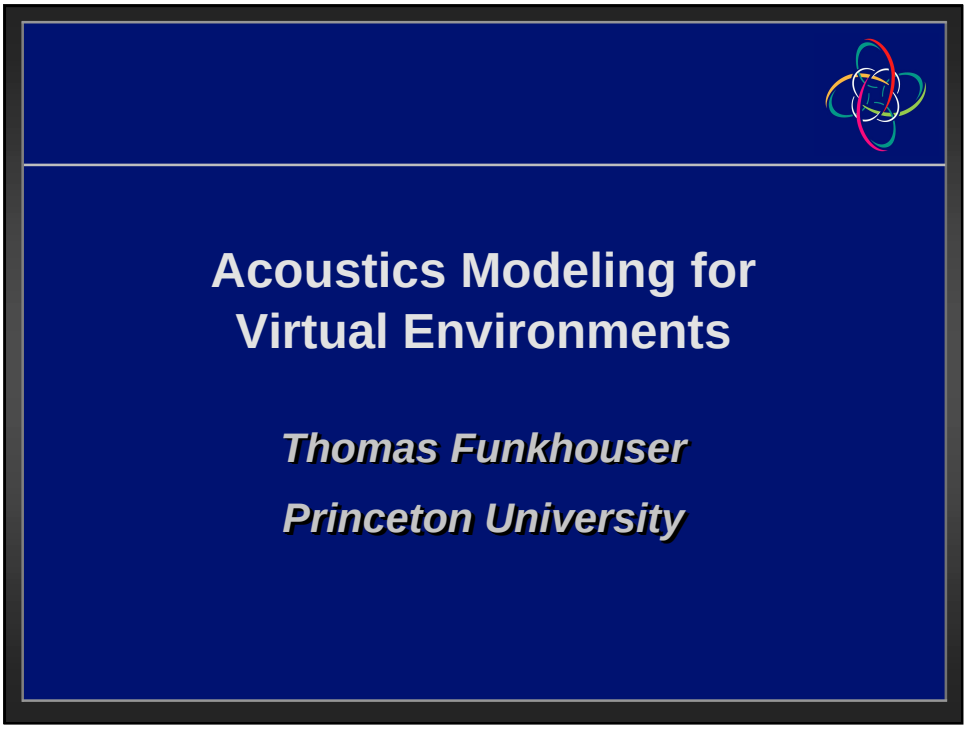
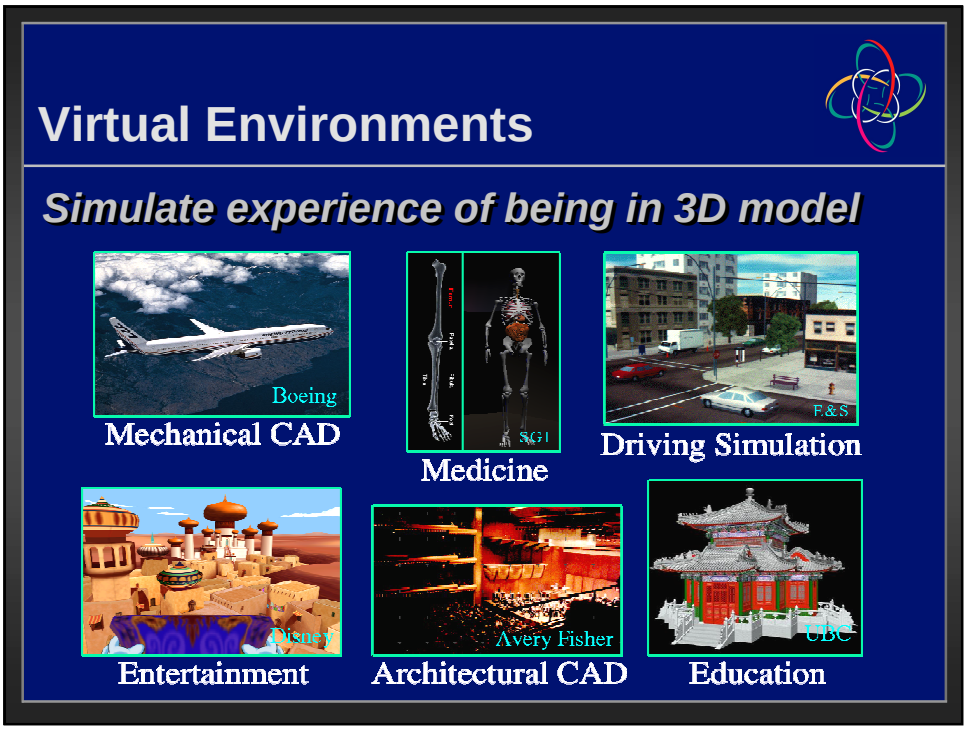

