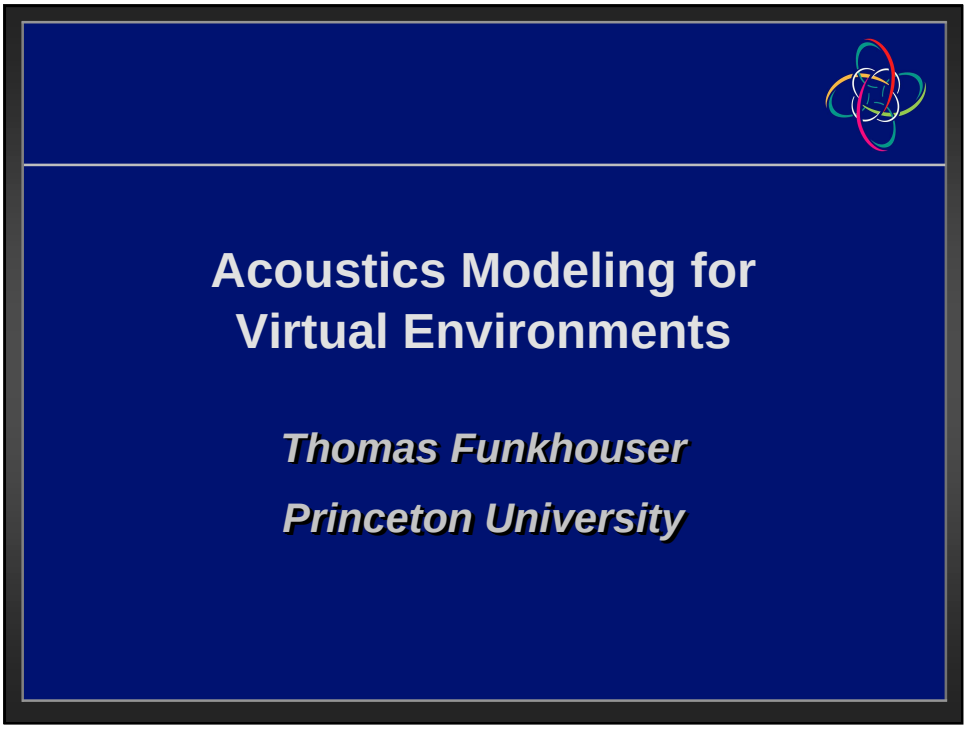
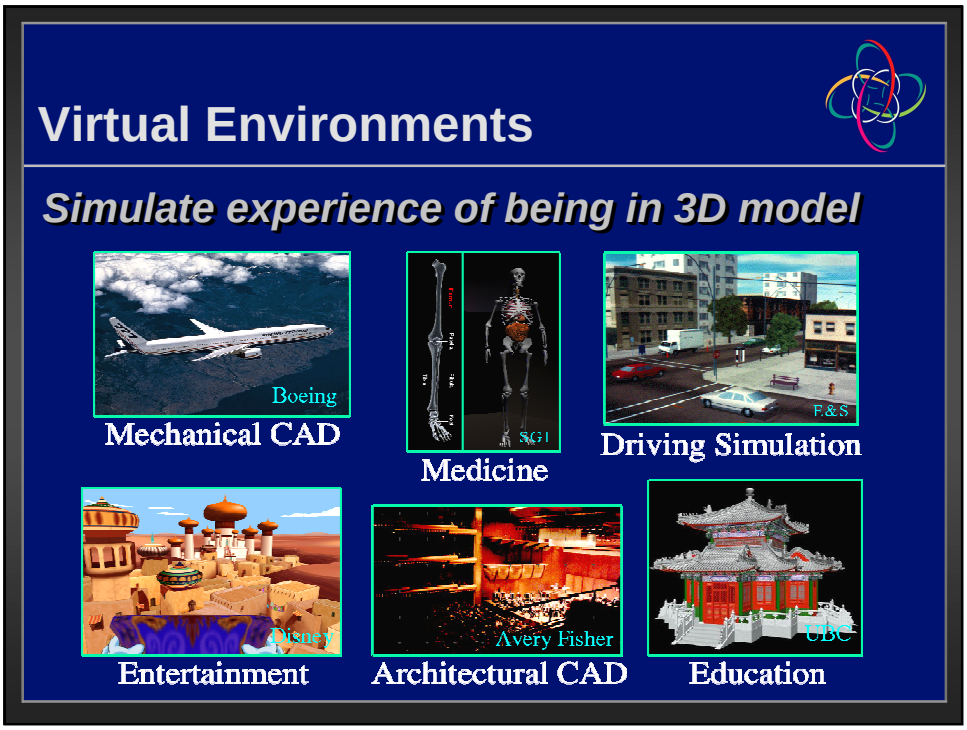

