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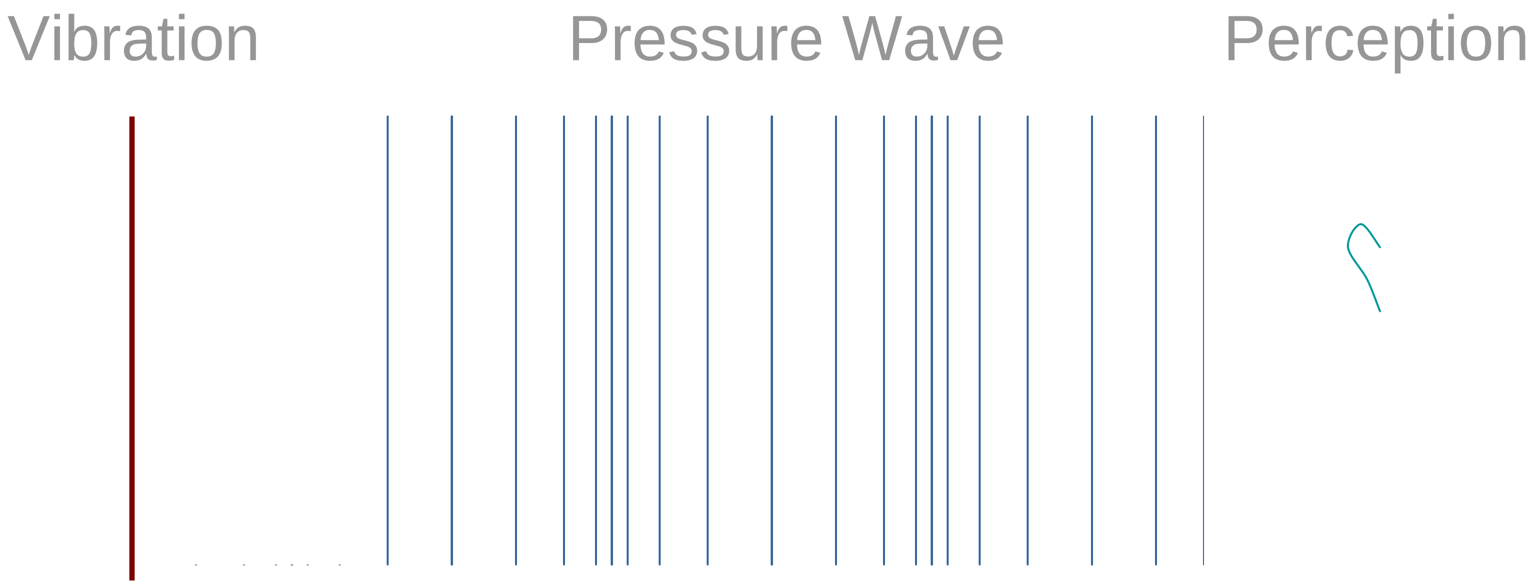
Sound in Nature

- Collisions lead to surface vibrations
- Vibrations create pressure waves in air
- Pressure waves are sensed by ear



Physically Based Sound

- Generate Sounds directly from physics
- Current trend: Recorded Sounds
- Problems with recorded sounds:
    - Difficult, expensive or dangerous to record (eg. Explosions)
    - Repetitiveness

A typical foley studio*

* Image taken from: http://www.marblehead.net/foley/index.html

Xylophone: Short Demo

Dices on Xylophone

Playing "*The Entertainer*"

There are more than 350 collisions in this short clip. The audio simulation for this demo runs at >500 FPS

Challenges

- Display: 30Hz
- Haptics: 1000 Hz
- Sound: 44,000Hz (at least)
  - Human auditory range: 20-22000Hz
- Simulation time-step must be ~10^{-5} s
- Stability may require even smaller time-steps
  - Most sound-producing systems are very stiff
- Scalability

Approach

- Brute force physical simulation infeasible
- Use analytical solution for surface dynamics
- Exploit human auditory perception

