Digital Sound

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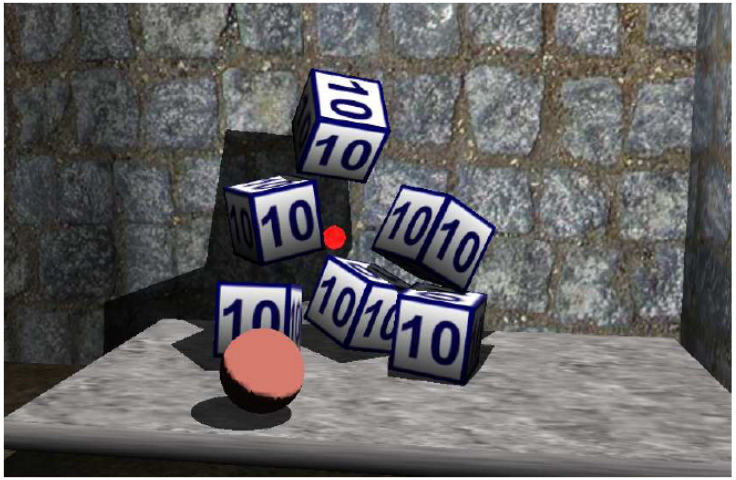
How can it be done?

- Foley artists manually make and record the sound from the real-world interaction

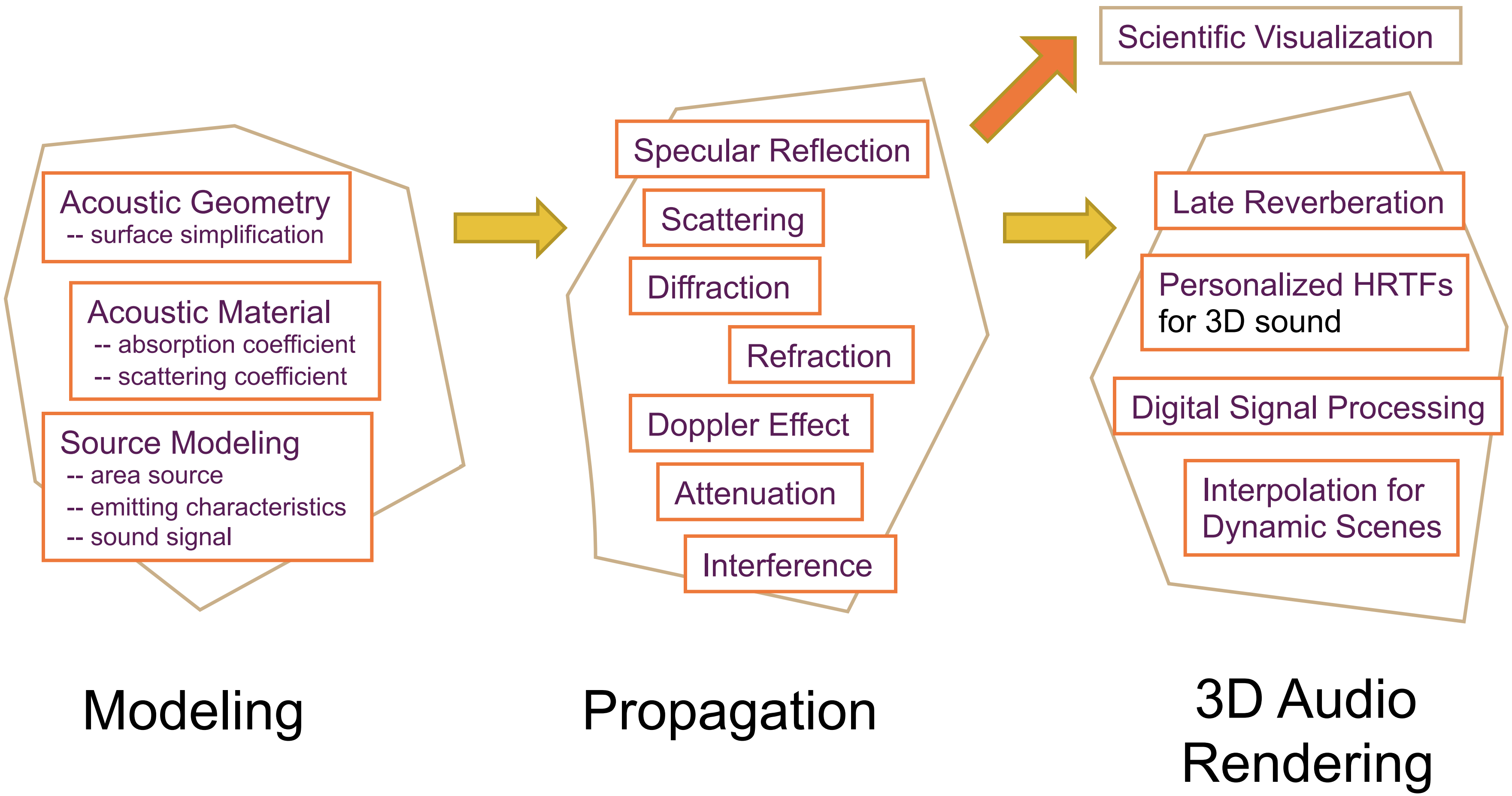
Lucasfilm Foley Artist

How about Computer Simulation?

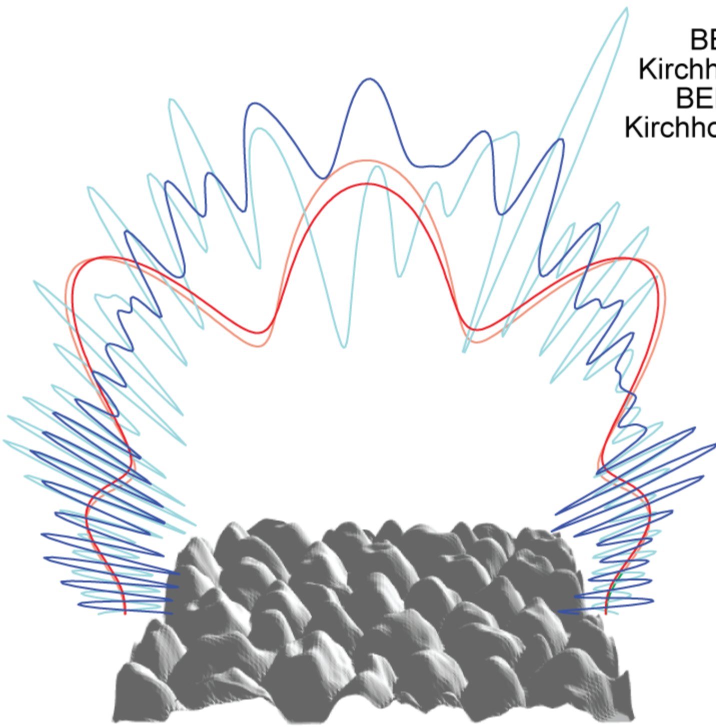
- Physical simulation drives visual simulation
  - Sound rendering can also be *automatically* generated via 3D physical interaction