Acoustics Modeling for
Virtual Environments
Thomas Funkhouser
Princeton University


Virtual Environments
Simulate experience of being in 3D model
Boeing
Mechanical CAD
SGI
Medicine
P&S
Driving Simulation
Disney
Entertainment
Avery Fisher
Architectural CAD
UBC
Education

Distributed Virtual Environments

Allow interaction among networked users

Group Training

Teleconferencing

E–Commerce

Communication

Battle Simulation

Networked Games

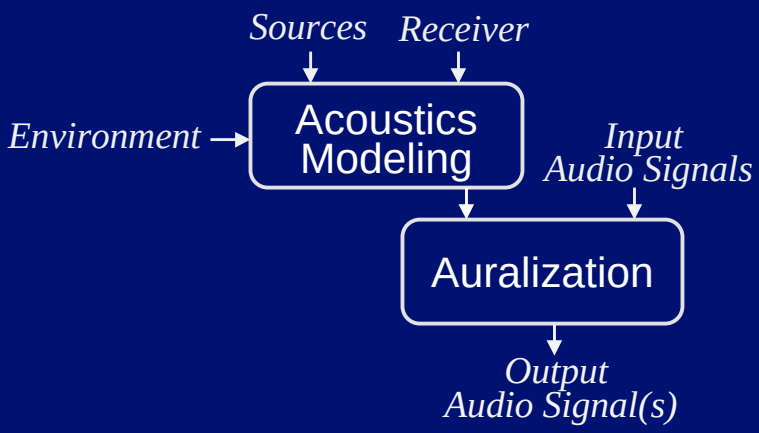
Acoustic Modeling

Spatialized sound facilitates ...

- Sense of presence
- Comprehension of space
- Localization of auditory cues
- Selectivity of audio signals (“cocktail