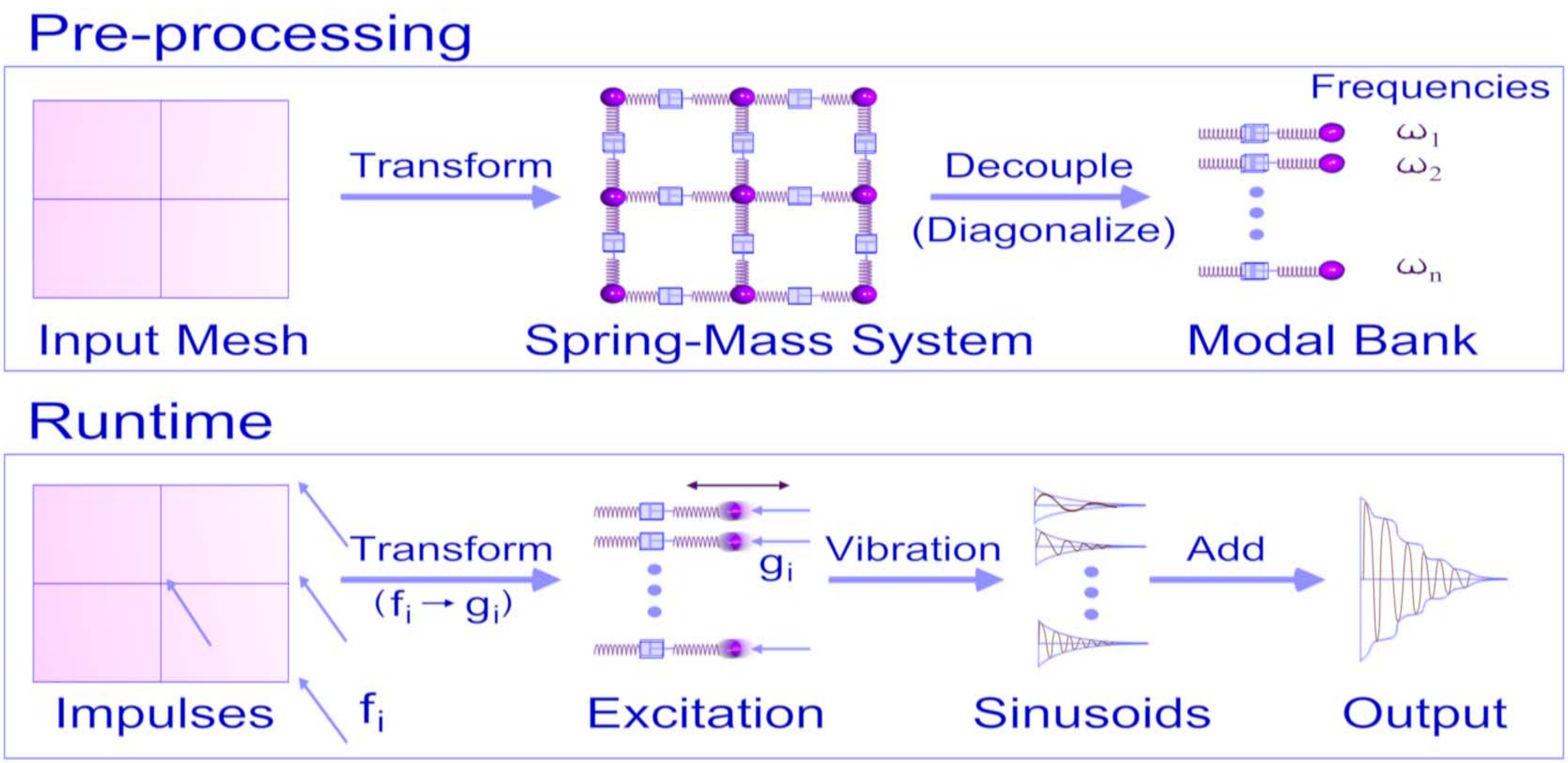
Approach: Features

- Simple to formulate and implement
- Handles surface meshes with arbitrary geometry and topology
- Handles both impact and rolling sounds elegantly
- Runs in real-time, low CPU utilization (~10%)
- Supports hundreds of sounding objects

