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

General Background

Physics-Based Synthesis

Example-Based Synthesis

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Conclusion and Discussion

Sound Rendering for Virtual Reality and Games

Interactive Audio Rendering



(R. Vantielcke - WipeoutHD on Playstation 3)

December 4, 2009

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Sound Rendering for Virtual Reality and Games

Interactive Audio Rendering



(R. Vantielcke - WipeoutHD on Playstation 3)

Traditional Approach Pre-Recordings Triggered

- + : Easy to implement
 - : Repetitive audio, discrepancies, lack of flexibility

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Physics-Based Synthesis

Example-Based Synthesis

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From Playback of Samples to Synthesis

Digital Sound Synthesis

■ Source modeling ← Sound propagation, Sound reception

Techniques

- Rigid body simulation
- Finite Element Method (FEM)



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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

Physics-Based Synthesis

Example-Based Synthesis

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Conclusion and Discussion

Controlling the Sound Simulation Challenges

Sound Coherent With Visuals

- Unpredictable character of sounds
- Real-time sound synthesis
- Parametrization and Expressiveness
 - Control and interactivity
 - Authoring

Physics-Based Synthesis

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Our Contribution

Three Research Axes

Physics-Based Sound synthesis

- Contact modeling
- Resonator modeling

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Three Research Axes

Physics-Based Sound synthesis

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

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Three Research Axes

Physics-Based Sound synthesis

- Contact modeling
- Resonator modeling
- Example-Based Sound Synthesis
 - Automatic analysis of pre-recordings
 - Flexible synthesis for physics-driven animation
- Perspectives on a Hybrid Model

Physics-Based Synthesis

Contact Modeling

Audio Texture Synthesis For Complex Contacts

Resonator Modeling

A Robust and Multi-Scale Modal Analysis

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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]



Additive synthesis

Direct computation of contact forces [*Avanzini et al.* '02]



Bristle model

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Contact Modeling

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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

Physics-Based Synthesis

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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
- HOW Can We Solve Them? By extracting
 - Excitation profiles from visual textures with
 - Adaptive resolution
 - [Picard et al., VRIPHYS'08]



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Method for Impact Sounds



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Method for Continuous Contact Sounds Extraction of Excitation Profiles



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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)

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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

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Real-Time Audio Management A Flexible Audio Pipeline

Simulations Driven by Ageia's PhysX (now NVIDIA)



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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]

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Vibration Models

Modal Analysis

Get a Sounding Object and its Geometry



2 Construct the FEM (ex: Tetrahedral Mesh)3 Apply Newton Second Law to DOF

$$M\ddot{d} + C\dot{d} + Kd = f \tag{1}$$

4 Eigendecomposition ⇒ Modal Parameters $M = LL^{-T}; \qquad L^{-1}KL^{-T} = V\Lambda V^{T} \qquad (2)$

where V = matrix of eigenvectors $\Lambda = \text{diagonal matrix}$ of eigenvalues

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Vibration Models

Modal Analysis

In Real-time: Modal synthesis



$$s(t) = \sum_{n=1}^{1} \mathbf{a}_{i} \sin(\mathbf{w}_{i}t) e^{-\mathbf{d}_{i}t}$$
(3)

Control for vibration models

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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

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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]

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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

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Robustness

Robust Even for Non-Manifold Geometries





Material: Aluminium

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Multi-Scale for Efficient Memory Usage

A Squirrel in Pine Wood



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A Squirrel in Pine Wood: Different FE resolutions



Frequency Content = f(Hexahedral FE Resolution)

- Higher resolution models
- Frequency centroid shift
- Convergence of the frequency content

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Comparison with Classical Approach

Sounding Bowl - Material: Aluminium



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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]



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Implementation of Signal-Based Models

What Are The Current Limitations?

- Processing is not generic
- Parametrizing is difficult

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Implementation of Signal-Based Models

What Are The Current Limitations?

Processing is not generic

Parametrizing is difficult

HOW Can We Solve Them? By

Retargetting example sounds
 To physics-driven animation
 [Picard et al., AES'09]

Our Approach



Sound and Virtuality

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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

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On-Line: Flexible Sound Synthesis

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

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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

Physics-Based Synthesis

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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
- Flexible Audio Shading Approach Additional, User-defined Resynthesis Schemes
 - Spectral domain adaptation/modification

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Resynthesis of the Original Recordings

• 94 recordings (14.6Mb) \approx 5000 grains + 94 Correlation Patterns (20% Gain)

Breaking Glass





 \triangleright

Rolling

Additional Material: http://www-sop.inria.fr/members/Cecile.Picard/ "'Supplemental AES"'

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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*

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Interactive Physics-Driven Animations

Simulations Driven by Sofa Framework



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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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A Hybrid Model for Fracture Events

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Sound Modeling When Nonlinearity Occurs

Problems of Single Models

- Vibration models assume linearity
- Example-based sounds are hard to parametrize

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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]

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Physics-Based Synthesis

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Fracture Events

Background

Frequently occur in virtual environments

Visual rendering
 [O'Brien et al. '99, '02]
 [Parker and O'Brien. '09]

 Sound rendering: Little research [Warren et al. '84] [Rath et al. '03]

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 [O'Brien et al. '99, '02]
 [Parker and O'Brien. '09]

Sound rendering: Little research [*Warren et al.* '84] [*Rath et al.* '03]

Challenges

- Event depends on the material involved
- Differents phases emerge from fracture event

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Parametrization of Our Hybrid Model

Selection Criteria

Hybrid model applied when nonlinearity occurs

- Techniques
 - FM synthesis
 - Audio grains



FM synthesis

Parametrization

- Smooth transition with vibration model
 - Coherence inside the hybrid model

Discussion

Sound and Virtuality

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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

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An Overview

Complex Contact Modeling

- 2D visual textures used as roughness maps
- Audible and position-dependent variations
- Detail-layer mechanisms

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Complex Contact Modeling

- 2D visual textures used as roughness maps
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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

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- Detail-layer mechanisms

Improved Modal Analysis for Resonator Modeling

- Complex non-manifold geometries can be handled
- Multi-scale resolution
- Coherence between simulation and audio
- Flexibility of Sound Design
 - Audio grains and correlation patterns
 - Dynamic retargetting to events
 - Extended sound synthesis capabilities

Physics-Based Synthesis

Example-Based Synthesis

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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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Complex Contact Modeling

- Two interacting textures
- Surface-based interactions
- Adequate perceptual experiments

Promising Directions for Future Work

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- Two interacting textures
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Improved Modal Analysis for Resonator Modeling

- Recent work from [Nesme et al. Siggraph'09]
- Investigations with GPU for in-line computation
- Complete integration in a virtual scene

Promising Directions for Future Work

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Example-Based Technique

- Clustering of similar grains
- Statistical analysis of correlation patterns
- Physics engine design

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Hybrid Model for Fracture Events

- Fracture sound simulation framework
- Tracking of relevant physical data

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Extensions and Applications 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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Acknowledgements

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Contributions

Extensions and Applications

- George Drettakis, François Faure, and Nicolas Tsingos
- *REVES* Team
 Marie-Paule Cani and the *Evasion* Team
- Paul G. Kry at the McGill University, Montréal



Eden Games, an ATARI game studio, Lyon

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