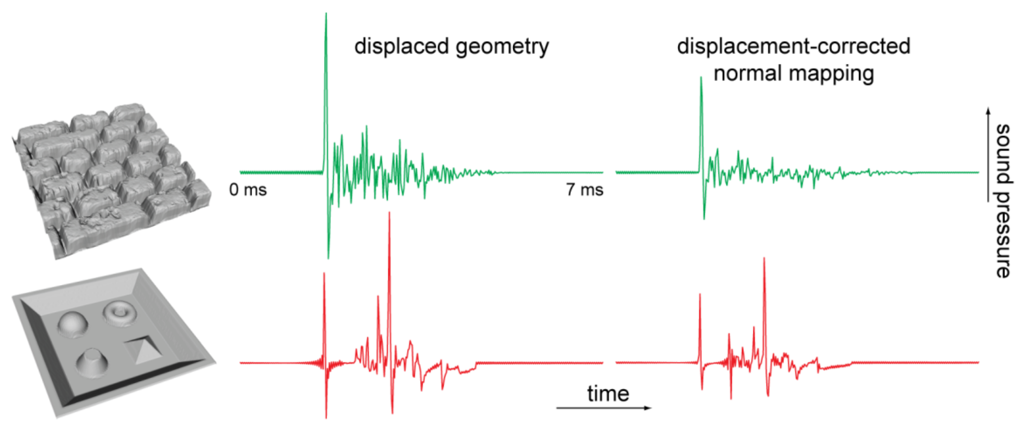


Sound Rendering: An Overview



Modeling Sound Material



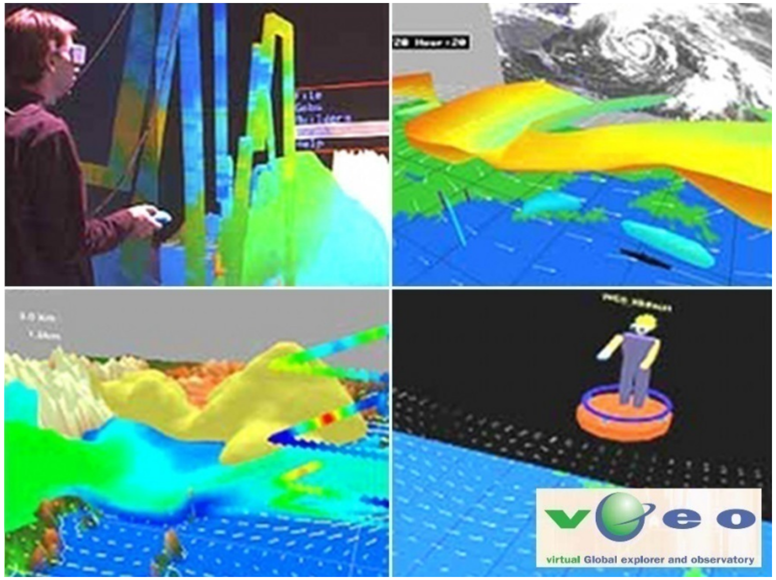


[Embrechts,2001] [Christensen,2005] [Tsingos,2007]

Applications

- Advanced Interfaces
- Multi-sensory Visualization

Minority Report (2002)



Multi-variate Data Visualization

Applications

- Games
- VR Training

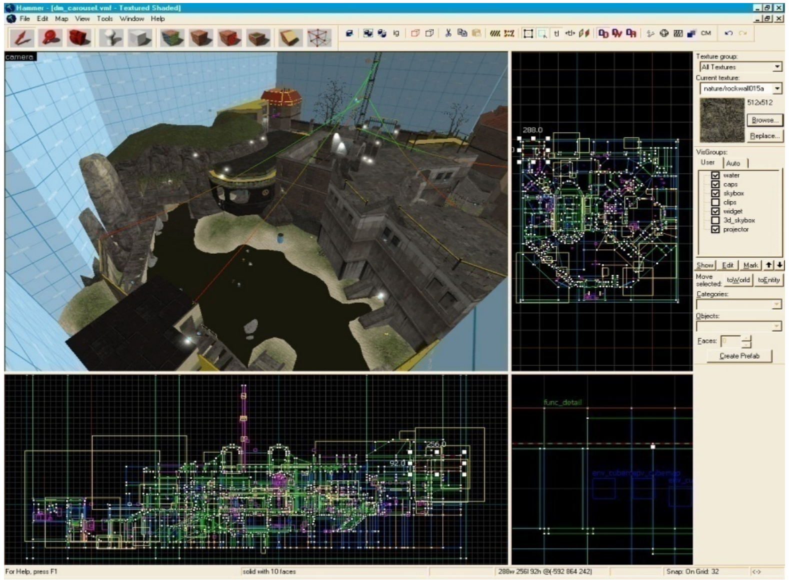
Game (Half-Life 2)

