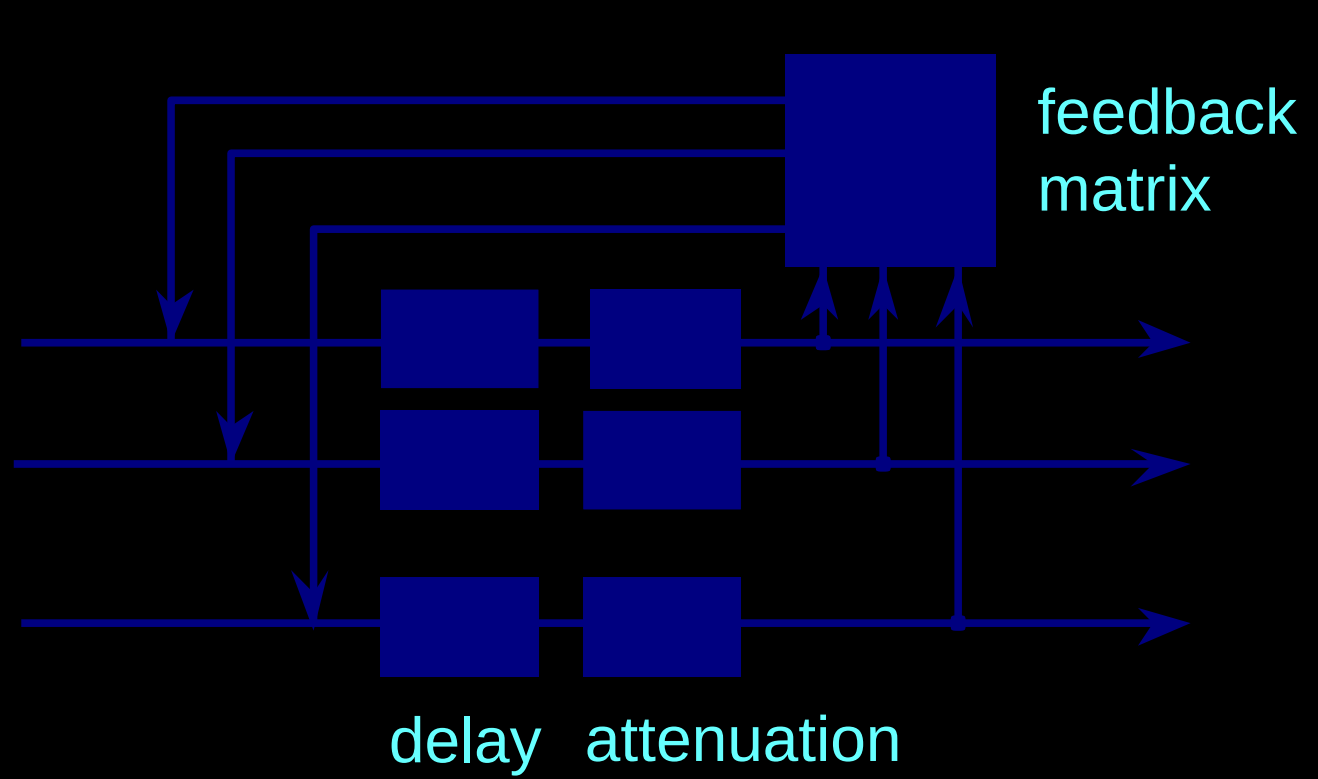
- Finite element methods
- ➢ Geometric path tracing = ray theory approximation
- Artificial reverberation



Acoustic Modeling Overview

Computational methods

- Finite element methods
- Geometric path tracing
- ➢ Artificial reverberation = perceptual approximation

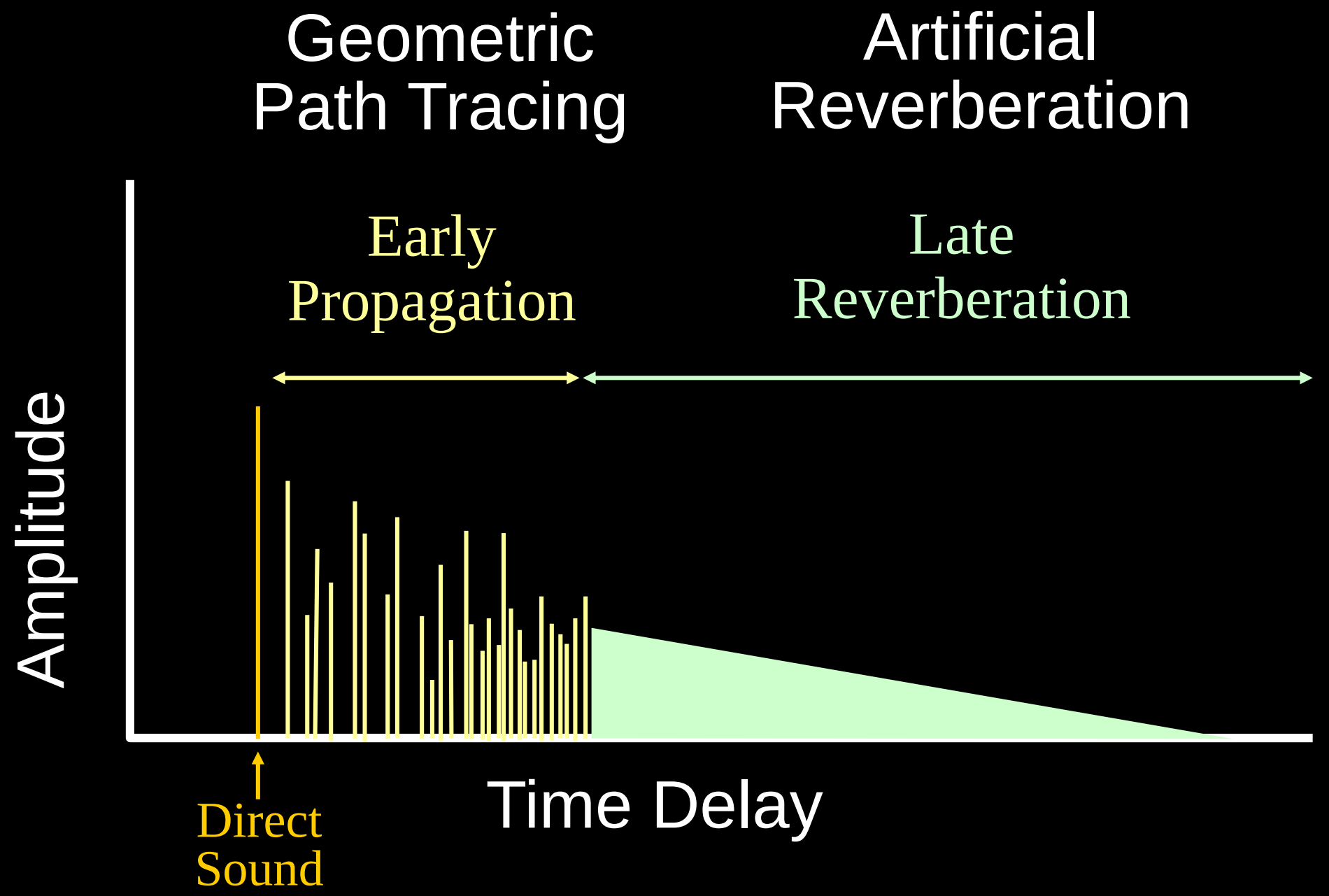


Feedback Delay Network

Jot

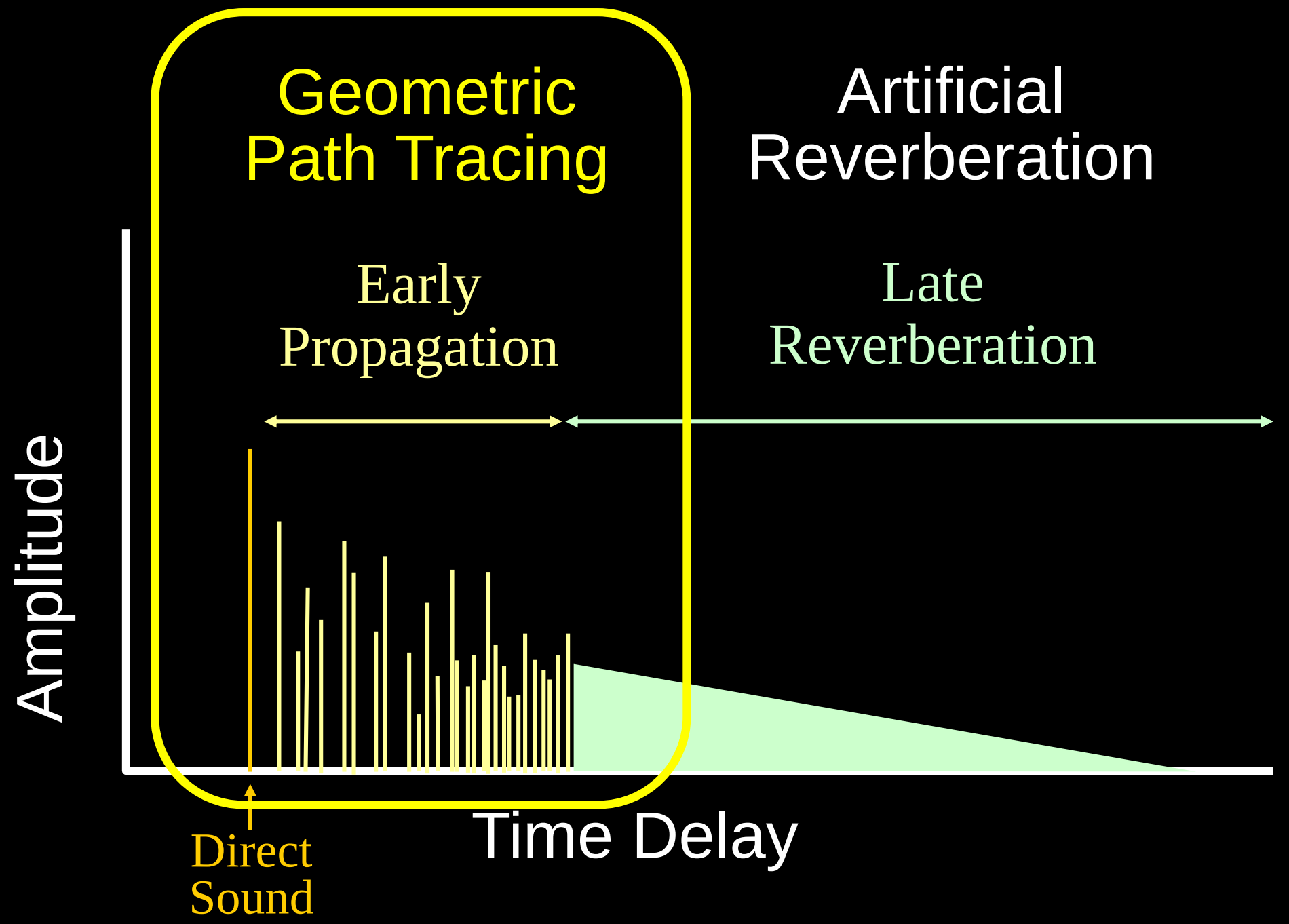
Acoustic Modeling Overview

Impulse response (early vs. late)



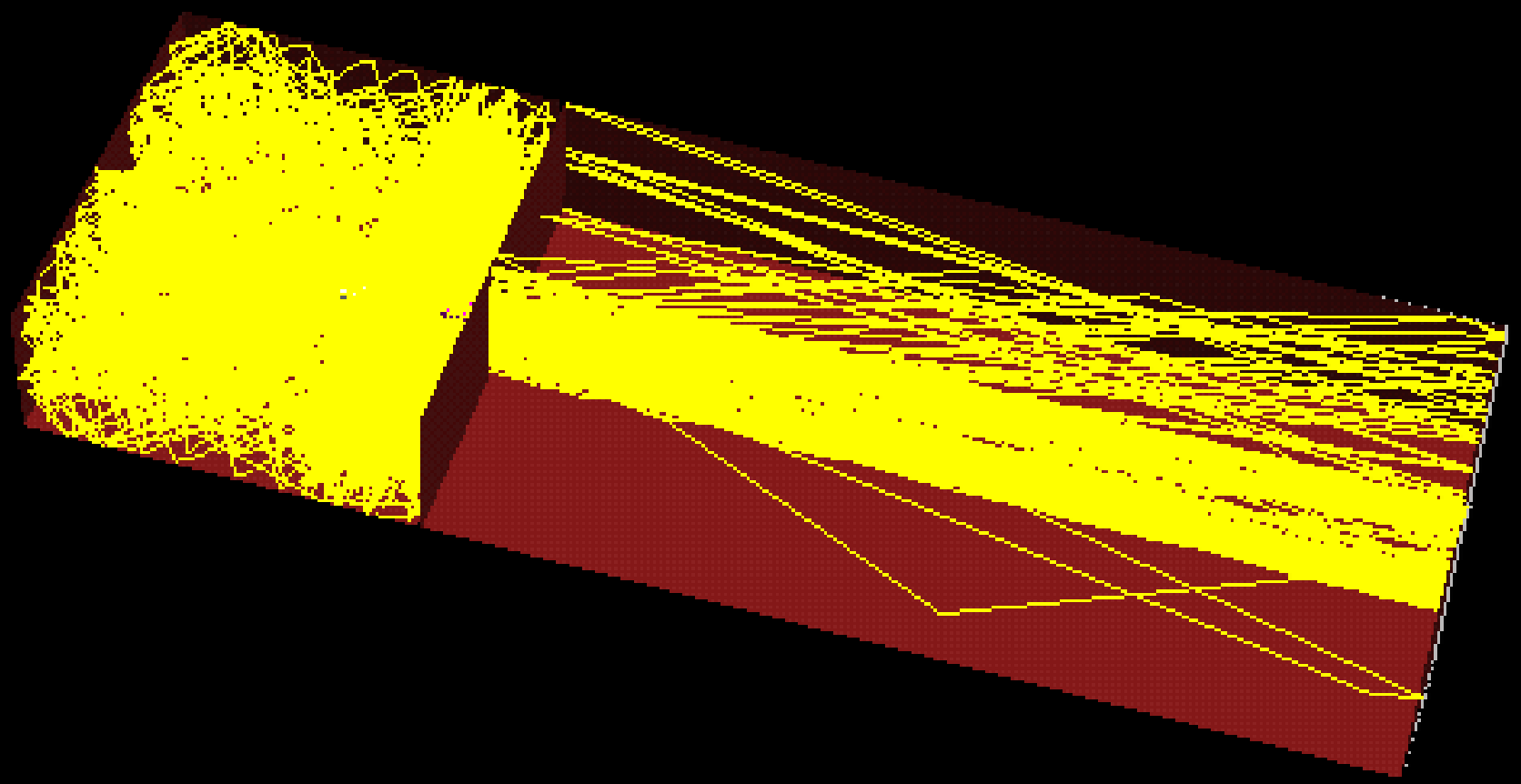
Acoustic Modeling Overview

Impulse response (early vs. late)



Geometric Path Tracing

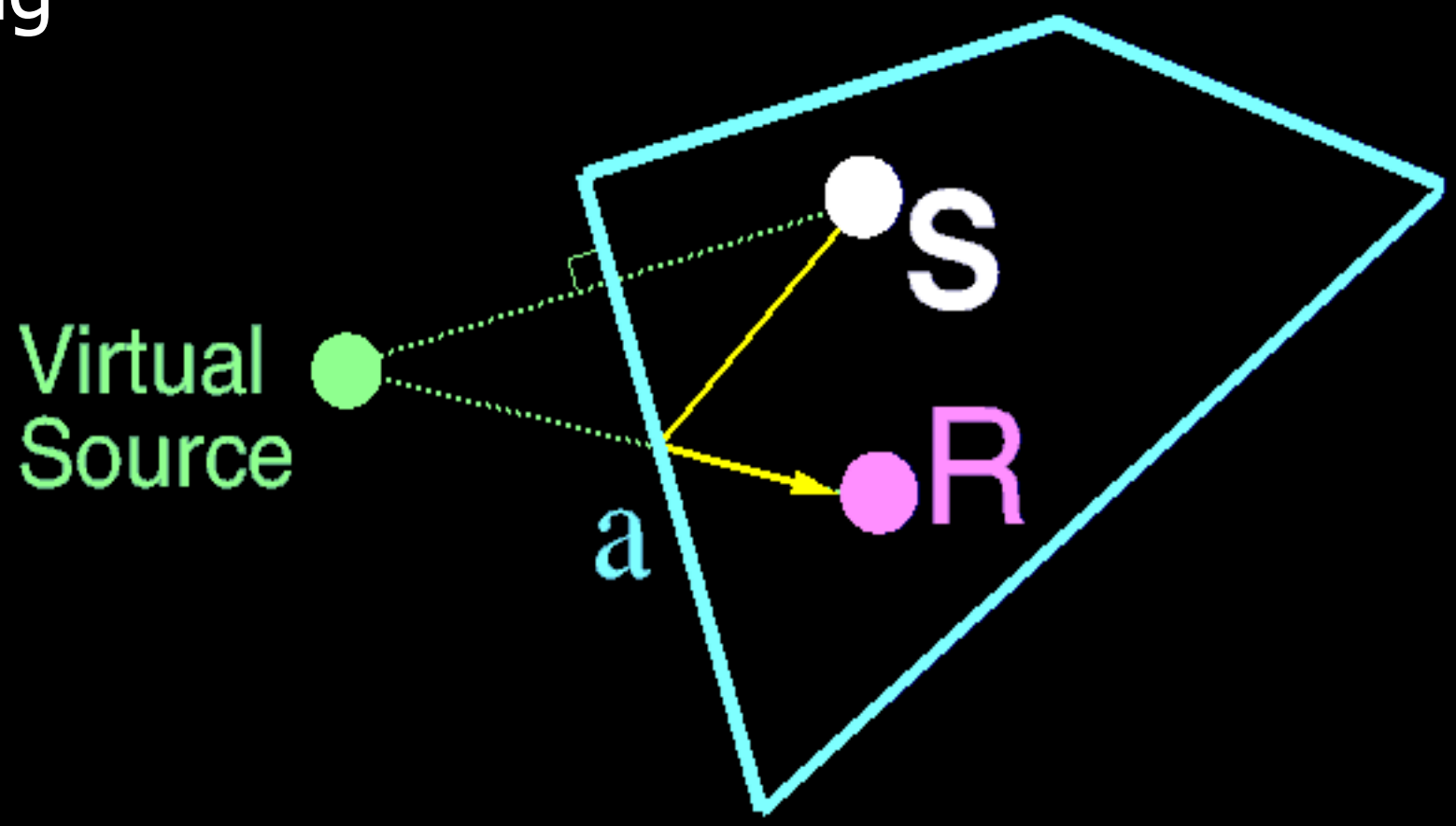
Challenge is to find early propagation paths efficiently



Geometric Path Tracing

Computational methods

- ➢ Image sources
- Ray tracing
- Beam tracing

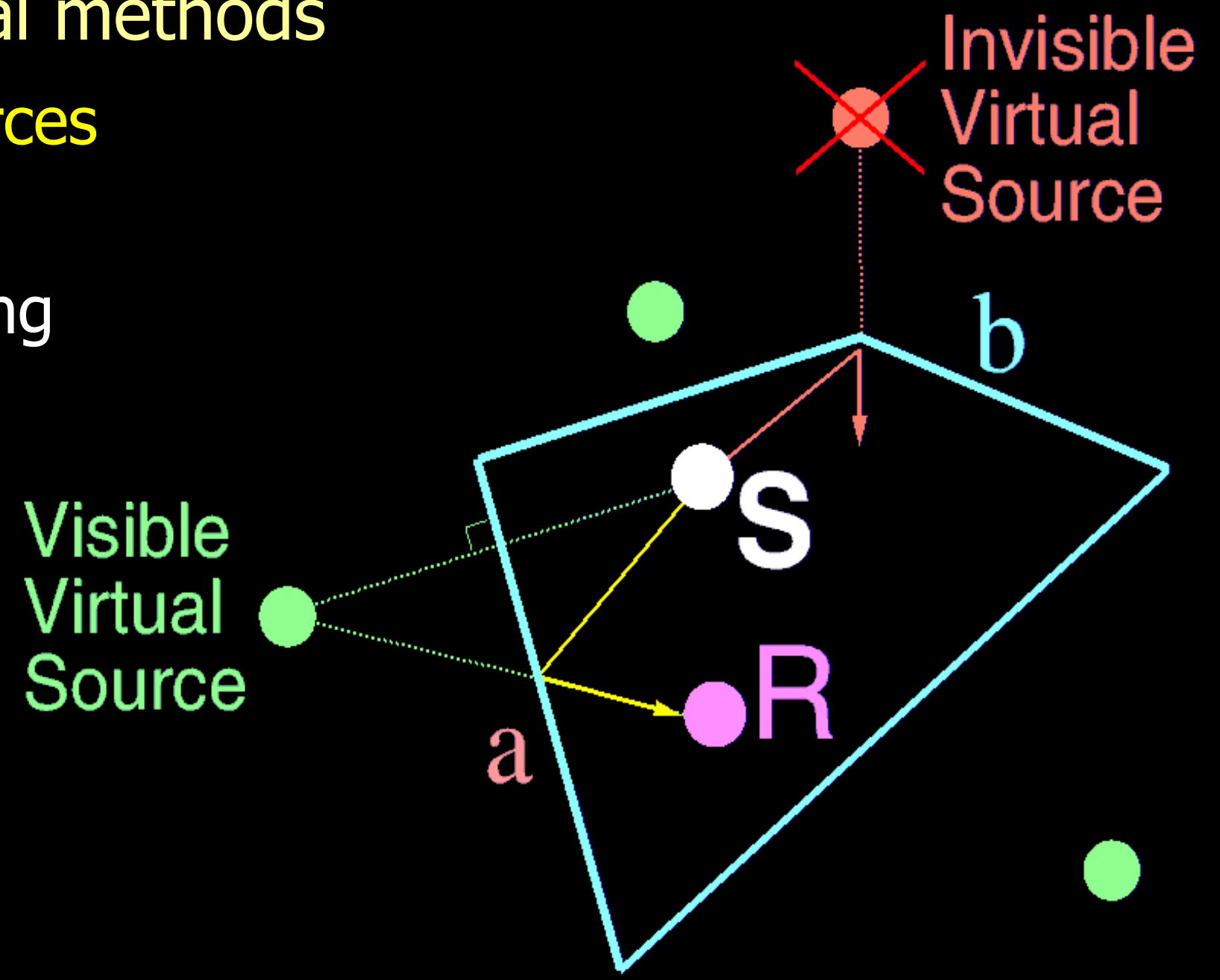


Model specular reflections with “virtual sources”