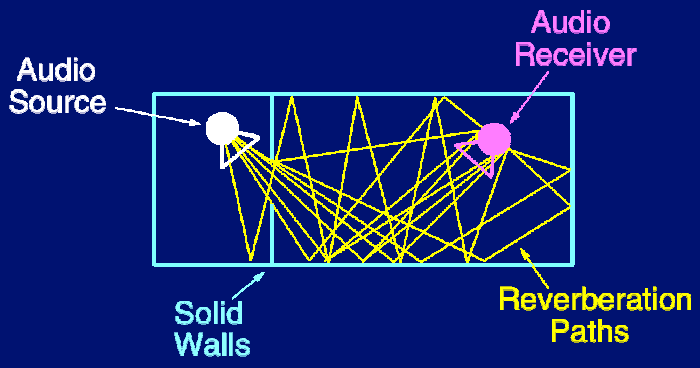
Modeling Environments

Simulate reverberations due to environment



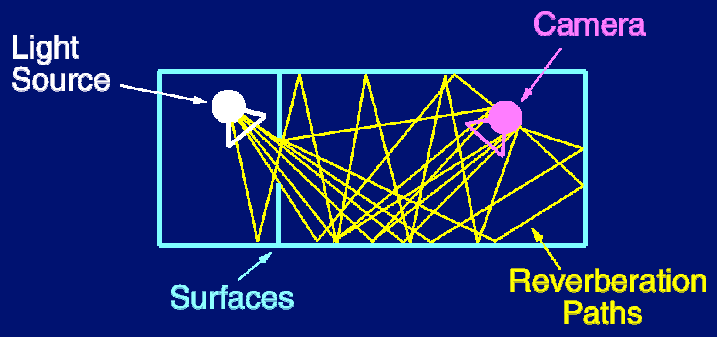
Geometric Acoustic Modeling

Spatialize sound by computing reverberation paths from source to receiver



Similarities to Graphics

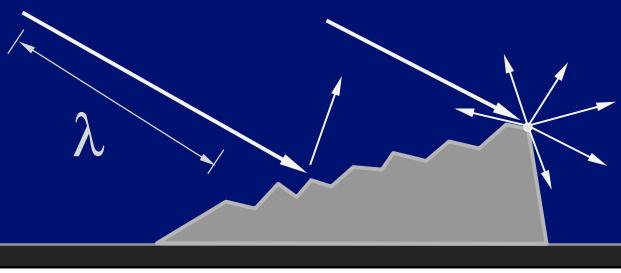
Both model wave propagation



Differences from Graphics I

Sound has longer wavelengths than light

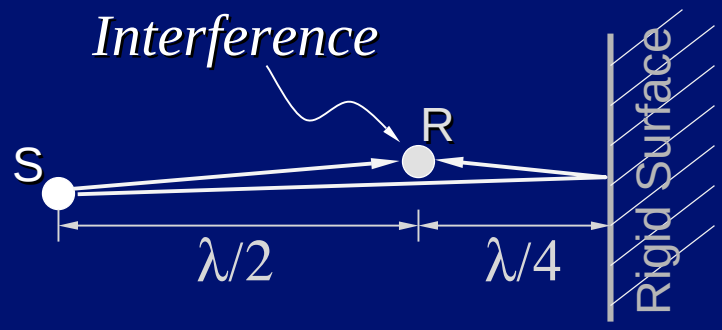
- Diffractions are significant
- Specular reflections dominate diffuse reflections
- Occlusions by small objects have little effect