Medical Personnel Training

Applications

- Acoustic Prototyping

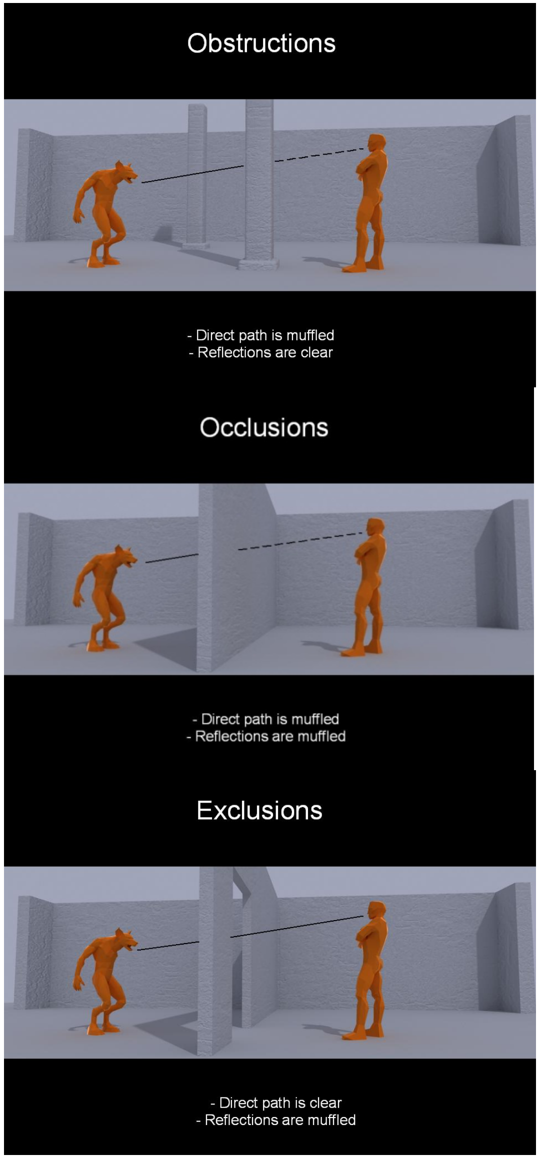
Symphony Hall, Boston



Level Editor, Half Life

Sound Propagation in Games

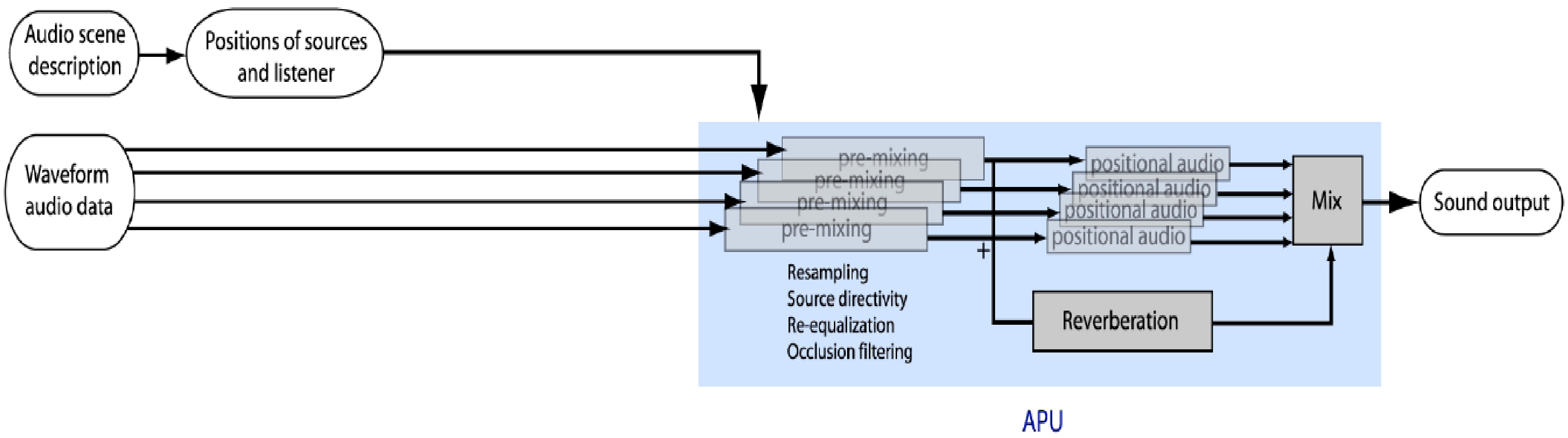
- Strict time budget for audio simulations
- Games are dynamic
  - Moving sound sources
  - Moving listeners
  - Moving scene geometry
- Trade-off speed with the accuracy of the simulation
- Static environment effects (assigned to regions in the scene)



3D Audio Rendering

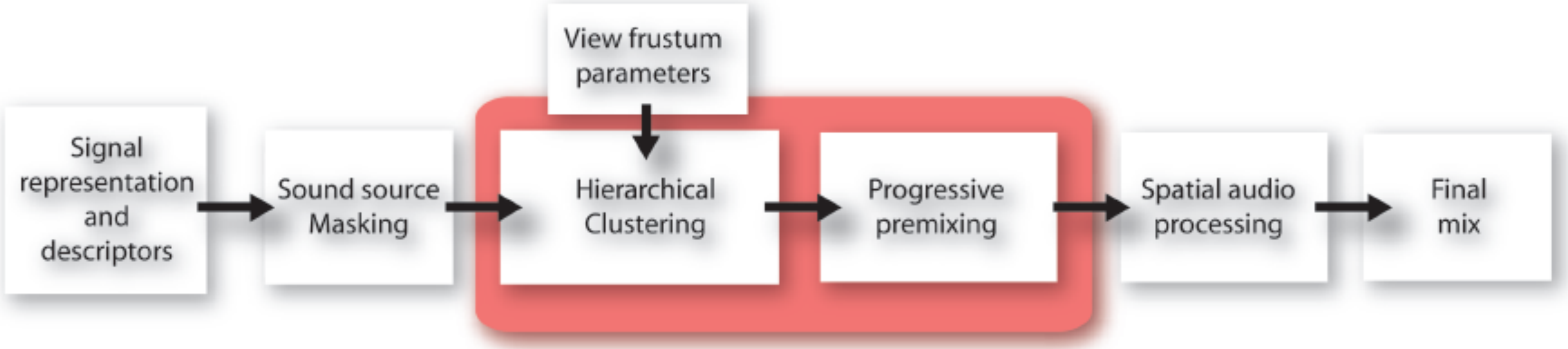
- Main Components
  - 3D Audio and HRTF
  - Artifact free rendering for dynamic scenes
  - Handling many sound sources

Traditional pipeline

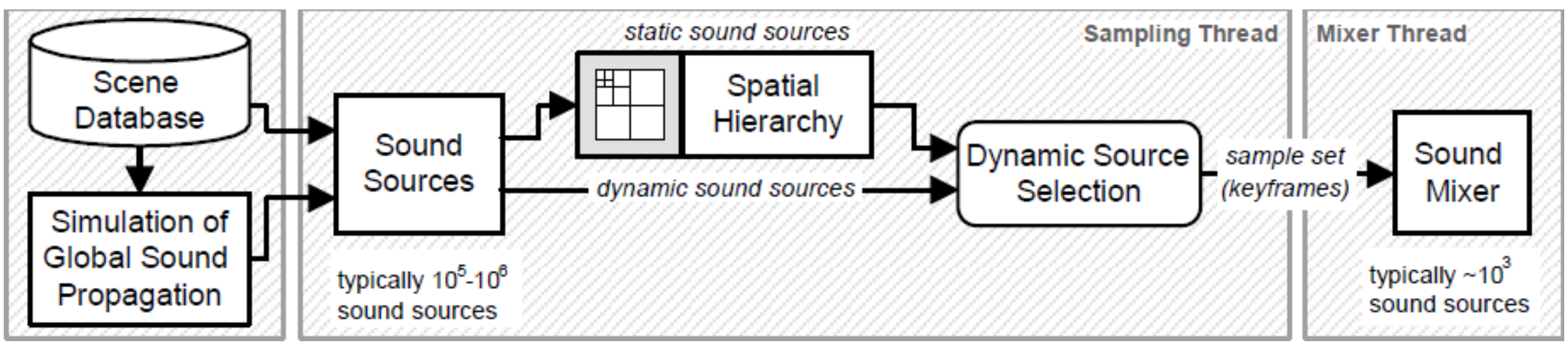


3D Audio Rendering

- Perceptual Audio Rendering [Moeck,2007]



- Multi-Resolution Sound Rendering [Wand,2004]