Acoustics Modeling for
Virtual Environments
Thomas Funkhouser
Princeton University


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

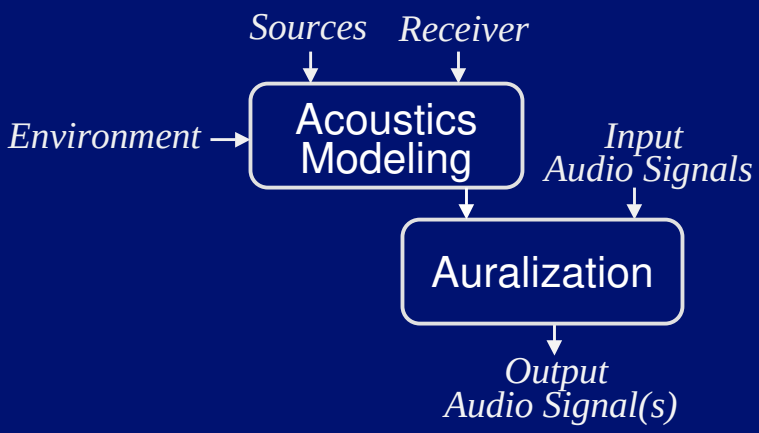
## Acoustic Modeling

*Spatialized sound facilitates ...*

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

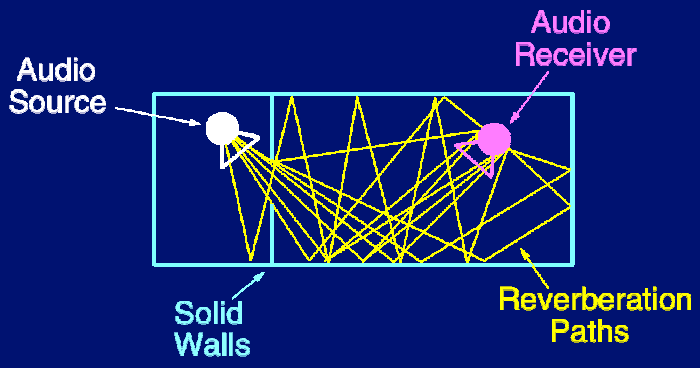
## Modeling Environments

***Simulate reverberations due to environment***



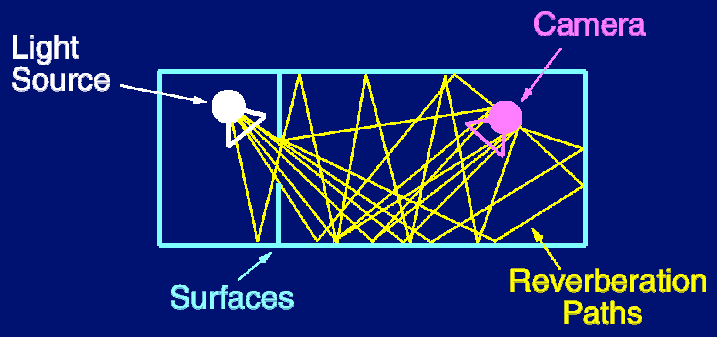

## Geometric Acoustic Modeling

***Spatialize sound by computing reverberation paths from source to receiver***



## Similarities to Graphics

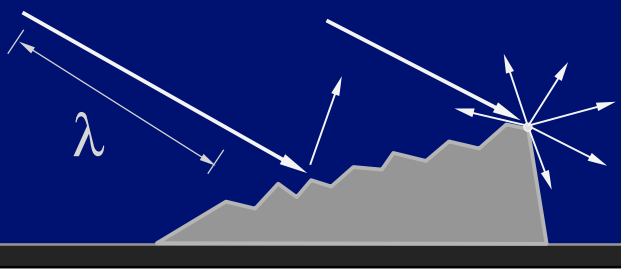
***Both model wave propagation***




## Differences from Graphics I

***Sound has longer wavelengths than light***

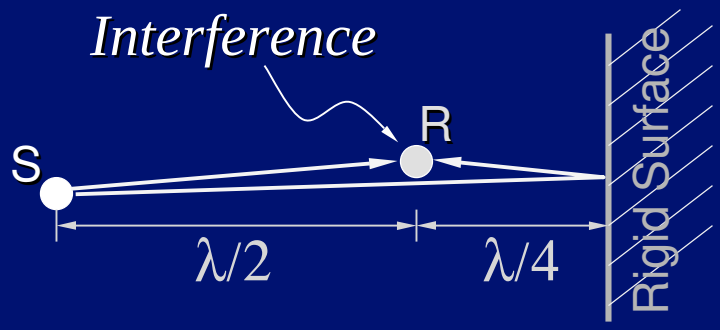
- Diffractions are significant
- Specular reflections dominate diffuse reflections
- Occlusions by small objects have little effect



