Expressive Sound Synthesis For Animation

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Defense for Ph.D. in Computer Science
Outline

1 Sound and Virtuality

2 Physics-Based Sound Synthesis
   - Contact Modeling
   - Resonator Modeling

3 Example-Based Synthesis
   - Flexible Sound Synthesis

4 Perspectives on a Hybrid Model
   - Motivation and Application

5 Conclusion and Discussion
   - Contributions
   - Extensions and Applications
Sound Rendering for Virtual Reality and Games

Interactive Audio Rendering

(R. Vantielcke - WipeoutHD on Playstation 3)
Interactive Audio Rendering

(R. Vantielcke - WipeoutHD on Playstation 3)

Traditional Approach
Pre-Recordings Triggered

+ : Easy to implement
- : Repetitive audio, discrepancies, lack of flexibility
From Playback of Samples to Synthesis

- **Digital Sound Synthesis**
  - Source modeling
  - Sound propagation, Sound reception

- **Techniques**
  - Rigid body simulation
  - Finite Element Method (FEM)
Sound and Virtuality

General Background

Motivation

Physics-Based Synthesis

Example-Based Synthesis

Perspectives on a Hybrid Model

Conclusion and Discussion

From Playback of Samples to Synthesis

- Digital Sound Synthesis
  - Source modeling
    - Sound propagation, Sound reception

- Techniques
  - Rigid body simulation
  - Finite Element Method (FEM)

- Physical Sound Simulation
  - Physical approach, easy parametrization, Low memory usage
  - Preprocess computation, Interface between physics and sound system
Controlling the Sound Simulation

Challenges

- **Sound Coherent With Visuals**
  - Unpredictable character of sounds
  - Real-time sound synthesis

- **Parametrization and Expressiveness**
  - Control and interactivity
  - Authoring
Our Contribution

Three Research Axes

- Physics-Based Sound synthesis
  - Contact modeling
  - Resonator modeling
Our Contribution

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  - Contact modeling
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- Example-Based Sound Synthesis
  - Automatic analysis of pre-recordings
  - Flexible synthesis for physics-driven animation
Our Contribution

Three Research Axes

- Physics-Based Sound synthesis
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- Example-Based Sound Synthesis
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  - Flexible synthesis for physics-driven animation

- Perspectives on a Hybrid Model
Overview

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Sound from Contacts

- **Dichotomy**
  - Impacts
  - Continuous contacts

- **Two Schemes for Contact Force Modelling**
  - Feed-forward scheme
    [van den Doel et al. '01]
  - Direct computation of contact forces
    [Avanzini et al. '02]
Contact Modeling

What Are The Current Limitations for Continuous Contacts?

- Rate for physics engine report
- No geometric details when using visual textures
- Authoring and control are challenging
What Are The Current Limitations for Continuous Contacts?

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HOW Can We Solve Them?

By extracting

- **Excitation profiles** from visual textures

with

- **Adaptive resolution**

  [Picard et al., VRIPHYS’08]
Method for Impact Sounds
Method for Continuous Contact Sounds

Extraction of Excitation Profiles
Synthesis of Excitation Profiles
For the Audio Force Modelling

- **Technique**
  - Extraction from the visual texture image
  - Re-sampling along the trajectory of the contact interaction (60Hz vs 44kHz)

- Based on the Complexity of the Histogram
  - Simple texture image: Gradient of the image intensity
  - Complex texture image: Isocurves of constant brightness (isophotes)
Complex Textures

Coding the Excitation Profiles

- Isophotes = Large amount of data
  How Can We Lighten the Info?

- By Coding the Excitation Profiles
  = Main Features + Noise Part

- Noise Part: Statistical approximation
Real-Time Audio Management
A Flexible Audio Pipeline

- Simulations Driven by Ageia’s PhysX (now NVIDIA)
Audio Texture Synthesis
A Solution for Interactive Simulations

- A Sound in Coherence with Visuals
- Flexible Resolution
- Adapted to Procedural Generation
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Vibration Models
Modal Analysis

- Generating Sounds Based on Physics Simulation
  - In computer musics
    [lovino et al. ’97, Cook ’02]
  - In computer graphics
    [Van Den Doel ’01, O’Brien et al. ’02]

- Improvements for Interactive Sound Rendering
  - Modal parameter tracking
    [Maxwell et al. ’07]
  - Frequency content sparsity
    [Bonneel et al.’08]
Vibration Models