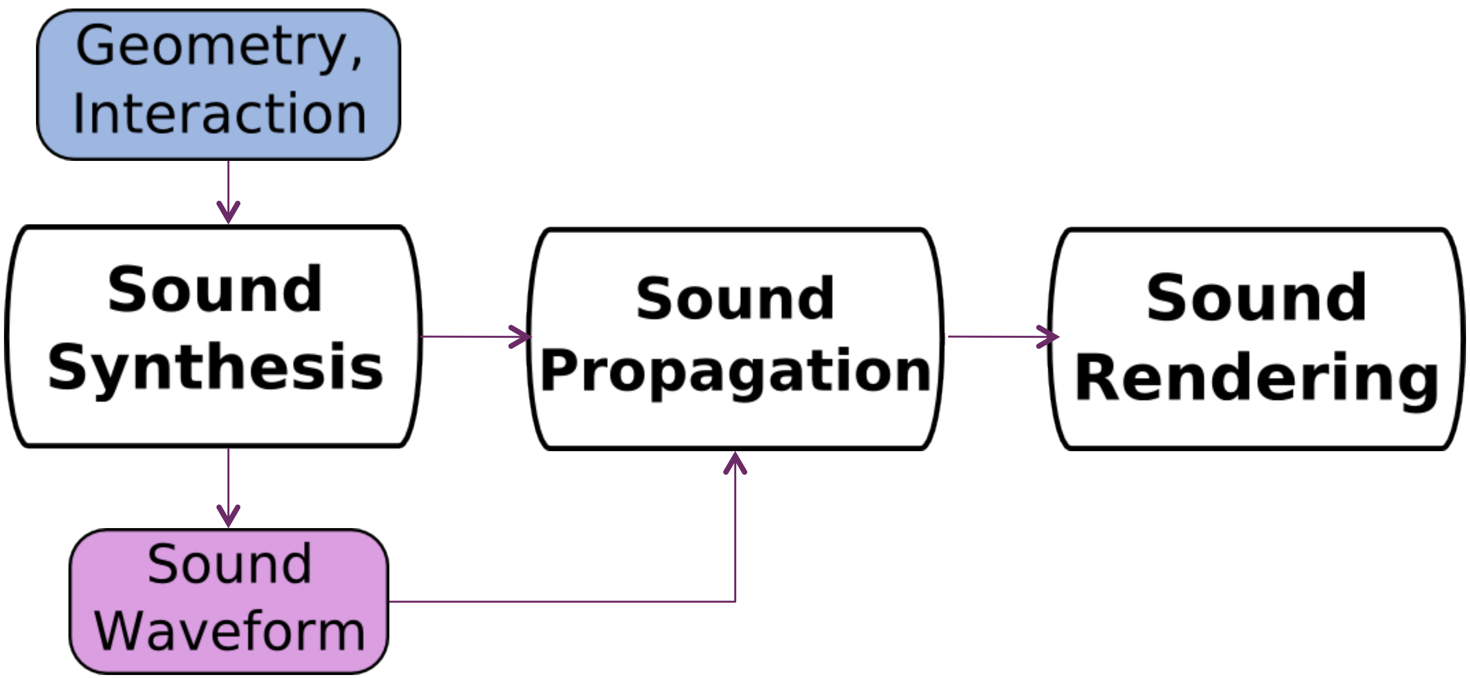


Overview of Sound Simulation

- The complete pipeline for sound simulation
  - Sound Synthesis
  - Sound Propagation
  - Sound Rendering