## Differences from Graphics II

***Sound waves are coherent***

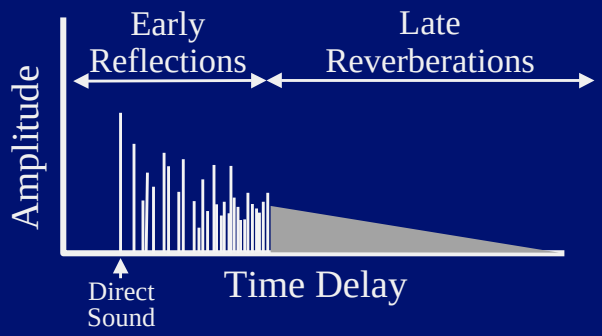
- Modeling phase is important




## 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

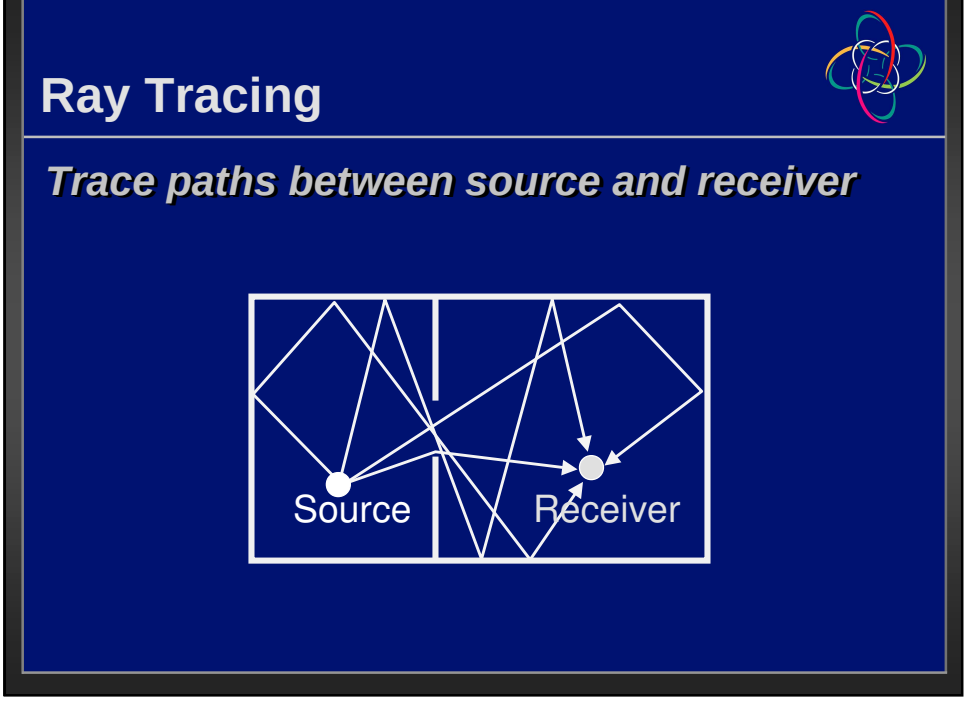
*Ray tracing* ←

*Boundary element methods*

*Image source methods*

*Beam tracing*

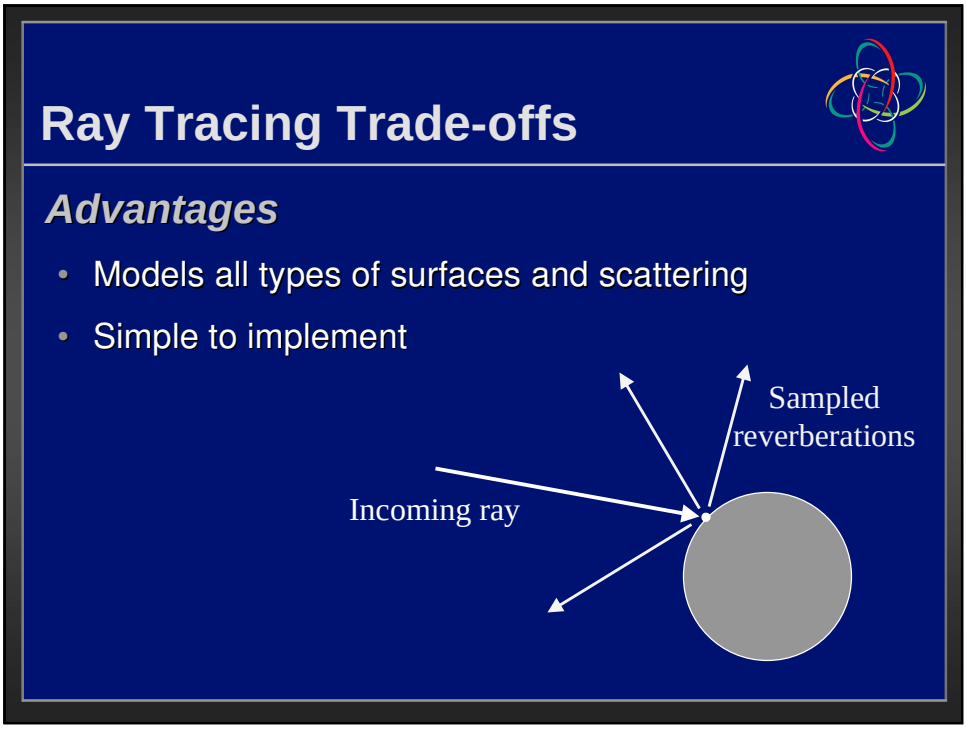
## Ray Tracing



***Trace paths between source and receiver***




## Ray Tracing Trade-offs



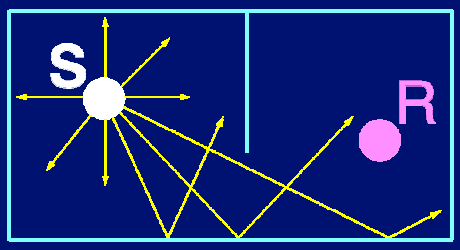
***Advantages***

- 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***

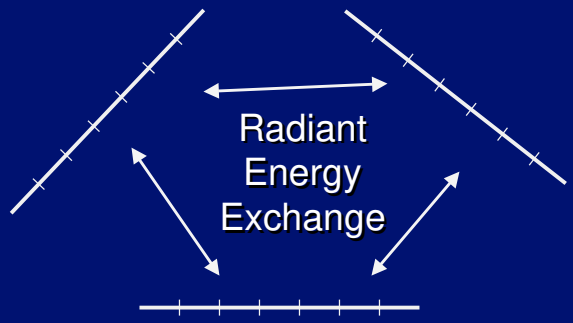
***Boundary element methods*** ←

***Image source methods***

***Beam tracing***

## Boundary Element Methods

***Solve wave equation over discretized surfaces***




## Boundary Element Trade-offs

***Advantages***

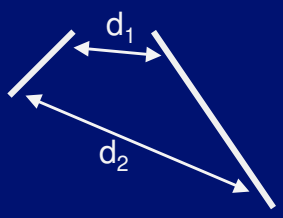
- Works well for low frequencies
- Simple formulation