Geometric Path Tracing

Computational methods

- ➢ Image sources
- Ray tracing
- Beam tracing

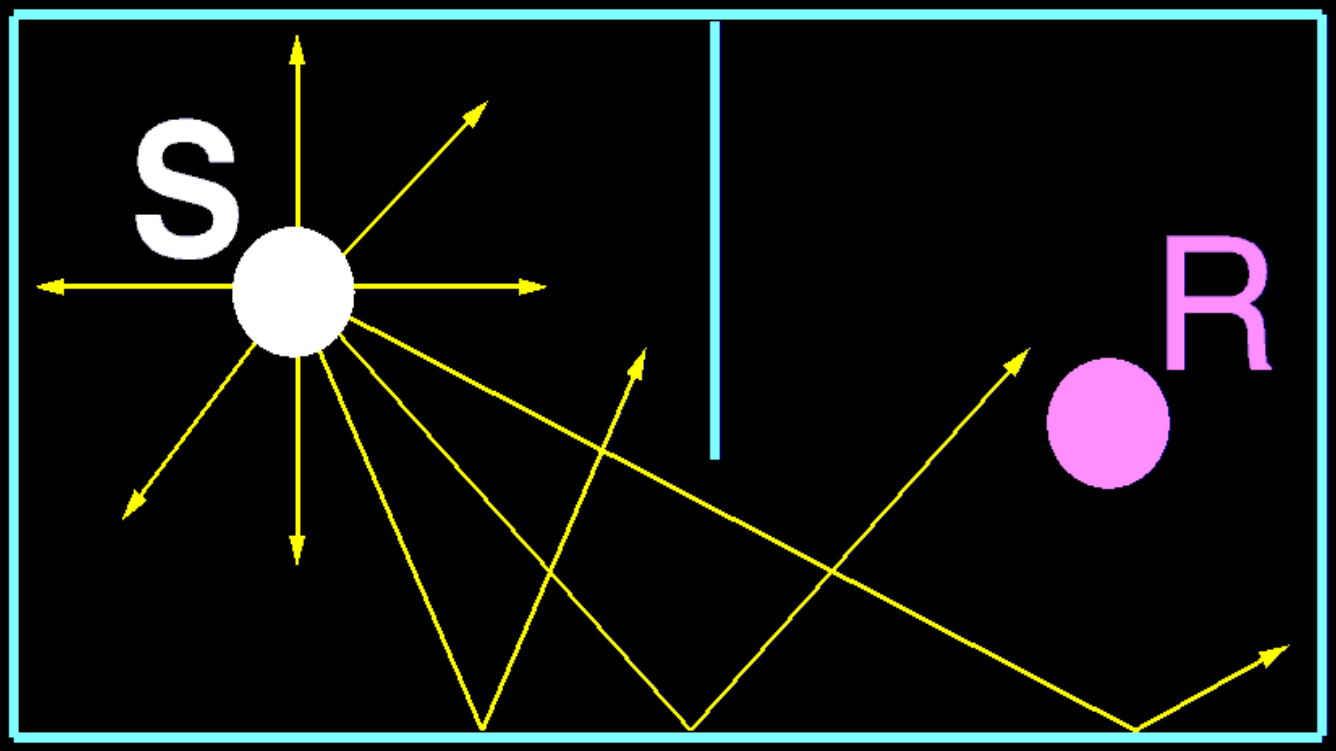


Model specular reflections with "virtual sources"

Geometric Path Tracing

Computational methods

- Image sources
- ➢ Ray tracing
- Beam tracing

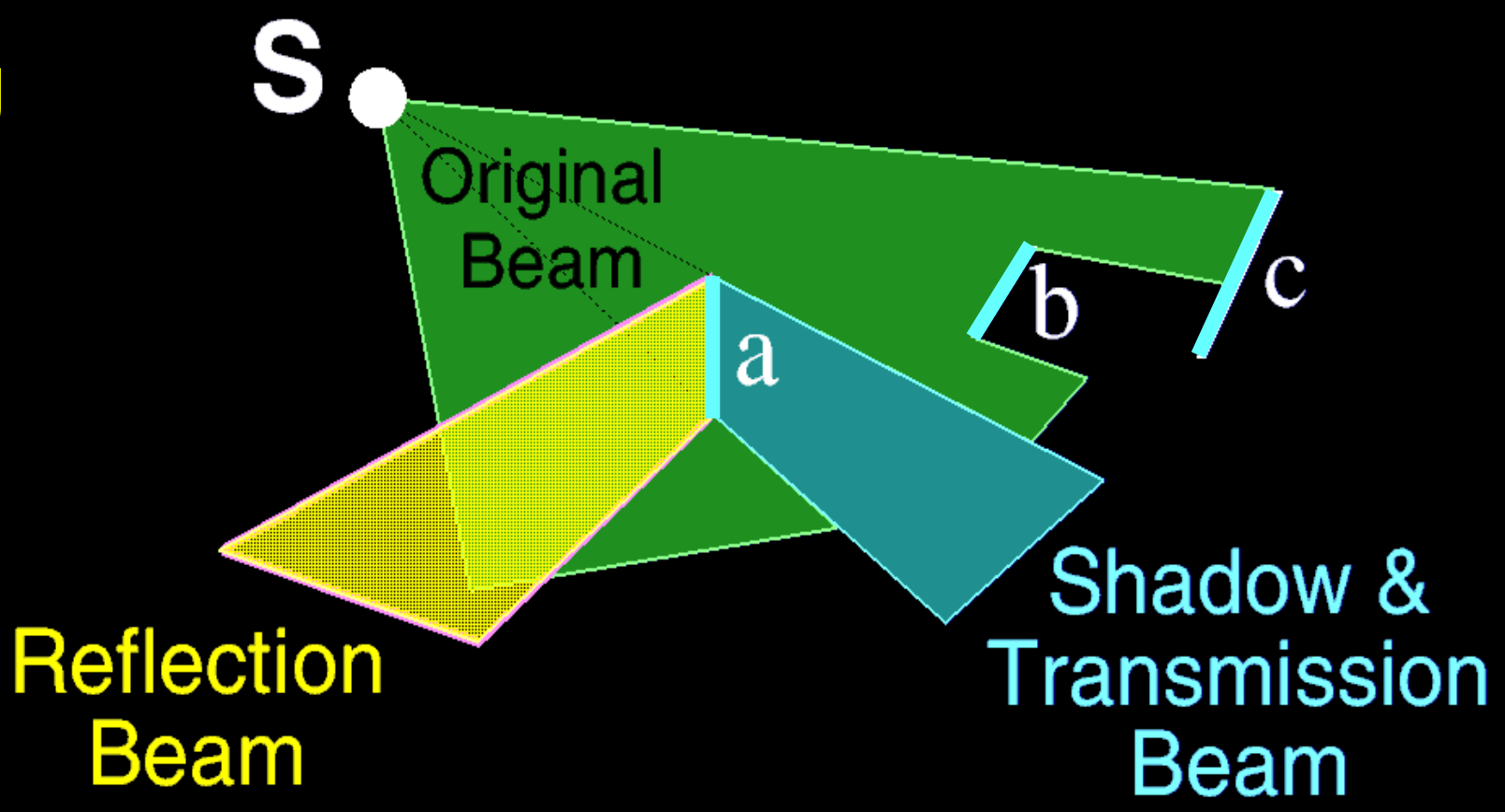


Trace rays from source

Geometric Path Tracing

Computational methods

- Image sources
- Ray tracing
- ➢ Beam tracing

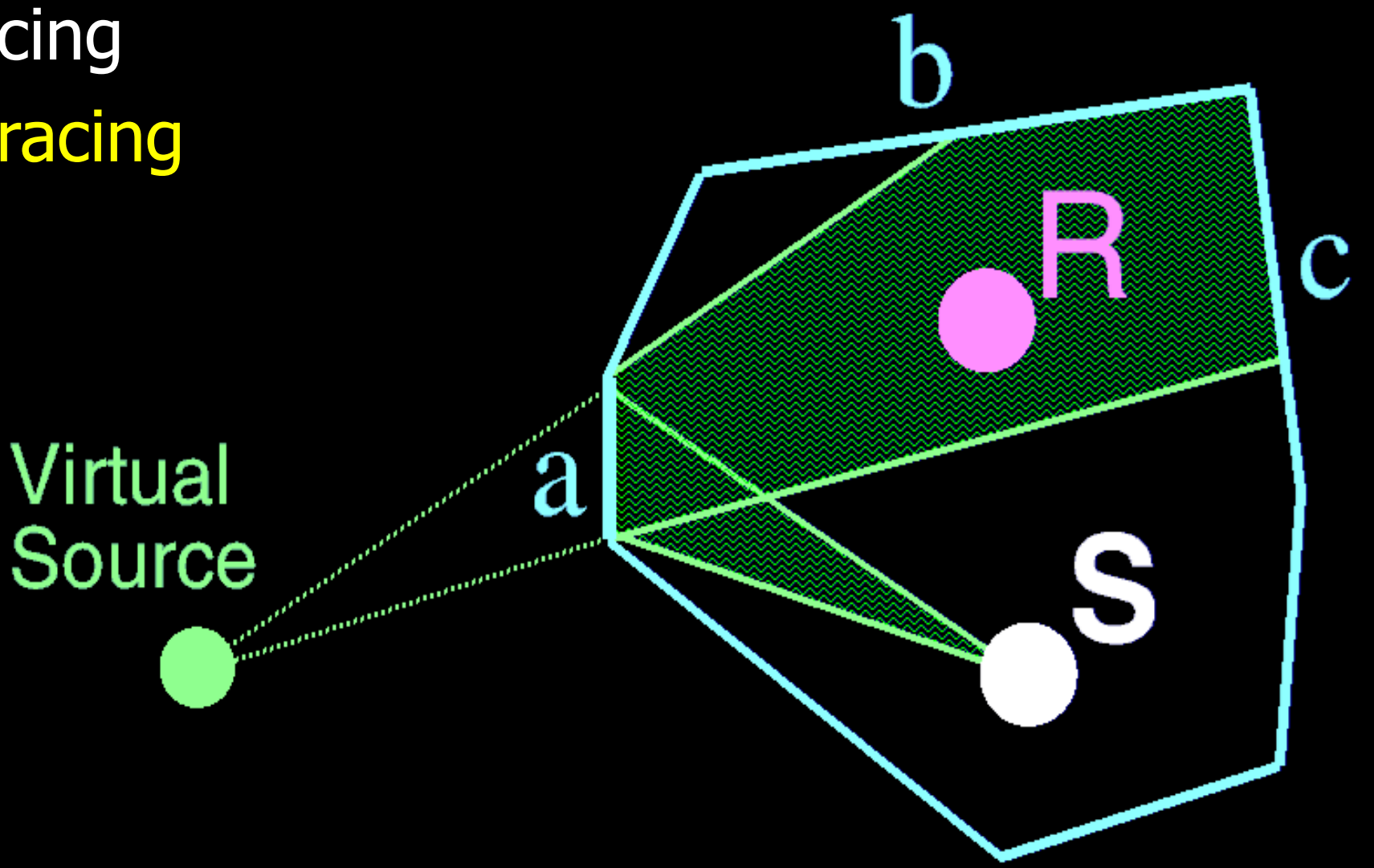


Trace beams (bundles of rays) from source

Geometric Path Tracing

Computational methods

- Image sources
- Ray tracing
- ➢ Beam tracing

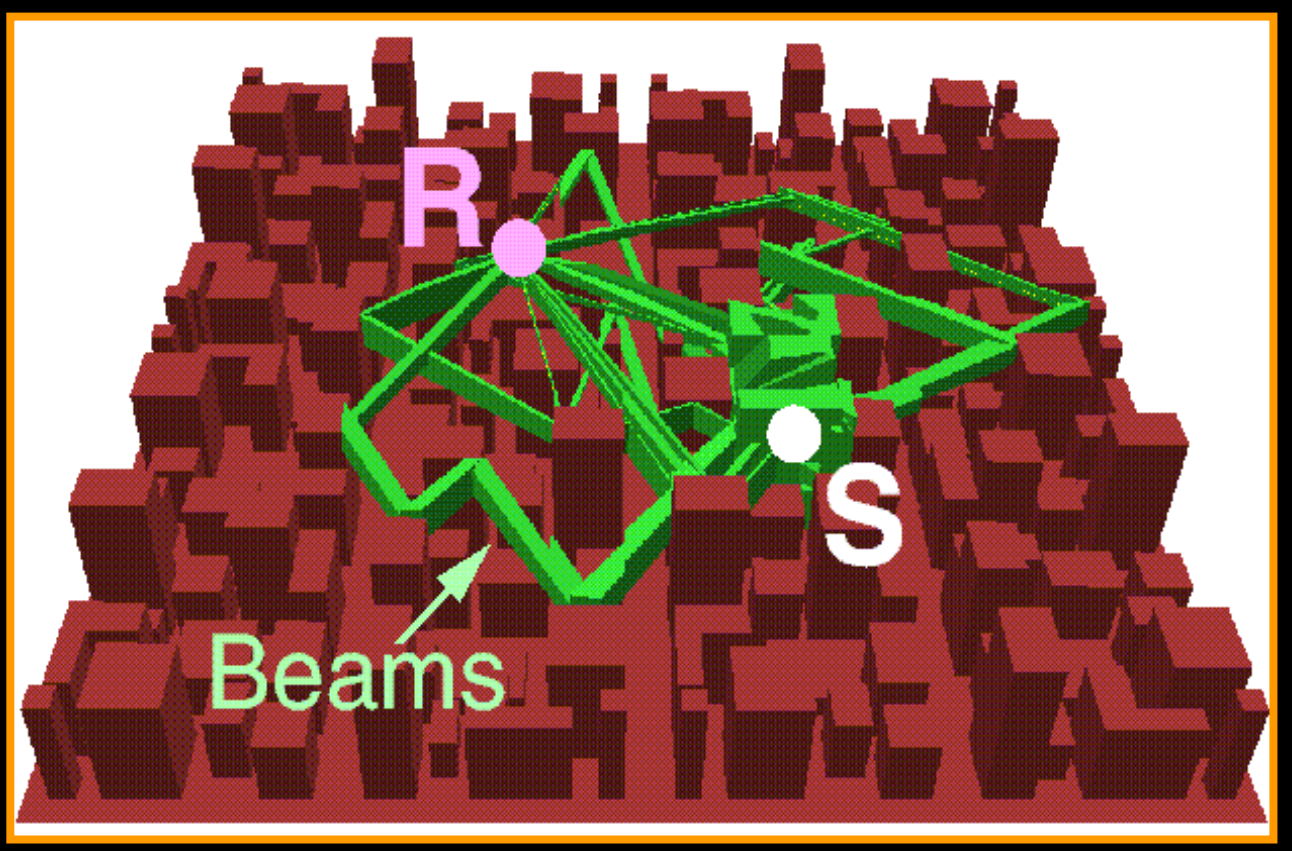


Beam Tracing Method

Key features

- Finds all propagation paths
- Models specular reflection, transmission, diffraction
- Updates at interactive rates as source/receiver move
- Scales for densely-occluded environments

Papers at
SIGGRAPH
1998, 1999, 2001



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- Moving sources

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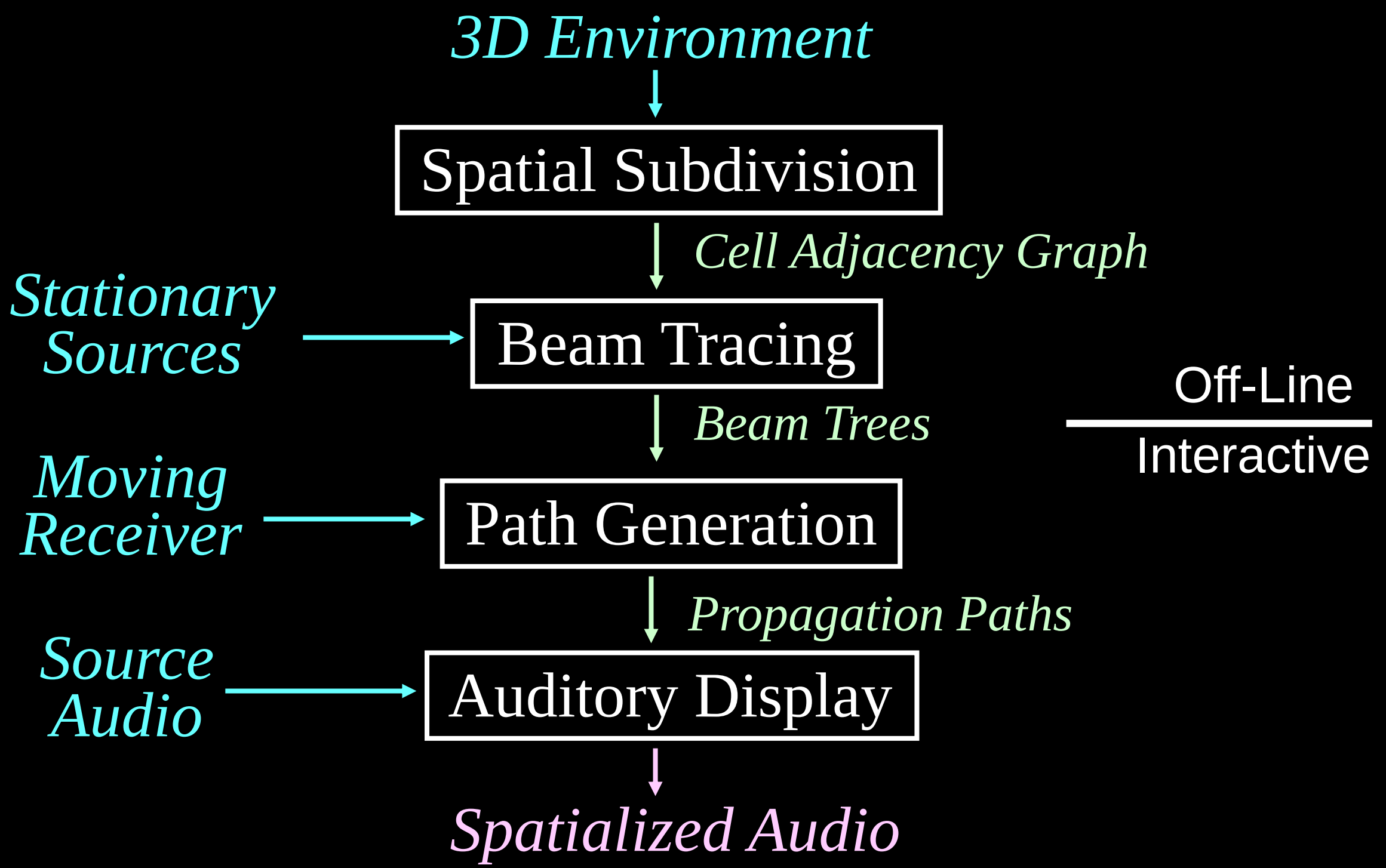
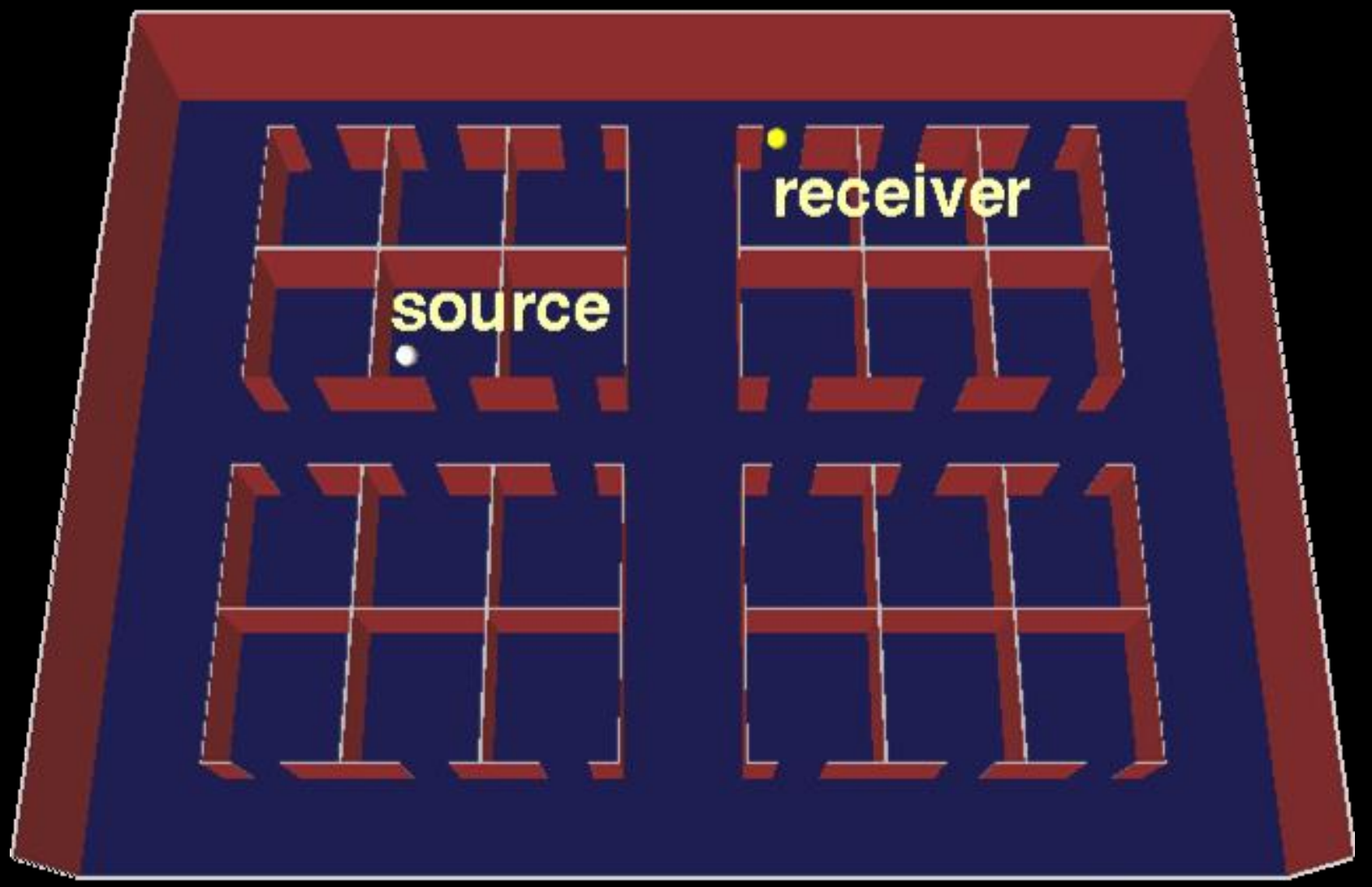
Beam Tracing Method