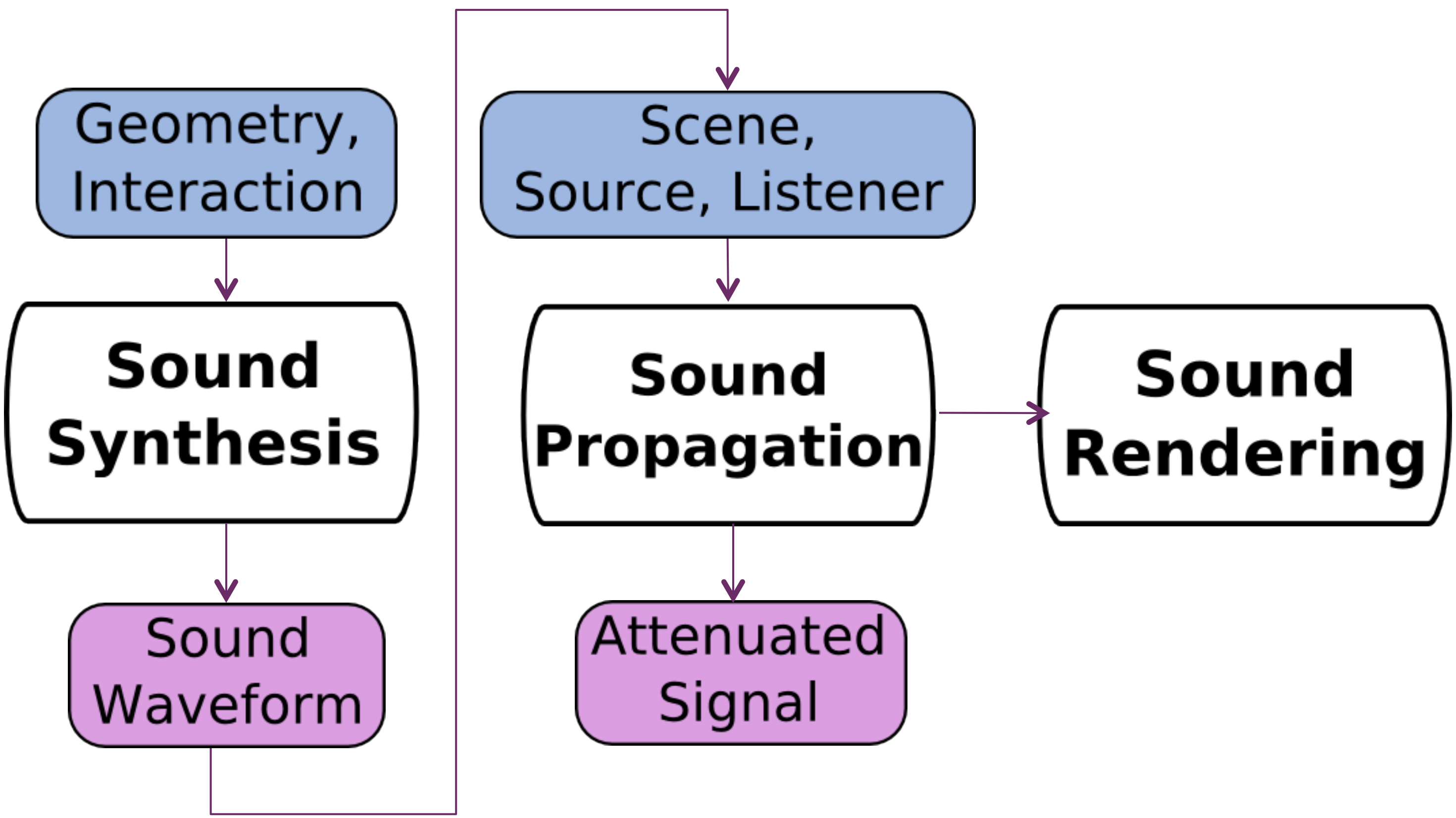
Overview of Sound Simulation

- Sound Synthesis



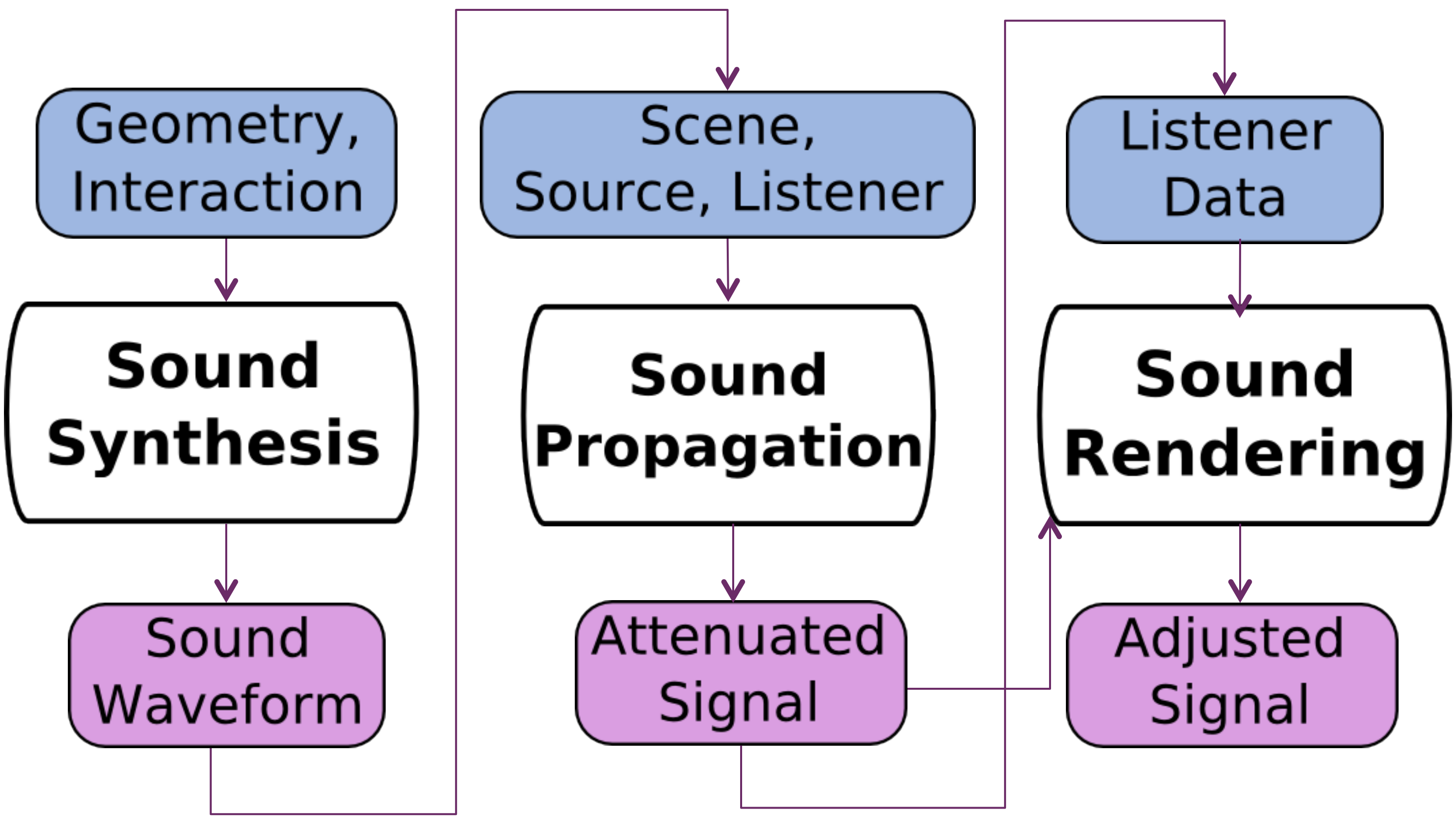
Overview of Sound Simulation

- Sound Propagation

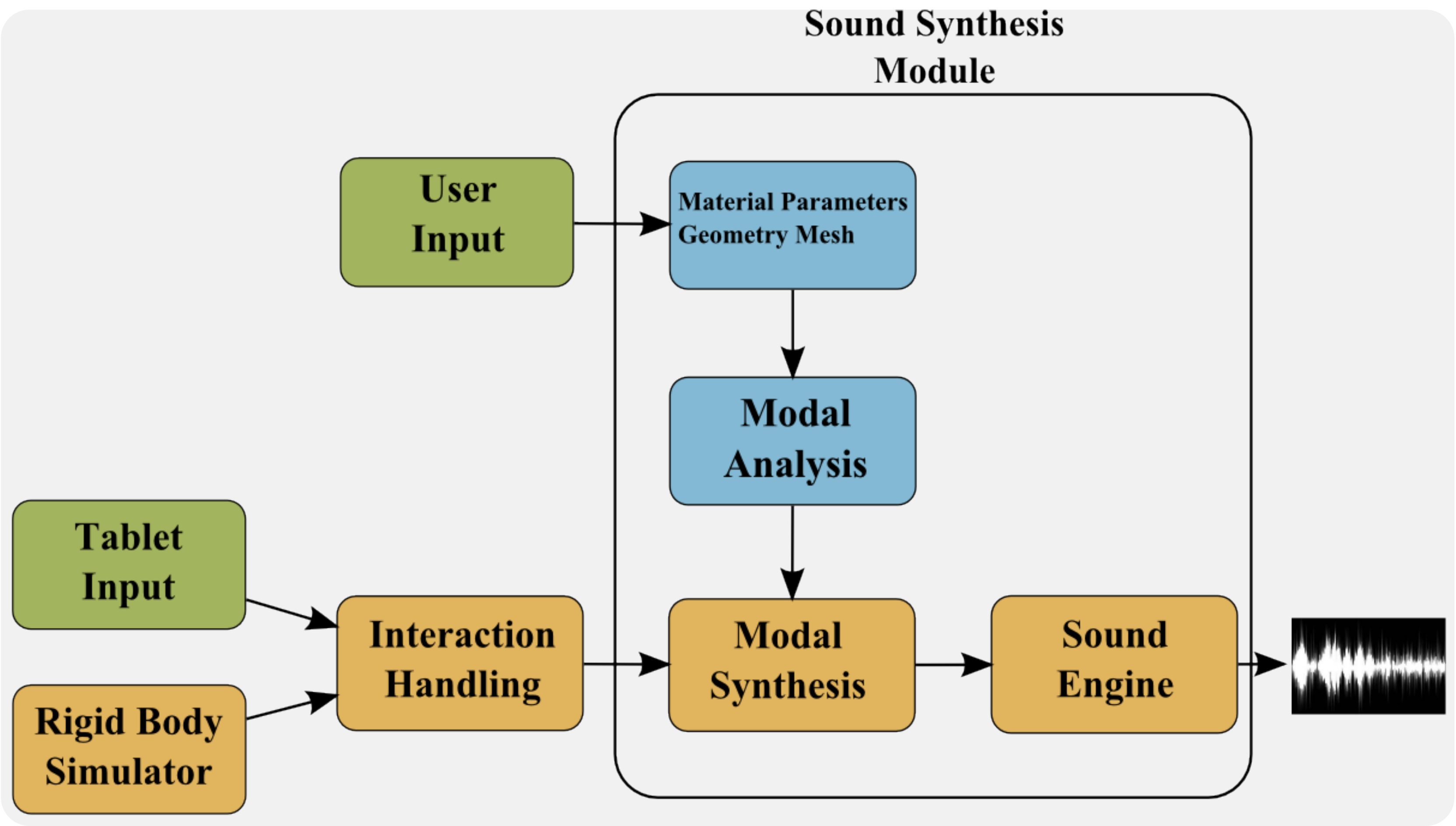


Overview of Sound Simulation

- Sound Rendering

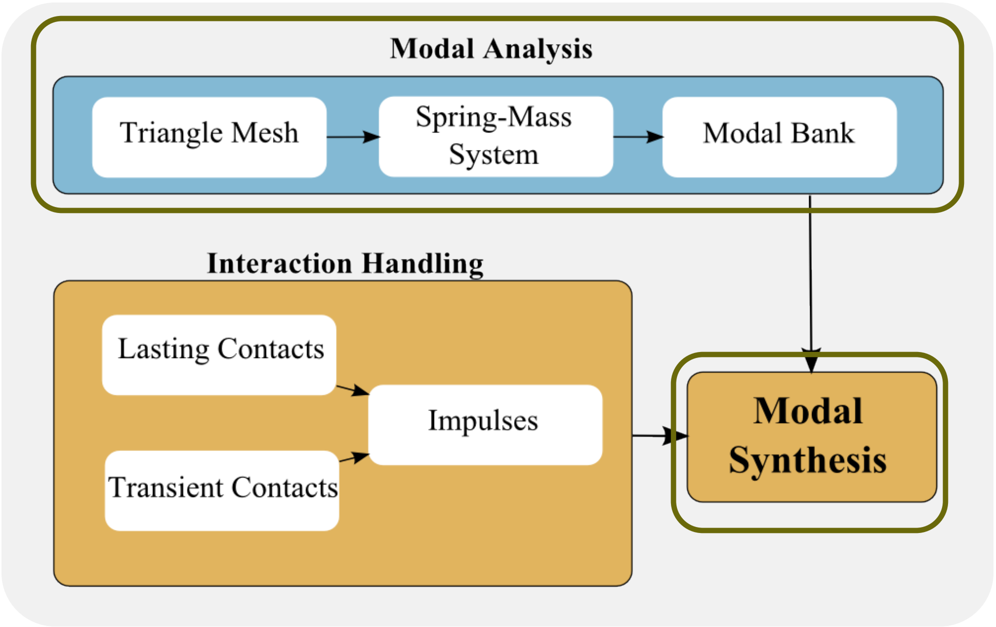


Synthesis System Overview



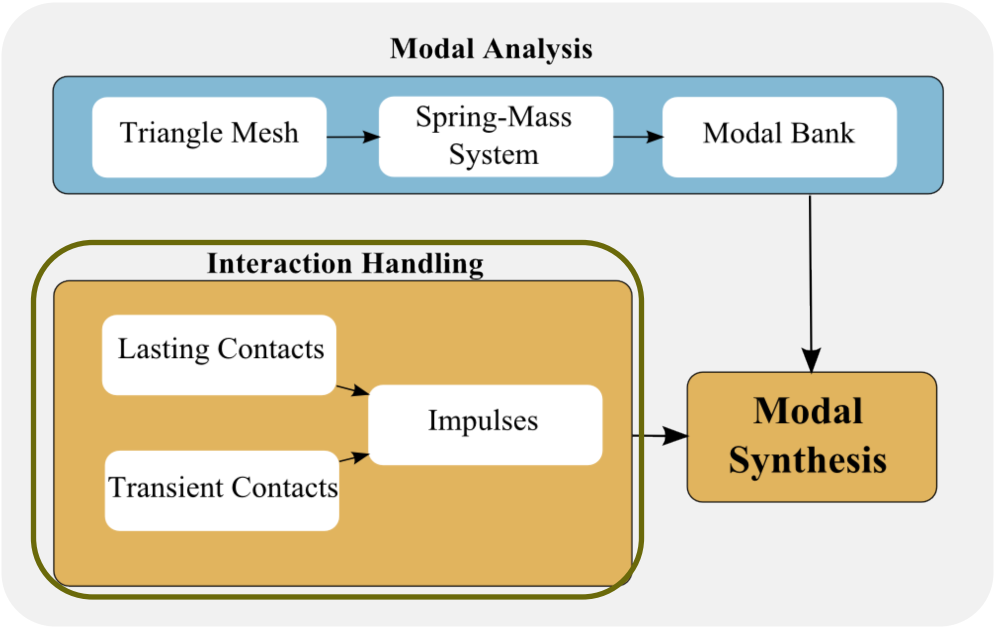
Synthesis System Overview

- Sound synthesis module
  - Modal Analysis: Raghuvanshi & Lin (2006)
  - Impulse response



Synthesis System Overview

- Interaction handling module
  - State detection: lasting and transient contacts
