Acoustical Modeling with Sonel Mapping

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Overview (1):

- **Motivation/Introduction**
  - Goal of this work
- **Photon Mapping**
  - A two-stage, global illumination method
- **Sonel Mapping**
  - A two-stage acoustical modeling method
- **Results**
  - Graphical illustrations
- **Summary**

Motivation (1):

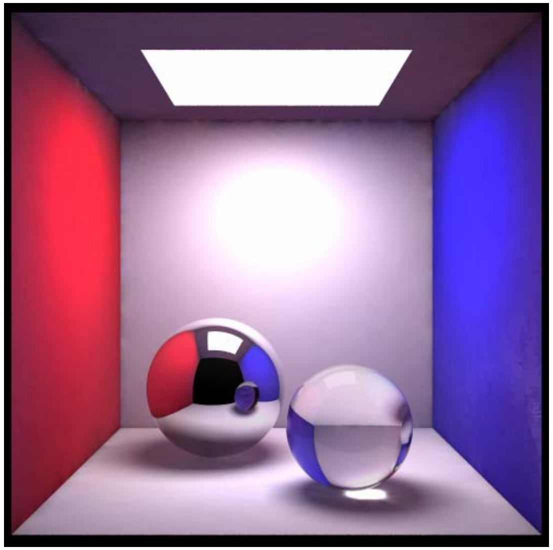
- **Sound is Essential to Immersive Environment**
  - Conveys basic information to the users
  - Allows users to orient themselves
  - Increases situational awareness
  - Helps increase immersion and hence presence
  - Can enhance perception of poor visual cues

Goal of this Work (1):

- **Develop a System Capable of "Accurately" Modeling the Acoustics of an Environment**
  - Many applications → computer games, virtual reality & virtual environments, simulators, room design etc…
  - Apply advancements, developments, and the vast knowledge base associated with the field of computer graphics (realistic image synthesis) and optics to acoustical modeling
    - This has lead to the development of a probabilistic, two-stage acoustical modeling method termed sonel mapping

Photon Mapping (1):

- **Developed by Henrik Wan Jensen (mid 90s)**
  - Efficient alternative to existing ray tracing techniques
  - Decouples illumination solution from scene geometry
    - Handles arbitrary geometry and complex models
    - Faster than existing methods




Photon Mapping (2):

- **Description**
  - Generates, stores & uses illumination as "points" (photons, the basic quantity of light)
  - Two-pass global illumination algorithm
    1. Photon tracing → building photon map by tracing photons from light sources through the model
    2. Rendering → rendering the model using info in the photon map to make rendering more efficient
  - Photon map → data structure used to store and process these "points"

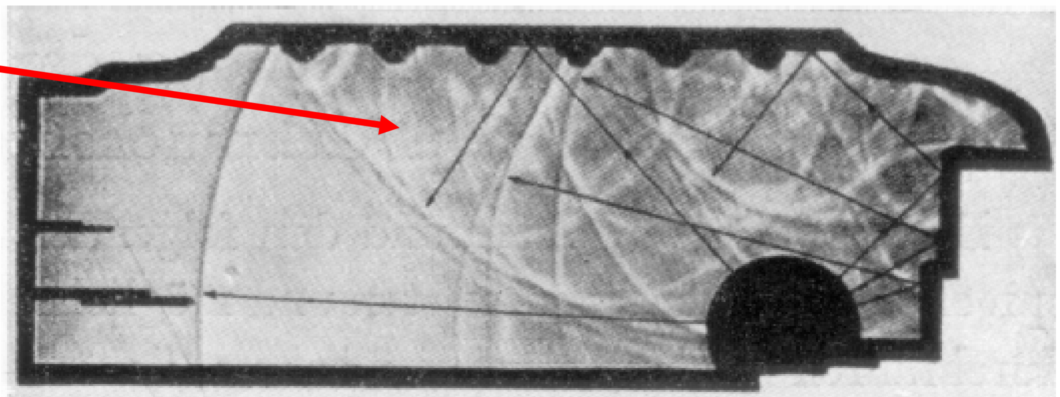
"Acoustical Photon Mapping" (1):

- **Photon Mapping is Essentially an Energy Propagation Modeling Method**
  - The energy happens to be light
  - Can such an approach be adapted for acoustical modeling ?
    - After all, with acoustical modeling it is still energy propagation that we are modeling → albeit acoustical energy

Defining the Problem (1):

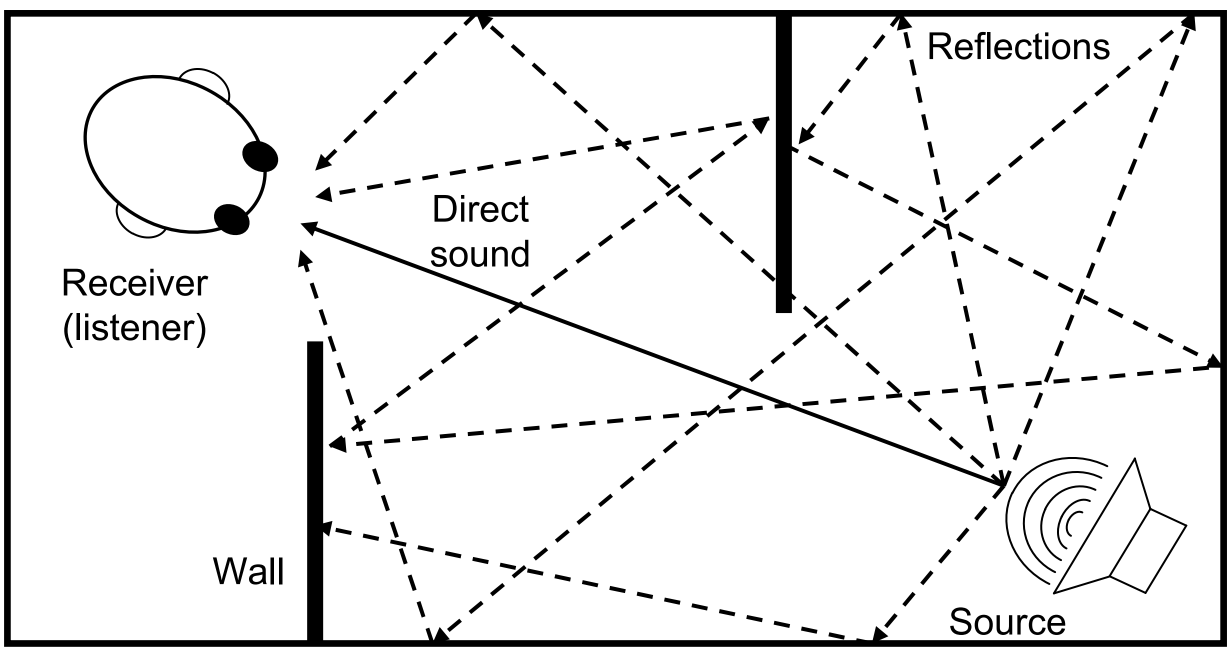
- **Sound: Mechanical Wave Phenomena**
  - Waves emitted from a source propagate through environment and interact with objects/surfaces
  - Determine the pattern of sound striking a listener involves following the propagation of a wave through the environment
    - Real world $\rightarrow$ continuous, complex objects, etc. making it a difficult task!