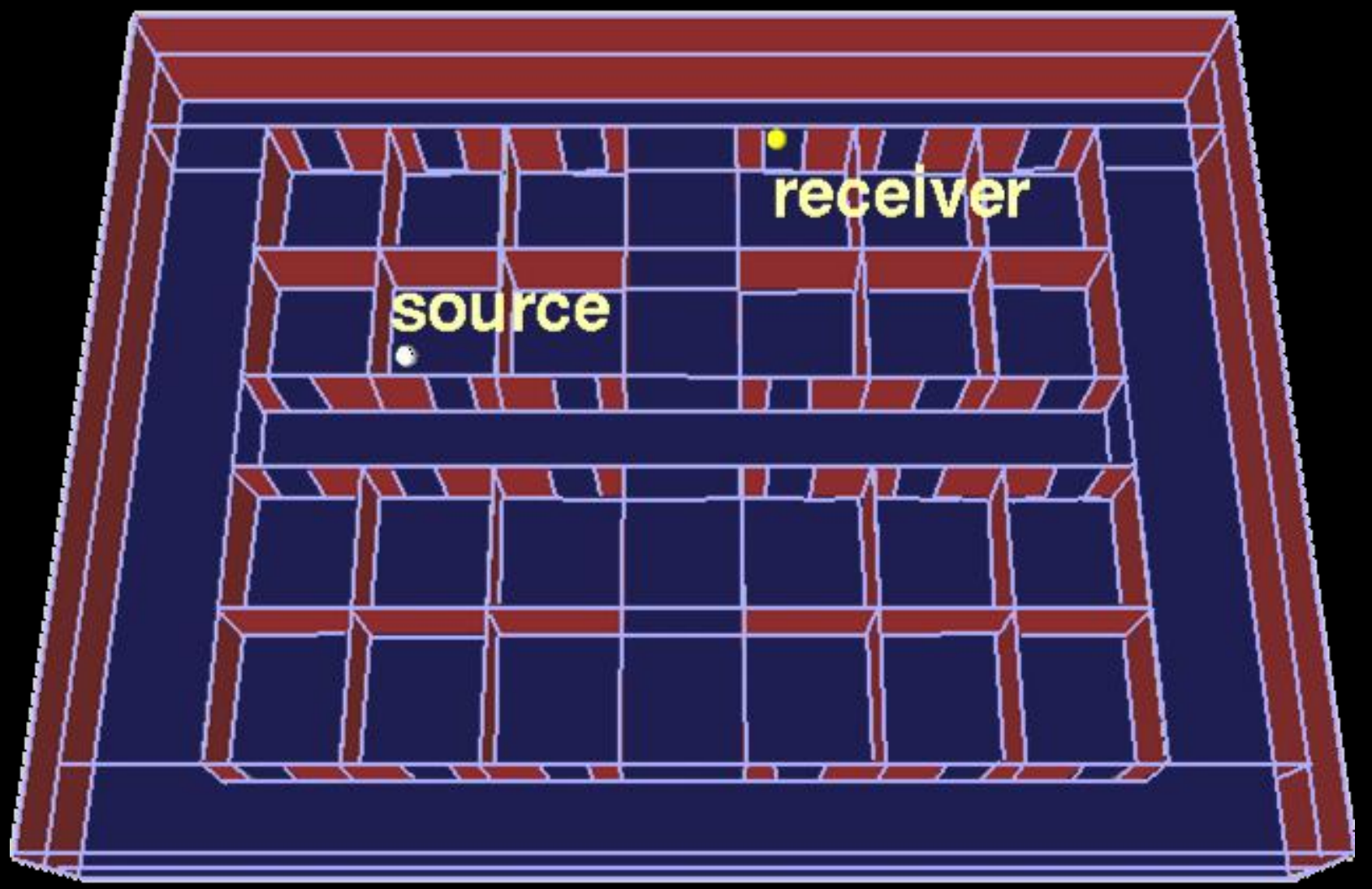


Beam Tracing Method

Input is source, receiver, and 3D environment



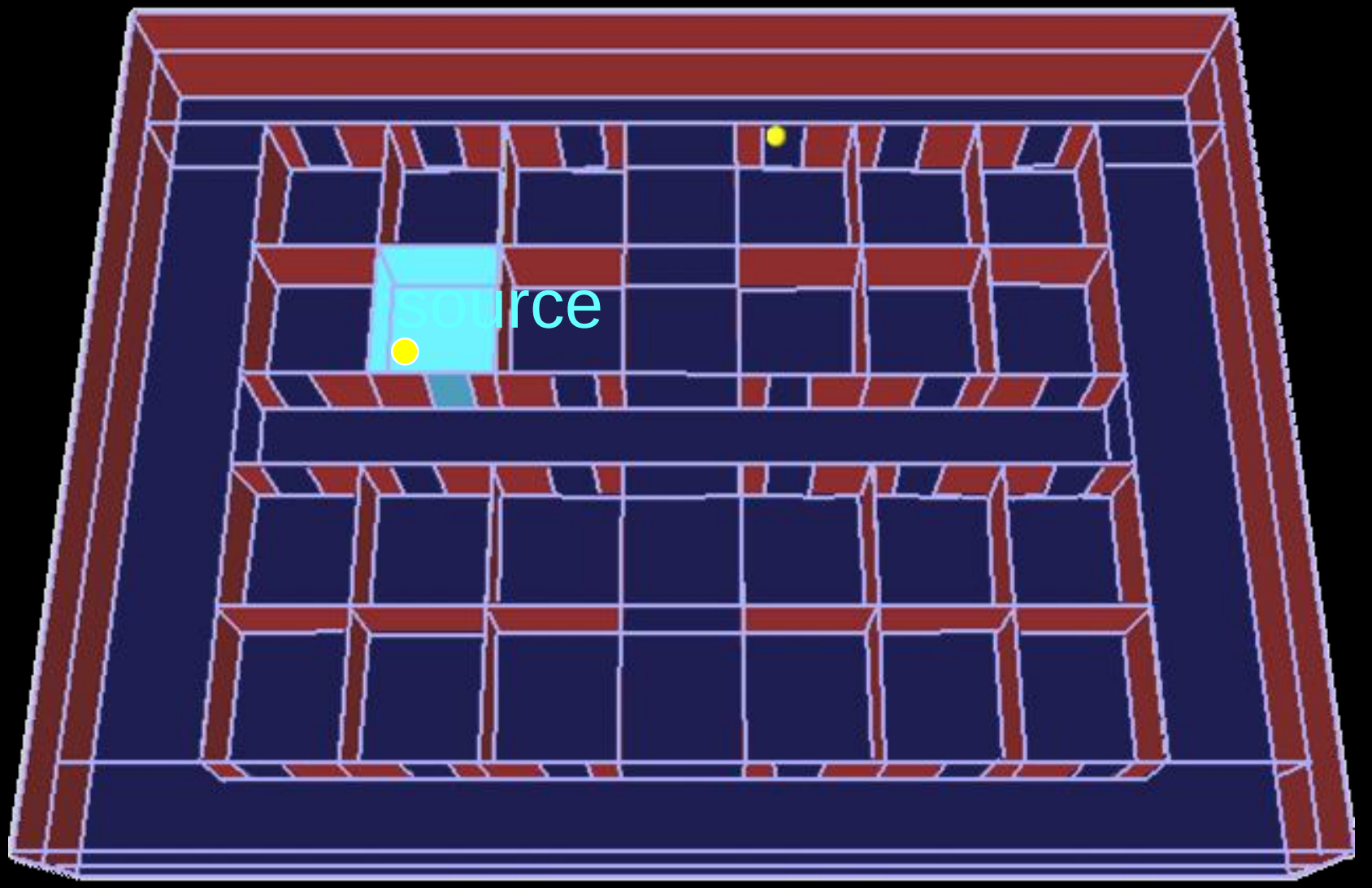
Step 1: Spatial Subdivision



Partition space into convex polyhedral cells

Step 2: Beam Tracing

Trace beams through cell adjacency graph



Step 2: Beam Tracing

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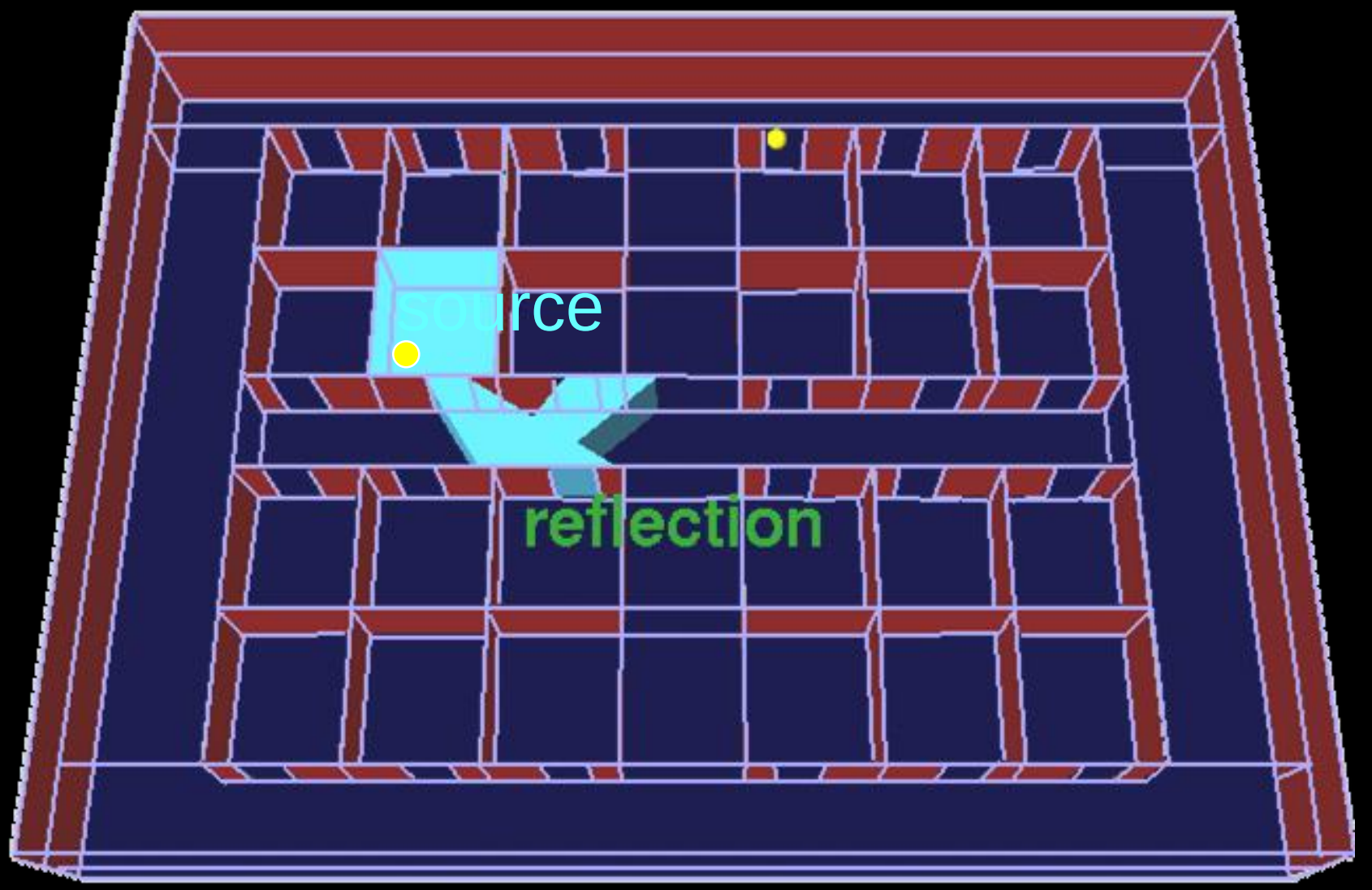

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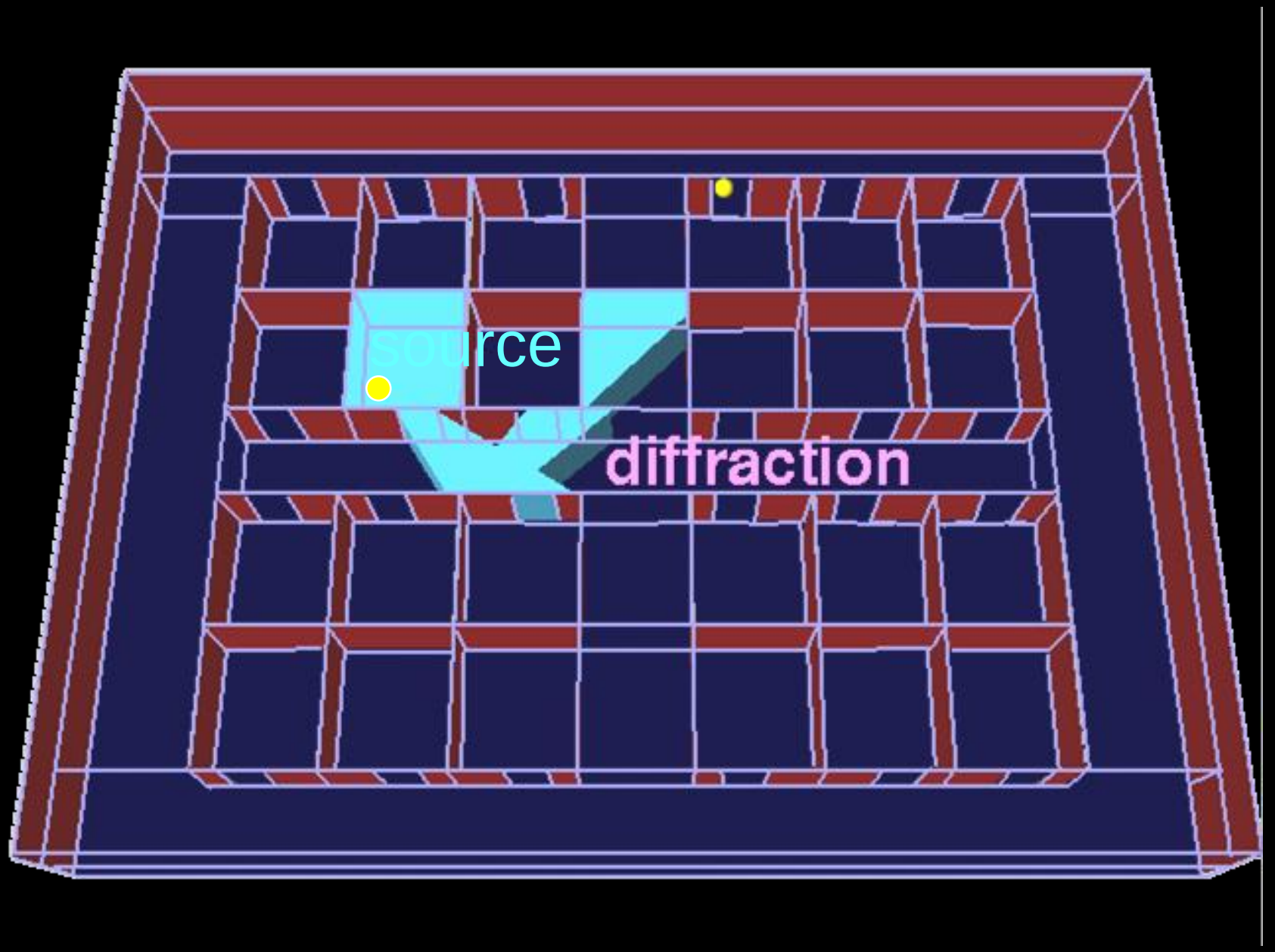

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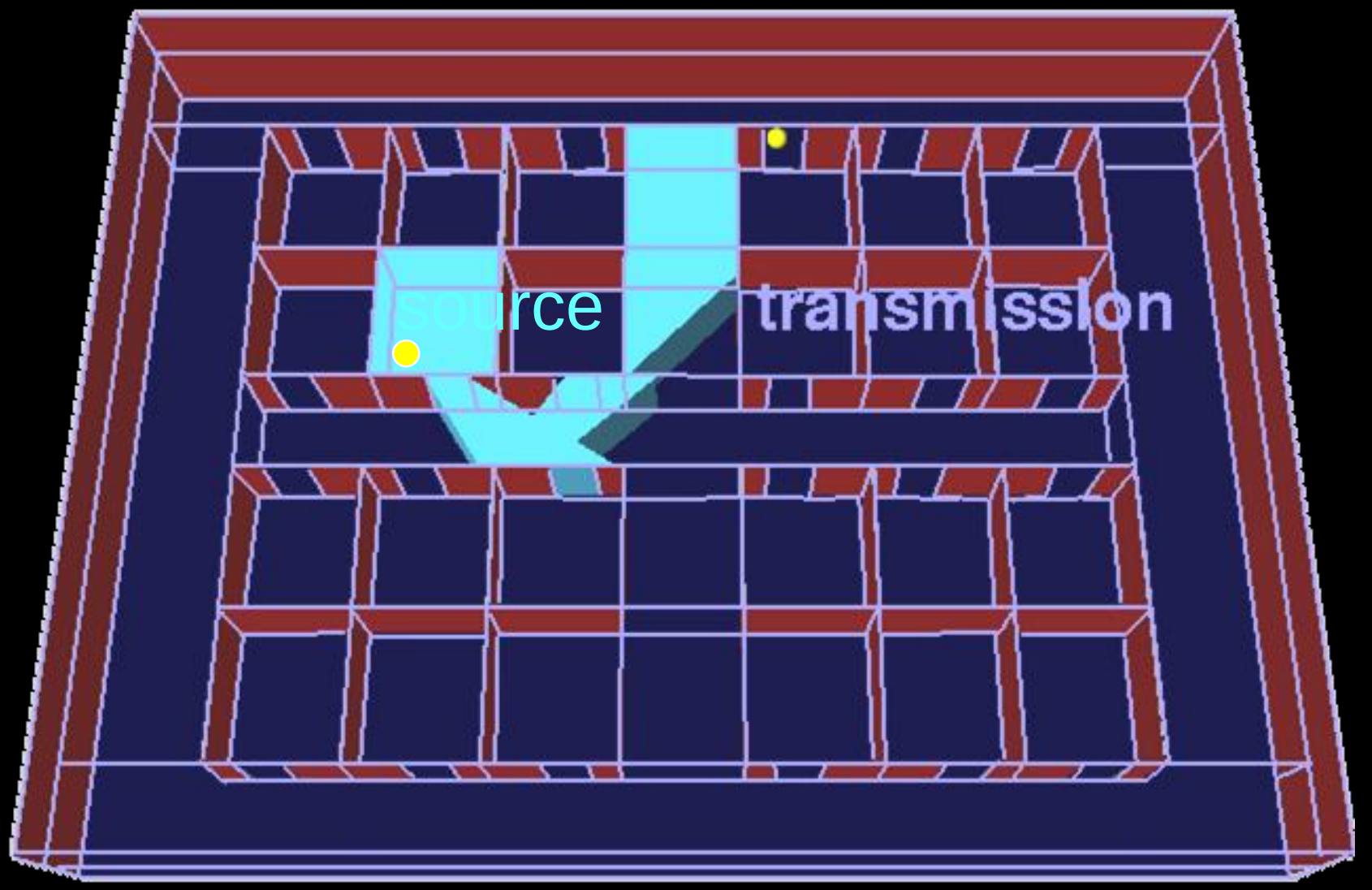

Step 2: Beam Tracing

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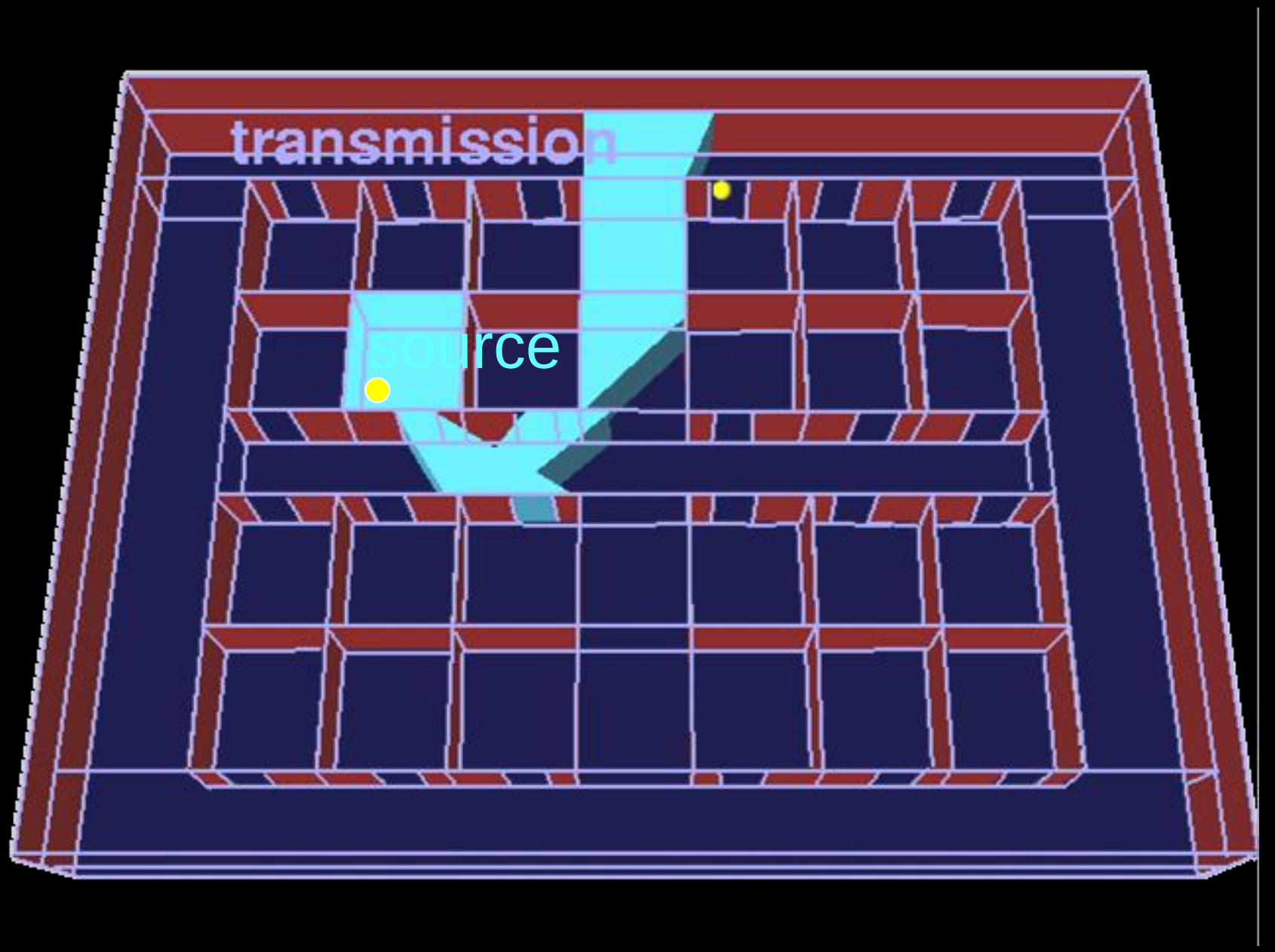