  - Converting interactions into impulses

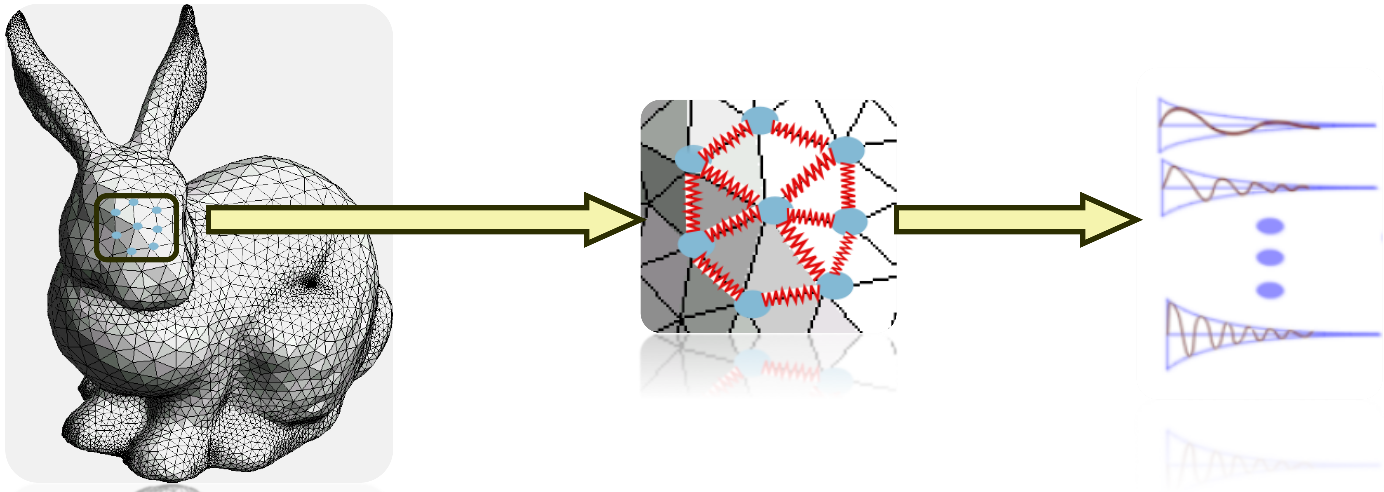


Modal Analysis

- Deformation modeling
  - Vibration of surface generates sound
  - Sound sampling rate: 44100 Hz
  - Impossible to calculate the displacement of the surface at sampling rate
  - Represent the vibration pattern by a bank of damped oscillators (modes)
- Standard technique for real-time sound synthesis

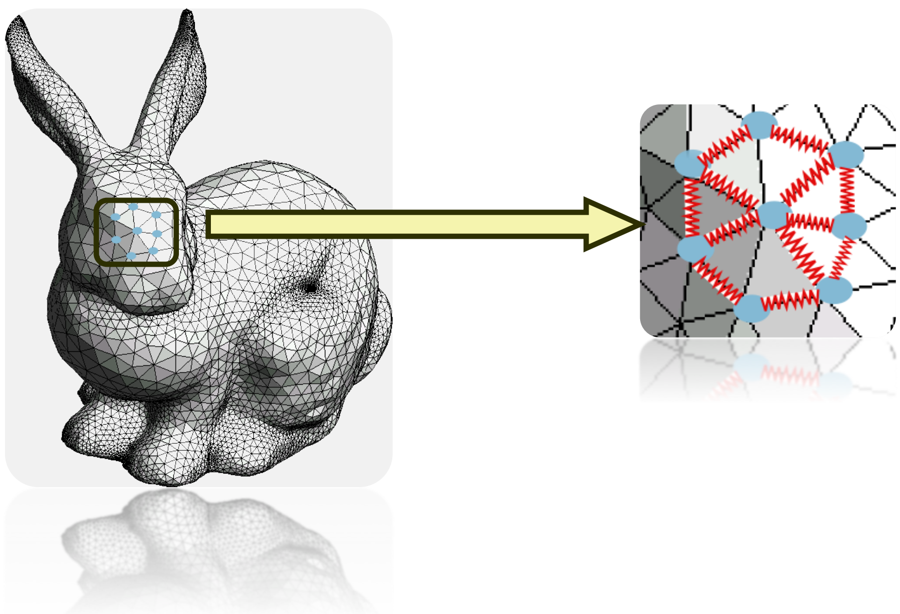
Modal Analysis

- Discretization
  - An input triangle mesh → a spring-mass system
  - A spring-mass system → a set of decoupled modes