Propagating acoustic (sonar) waves



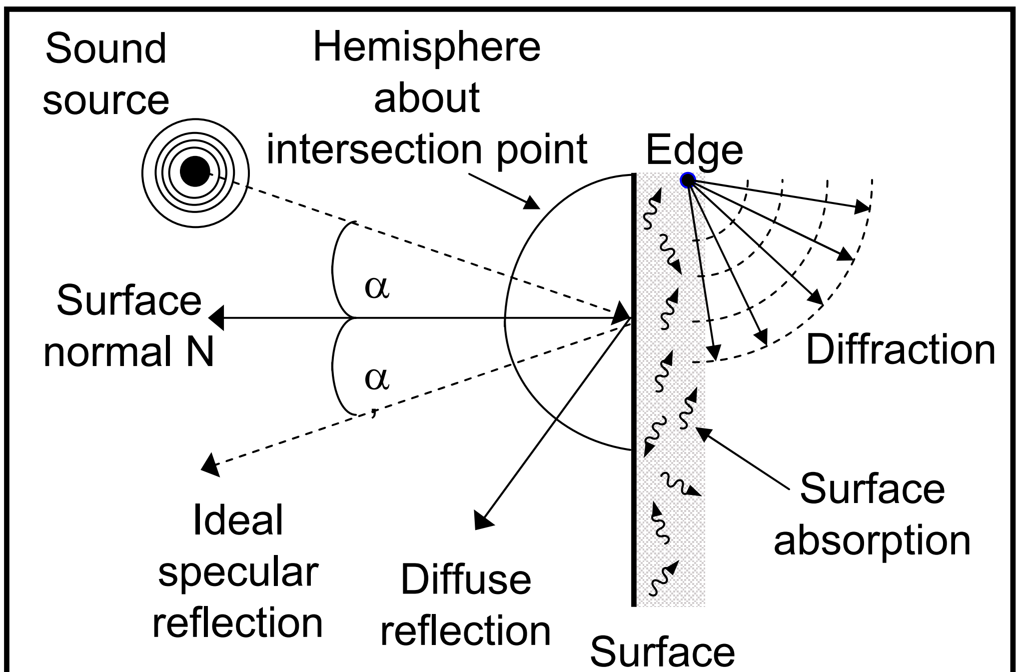
Defining the Problem (2):

- **Basic Idea of Sonel Mapping**
  - Approximate mechanical wave propagation with a collection of small discrete packets (sonels)
    - Trace sonels through environment as they interact with objects / surfaces → expensive!



Defining the Problem (3):

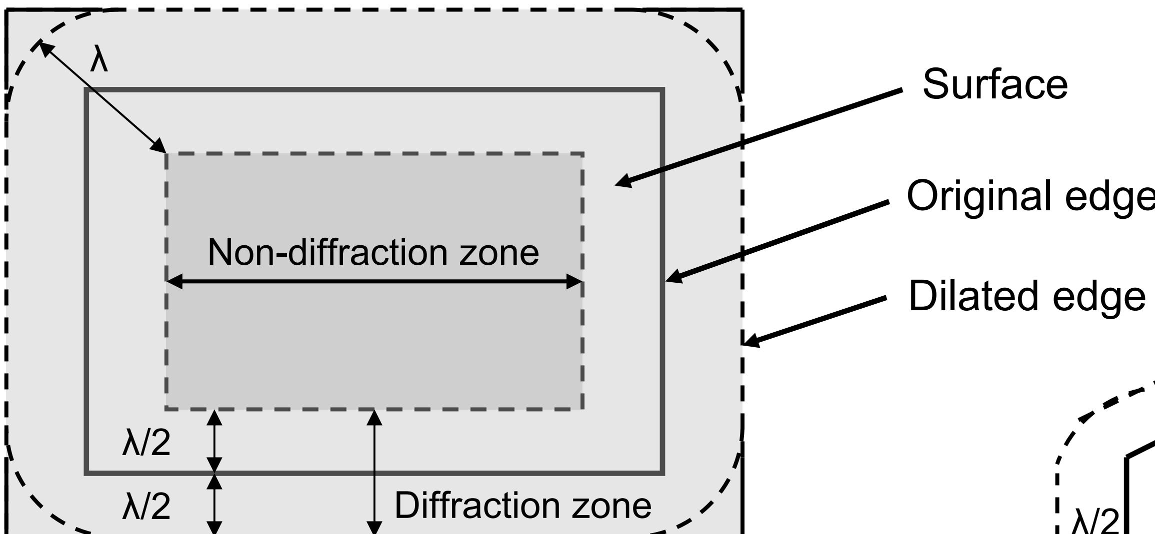
- **A Problem**
  - When a sonel strikes a surface it can do many things
    - Tracing the sonel will involve splitting it into multiple sonels when it strikes a surface → difficult and expensive

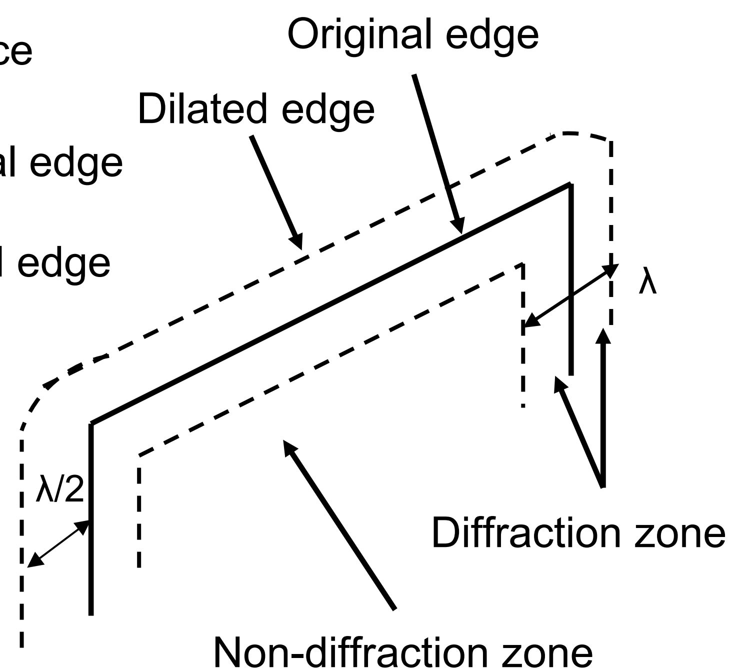


- **Solution**
  - Only one interaction at each sonel-surface interaction point is chosen