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

## 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***

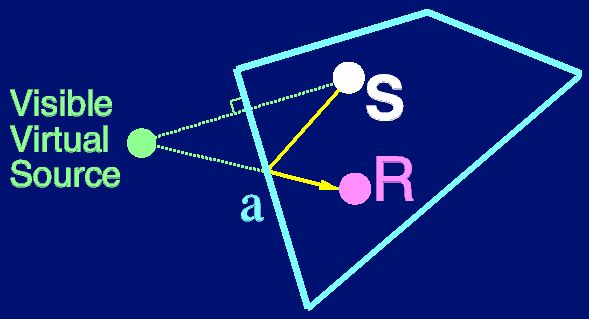
***Image source methods*** ←

***Beam tracing***

## Image Source Methods



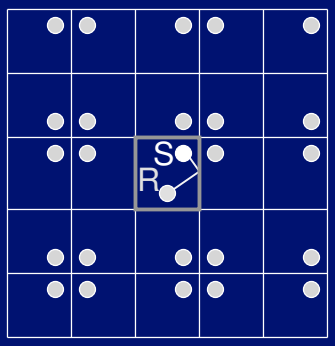
*Consider direct paths from "virtual sources"*




## Image Source Trade-offs

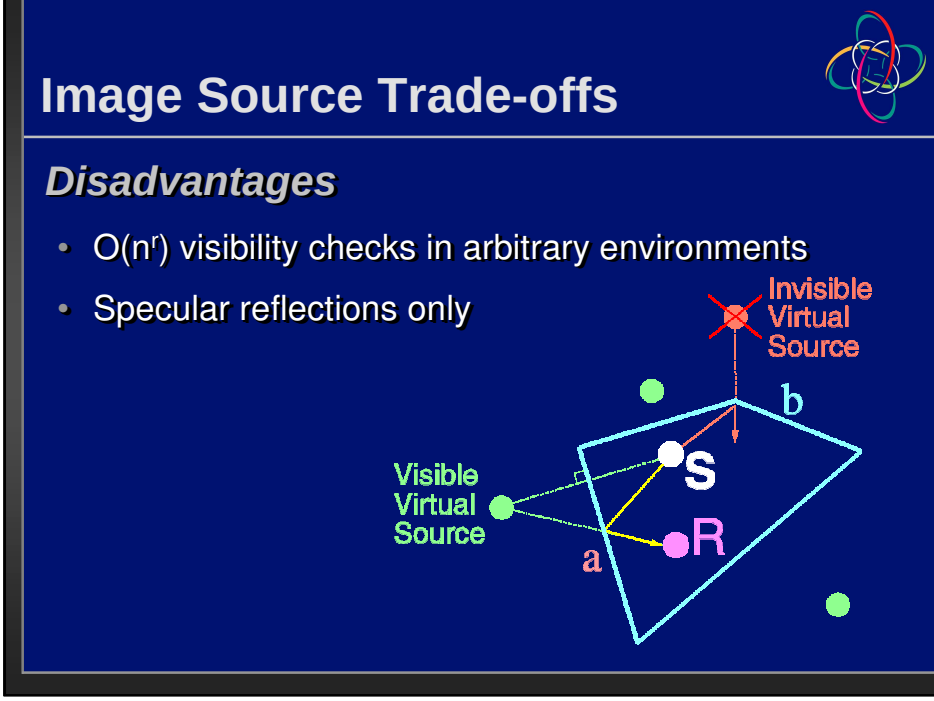
*Advantages*