Modal Analysis

1. Get a Sounding Object and its Geometry

2. Construct the FEM (ex: Tetrahedral Mesh)

3. Apply Newton Second Law to DOF

\[
M \ddot{d} + C \dot{d} + Kd = f
\]  

4. Eigendecomposition \( \Rightarrow \) Modal Parameters

\[
M = LL^{-T}; \quad L^{-1}KL^{-T} = V\Lambda V^T
\]  

where \( V \) = matrix of eigenvectors
\( \Lambda \) = diagonal matrix of eigenvalues
Vibration Models
Modal Analysis

In Real-time:
- Modal synthesis

\[ s(t) = \sum_{n=1}^{1} a_i \sin(w_i t) e^{-d_i t} \]  \hspace{1cm} (3)

- Control for vibration models
Vibration Models
Modal Analysis

- What Are The Current Limitations?
  - Meshing is difficult
  - No real control on the FEM resolution
  - No clear interface between physics and audio
Vibration Models

Modal Analysis

■ What Are
   The Current Limitations?
   ■ Meshing is difficult
   ■ No real control on the FEM resolution
   ■ No clear interface between physics and audio

■ HOW Can We Solve Them?
   By proposing
   ■ A **robust** and **multi-scale** modal analysis
     which is
   ■ **Coherent** with the physics simulation
     [Picard et al., DAFx’09]
Our Deformation Model

- Inspired from Work by Nesme et al. [Nesme et al.’06]

- Technique
  Merged voxels used as **Hexahedral Finite Elements**

- Implementation with the **Sofa Framework**

- Validation of the Model
  Tests on a metal cube
Robustness

Robust Even for Non-Manifold Geometries

Material: Aluminium
Multi-Scale for Efficient Memory Usage

A Squirrel in Pine Wood

3x3x3

4x4x4

8x8x8

9x9x9

C. Picard-Limpens

December 4, 2009
Multi-Scale for Efficient Memory Usage

A Squirrel in Pine Wood: Different FE resolutions

3x3x3  4x4x4  8x8x8  9x9x9

Frequency Content = f(Hexahedral FE Resolution)

- Higher resolution models
- Frequency centroid shift
- Convergence of the frequency content
Comparison with Classical Approach

Sounding Bowl - Material: Aluminium

Classical Approach (816 modes)  
Our Approach (75 modes)

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C. Picard-Limpens
December 4, 2009
Expressive Sound Synthesis For Animation
A Robust and Multi-Scale Modal Analysis
A Solution for Sound Synthesis

- Realistic
- Adapted to Non-Manifold Geometries
- Resources Flexibility
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Implementation of Signal-Based Models

- Concatenative Synthesis [Roads '91, Schwarz '06]
- Sound Textures Based on Physics [Cook '99] [Dobashi et al. '03, Zheng et al. '09]
- Authoring and Interactive Control [Cook '02]

[Dobashi et al.'03]

[Cook '99]
Implementation of Signal-Based Models

What Are
The Current Limitations?

- Processing is not generic
- Parametrizing is difficult
Implementation of Signal-Based Models

What Are The Current Limitations?
- Processing is not generic
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HOW Can We Solve Them?
By
- Retargetting example sounds To physics-driven animation

[Picard et al., AES’09]
Our Approach

1. Dictionary of Audio Grains: Impulsive / Continuous
2. Correlation Patterns

Retargetting to Animation

Audio Recording

SINUSOIDAL

Transient

Object Geometry
Virtual Environment

Retargetting Example Sounds

Rigid-Body Simulation

Define Procedures

Build Collision Structures

Video Renderer

Audio Renderer

Preprocessing Interactive

Retargetting With Audio

Our Contributions

C. Picard-Limpens December 4, 2009 Expressive Sound Synthesis For Animation
Preprocess: A Generic Analysis

- Impulsive and Continuous Contacts
  - Spectral Modeling Synthesis (SMS) [Serra ’97]

- Automatic Extraction of Audio Grains
  - Dictionary: Impulsive/Continuous

- Generation of Correlation Patterns between original recordings and audio grains
On-Line: Flexible Sound Synthesis

- Resynthesis of the Original Recordings
  - Candidate grains: max. correlation amplitude
On-Line: Flexible Sound Synthesis

- Resynthesis of the Original Recordings
  - Candidate grains: max. correlation amplitude

- Interactive Physics-Driven Animations
  - Physics Info for Retargetting
    - Contact type: impulsive or continuous?
    - Penetration force and relative velocity
On-Line: Flexible Sound Synthesis