Diffraction/Non-Diffraction Zone (1):

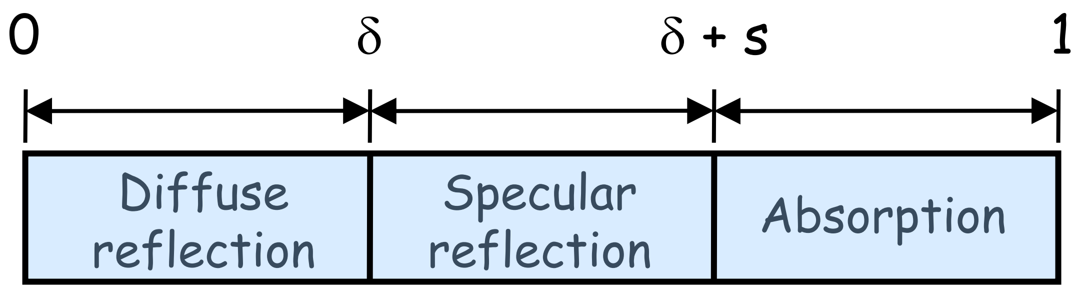
- **Determining the Type of Interaction**
  - Each surface is dilated by an amount equal to $\lambda/2$
  - Each surface is divided into two regions
    - Non-diffraction zone and diffraction zone





Non-Diffraction Zone (1):

- **Russian Roulette**
  - One of specular / diffuse reflection or absorption is chosen probabilistically based on the parameters of the surface and sonel and a random number ξ



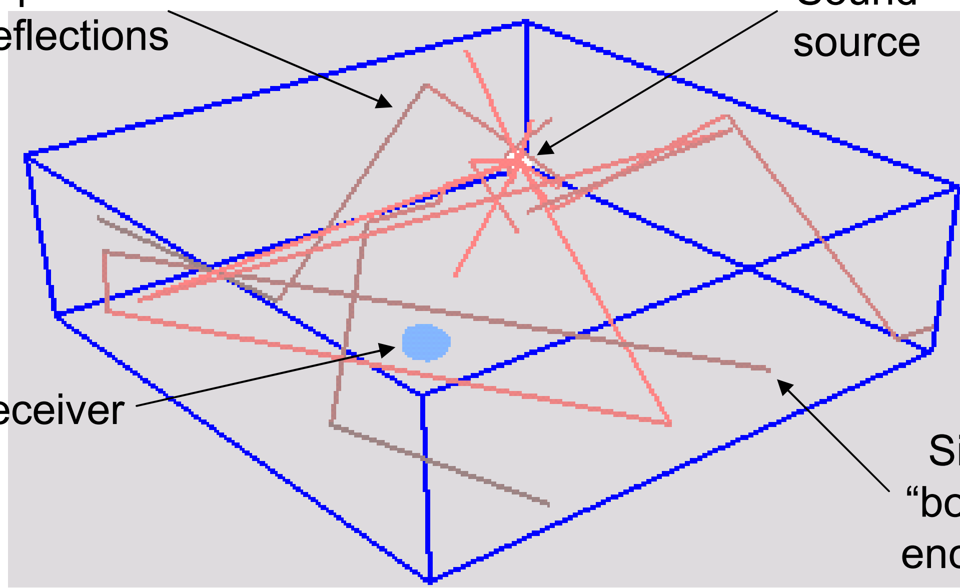
$\delta \rightarrow$ diffuse reflection coeff.

$s \rightarrow$ specular reflection coeff.

  - Only one interaction is chosen instead of multiple paths inherent in deterministic approaches
    - Leads to tremendous computational savings!
    - Paths of arbitrary length can be explored unlike traditional deterministic approaches

Non-Diffraction Zone (2):

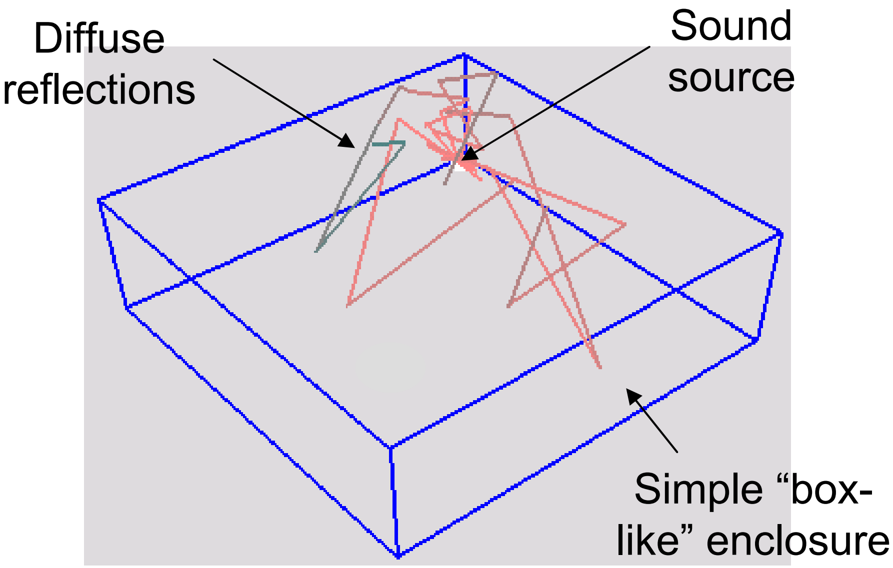
- **Specular Reflections**
  - Assume ideal specular reflections
  - Angle of reflection equals angle of incidence