- Simple for rectangular rooms




*Virtual Sources arranged in grid pattern*

## Image Source Trade-offs

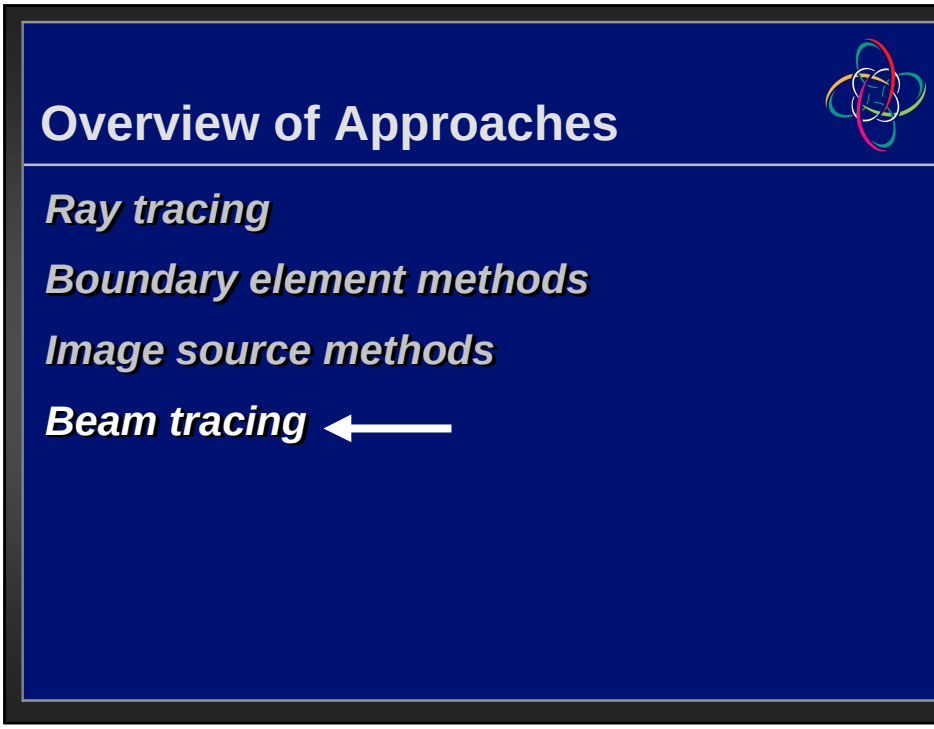


***Disadvantages***

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



## Overview of Approaches



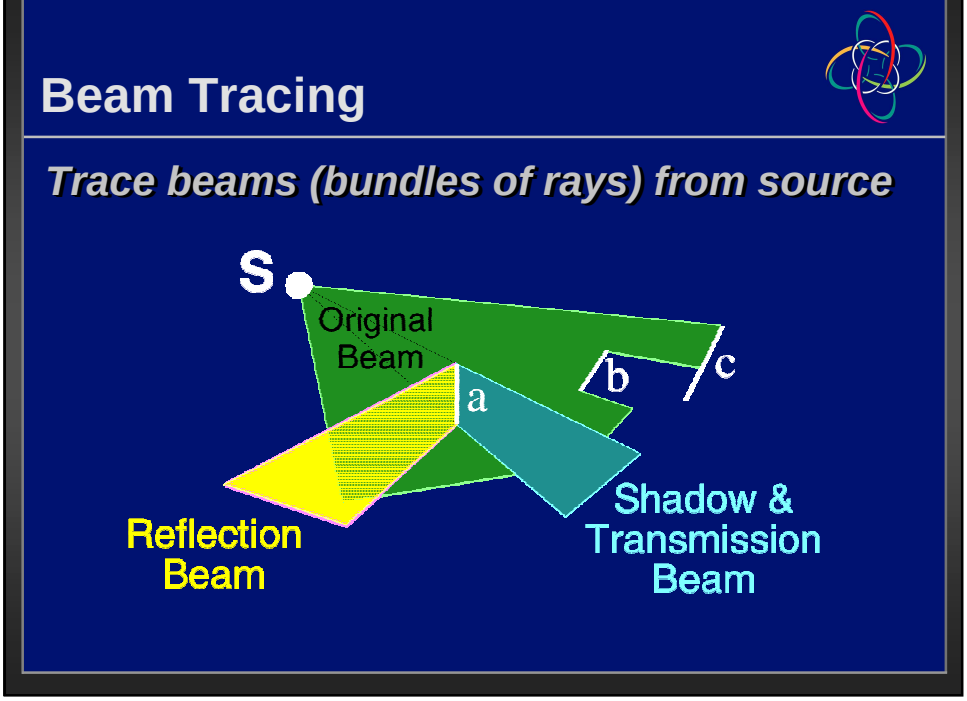
***Ray tracing***

***Boundary element methods***

***Image source methods***

***Beam tracing*** ←

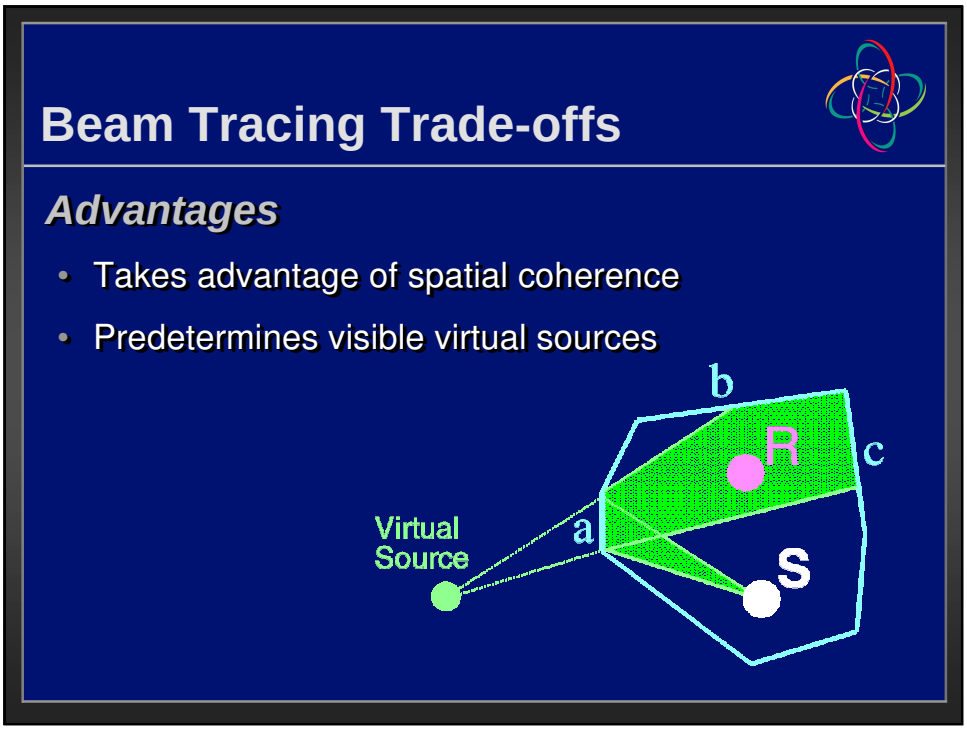