Differences from Graphics II

Sound waves are coherent

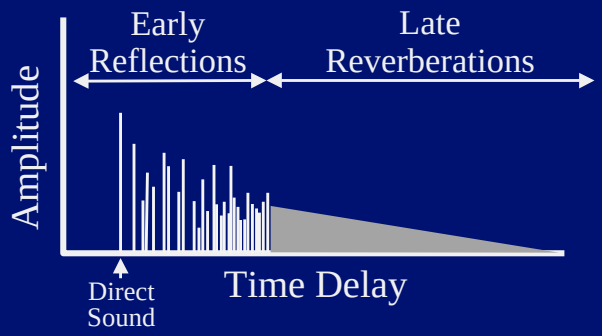
- Modeling phase is important



Differences from Graphics III

Sound travels more slowly than light

- Reverberations are perceived over time



Overview of Approaches

Ray tracing

Boundary element methods

Image source methods

Beam tracing

Overview of Approaches

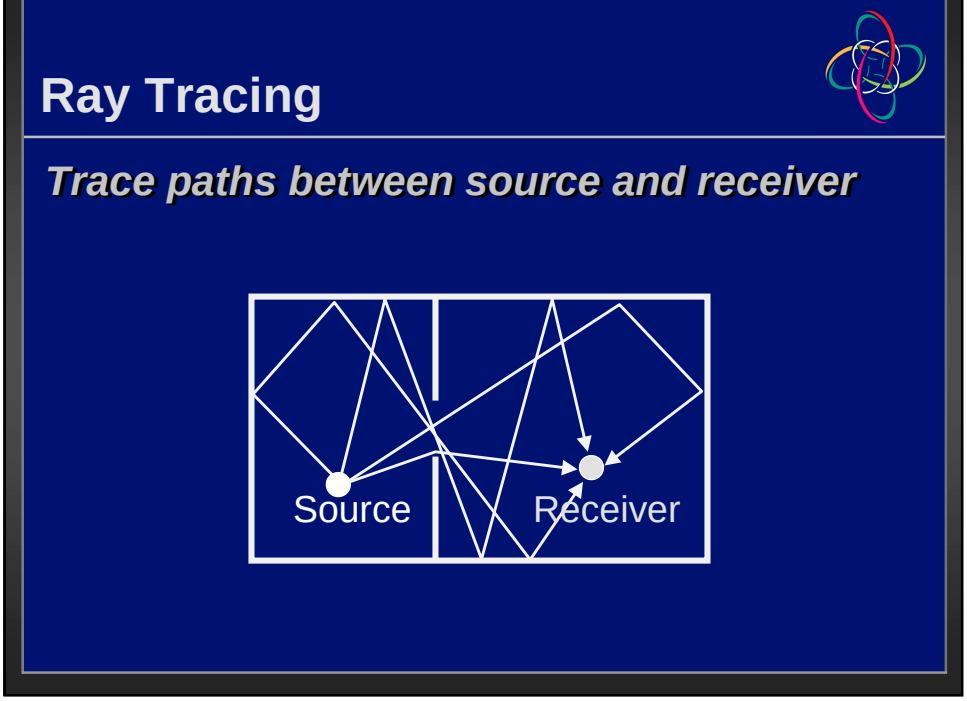
Ray tracing ←

Boundary element methods

Image source methods

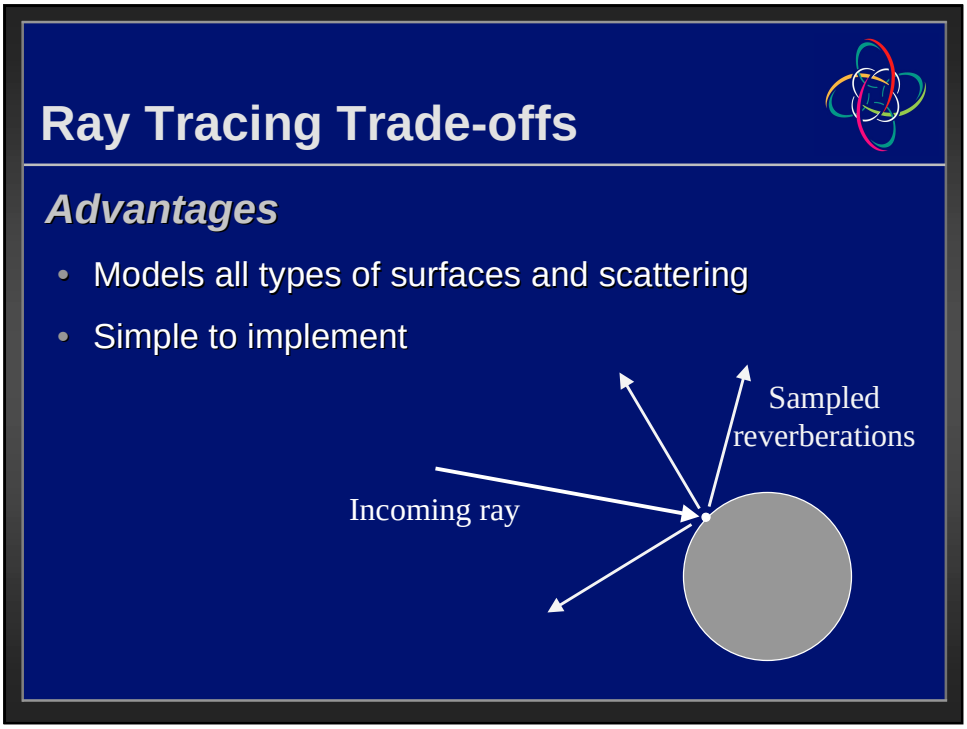
Beam tracing

Ray Tracing



Trace paths between source and receiver

Ray Tracing Trade-offs



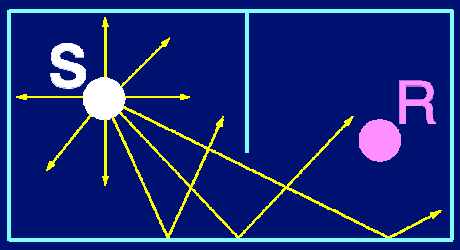
Advantages

- Models all types of surfaces and scattering
- Simple to implement

Ray Tracing Trade-offs

Disadvantages

- Subject to sampling errors (aliasing)
- Depends on receiver position



Overview of Approaches

Ray tracing

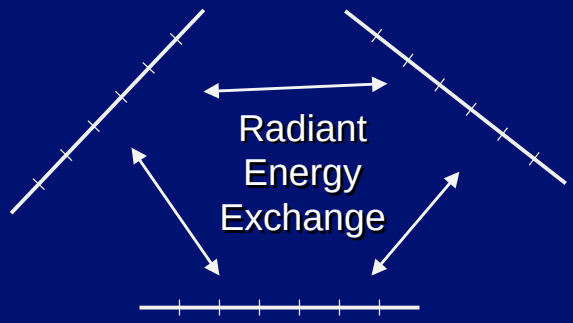
Boundary element methods ←

Image source methods

Beam tracing

Boundary Element Methods

Solve wave equation over discretized surfaces



Boundary Element Trade-offs

Advantages

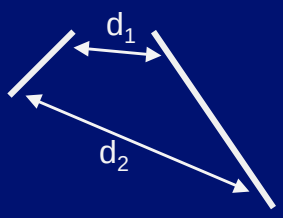
- Works well for low frequencies
- Simple formulation