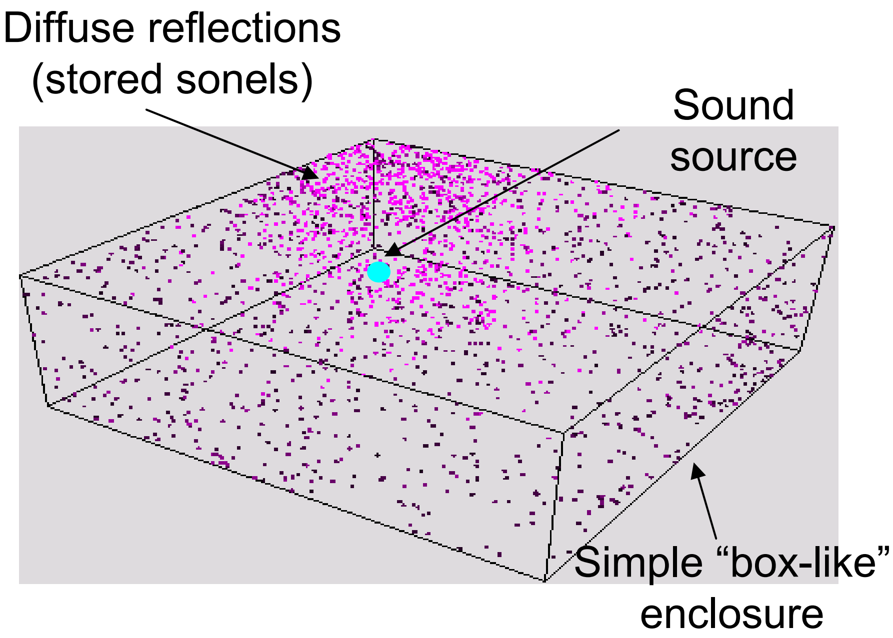
Simple example of specular reflections only in a simple "box-like" environment

Non-Diffraction Zone (3):

- Diffuse Reflections
  - Assume ideal (Lambertian) reflections
    - Reflection direction is completely random
  - Diffuelsy reflected sonels are stored in sonel map



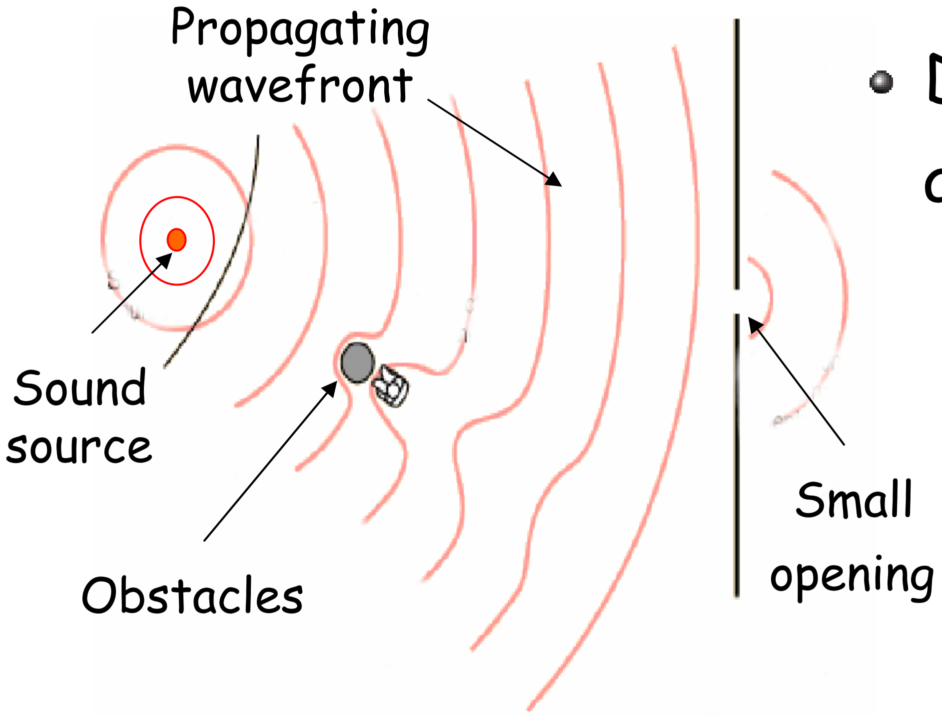
Diffuse reflections only in a simple "box-like" environment



Sonels stored in the sonel map

Diffraction Zone (1):

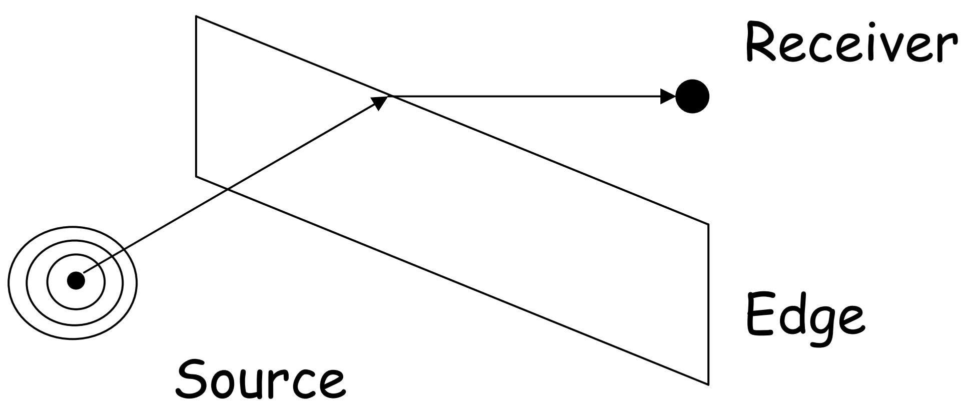
- **What is Diffraction ?**
  - Bending of sound waves around corners & obstacles
  - Spreading out of sound waves through small openings
  - Allows us to hear sounds around corners & barriers



- Dependent on wavelength and obstacle size
  - Increases as the ratio between wavelength and obstacle size increases

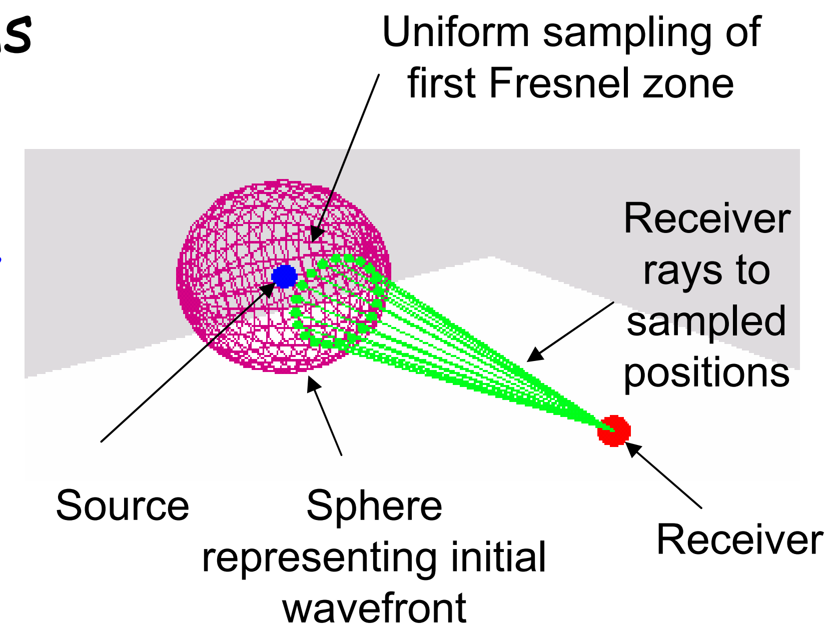
Diffraction Zone (2):

- **Focus of this Work is Edge Diffraction**
  - Concerned with the behavior of a wave when it encounters an edge
    - Edges are commonly found in acoustical modeling applications → typical in offices, homes, theatres, concert halls etc. e.g., sound waves bending around corners, doors etc.