Outline

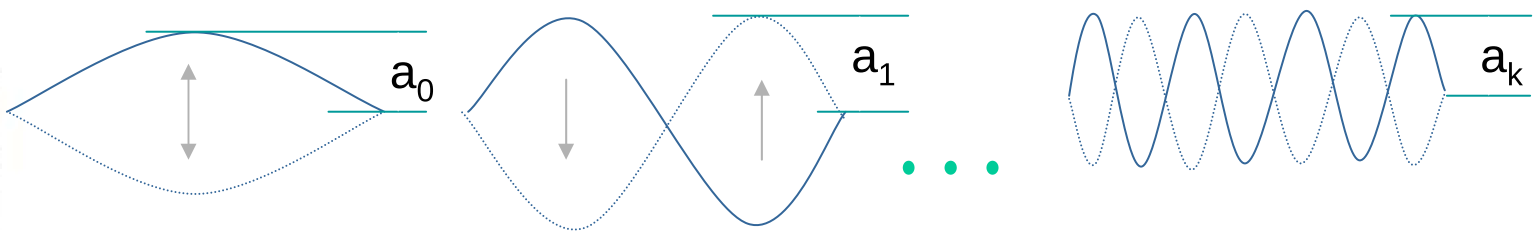
- Basic Approach
- Exploiting Perception
- Demos
- Summary
- Acknowledgements

Overview



Pre-processing
Transform
Decouple
(Diagonalize)
Frequencies
ω_1
ω_2
ω_n
Input Mesh
Spring-Mass System
Modal Bank
Runtime
Transform
$(f_i \rightarrow g_i)$
g_i
Vibration
Add
f_i
Impulses
Excitation
Sinusoids
Output

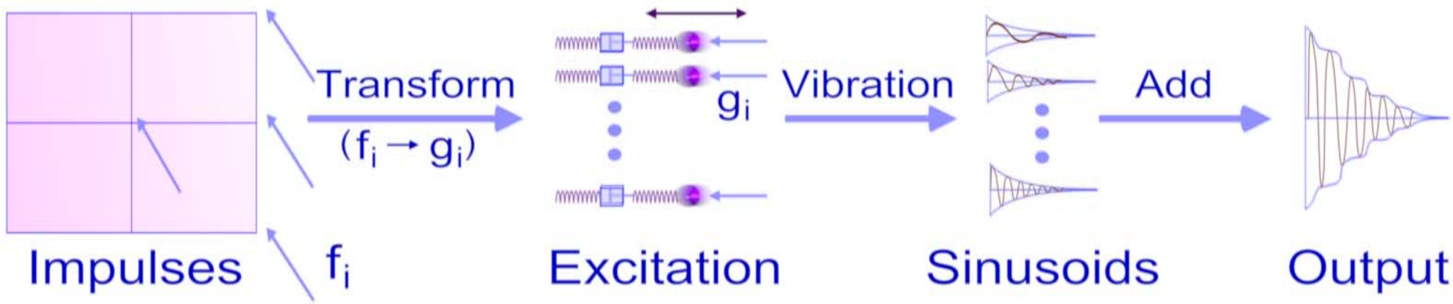
Modal Decomposition



Frequency = f_0 Frequency = $f_1 = 2*f_0$ Frequency = $f_k = k*f_0$

- Each mode represents a mode of vibration
- Frequency of a mode is fixed
- Applying impulse excites modes of vibration
- Position of impact determines proportion of modes

Sound Synthesis



- Rigid Body Simulator provides impulses
- Transform to mode amplitudes
- Sound synthesized by adding the modes' sinusoids
- **Adding damped sinusoids is very fast**