Step 2: Beam Tracing

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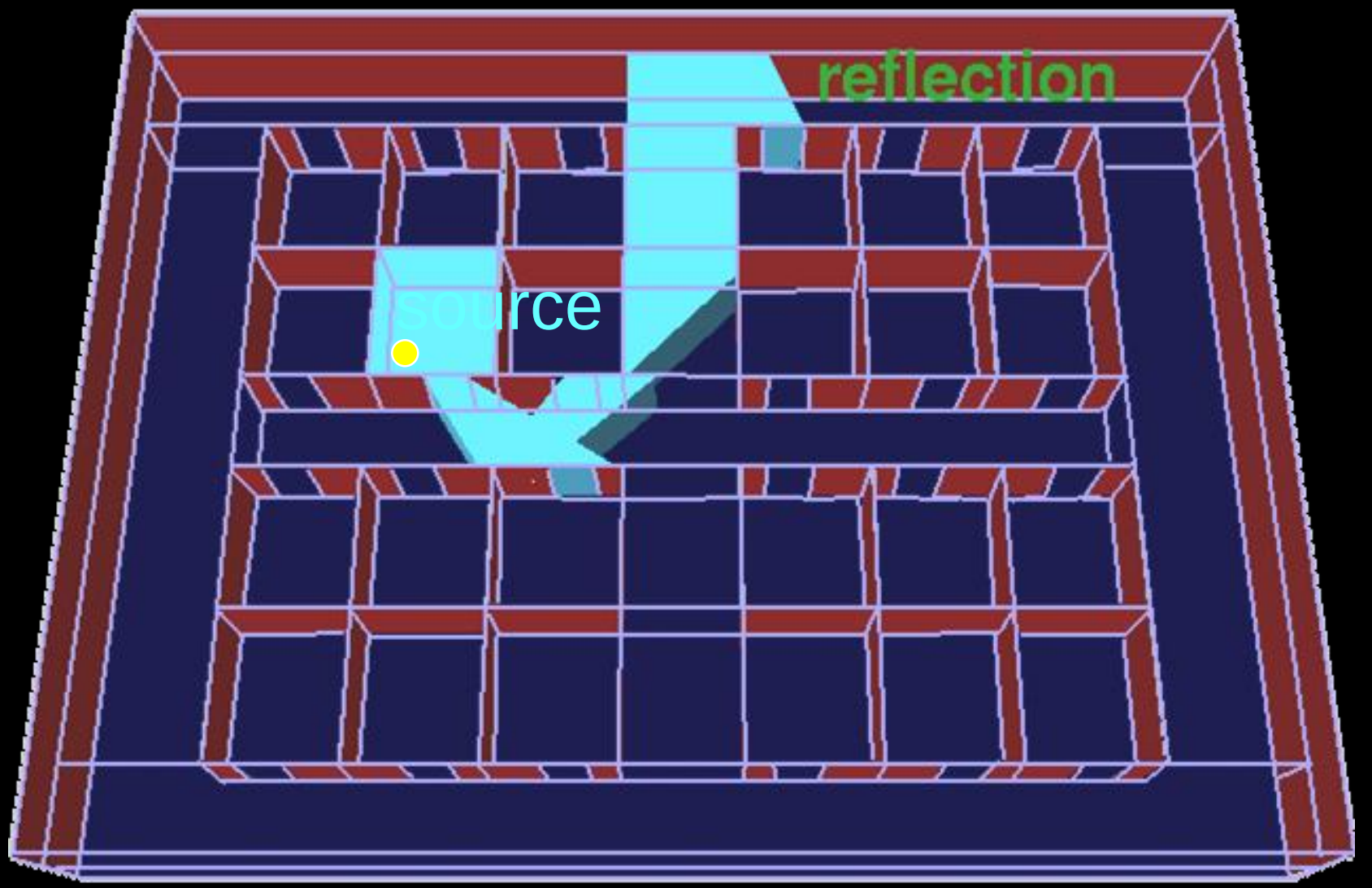
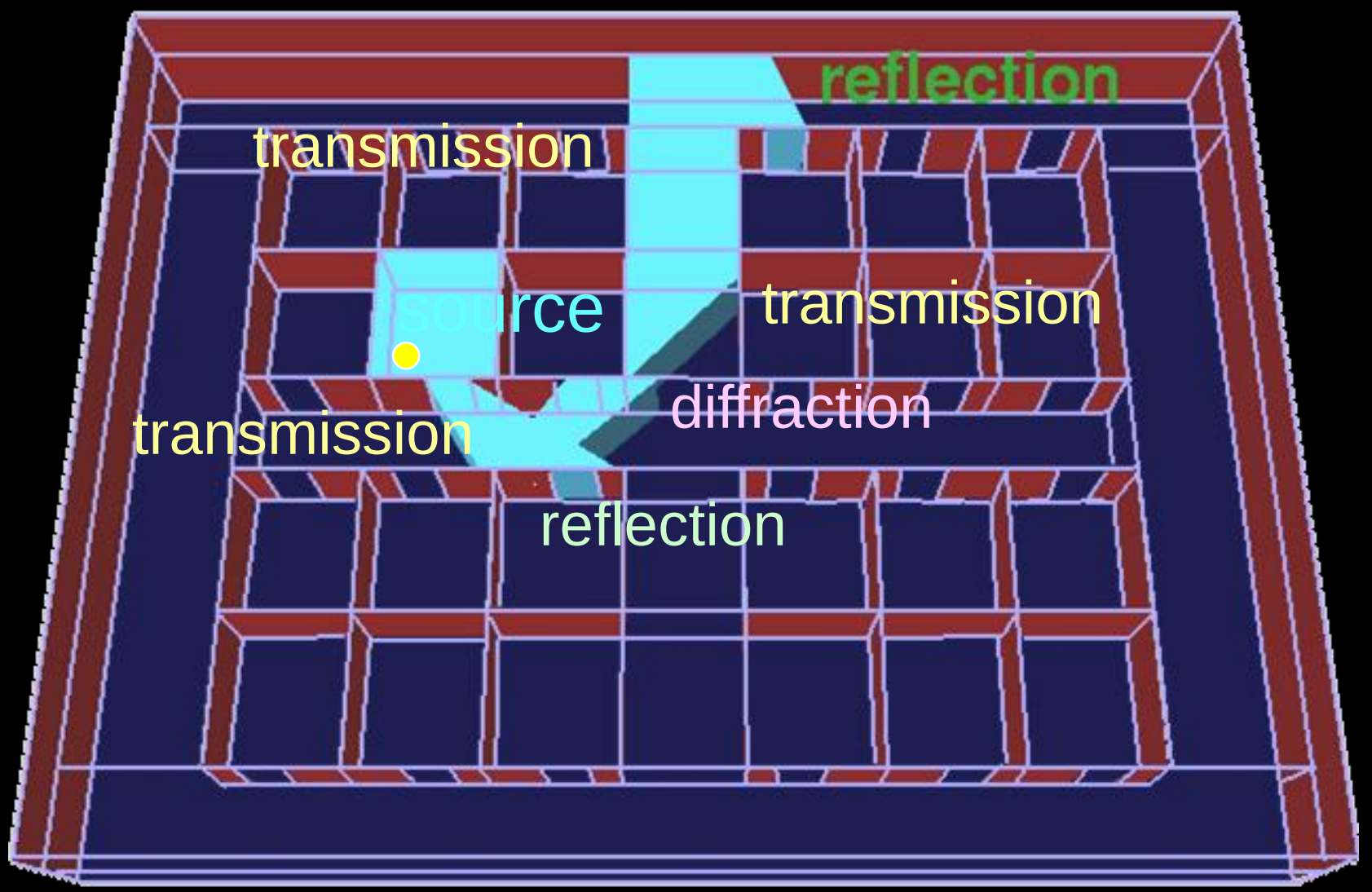


Step 2: Beam Tracing

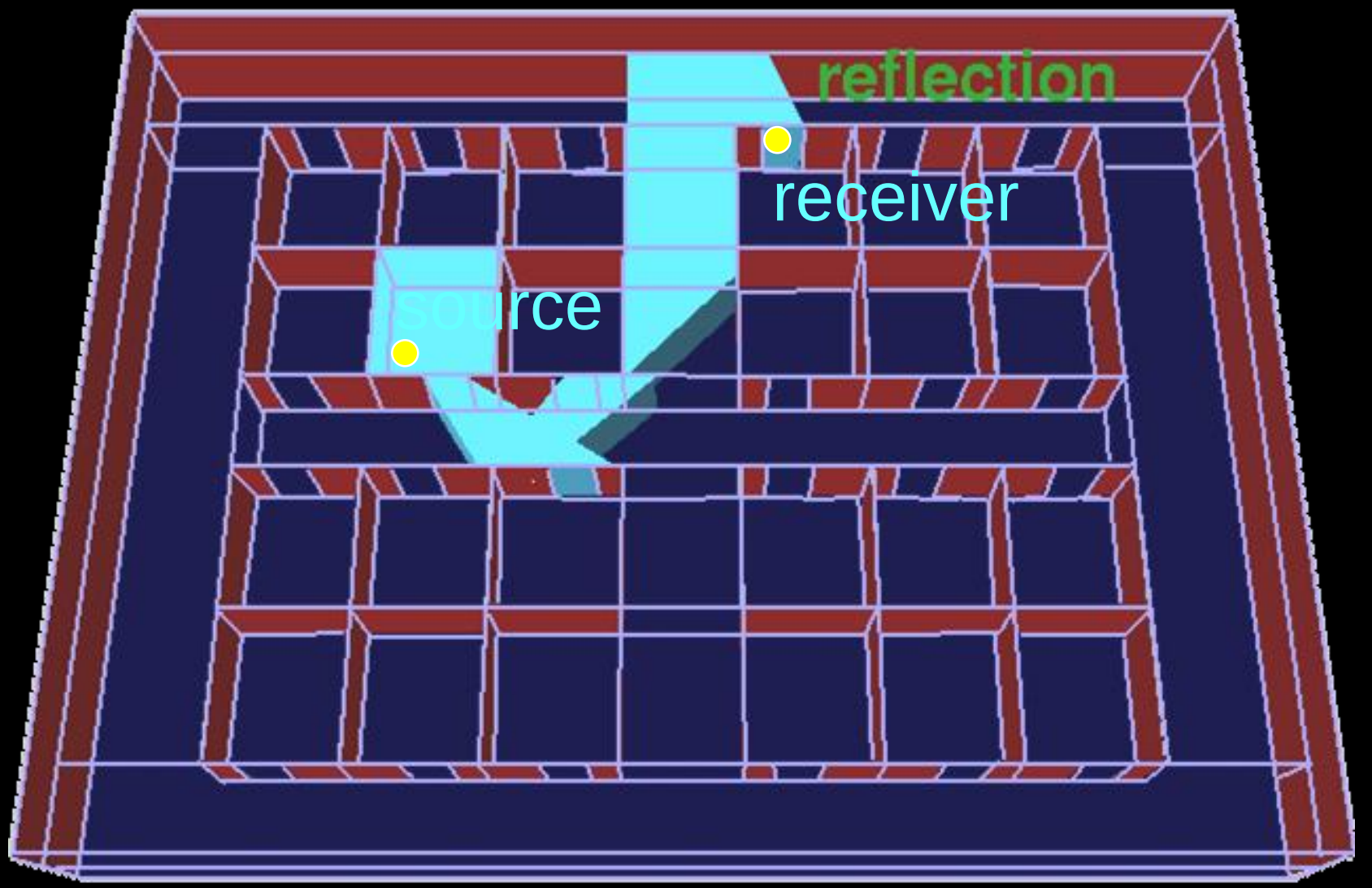
Store all beams in a tree data structure



Beam tree encodes regions reached by different sequences of scattering from source

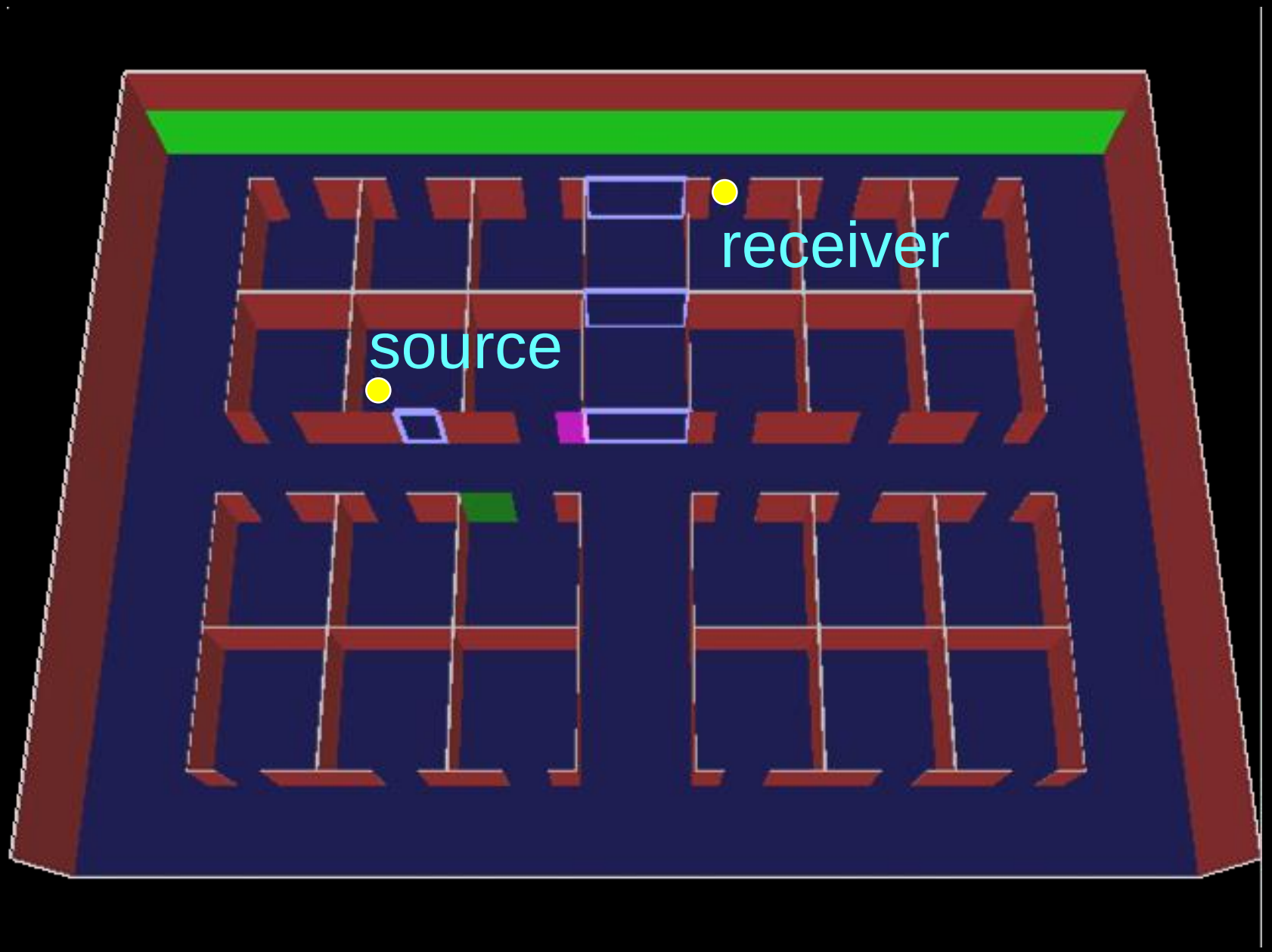
Step 3: Path Generation

For each beam containing receiver ...