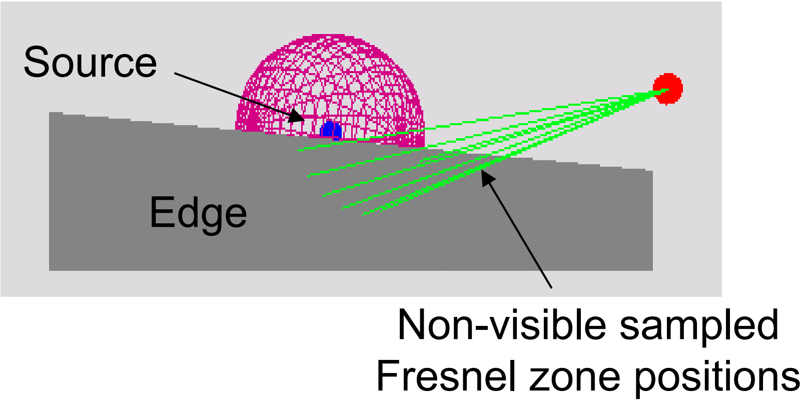
Diffraction Zone (3):

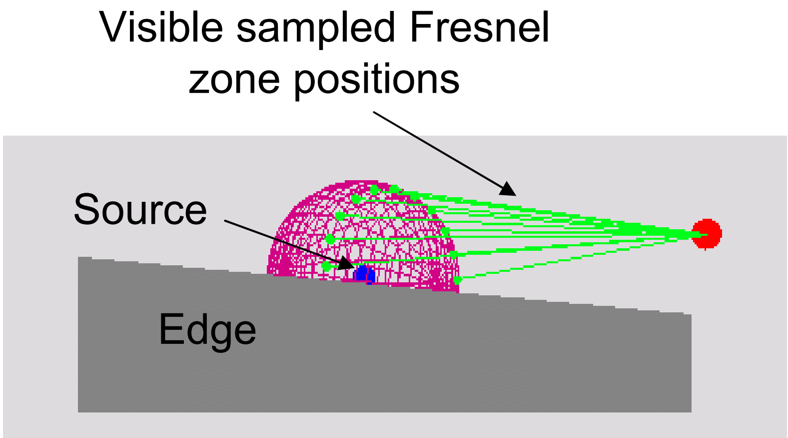
- **Huygens-Fresnel Principle: Initial Wavefront**
  - Wavefront emitted from source propagates until reaching position of diffracting sonel on edge
  - Divided into a number of Fresnel zones → adjacent Fresnel zones are separated by $\lambda/2$
  - Each Fresnel zone contains secondary sources
  - Total energy reaching the receiver → sum energy of the secondary sources in first Fresnel zone



Diffraction Zone (4):

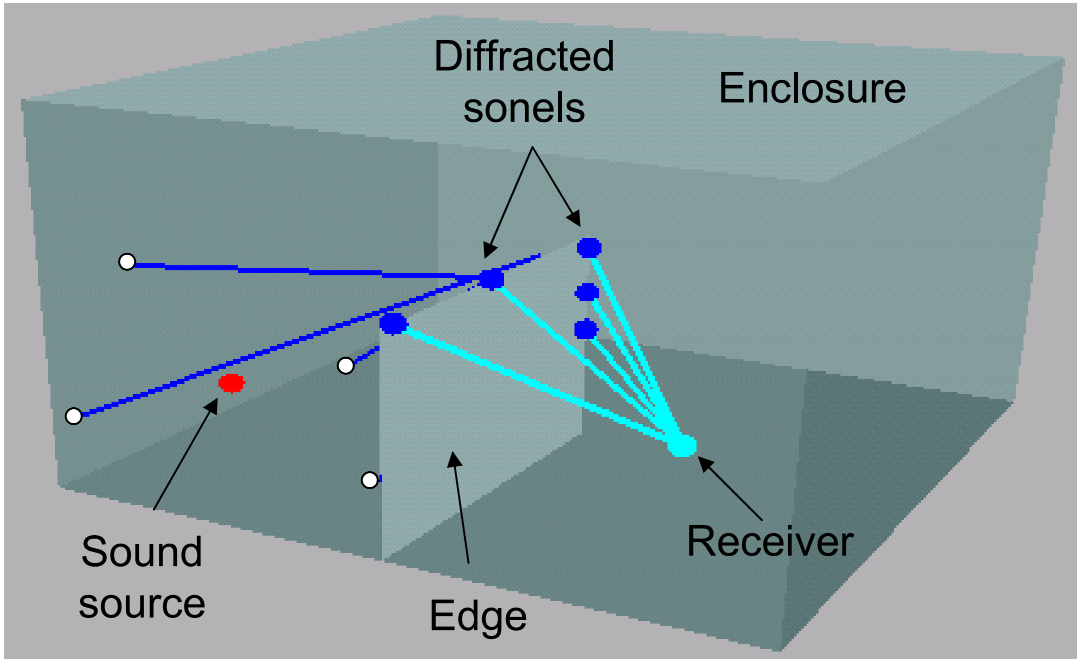
- **Sampling the First Fresnel Zone**
  - Account for wavefront obstruction
    - Sample first Fresnel zone by sending out "shadow" (or "feeler") rays from the receiver to determine how much of first zone is visible
    - Weigh the energy of the first zone reaching the receiver by the percentage of "visible" rays