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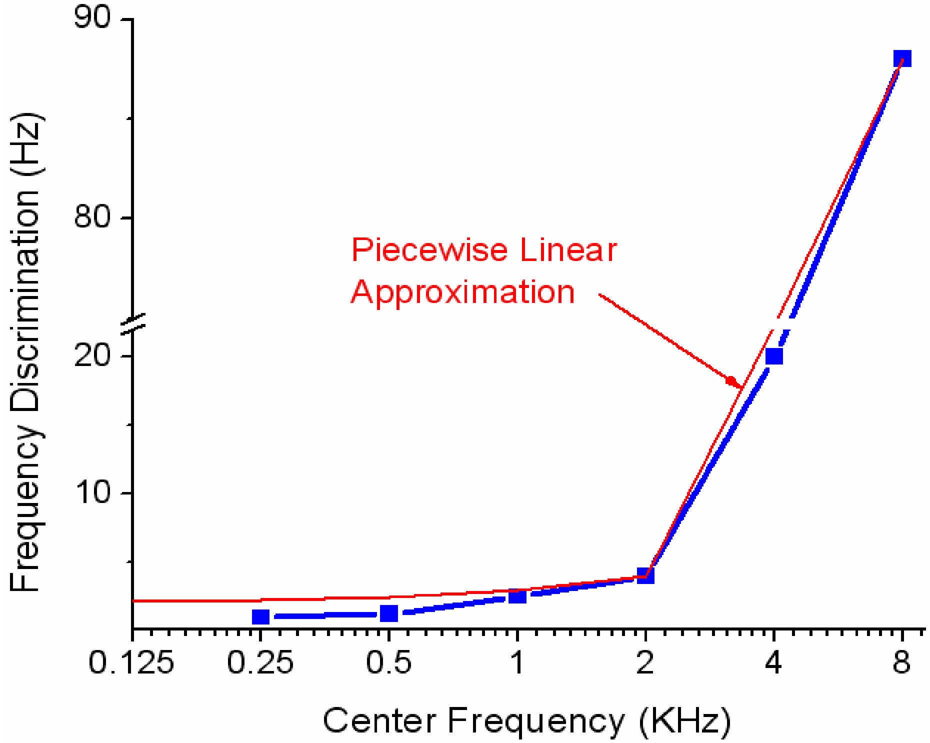
Mode Compression

- Humans can't distinguish two frequencies arbitrarily close to each other [Sek et. al., 1995*]



*Sek, A., and Moore, B. C. 1995. Frequency discrimination as a function of frequency, measured in several ways. J. Acoust. Soc. Am. 97, 4 (April), 2479–2486.

Quality Scaling

- A typical audio scene consists of foreground and background sounds
- Idea: Give more importance to foreground sounds
- Higher intensity sounds are considered to be foreground
- **Provides a graceful way to adapt to variable time constraints**