$$B_i = E_i + \rho_i \sum B_j F_{ij}$$

Boundary Element Trade-offs

Disadvantages

- Complex function stored with each element
- Form factors must model diffractions & specularities
- Elements must be much smaller than wavelength



$$|d_1 - d_2| << \lambda$$

Overview of Approaches

Ray tracing

Boundary element methods

Image source methods ←

Beam tracing

Image Source Methods

Consider direct paths from "virtual sources"

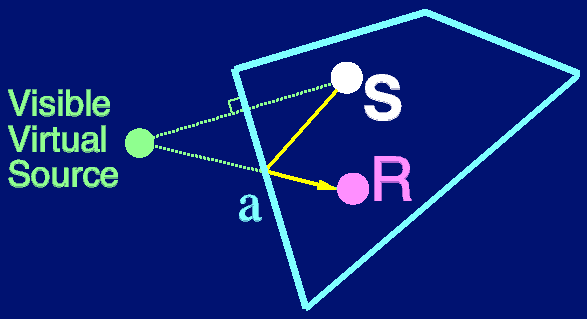
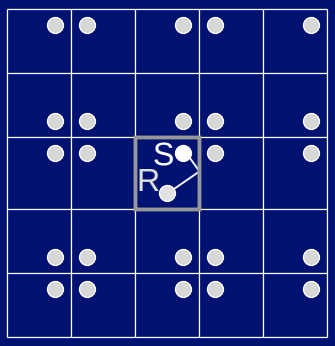


Image Source Trade-offs

Advantages

- Simple for rectangular rooms

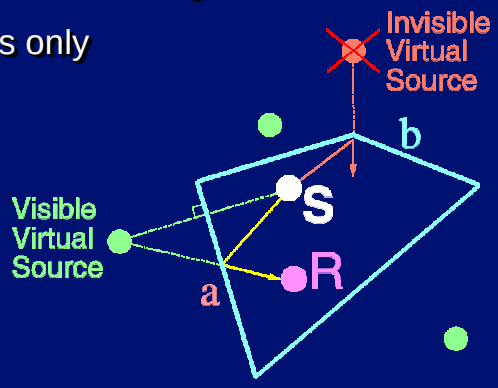


Virtual Sources arranged in grid pattern

Image Source Trade-offs

Disadvantages

- $O(n^r)$ visibility checks in arbitrary environments
- Specular reflections only