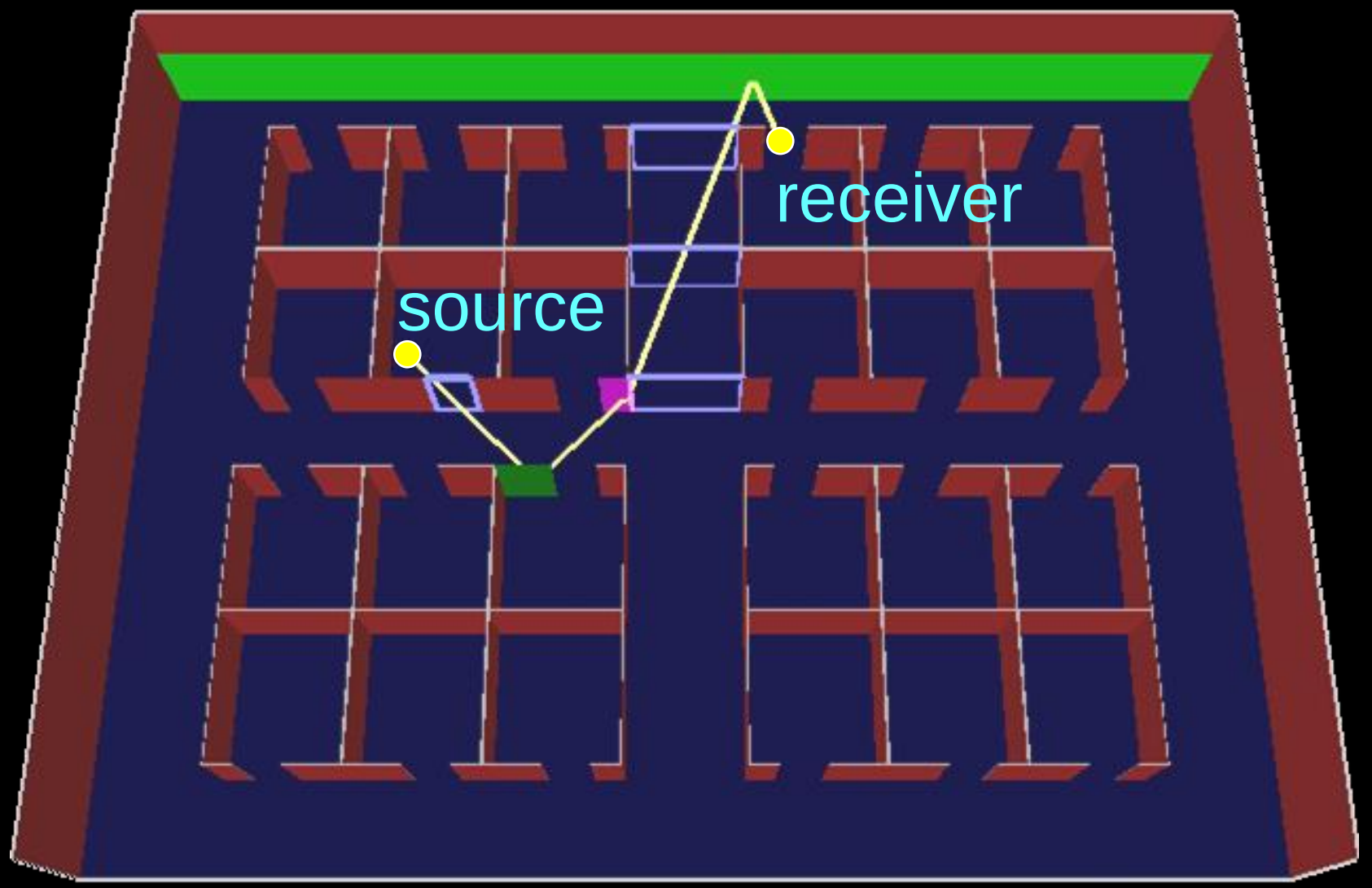
Step 3: Path Generation

Lookup propagation sequence in beam tree



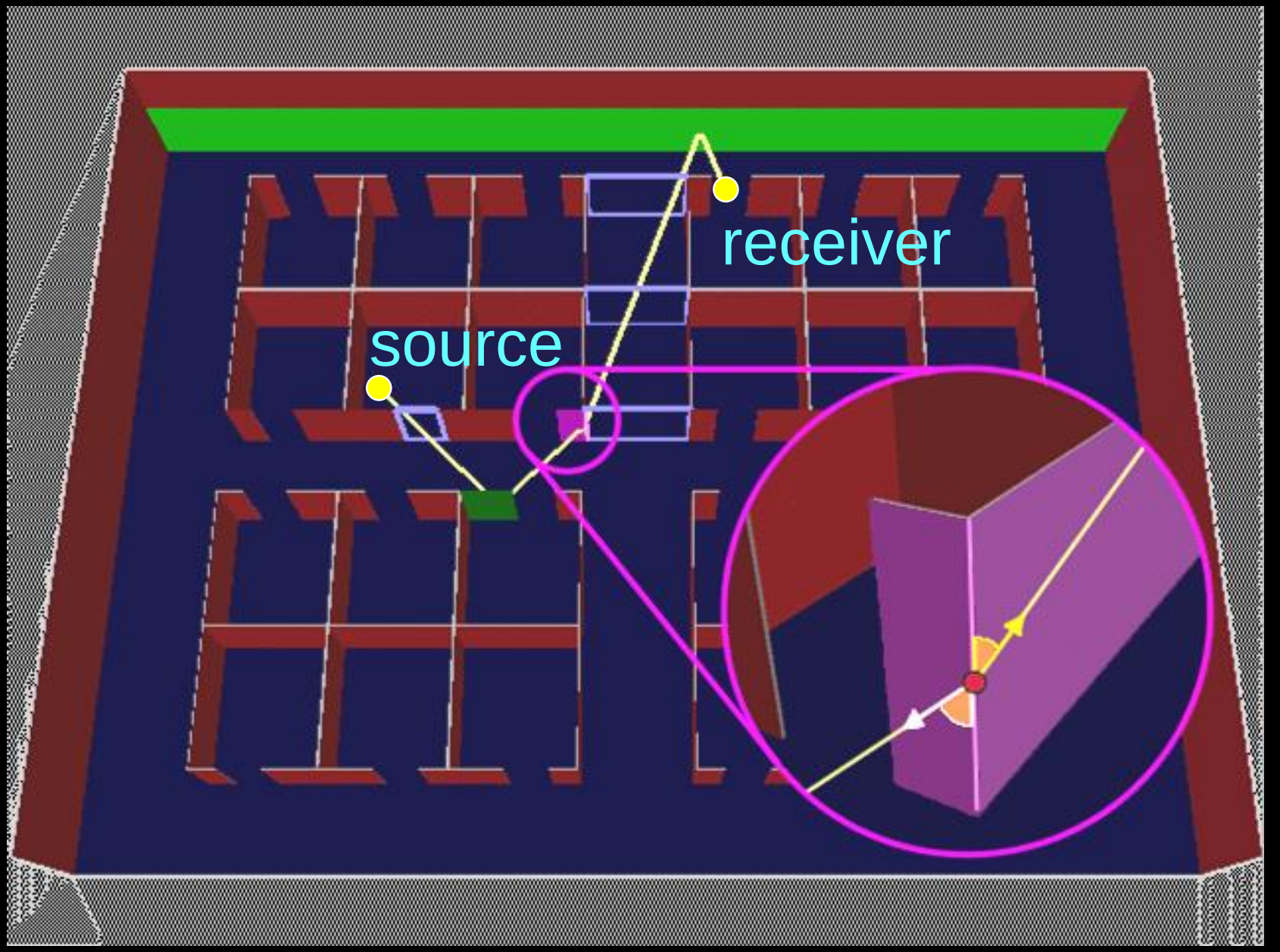
Step 3: Path Generation

Construct shortest path along sequence



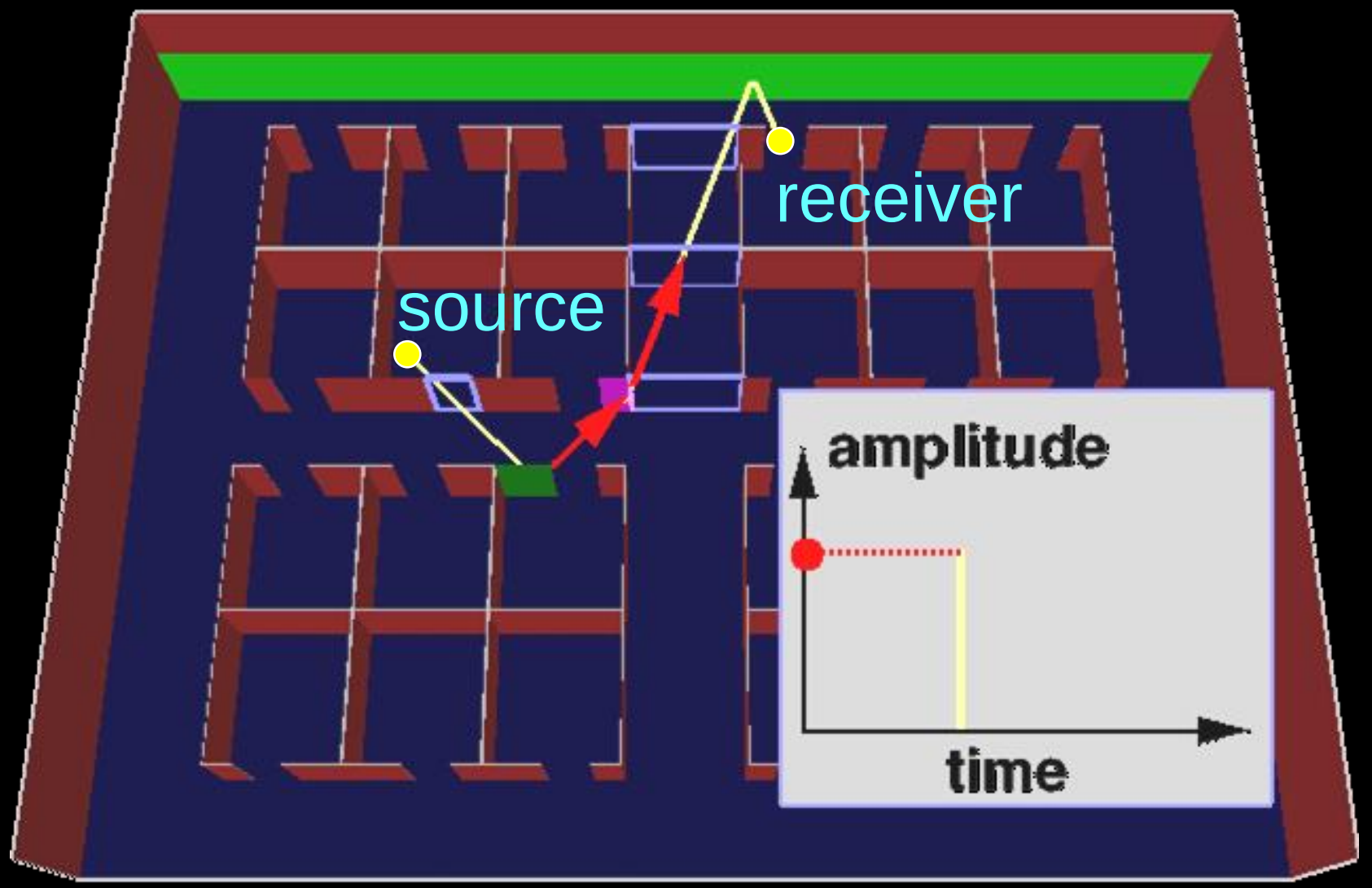
Step 3: Path Generation

Solve equal angle constraints for diffractions



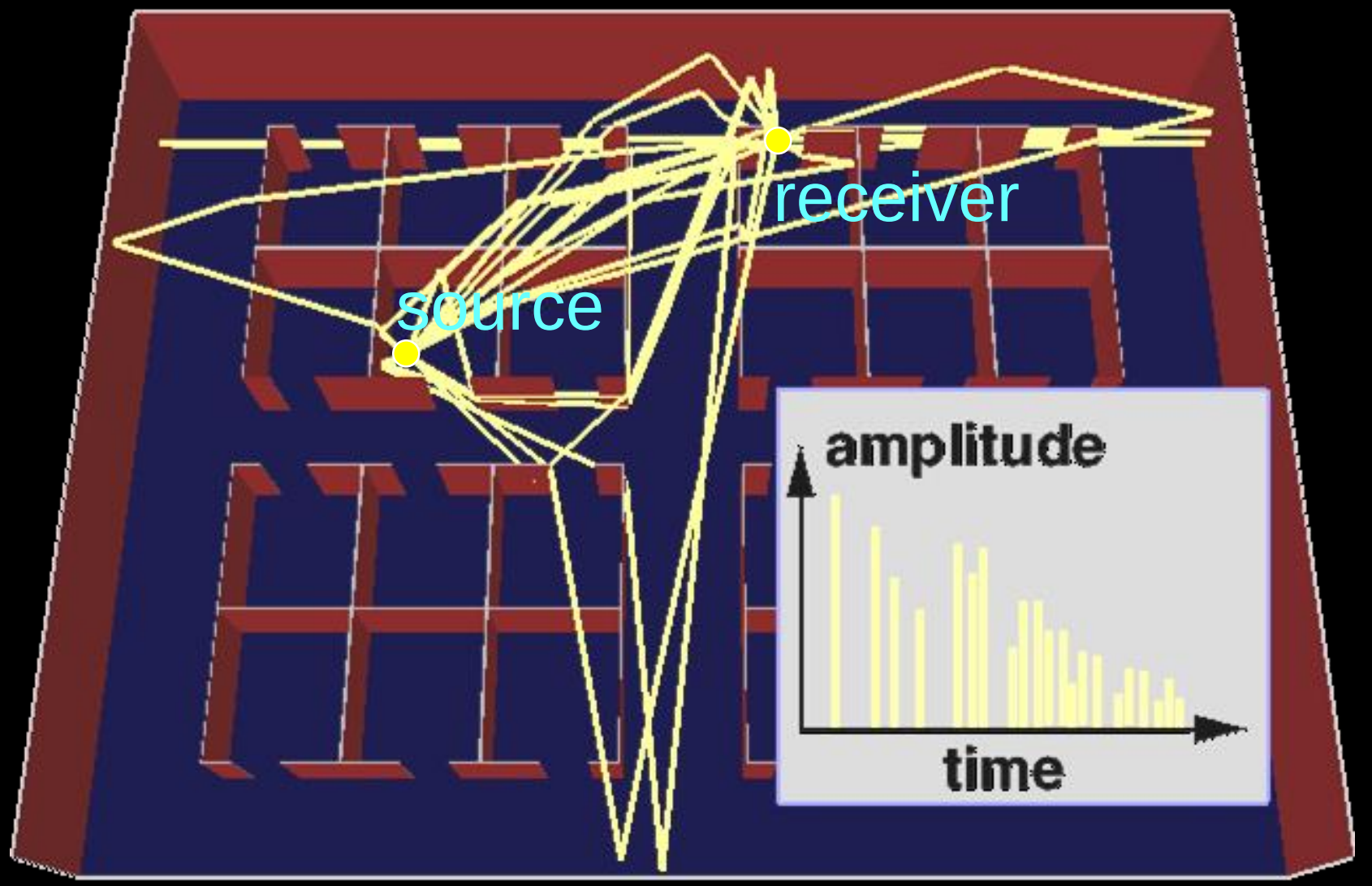
Step 4: Auralization

Apply filter for each propagation path

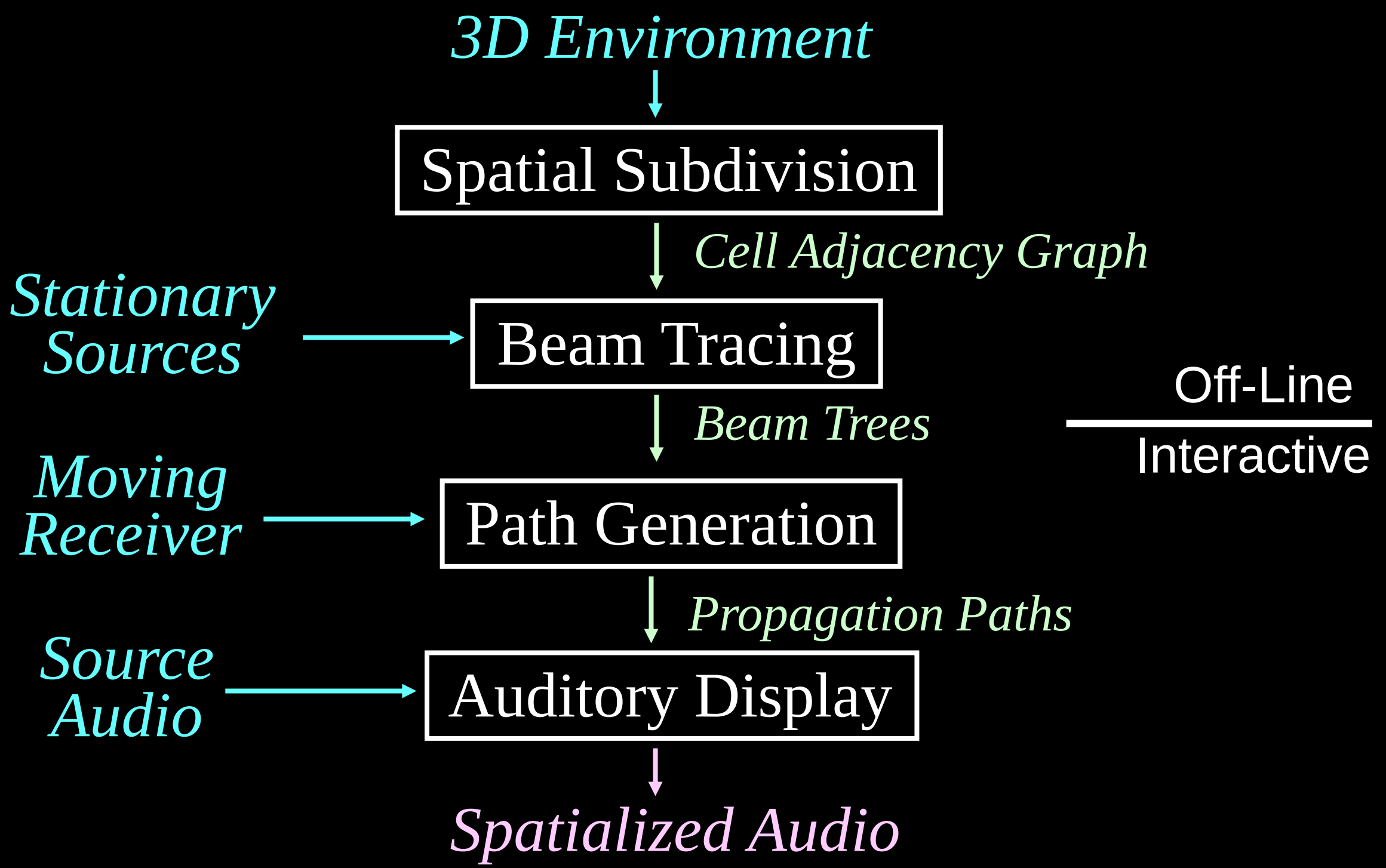


Step 4: Auralization

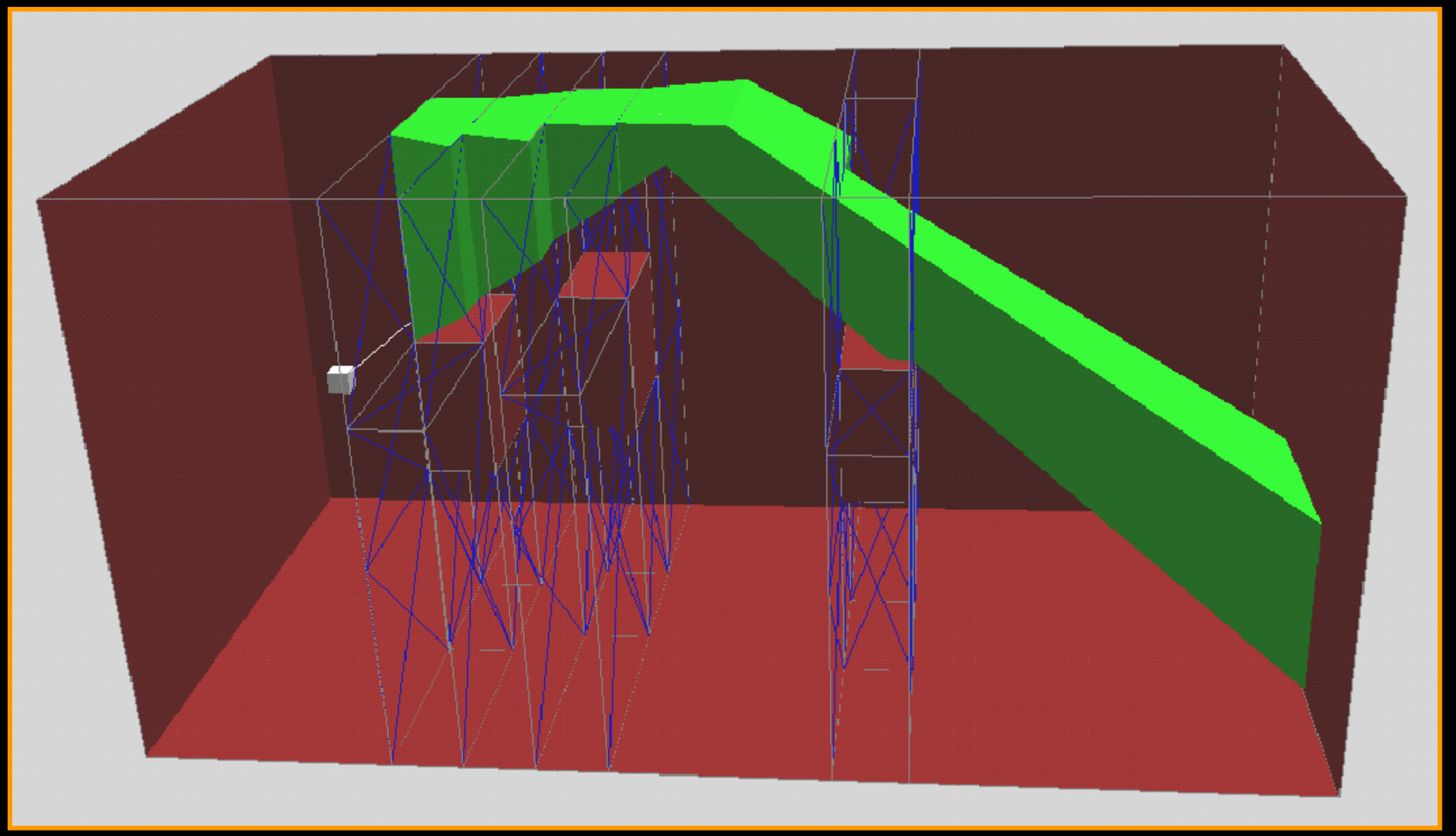
Combine paths to model early response



Beam Tracing Method

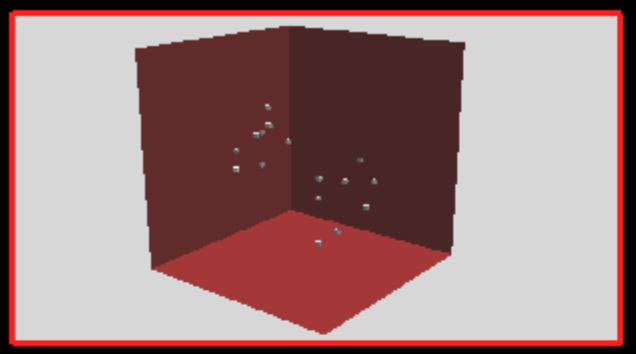


Beam Tracing Demo

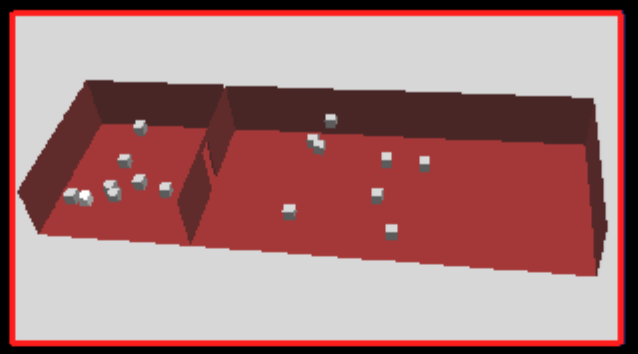


Experimental Results

Test propagation path update rates in
large environments with several reflections