## Beam Tracing



***Trace beams (bundles of rays) from source***




## Beam Tracing Trade-offs



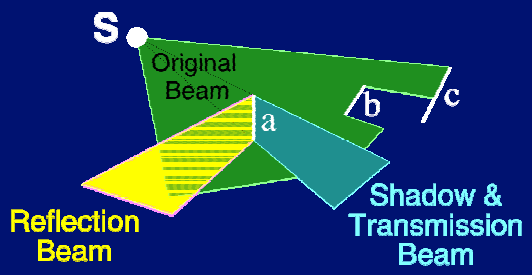
***Advantages***

- Takes advantage of spatial coherence
- Predetermines visible virtual sources

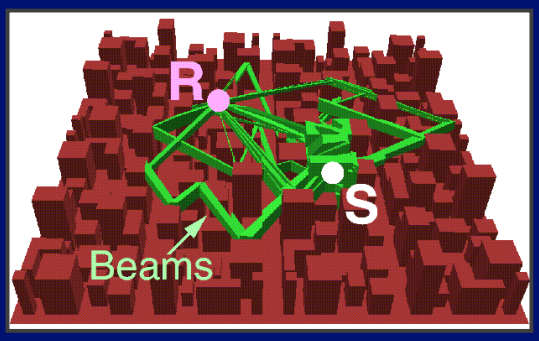
## Beam Tracing Trade-Offs

### *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