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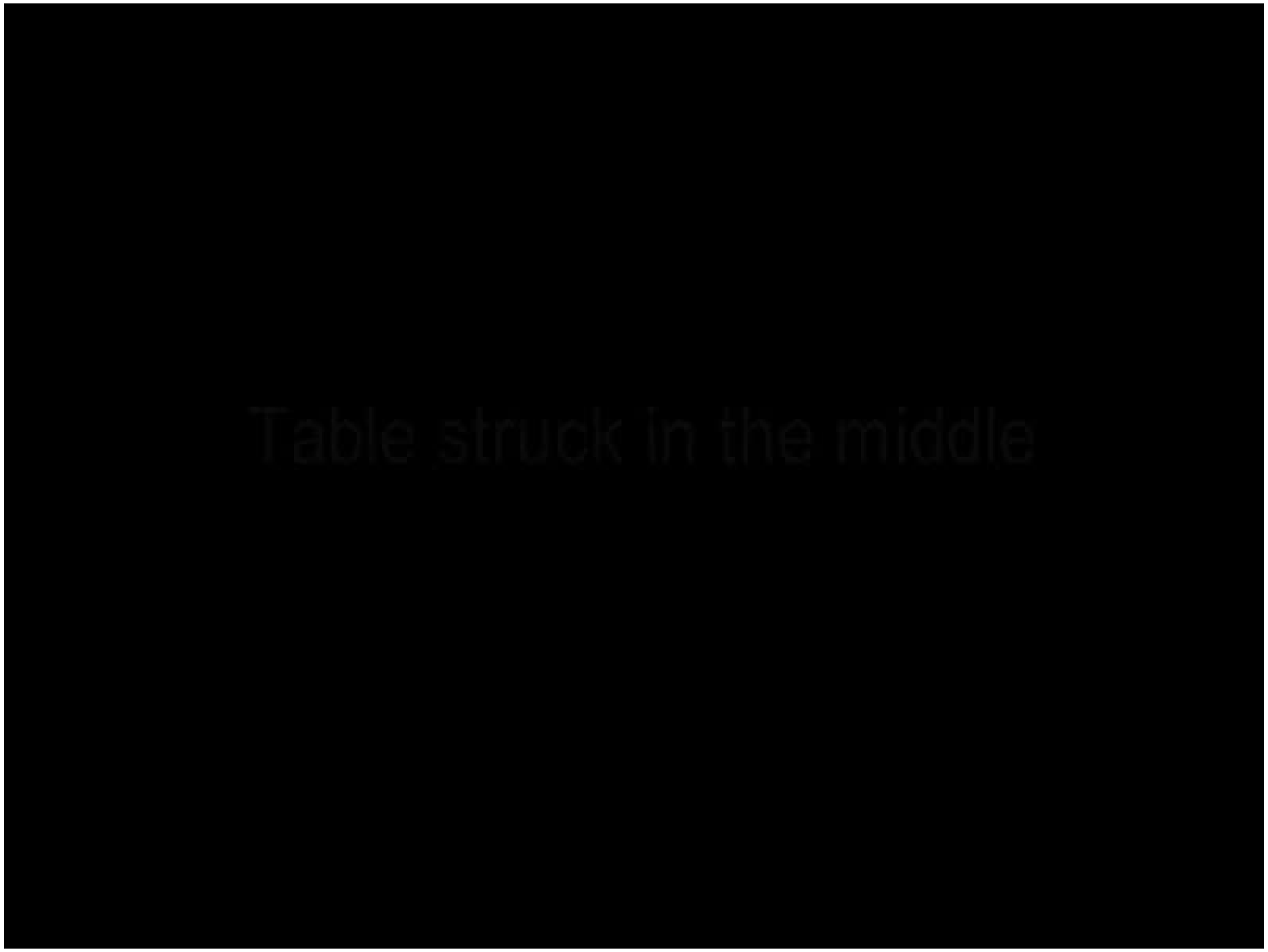
Implementation Details

- System: 3.4 GHz Pentium 4 Laptop, 1 GB RAM
- Graphics: GeForce 6800 Go, 256 MB
- Sound: Creative Sound Blaster Audigy 2 ZS
- Software
  - SWIFT++ (Collision Detection)
  - DEEP (Penetration Depth Computation)
  - Pulsk (UNC In-house Rigid Body Simulation)
  - G3D (Rendering)
- OpenAL/EAX (Hardware Accelerated Propagation Modeling)