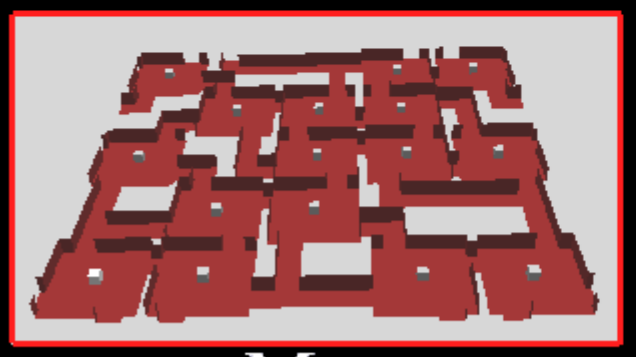


Box
6 Polygons

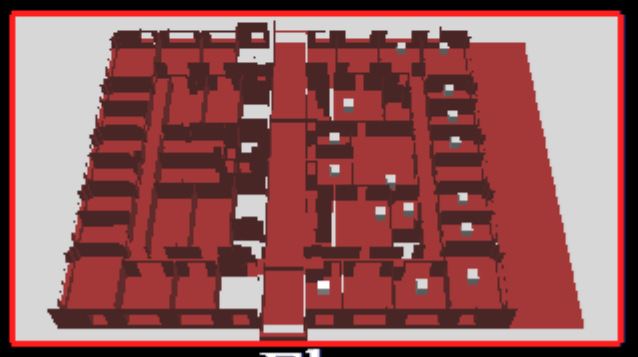


Rooms
20 Polygons

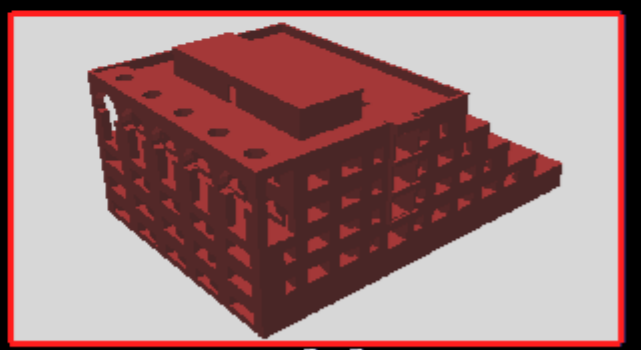
Suite
184 Polygons



Maze
602 Polygons



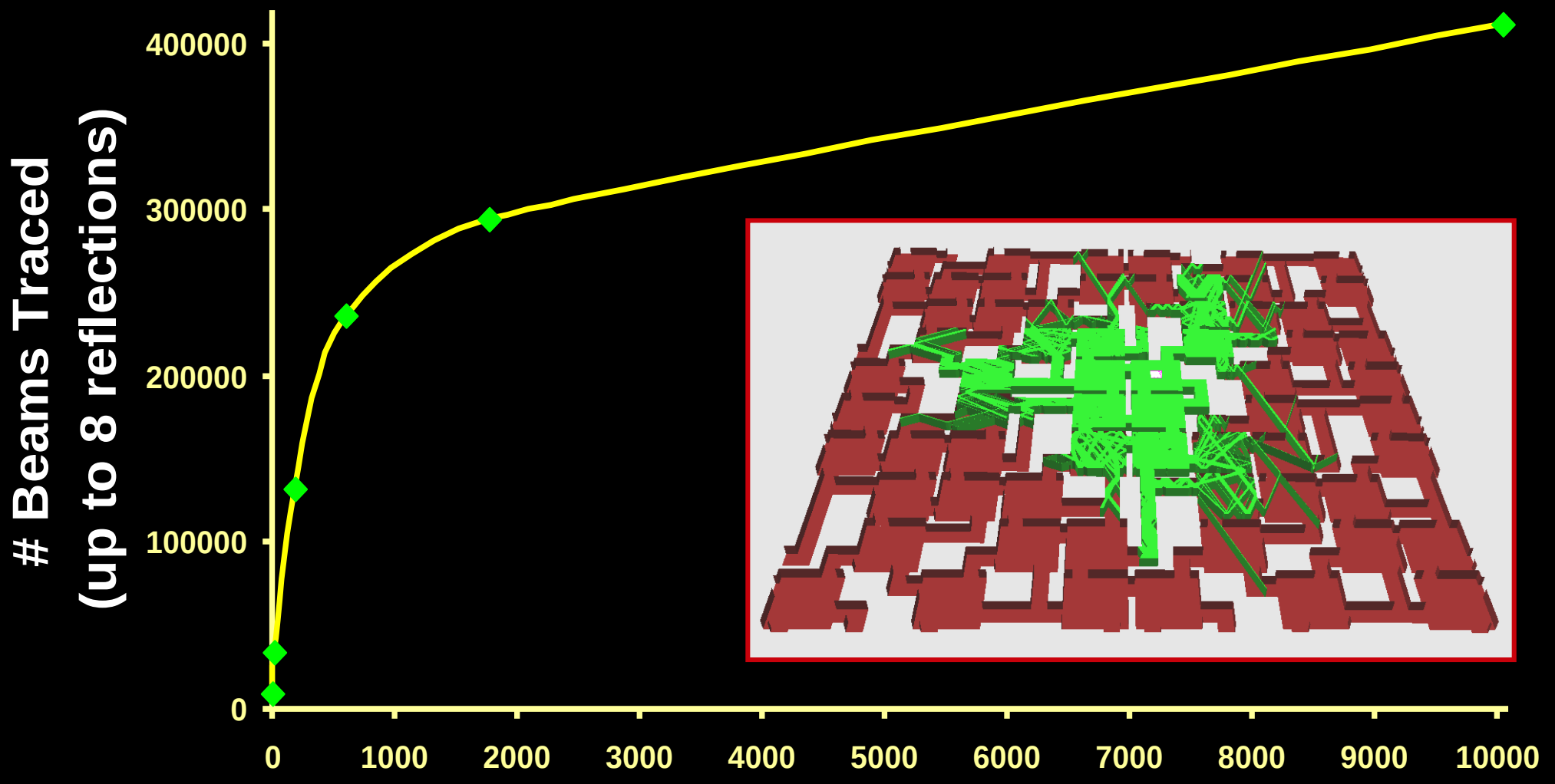
Floor
1,772 Polygons



Building
10,057 Polygons

Beam Tracing Results

Beam tree does not necessarily grow with global complexity of environment

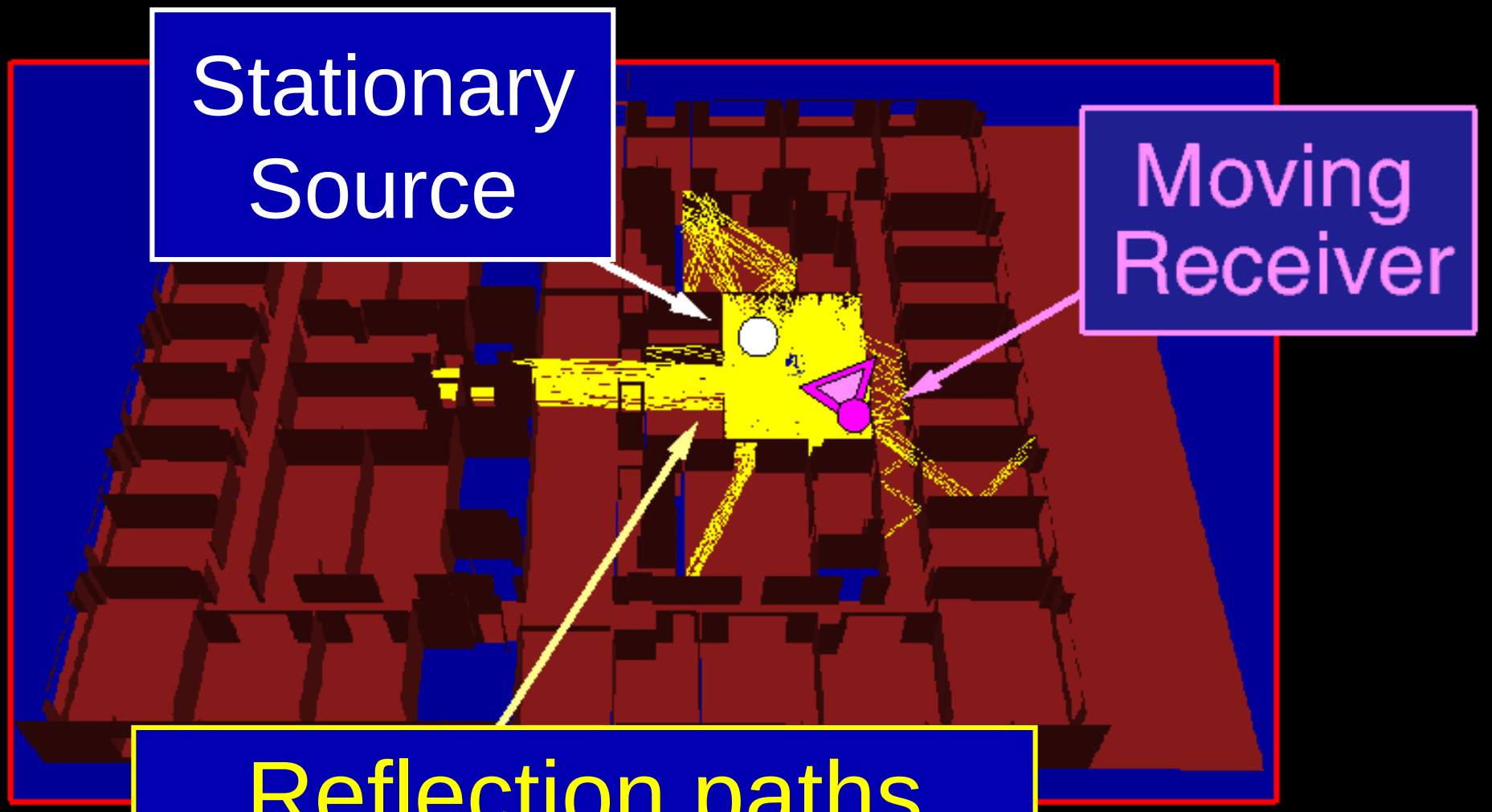


Path Generation Results

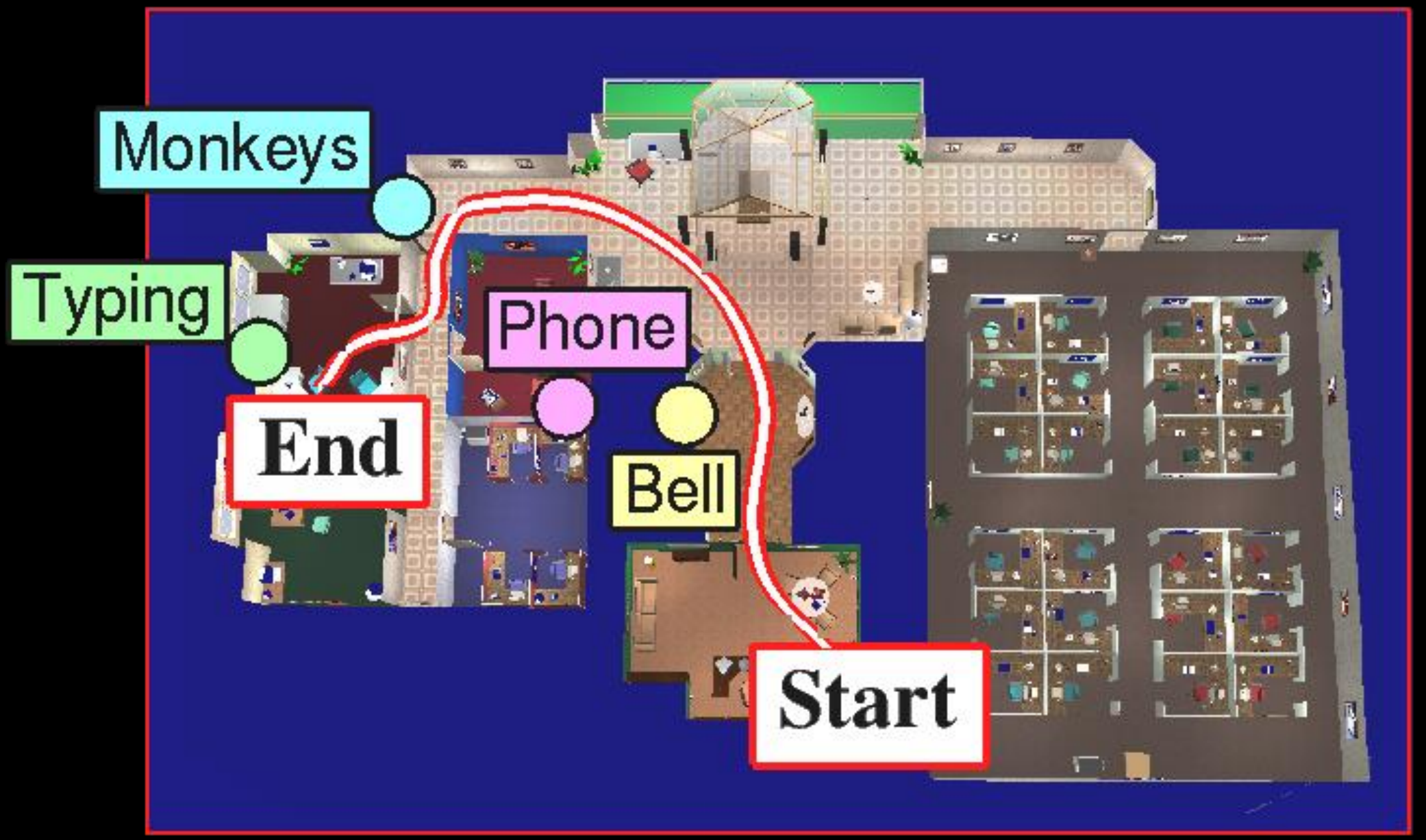
Propagation paths updated interactively …
even for large environments

195MHz CPU (1998)