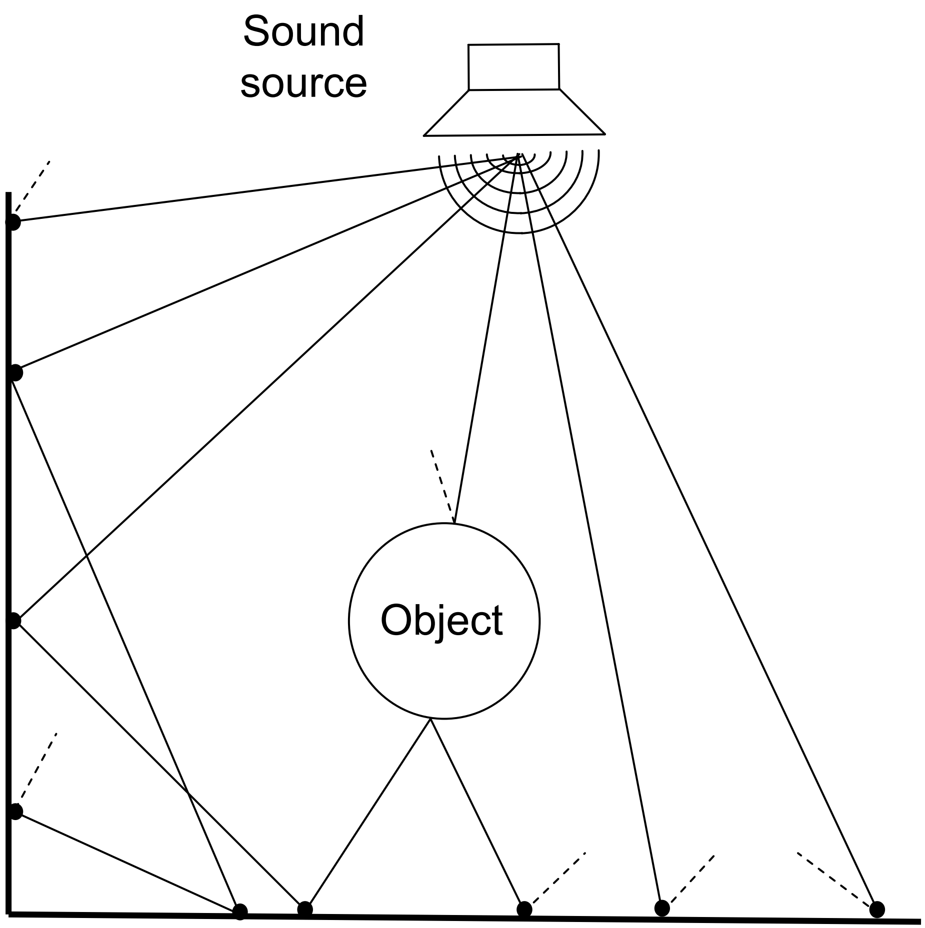
Diffraction Zone (5)

- **Graphical illustration**
  - Direct path between sound source and receiver is occluded but sonels diffracted at the edge still reach the receiver



A Two Stage Approach – Stage 1 (1):

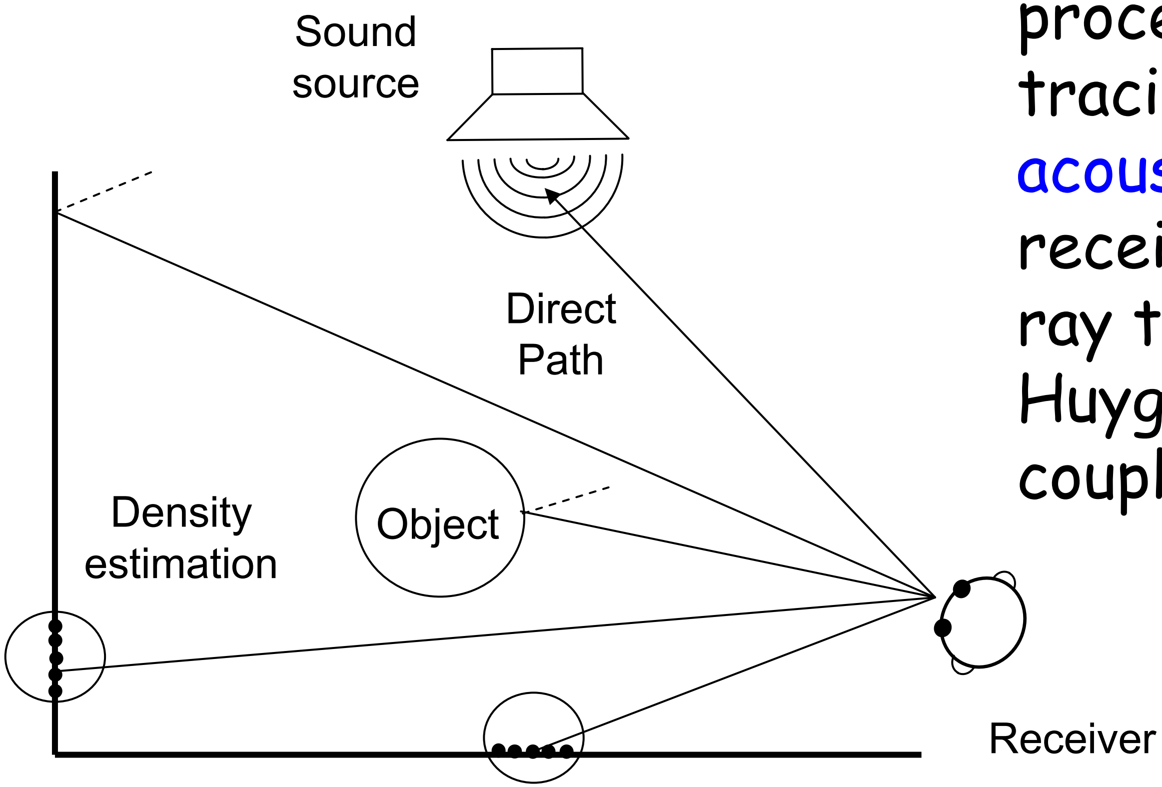
- **Sonel Tracing Stage**



- Purpose of the sonel tracing stage is to populate the sonel map
- Sonels are emitted from the sound source and traced through the environment while recording any interactions with any surfaces/objects they may encounter
- Diffuse reflected sonels are stored in the sonel map

A Two Stage Approach – Stage 2 (1):