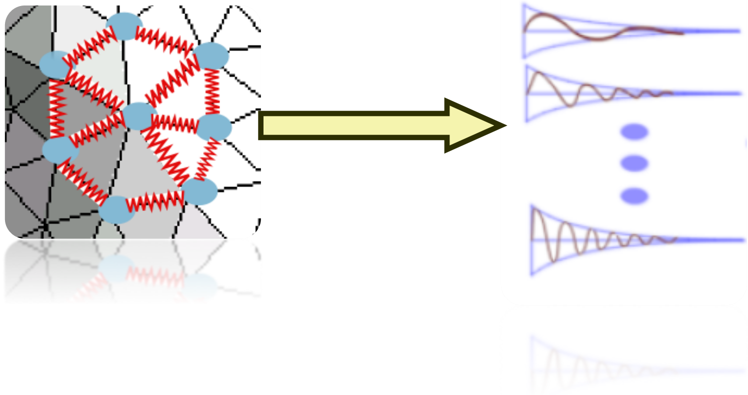
Modal Analysis

- The spring-mass system set-up
  - Each vertex is considered as a mass particle
  - Each edge is considered as a damped spring



Modal Analysis

- Coupled spring-mass system to a set of decoupled modes

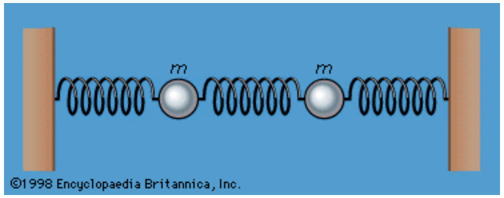


Modal Analysis

- A discretized physics system
  - We use spring-mass system

$$\boxed{K}(d) + \boxed{C}(d, \dot{d}) + \boxed{M}(\ddot{d}) = f$$

Stiffness Damping Mass

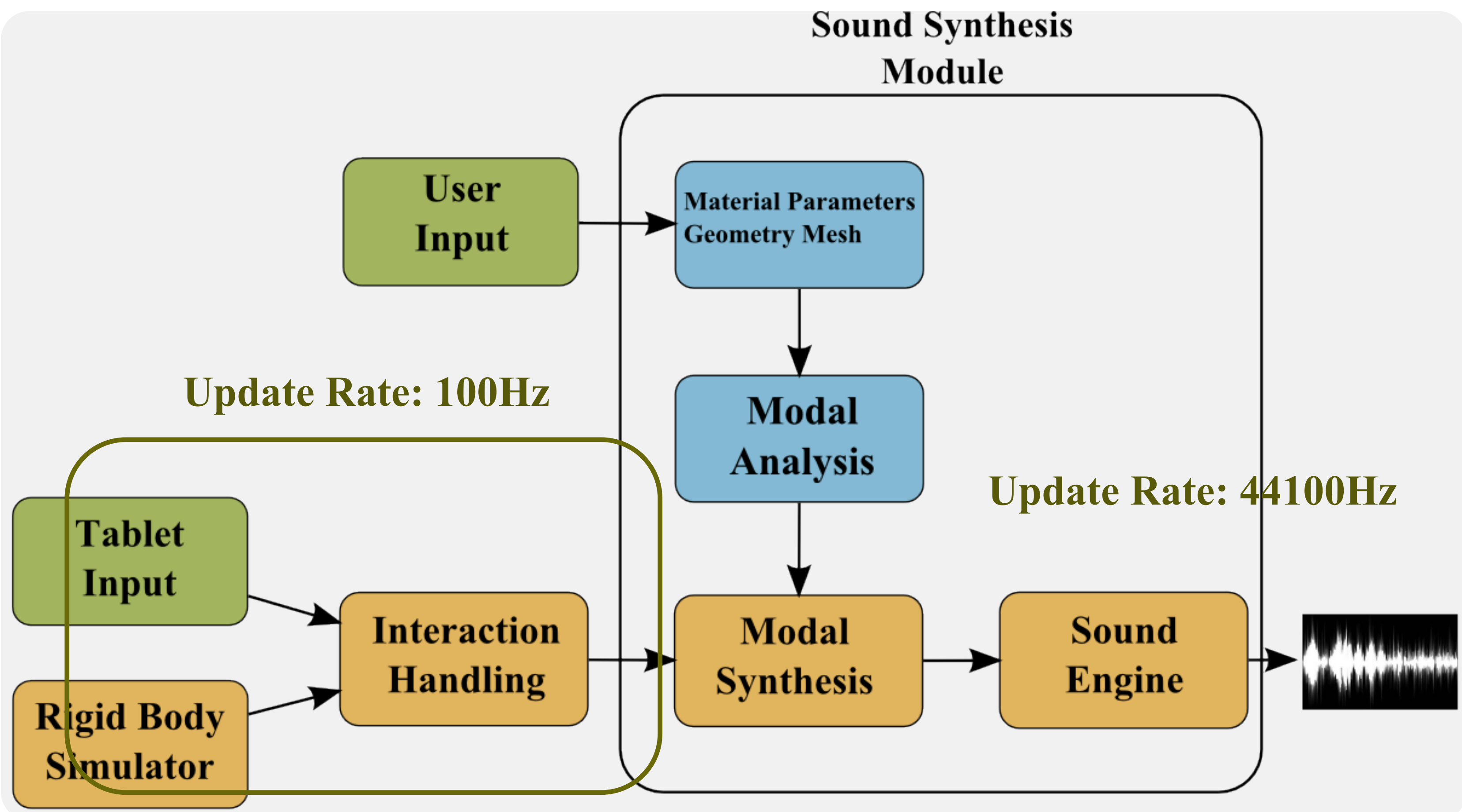


- Small displacement, so consider it linear

$$\boxed{K}d + \boxed{C}\dot{d} + \boxed{M}\ddot{d} = f$$

Stiffness Damping Mass

Handling Lasting Contacts

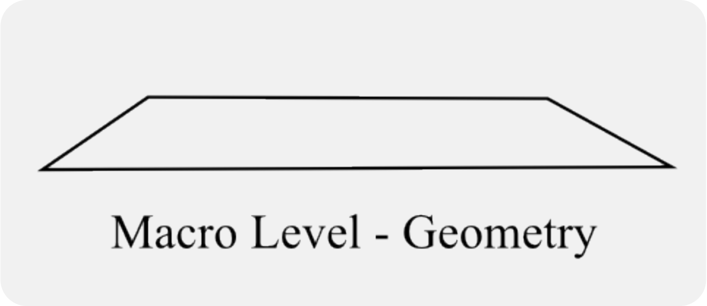


One Possible Solution

- Three levels of simulation
  - Macro level: simulating the interactions on the overall surface shape
  - Meso level: simulating the interactions on the surface material bumpiness
  - Micro level: simulating the interactions on the surface material roughness

Three-level Simulation

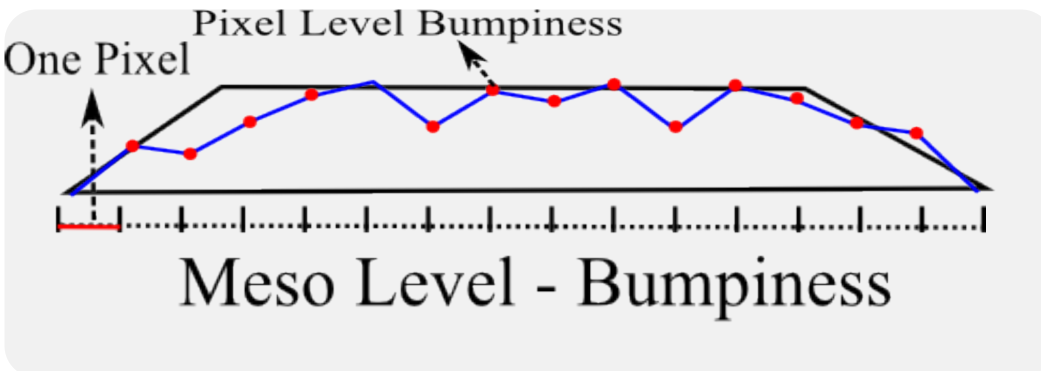
- Macro level: Geometry information
  - Update rate: 100’s Hz
- Update rate does not need to be high



  - The geometry information is from the input triangle mesh, and contacts are reported by collision detection in the physics engine.