Path Generation Demo



Auralization Video I

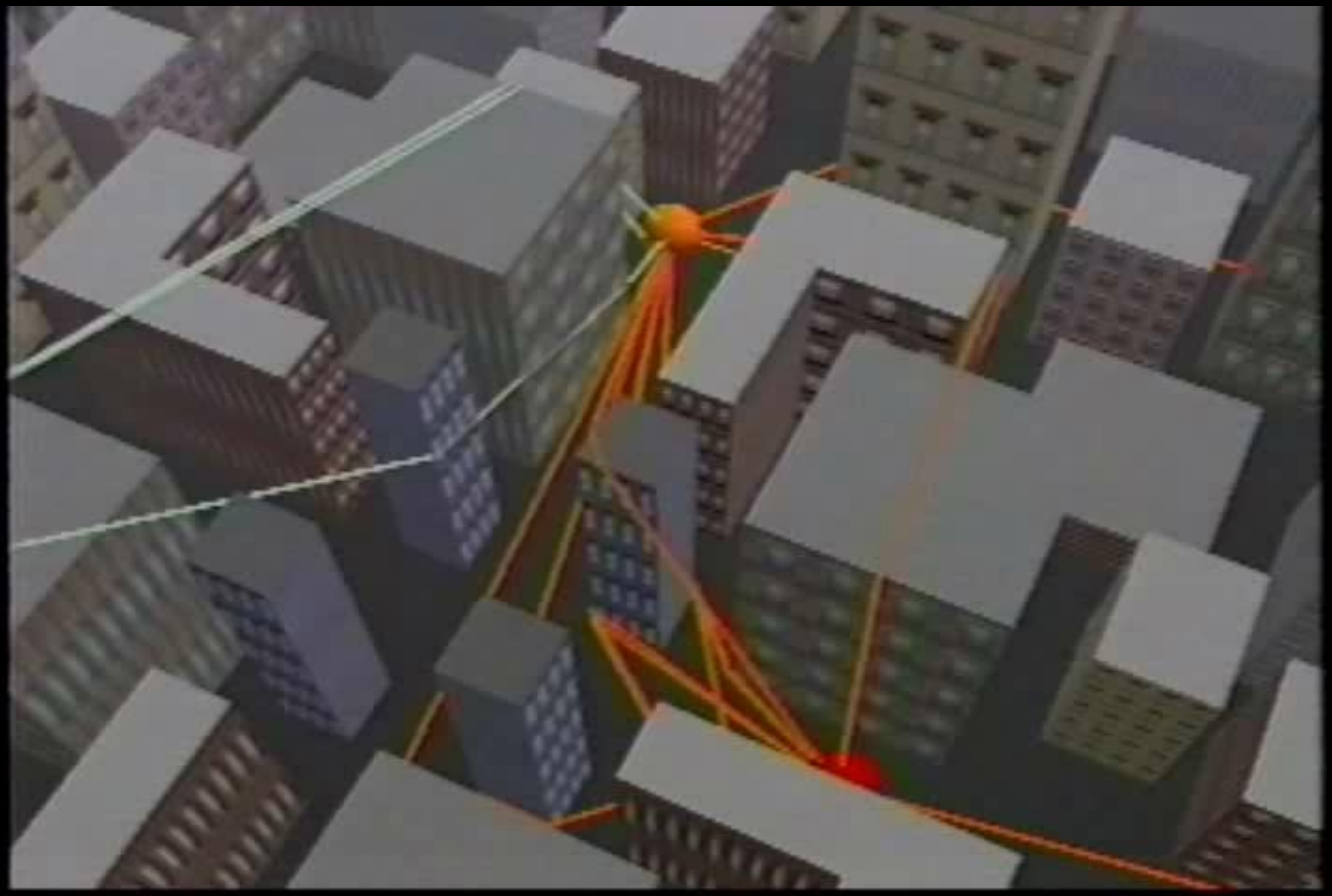


Specular reflection only

Auralization Video I

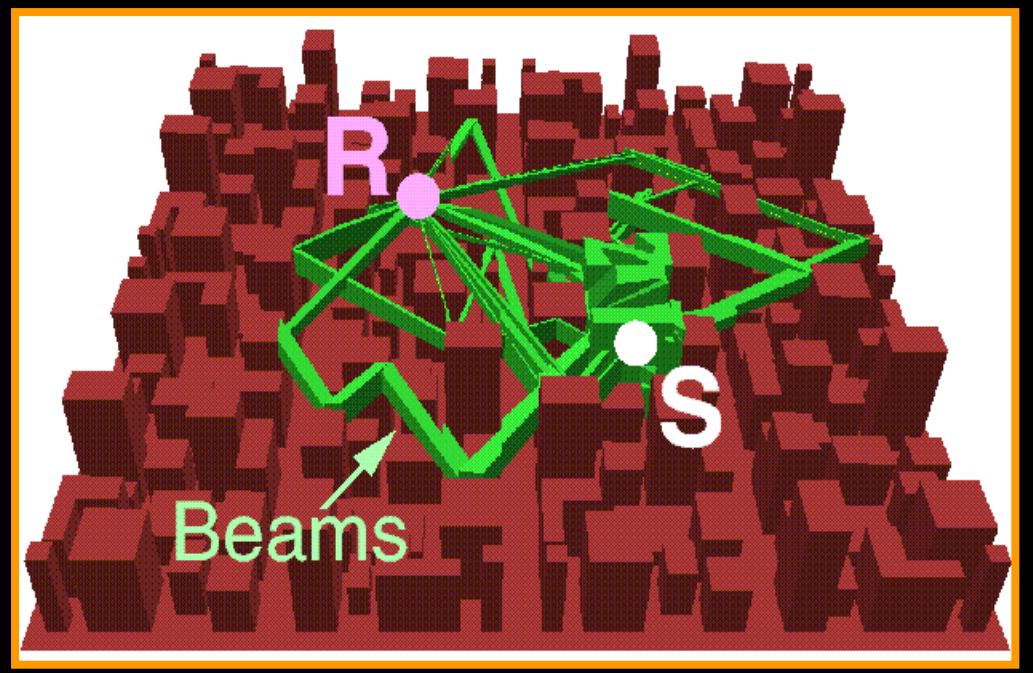
Specular reflection only

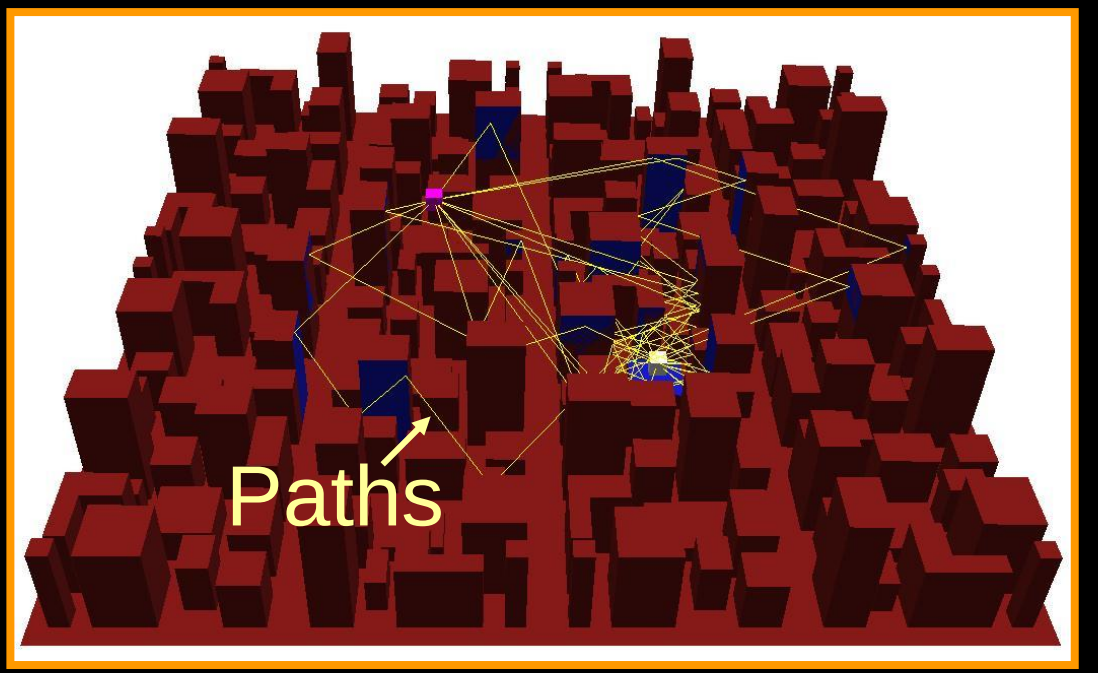
Auralization Video II

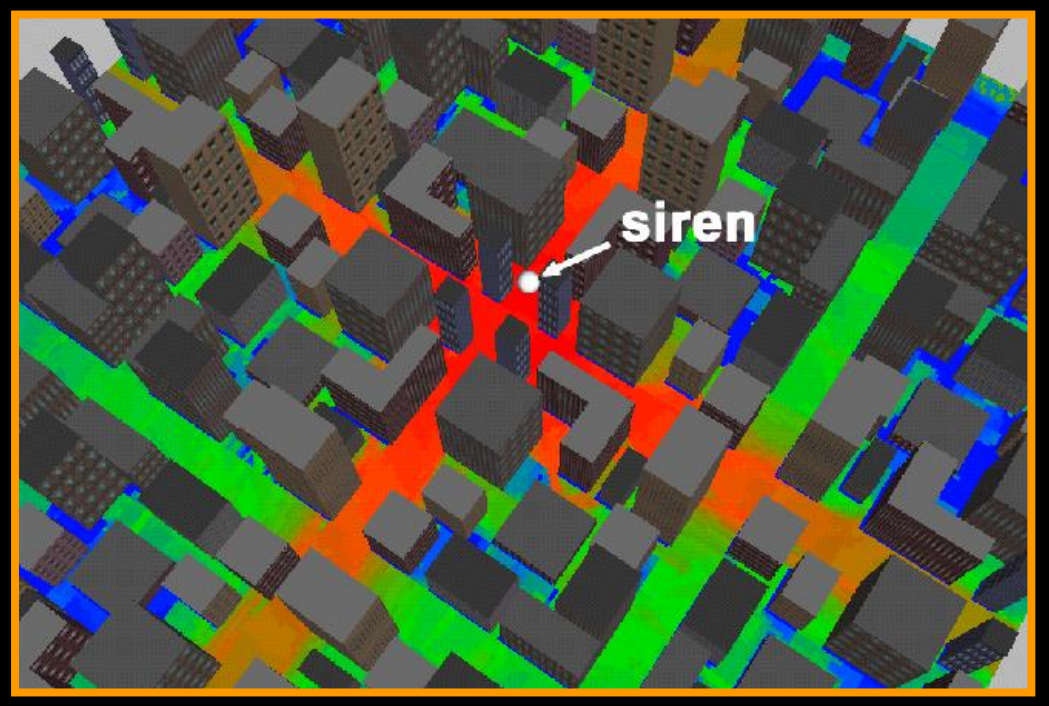


Diffraction and specular reflection

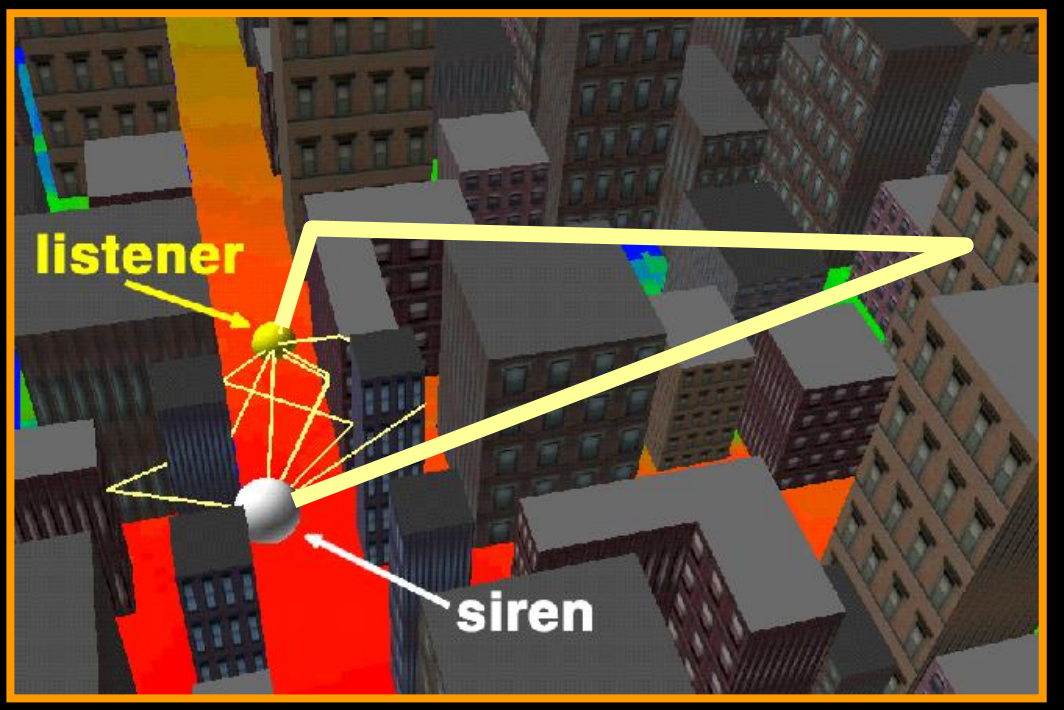
Diagnostic Results





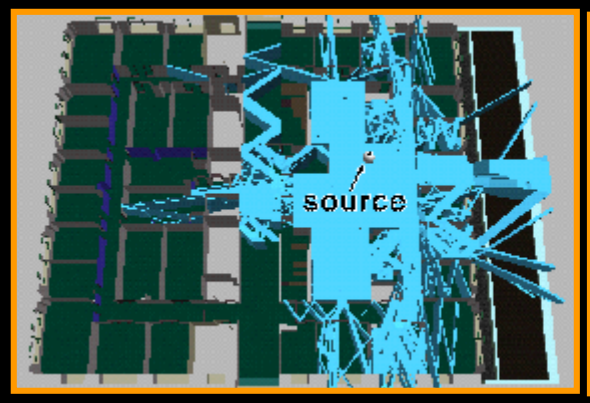


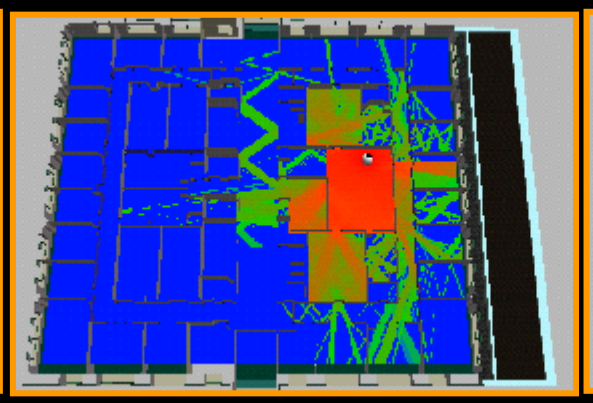
Power

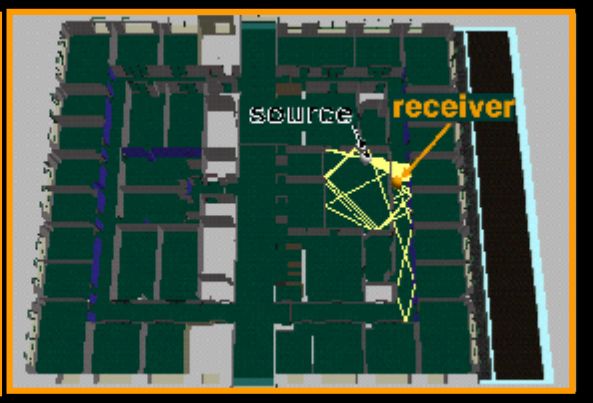


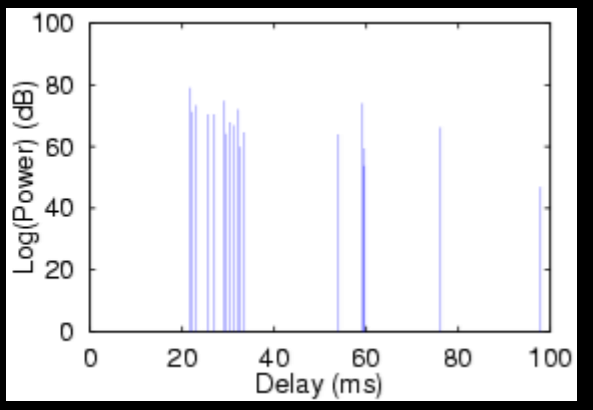
Power + Paths

Diagnostic Results

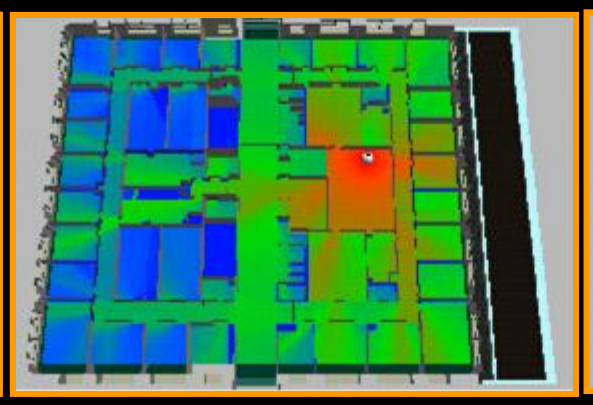


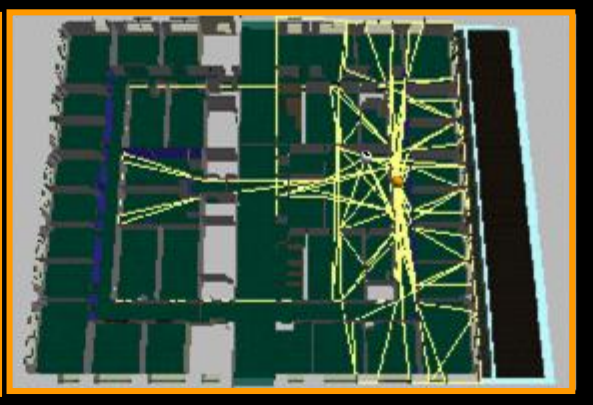


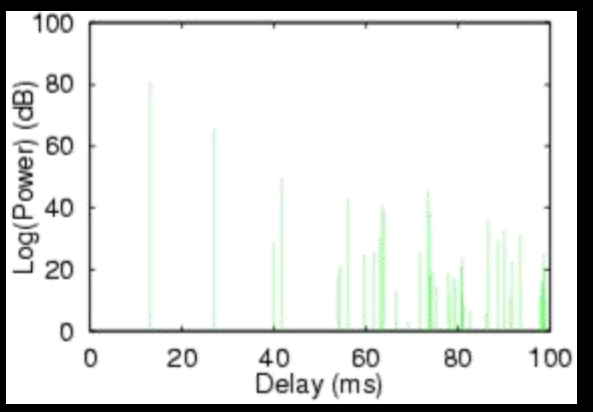




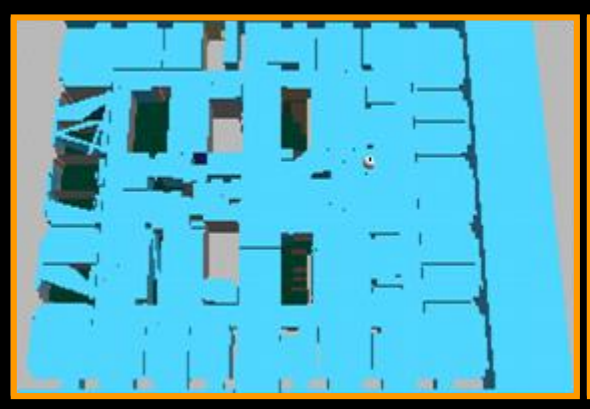
Specular Reflection Only

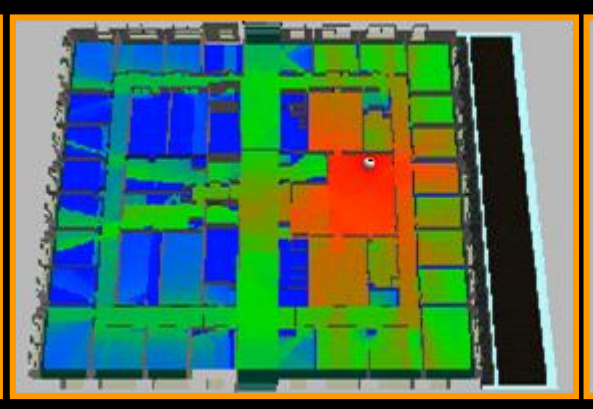


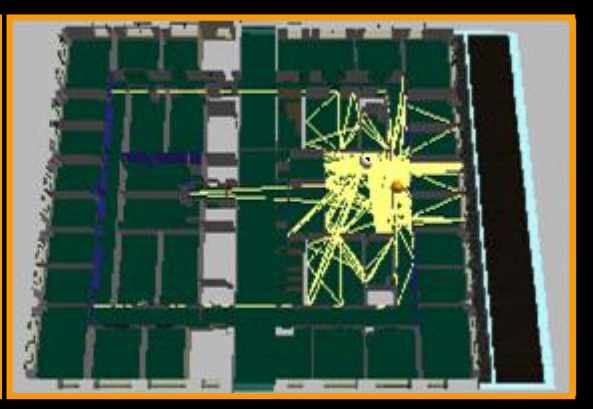


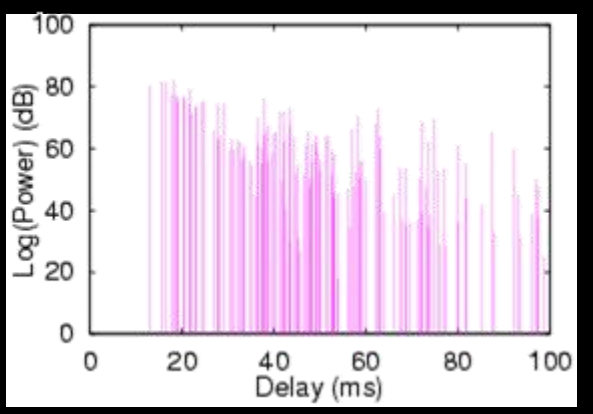


Diffraction Only









Specular Reflection + Diffraction

Talk Outline

Introduction

Acoustic modeling overview

Beam tracing method

- Stationary sources
- Moving sources ←

Conclusion

Future work

Multi-Player Game System

Client A

Client C

Player Audio & Viewpoints

Network

Spatialized Audio

Client B

Audio Server

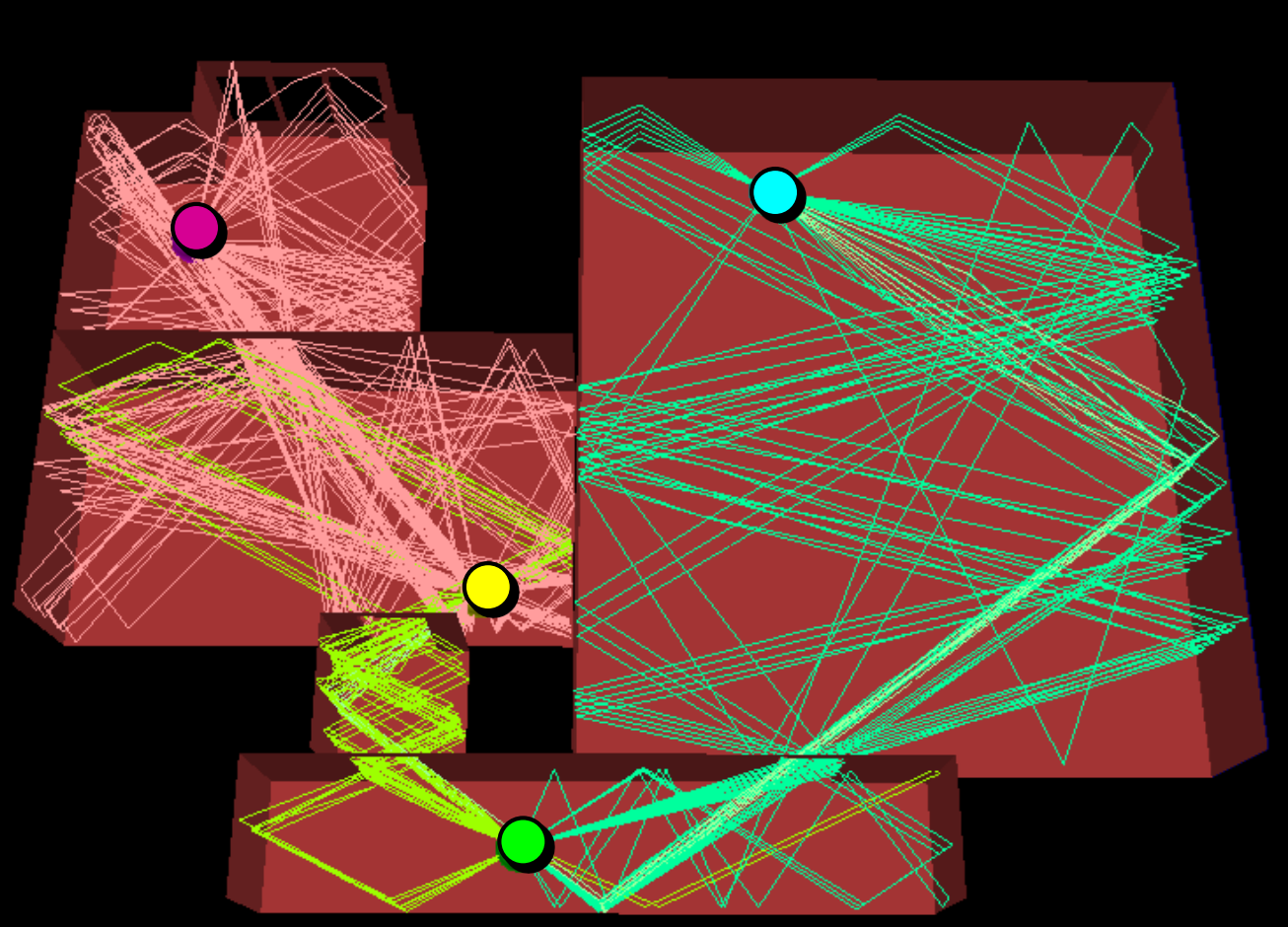
Client D

Moving Sources & Receivers

The audio server must ...

- find reflection paths between all pairs of avatars, ...
- with real-time update rates, ...
- as the avatars move.

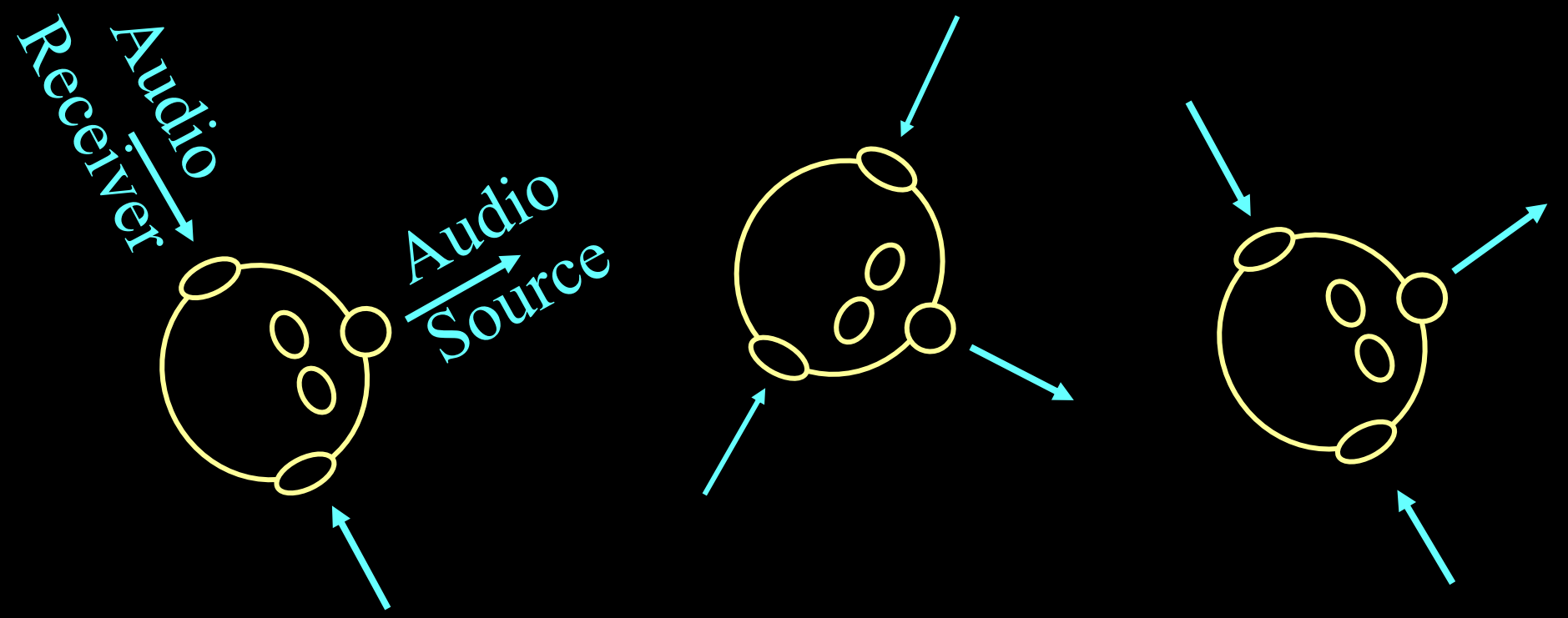
Real-time
Path Tracing



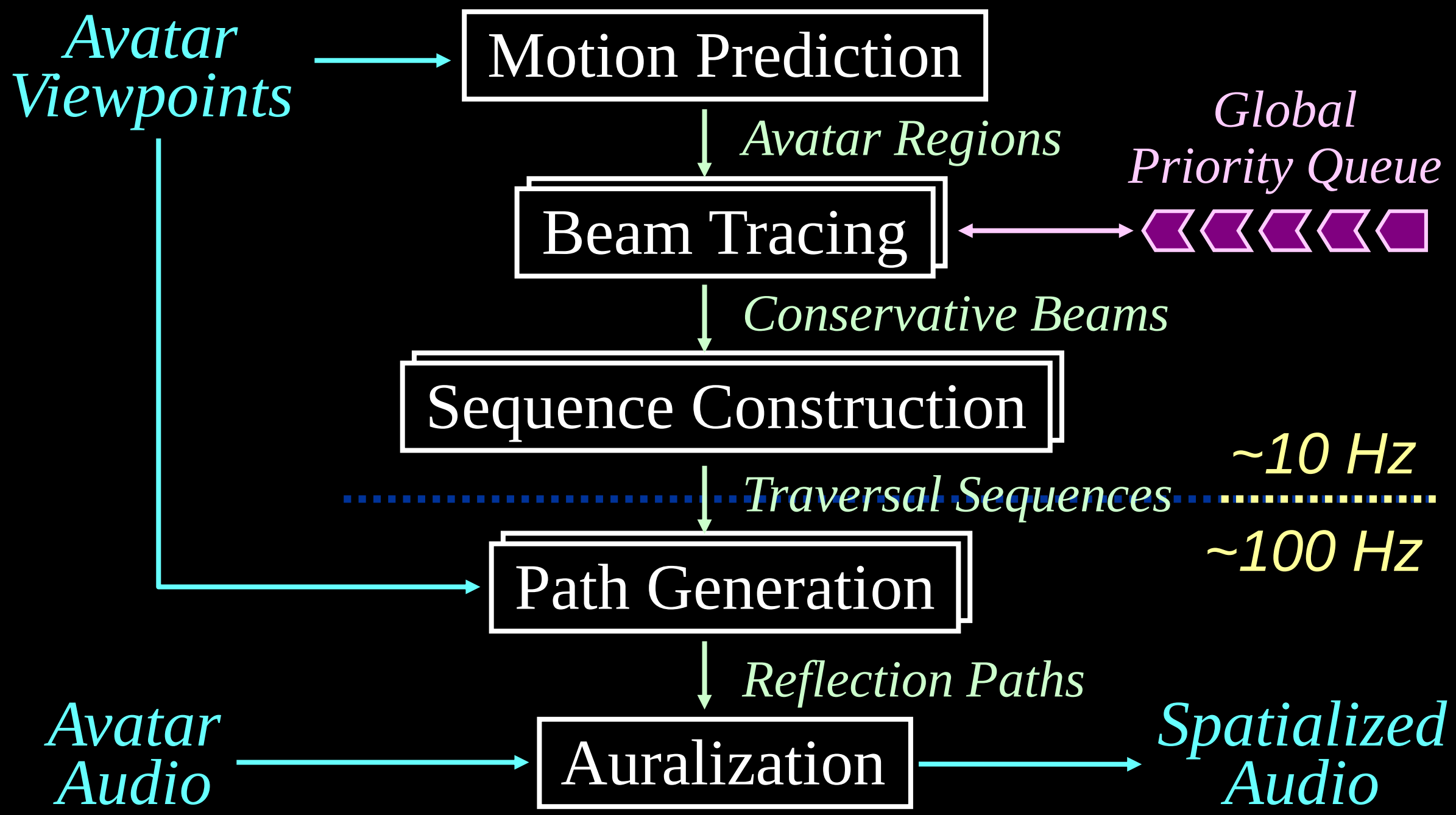
Real-Time Beam Tracing

Trace beams for predicted sources/receivers in real-time

- Amortized beam tracing
- Priority-driven beam tracing
- Bidirectional beam tracing
- Time-critical computing

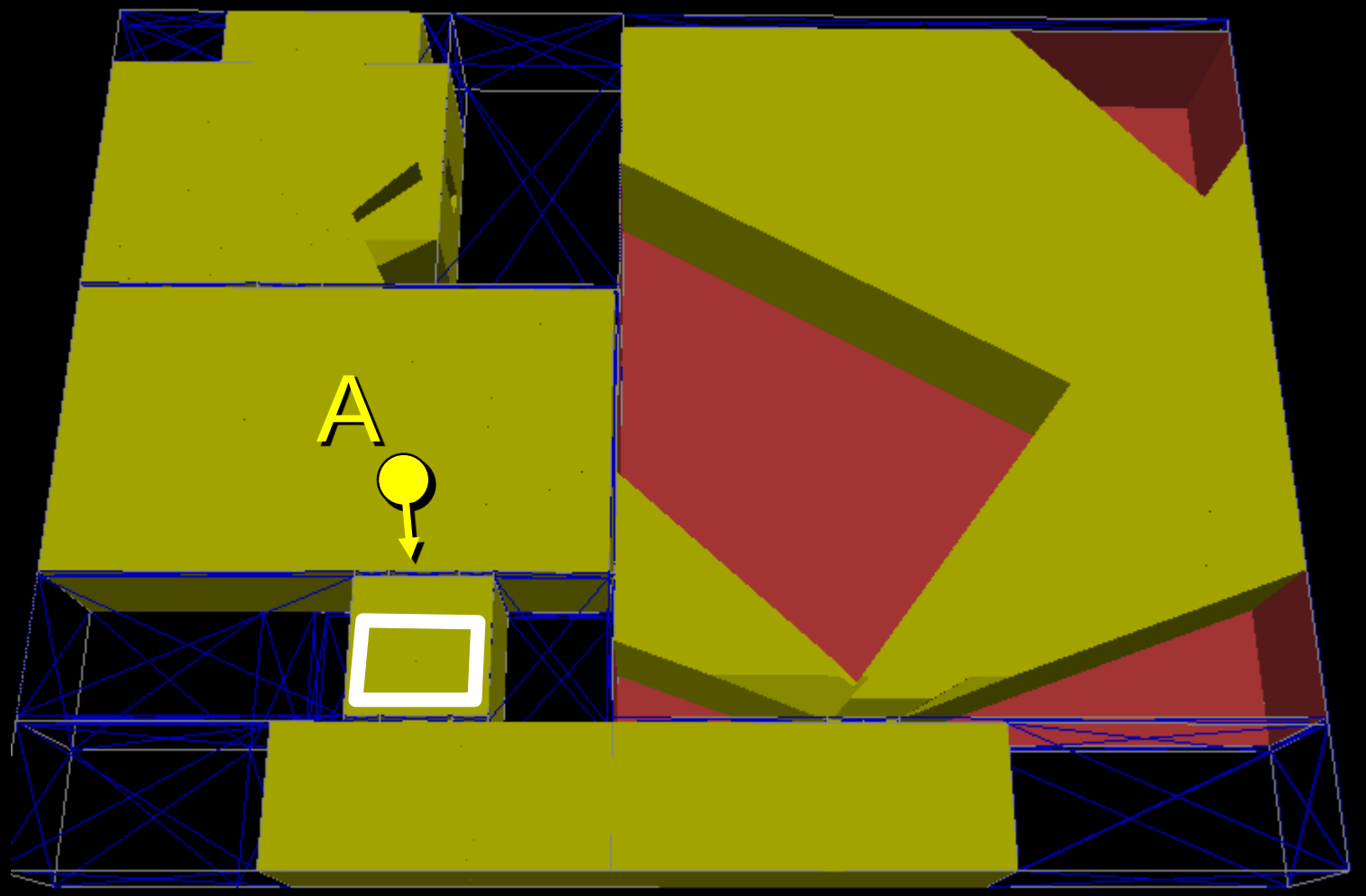


Real-Time System Organization



Amortized Beam Tracing

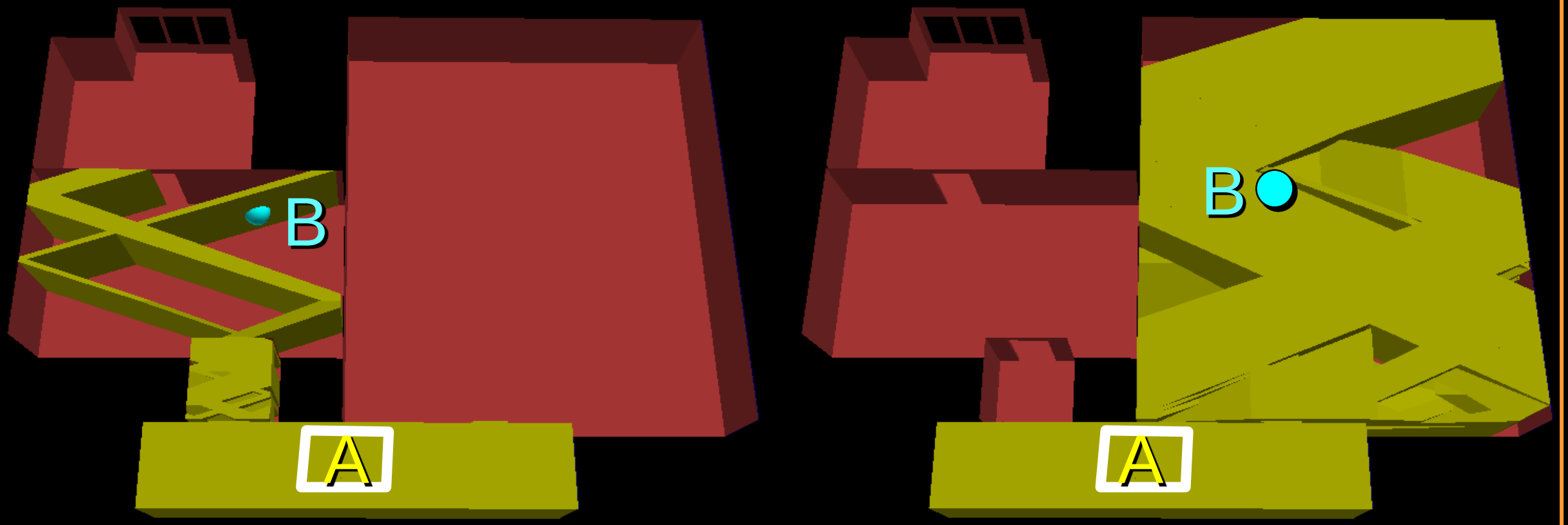
Trace beams from predicted avatar locations