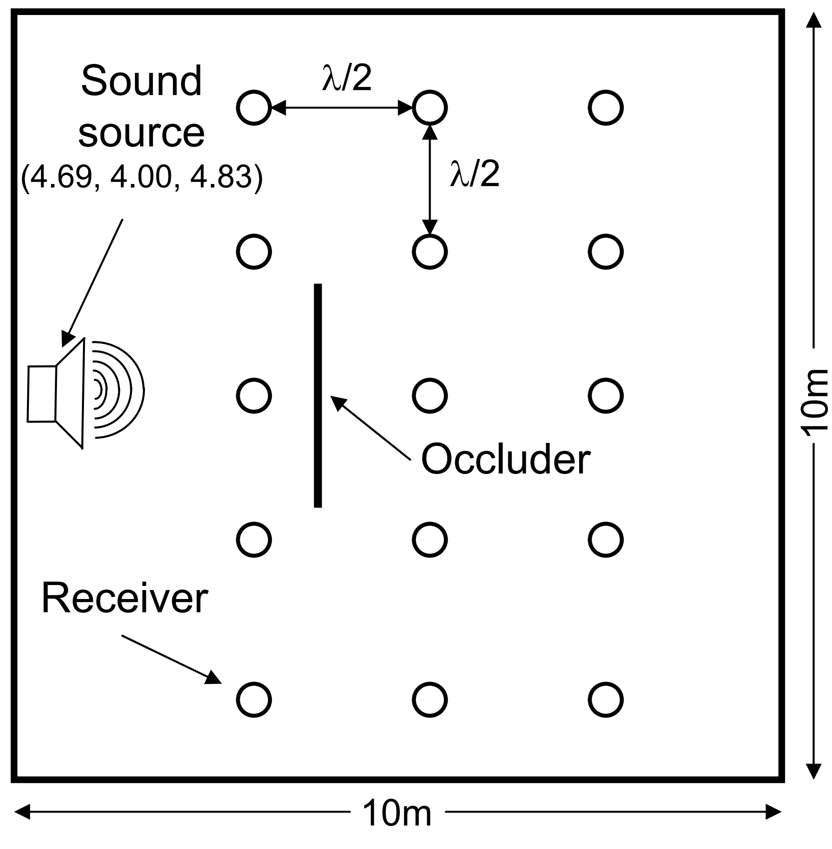
- Acoustical Rendering Stage



• Once sonel map has been constructed, complete energy transmission process is computed by tracing out "receiver acoustic rays" from the receiver using Monte-Carlo ray tracing and the Huygens'-Fresnel principle coupled with the sonel map

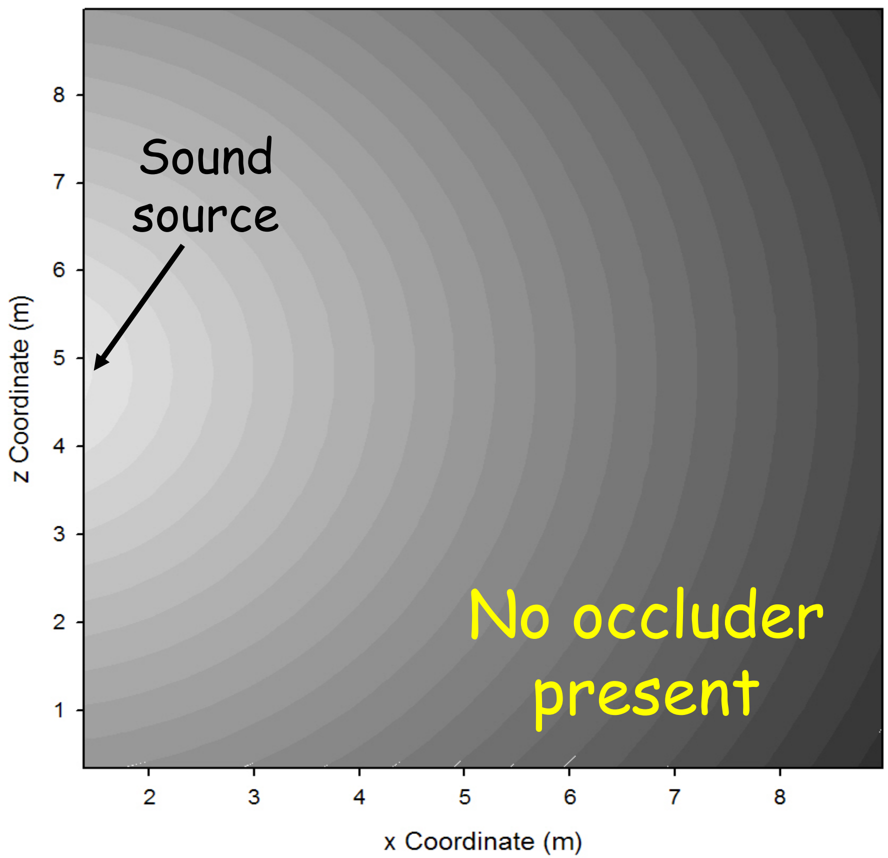
Graphical Illustrations (1):

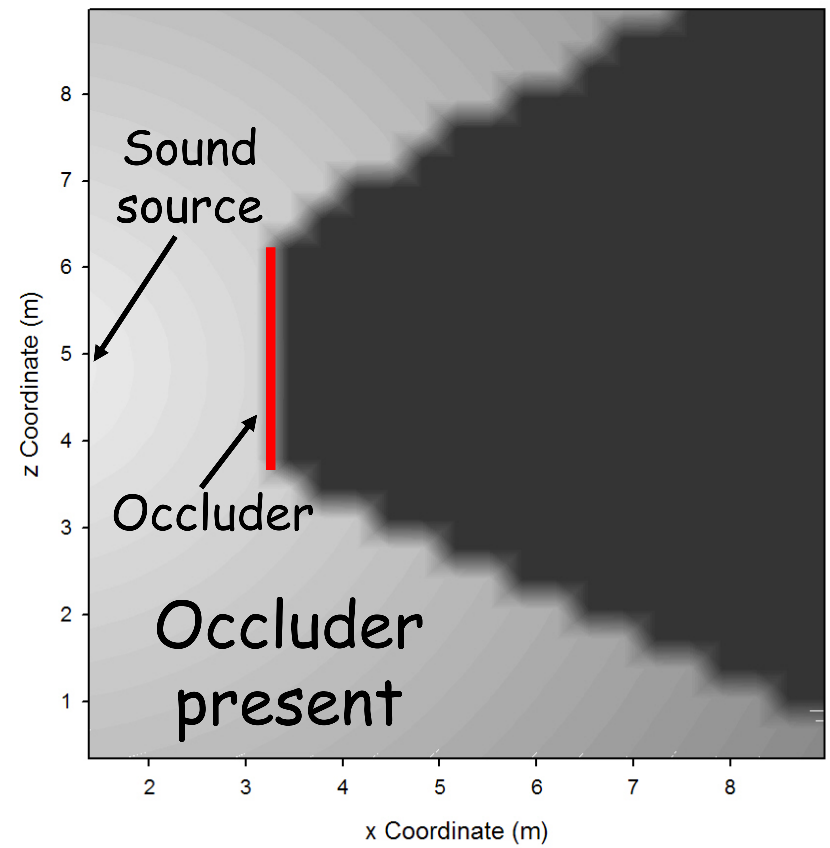
- **Simple "Box-Like" Room**
  - Sound energy propagation for a stationary sound source and various receiver & occluder set-ups
  - Grid of receiver positions on the x-z plane (const. y)
    - Spacing between positions on both axis is one half of a wavelength