Position Dependent Sounds



Analysis

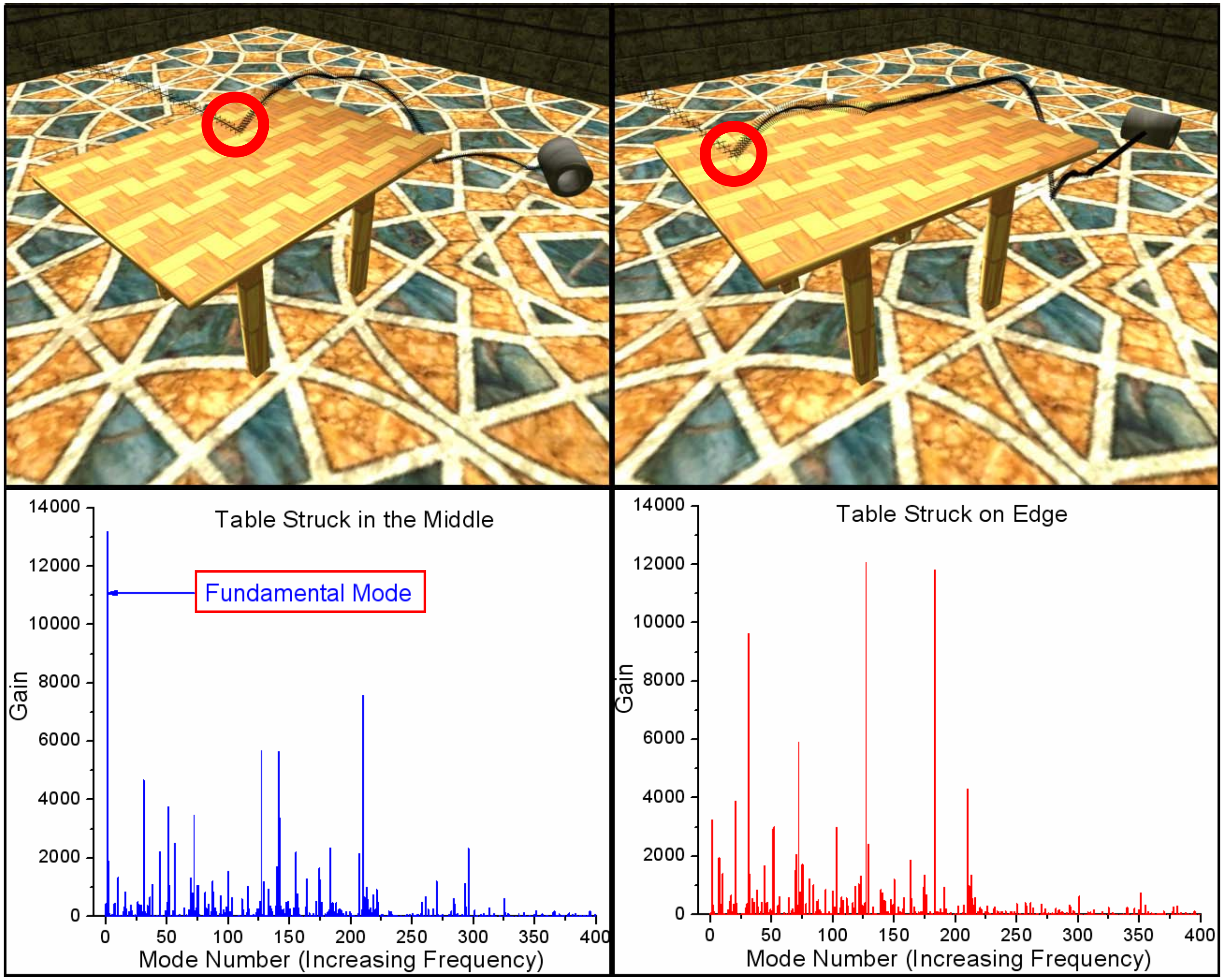