Beams from box over-estimate paths from points in box

Priority-Driven Beam Tracing

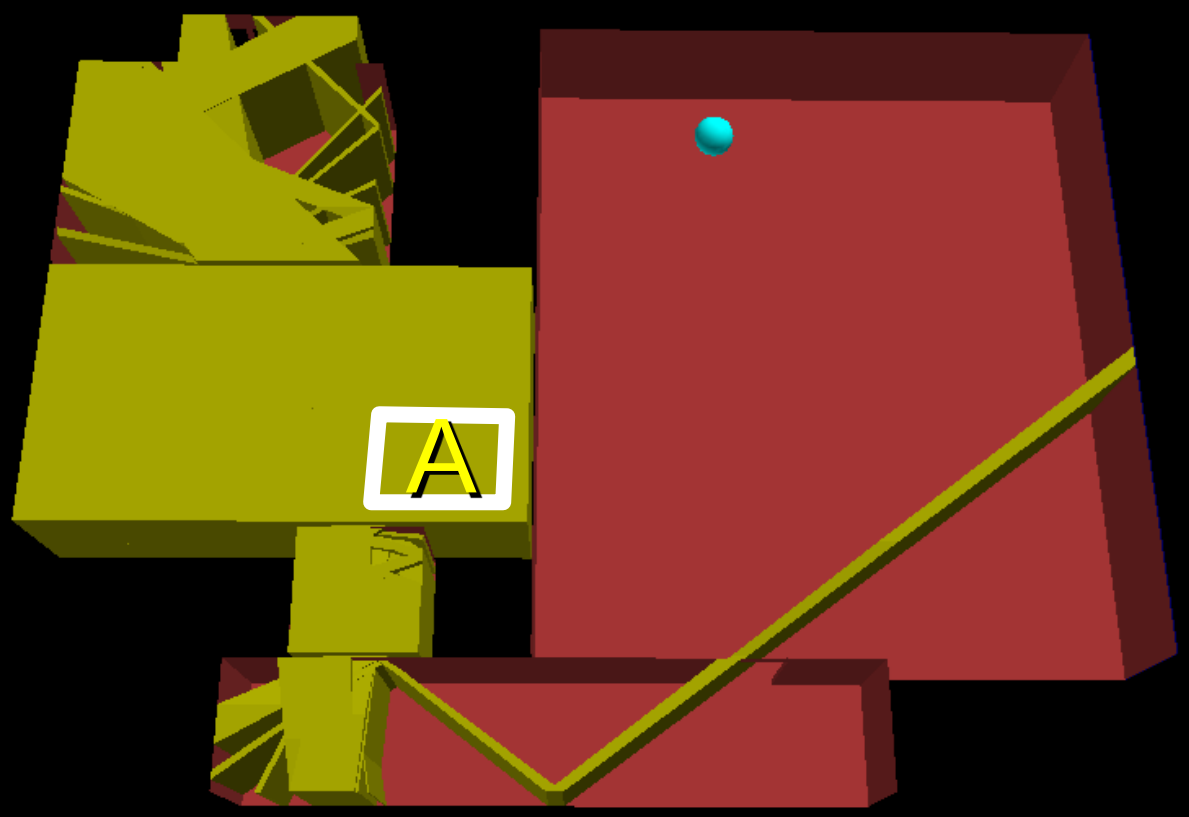
Prioritize beams based on locations of other avatars



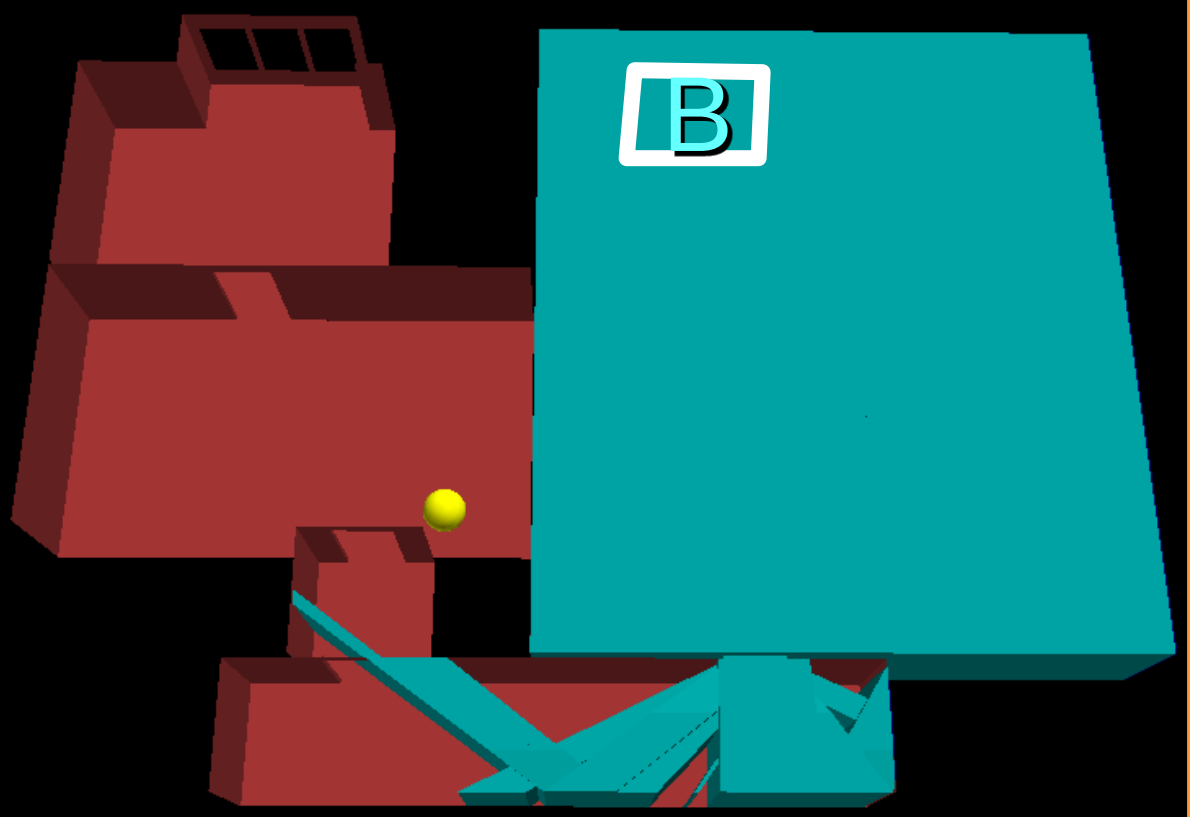
400 beams with shortest paths to “B”

Bidirectional Beam Tracing

Combine beams traced from every avatar



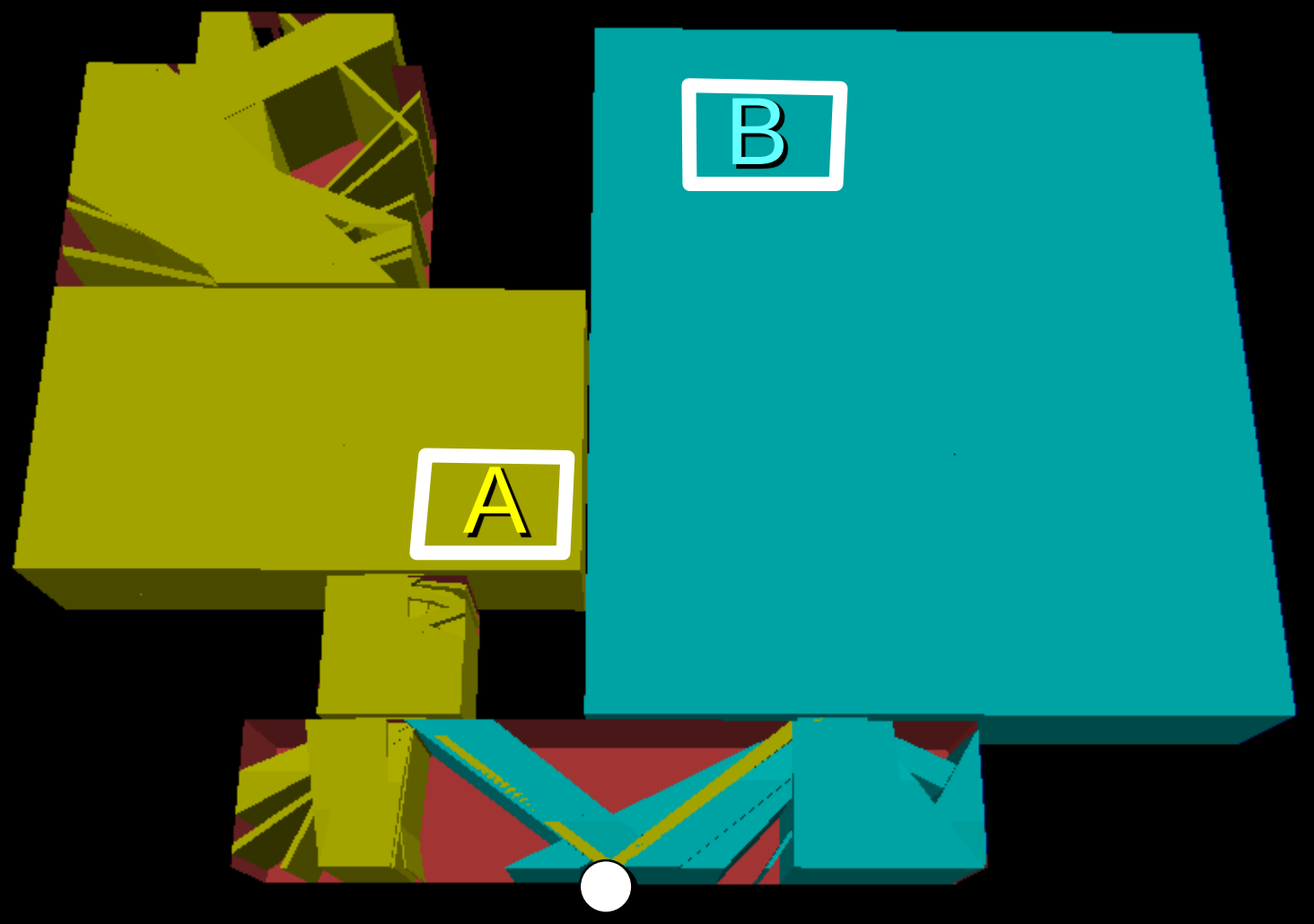
Beams from “A”
(up to 2 reflections)



Beams from “B”
(up to 2 reflections)

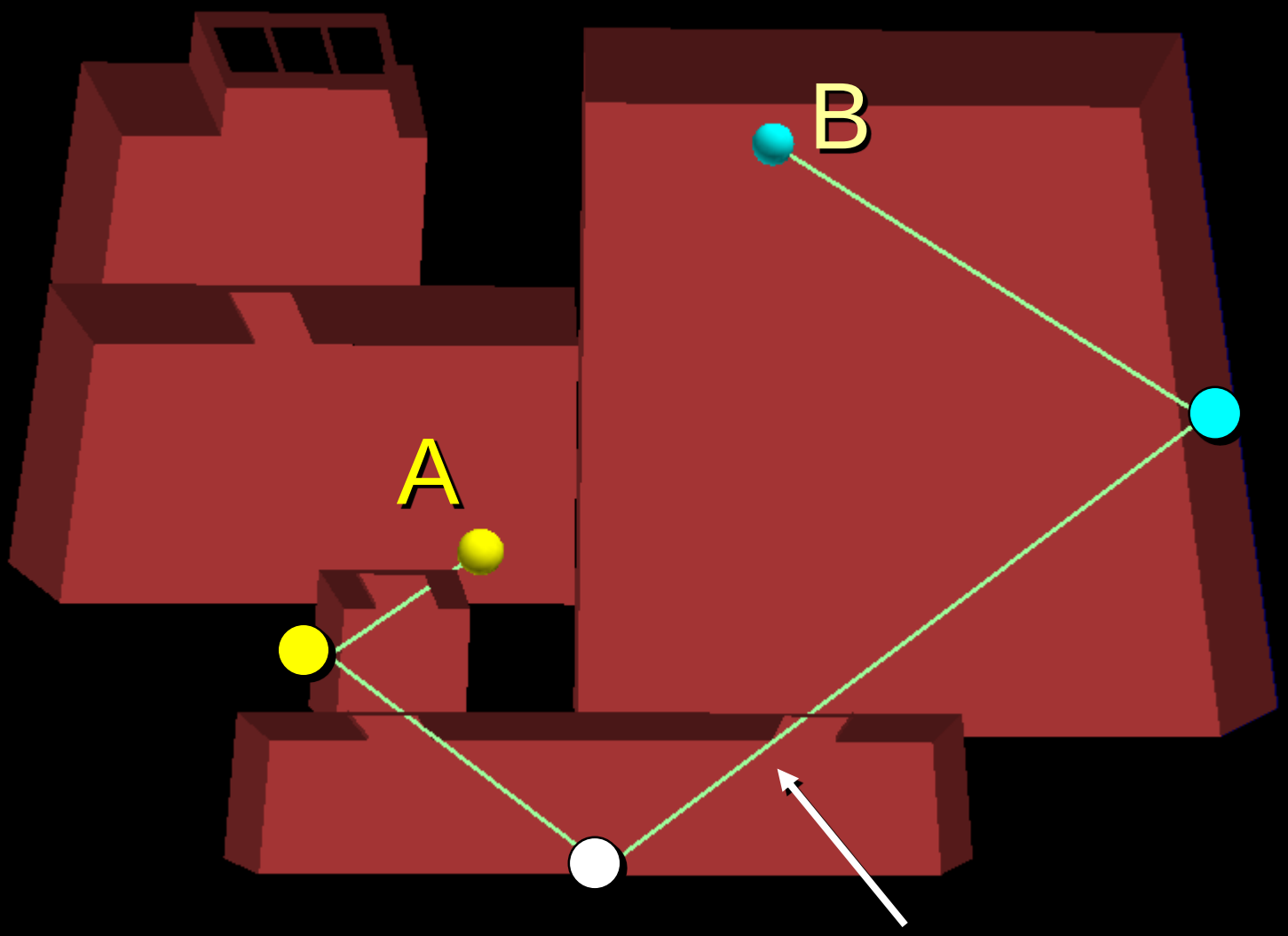
Bidirectional Beam Tracing

Combine beams traced from every avatar

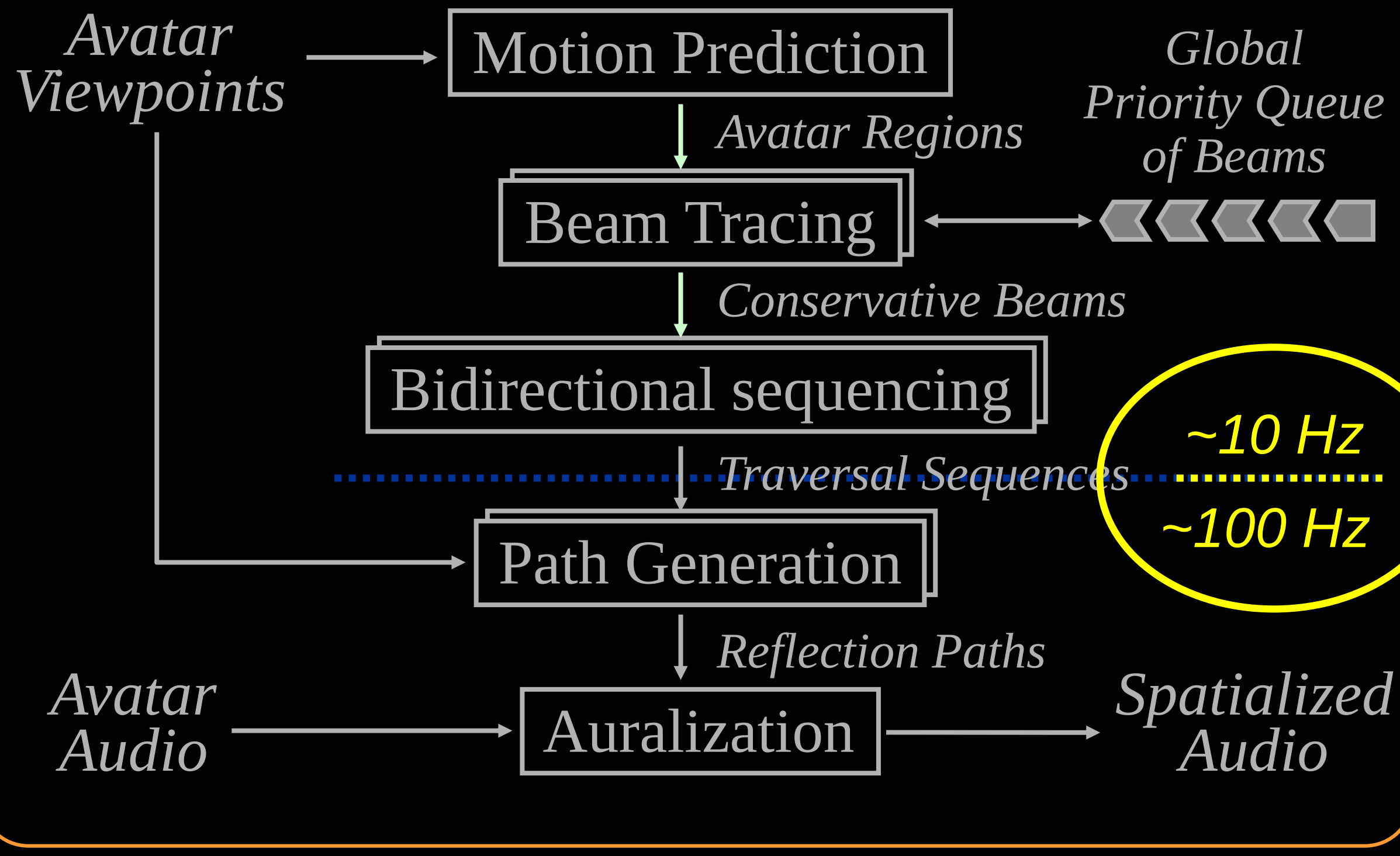


Bidirectional Beam Tracing

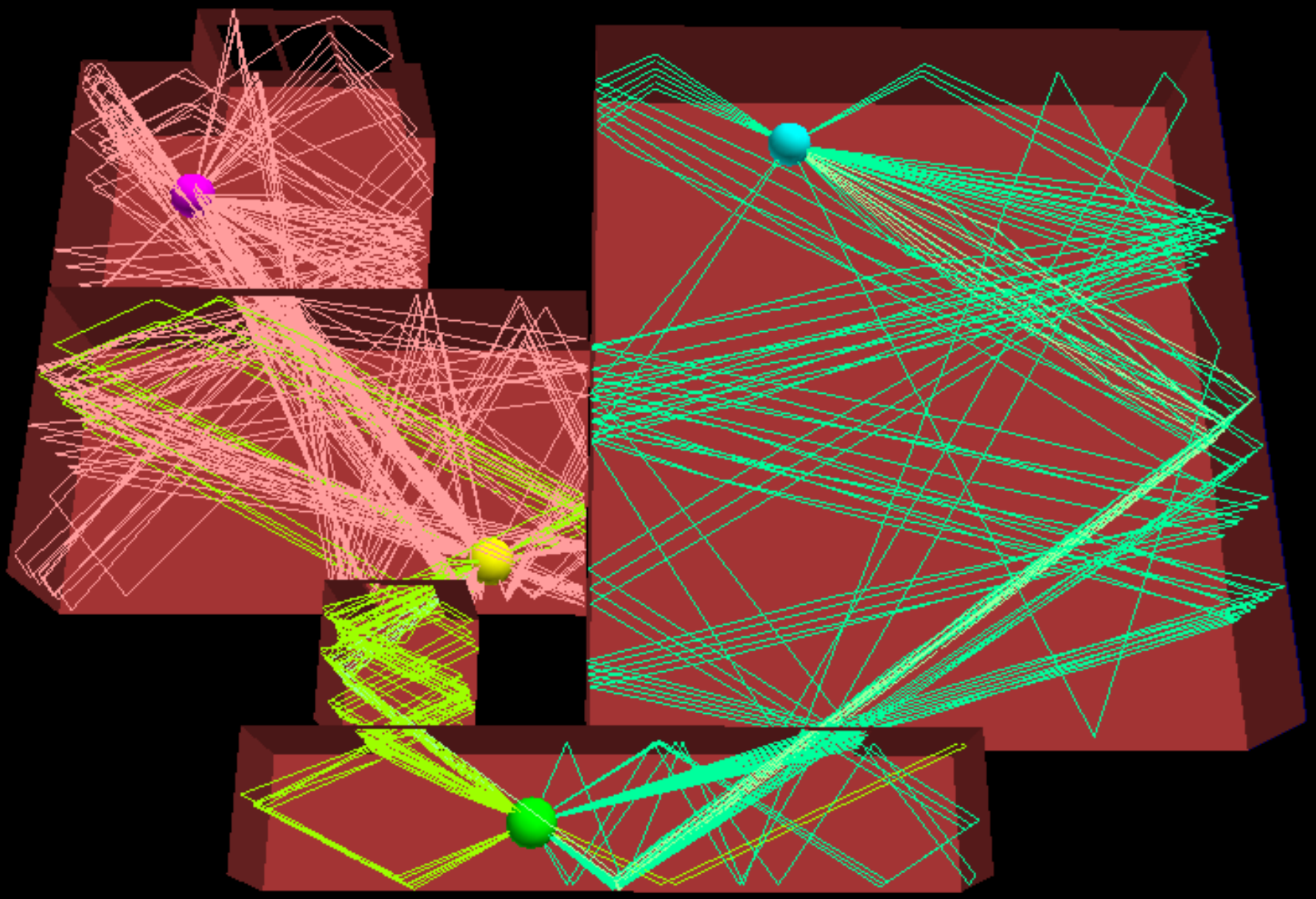
Combine beams traced from every avatar



Predictive Time-Critical Computing



Real-Time Beam Tracing



Specular reflection only

Summary

Physically-based acoustic modeling

- Localization of sound sources
- Comprehension of space
- Sense of presence

Beam Tracing Methods

- Precomputation, conservative, convex
- Amortized, priority-driven, bidirectional, adaptive, etc.
- Predictive time-critical computing

Results

- Interactive computation of sound propagation paths
- Real-time auralization as sources/receivers move

Limitations of Current Method

Only densely-occluded environments

- Building interiors, cities, etc.

Only specular reflection, transmission, and diffraction

- Hard, locally reacting surfaces without diffusion

Only frequency-independent convolution in real-time

- Need sound card with sufficient filtering performance (e.g., Lake Huron)

Future Work

More general environments

- Locally complex environments
- Curved surfaces

Better scattering models

- Diffuse reflections
- Multiresolution obstacles

Designer tools

- Refine geometry/materials to achieve acoustic goals

Take better advantage of psychoacoustics

- Find perceptually similar approximations

Thank You ...

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http://www.cs.princeton.edu/~funk

2D Beam Tracing