Overview of Approaches

Ray tracing

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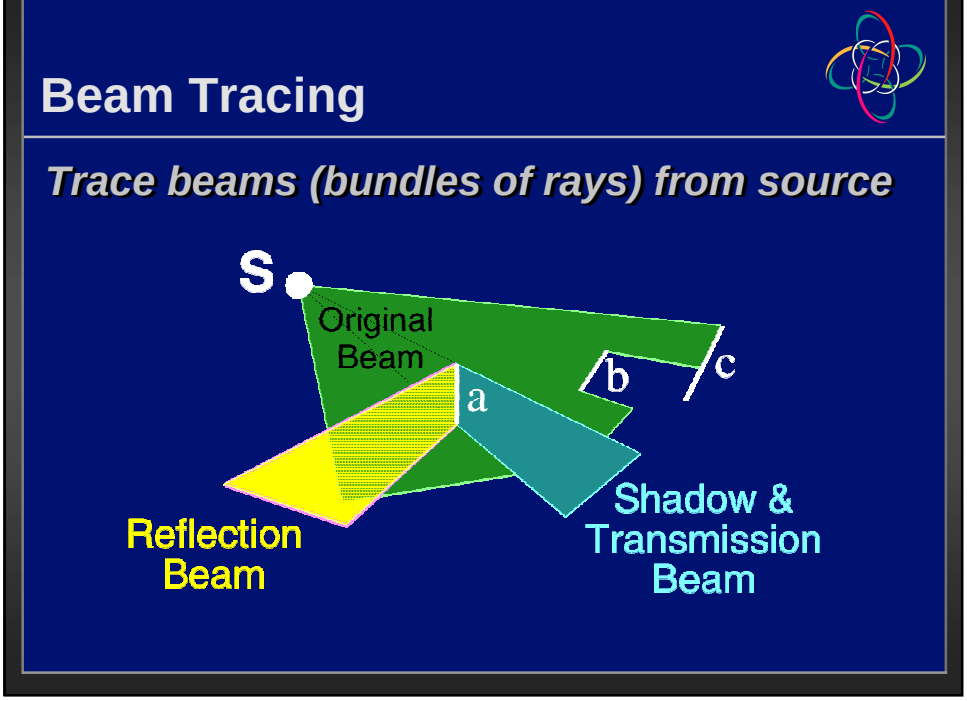
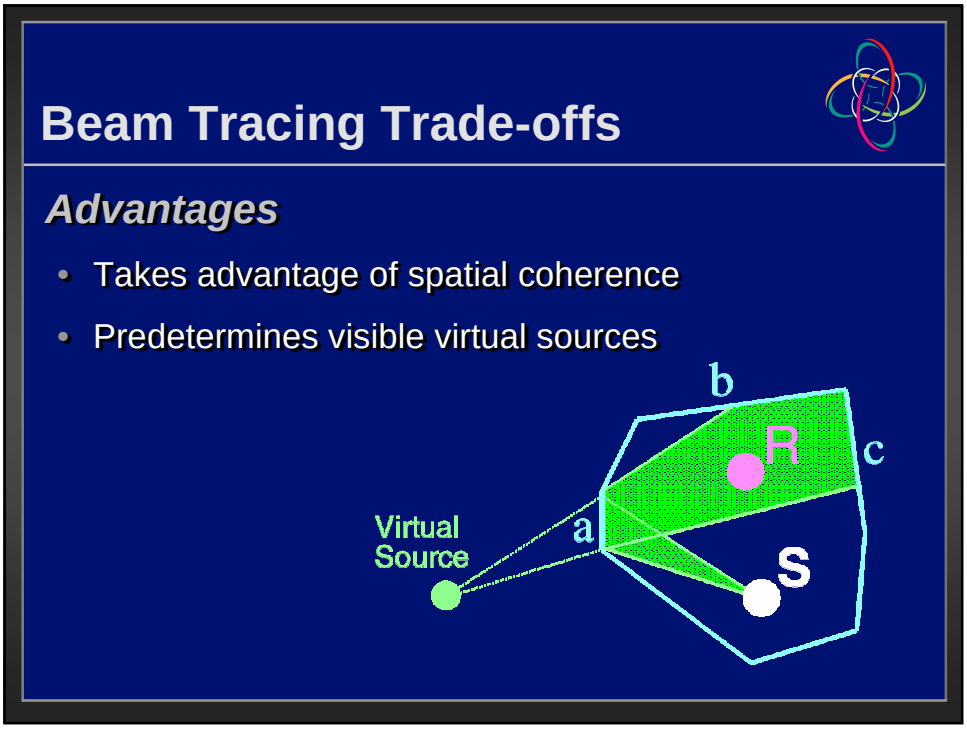
Beam tracing ←

Beam Tracing



Trace beams (bundles of rays) from source

Beam Tracing Trade-offs



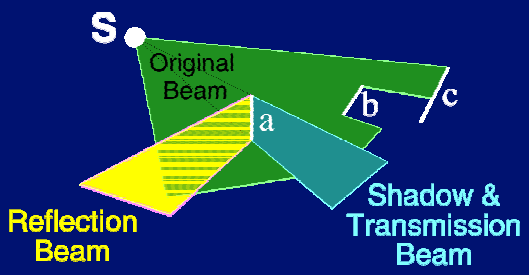
Advantages

- Takes advantage of spatial coherence
- Predetermines visible virtual sources

Beam Tracing Trade-Offs

Disadvantages

- Difficult for curved surfaces or refractions
- Requires efficient polygon sorting and intersection



Recent Work in Beam Tracing

Interactive performance

- Update reverberation paths many times per second