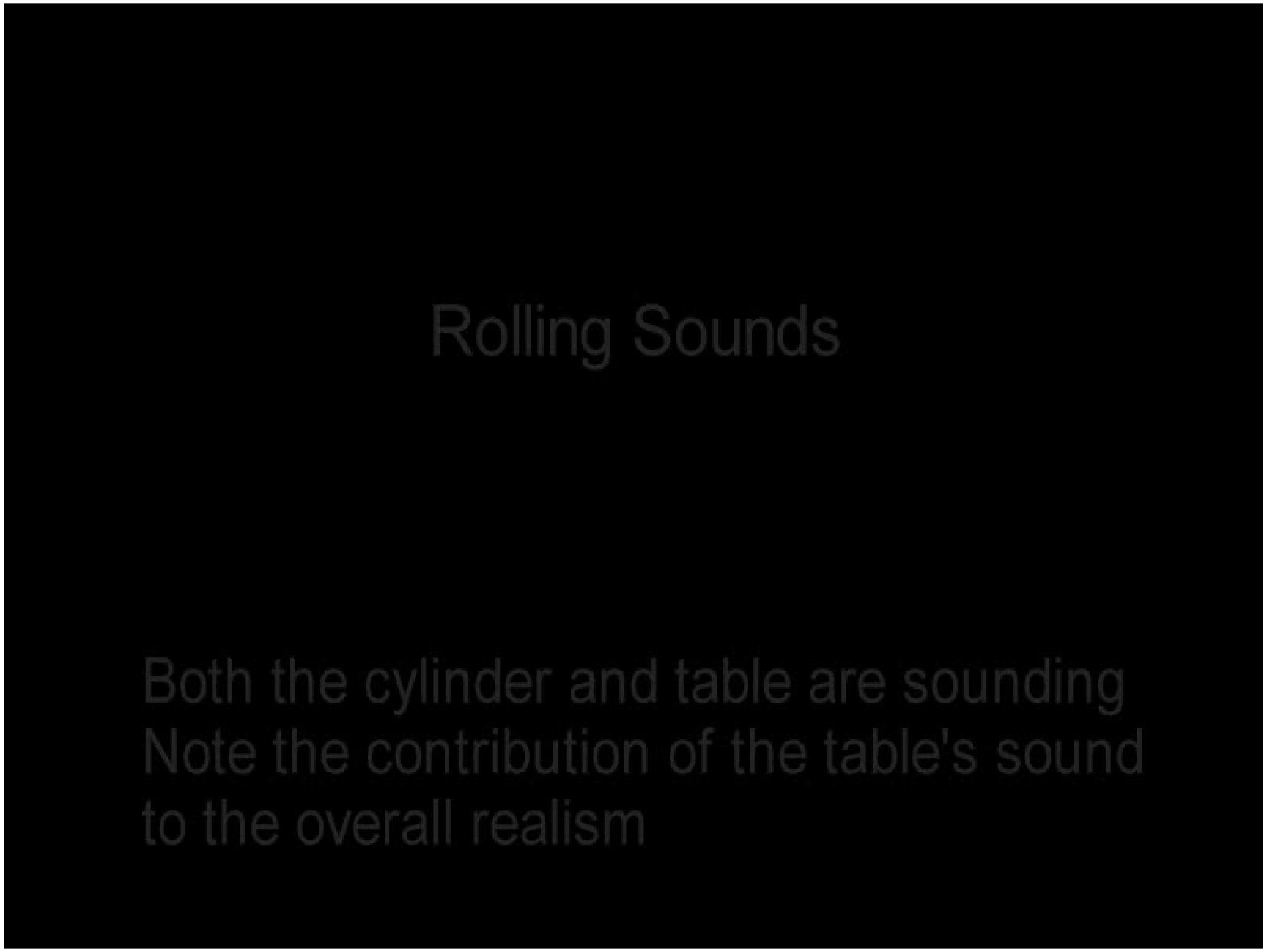