Three-level Simulation

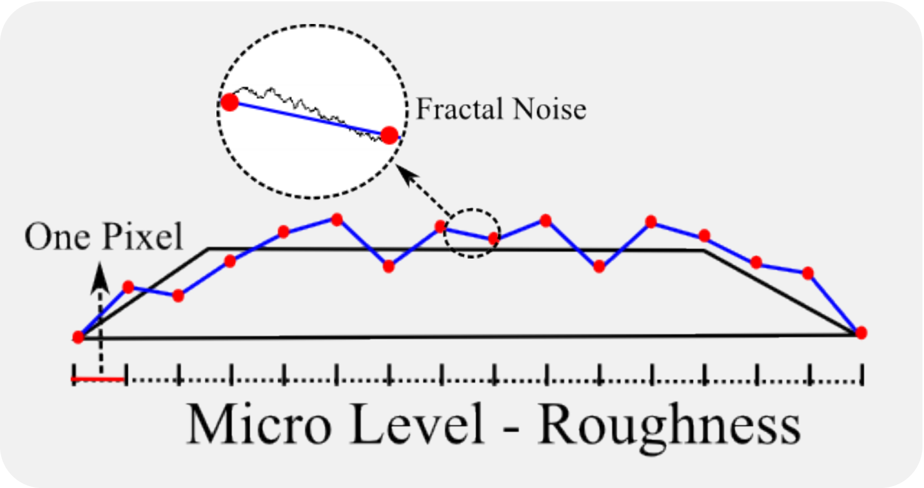
- Meso level: Bumpiness



  - Bump mapping is ubiquitous in real-time graphics rendering
  - Bump maps are visible to users but transparent to physics simulation

Three-level Simulation

- Micro level simulation: Van den Doel et al. 01



  – Fractal noise is used to simulate the micro-level interaction

Live demo of only micro-level simulation enabled
And both micro, meso, and macro-level simulation enabled

Three-level Simulation

- Advantages:
  - Fast and simple. Makes real-time sound synthesis driven by complex interaction possible.
  - Captures the richness of sound varying at three levels of resolution
  - Visual and auditory feedbacks are consistent

Video Demonstration

http://gamma.cs.unc.edu/SlidingSound/SlidingSound.html

http://gamma.cs.unc.edu/MultiDispTexture/

Integration with Touch-Enabled Interfaces

- **Multi-Touch Display**
  - Camer tracking user hand gesture; sense of touch provided by display surfaces
- Haptic Devices
  - Existing physics engine provides sufficient information for user-object interaction

Virtual Musical Instrument

http://gamma.cs.unc.edu/TabletopEnsemble/

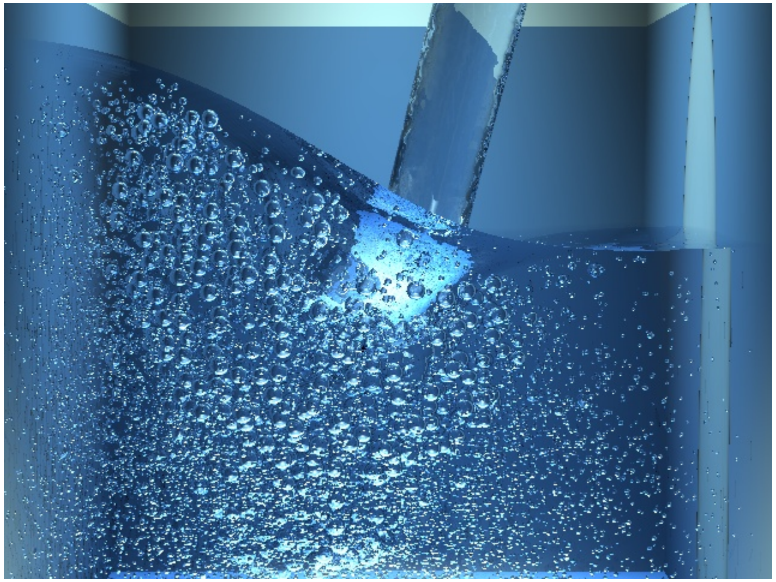
http://gamma.cs.unc.edu/vMusic/

Sounding Liquids

- Work in physics and engineering literature since 1917
  - Sound generated by resonating bubbles
- *Physically-based Models for Liquid Sounds* (van den Doel, 2005)
  - Spherical bubble model
  - No fluid simulator coupling
    - Hand tune bubble profile

Background (Fluid)

- Grid-based methods
  - Accurate to grid resolution
    - Bubbles can be smaller
  - Slow
  - Can be two-phase



Background (Fluid)

- Shallow Water Equations
  - Simulate water surface
    - No breaking waves
  - Real time
  - One phase
    - Explicit bubbles

Overview

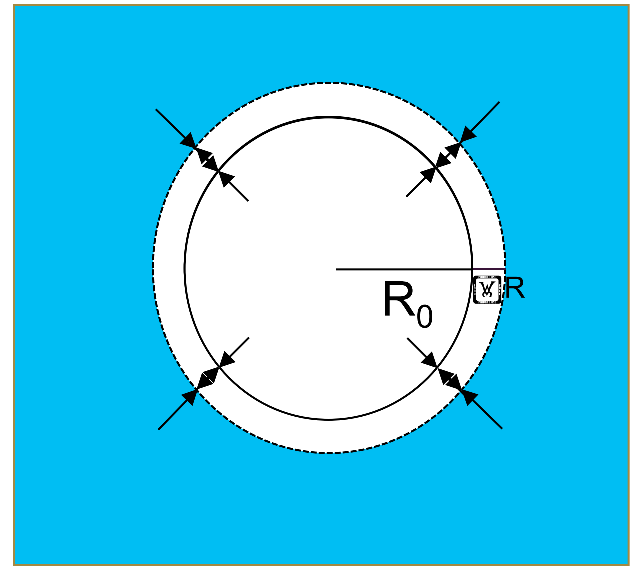
- Generate sound from existing fluid simulation
  - Model sound generated by bubbles
- Apply model to two types of fluid simulators
  - **Particle-Grid-based**
    - Extract bubbles
    - Process spherical and non-spherical bubbles
    - Generate sound
  - **Shallow Water Equations**
    - Processes surface
      - Curvature and velocity
    - Select bubble from distribution
    - Generate sound

Mathematical Formulations

- **Spherical Bubbles**

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{3\gamma p_0}{\rho R_0^2}}$$

$$\tau(t) = Asin(2\pi f(t)t)e^{-dt}$$



- **Non-spherical bubbles**
  - Decompose into a spherical harmonics

$$f_n^2 \approx \frac{1}{4\pi^2}(n-1)(n+1)(n+2)\frac{\sigma}{\rho R_0^3}$$

Video Demonstration

http://gamma.cs.unc.edu/SoundingLiquids/

Summary

- Simple, automatic sound synthesis
- Applied to two fluid simulators
  - Interactive, shallow water
  - High-quality, grid based