Graphical Illustrations (2):

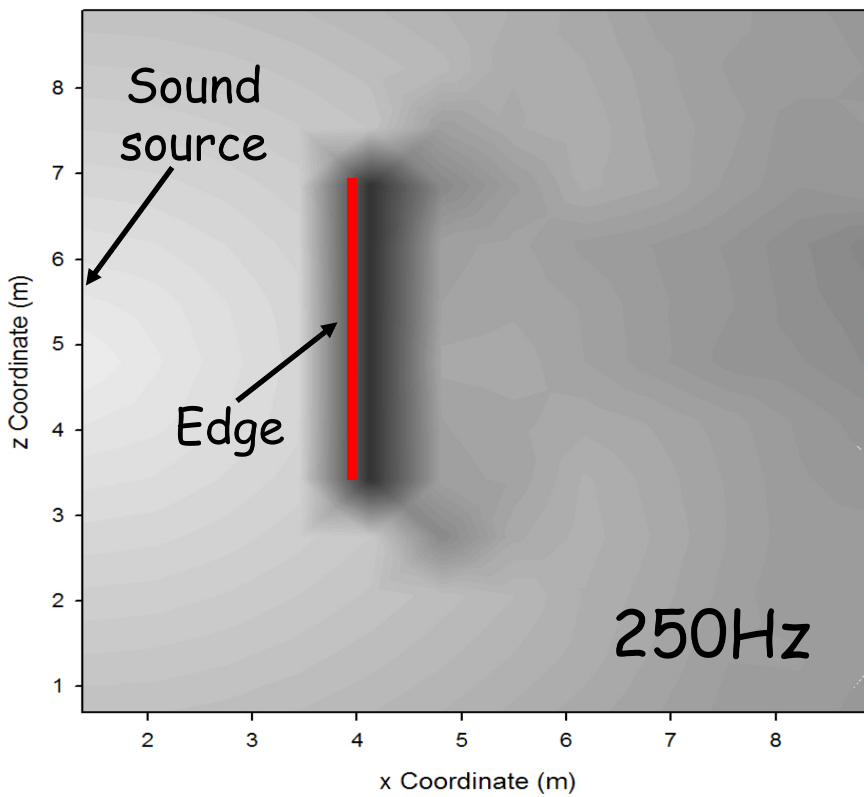
- **Direct Sound (500Hz)**
  - All surfaces were perfect absorbers → direct sound only (when not occluded)

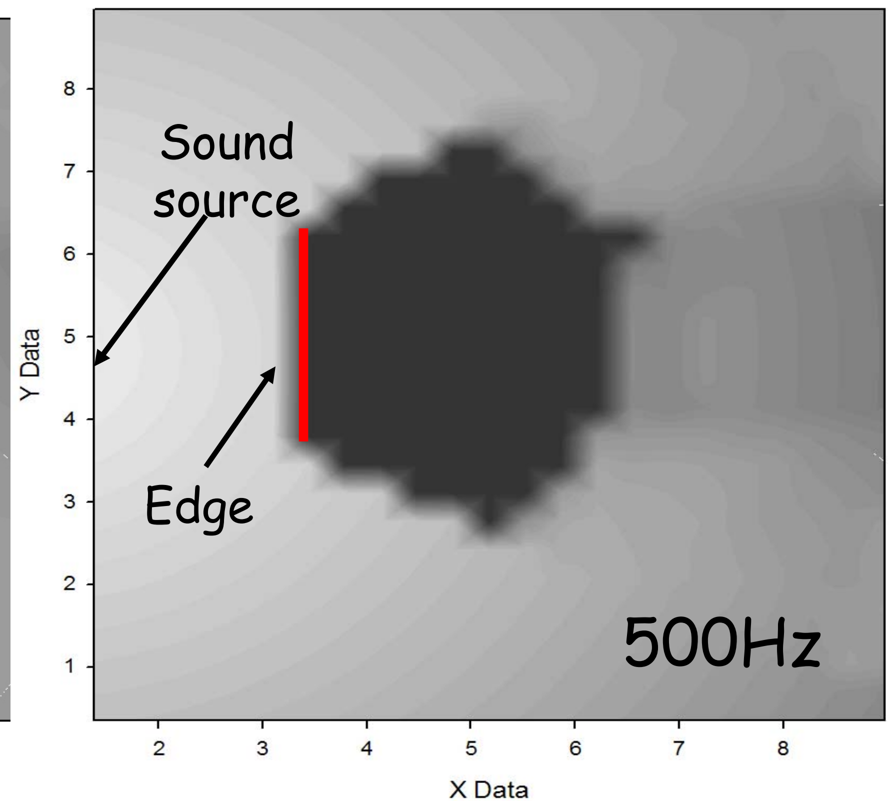




Graphical Illustrations (3):

- **Obstruction (Edge)**
  - Obstruction present blocking direct path of some receivers → diffraction present
  - All surfaces were perfect absorbers





Experiments (1):

- **Validation of Sonel Mapping**
  - Comparing reverberation time computed with sonel mapping vs. theoretical results → Kapralos et. al. HAVE 2004
  - Effectiveness of a Russian roulette approach to acoustical modeling (Russian roulette vs. deterministic approaches)→ Kapralos et. al. AES 2005
  - Applying the Huygens'-Fresnel principle to acoustical diffraction modeling → Kapralos et. al. HAVE 2005
  - Effectiveness of sonel mapping as a complete system → Kapralos et. al. ICASSP 2006

Conclusions (1):

- **Sound is Crucial in Immersive Systems**
  - Incorporating accurate and realistic environmental sound information requires effective and efficient acoustical modeling
    - Sonel mapping is such an approach
  - Sonel mapping is a stochastic, particle-based energy transport model applied to acoustical modeling
    - Photon mapping and Huygens'-Fresnel principle
    - Can model various acoustical phenomena in an efficient manner

Future Work (1):

- **Various "Open Problems" Remain**
  - Would like to address the acoustical modeling of sounds in the very near field (e.g., less than one meter)
    - Can allow for modeling effects such as one person whispering in the ear of another → accurately modeling this is a difficult task!
  - User Tests
    - Perform user-based studies and account for the "human factor" → ultimately, a human will be the end user!

The End…

Thank You!

Any Questions ?

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