- Resynthesis of the Original Recordings
  - Candidate grains: max. correlation amplitude

- Interactive Physics-Driven Animations
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- Flexible Audio Shading Approach
  Additional, User-defined Resynthesis Schemes
  - Spectral domain adaptation/modification
Resynthesis of the Original Recordings

- 94 recordings (14.6Mb)
  ≈ 5000 grains + 94 Correlation Patterns (20% Gain)

- Breaking Glass
- Shooting Gun
- Rolling

Additional Material:
http://www-sop.inria.fr/members/Cecile.Picard/
"Supplemental AES"
Flexible Audio Shading Approach

- Easy Implementation of Time-Scaling
  - Faster Rolling
  - Slower Breaking

- Synthesis of An Infinity Similar Audio Events by varying the audio content
  - Rythmic pattern from Breaking Stone
    New material content: *stone* and *gun*
  - Rythmic pattern from Breaking Glass
    New material content: *ceramic*
Interactive Physics-Driven Animations

Simulations Driven by *Sofa Framework*

[Image of simulations driven by Sofa Framework]
Retargetting Example Sounds
A Solution for Interactive Simulations

- Variety
- Adapted to Scenarios
- Small Memory Footprint
  Real-Time Rendering

An attractive solution for industrial applications
(Eden Games, an ATARI game studio)
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Sound Modeling
When Nonlinearity Occurs

- Problems of Single Models
  - Vibration models assume linearity
  - Example-based sounds are hard to parametrize

Motivation
A Hybrid Model for Fracture Events

Conclusion and Discussion
Sound Modeling
When Nonlinearity Occurs

- Problems of Single Models
  - Vibration models assume linearity
  - Example-based sounds are hard to parametrize

- Previous Work
  - Modeling nonlinearities
    - [O’Brien et al. ’01, Chadwick et al. ’09]
    - [Cook ’02]
Fracture Events

- **Background**
  - Frequently occur in virtual environments
  - Visual rendering
    - \textit{O’Brien et al.} ‘99, ’02
    - \textit{Parker and O’Brien}. ‘09
  - Sound rendering: Little research
    - \textit{Warren et al.} ‘84
    - \textit{Rath et al.} ‘03
Fracture Events

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- **Challenges**
  - Event depends on the material involved
  - Differents phases emerge from fracture event
Parametrization of Our Hybrid Model

- **Selection Criteria**
  - Hybrid model applied when nonlinearity occurs

- **Techniques**
  - FM synthesis
  - Audio grains

- **Parametrization**
  - Smooth transition with vibration model
  - Coherence inside the hybrid model
Discussion

- Prospective model
- Possible problem: report from the physics engine
- Simplicity of the tools allows real-time rendering
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Synthesis of Sounds for Animation

Difficulties

- Audio-Visual Coherence
- Extremely Dynamic Character
- Precision of Synthesis
- Large Variety of Objects
Contributions

An Overview

- **Complex Contact Modeling**
  - 2D visual textures used as roughness maps
  - Audible and position-dependent variations
  - Detail-layer mechanisms
Contributions
An Overview

- **Complex Contact Modeling**
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- **Improved Modal Analysis for Resonator Modeling**
  - Complex non-manifold geometries can be handled
  - Multi-scale resolution
  - Coherence between simulation and audio
Contributions

An Overview

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- **Flexibility of Sound Design**
  - Audio grains and correlation patterns
  - Dynamic retargetting to events
  - Extended sound synthesis capabilities
Contributions

Perspectives

- A Prospective Hybrid Model for Complex Physical Phenomena
  - Focus on Nonlinearity
  - Combination of physically based and example-based methods
  - Application Case: Fracture Events
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Promising Directions for Future Work

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  - Two interacting textures
  - Surface-based interactions
  - Adequate perceptual experiments
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  - Recent work from [Nesme et al. Siggraph'09]
  - Investigations with GPU for in-line computation
  - Complete integration in a virtual scene
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- **Example-Based Technique**
  - Clustering of similar grains
  - Statistical analysis of correlation patterns
  - Physics engine design
Promising Directions for Future Work

- Hybrid Model for Fracture Events
  - Fracture sound simulation framework
  - Tracking of relevant physical data
Conclusion

- New Physically Based Algorithms for Sound Rendering
- Flexibility of Sound Modeling
- Ideas on an Adequate Hybrid Sound Model

Additional info:
http://www-sop.inria.fr/members/Cecile.Picard/
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