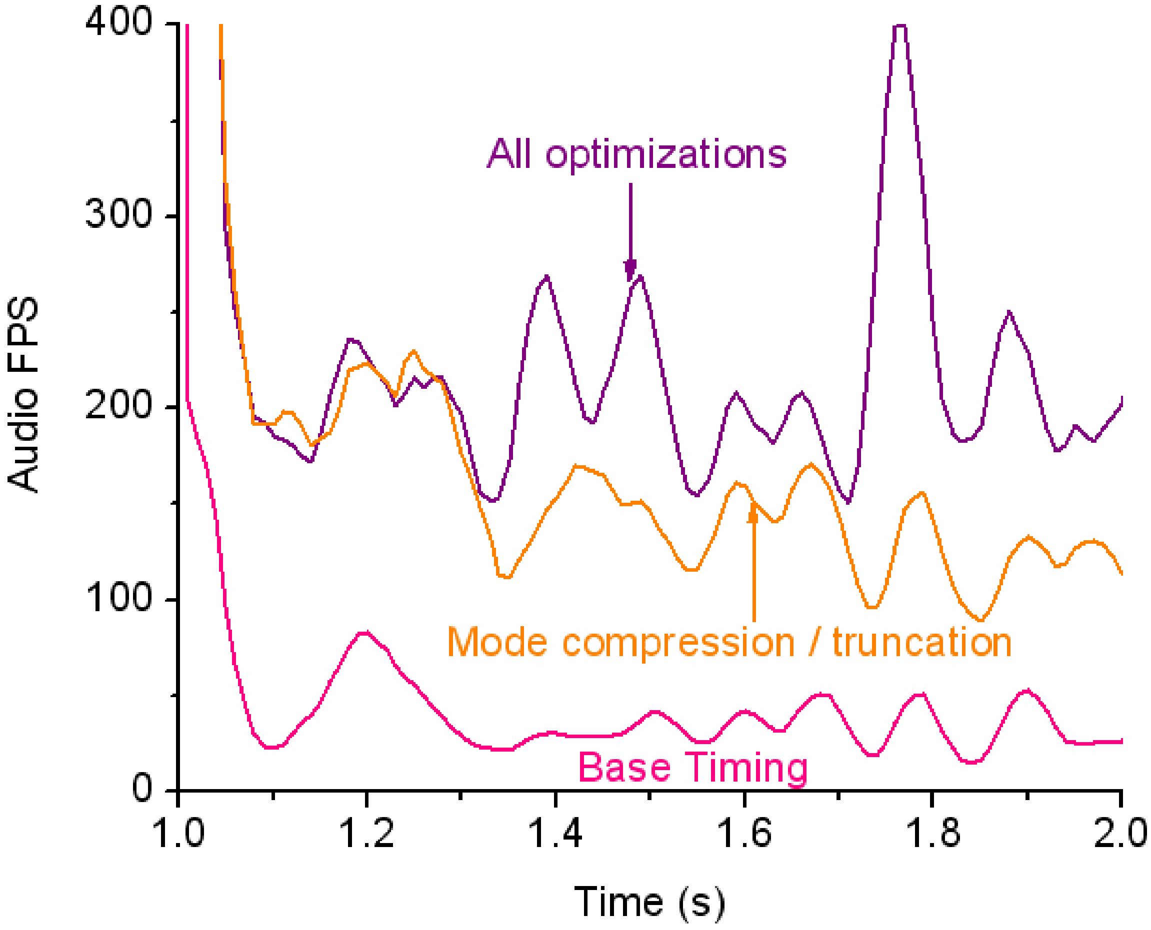
Table Struck in the Middle
Fundamental Mode
Gain
Mode Number (Increasing Frequency)
Table Struck on Edge
Gain
Mode Number (Increasing Frequency)

Rolling Sounds



Efficiency

Efficiency: Analysis



Realism

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Summary

- Simple formulation and easy to implement
- Works on arbitrary surface meshes
- Acceleration techniques exploiting auditory perception
- Well suited for Games with their real-time requirements with variable time constraints

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- Nico Galoppo (In-house Rigid Body Simulator)
- Stephen Ehmann (SWIFT++: Collision Detection)
- Young J. Kim (DEEP: Penetration Depth Computation)
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- UNC GAMMA Group (http://gamma.cs.unc.edu)

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- RDECOM

Thank You!

Questions?

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

References

- *Raghuvanshi, N., and Lin, M. C.,* **Interactive Sound Synthesis for Large Scale Environments***. In SI3D '06: Proceedings of the 2006 symposium on Interactive 3D graphics and games, ACM Press, New York, NY, USA, 101-108*.