Proposta Corso di Dottorato

Michele Ducceschi

Titolo del corso: An Introduction to Physical Modelling Sound Synthesis
Docente: Michele Ducceschi
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Ore frontali di lezione: 10
Periodo di lezione: II ciclo
Settore/i disciplinare del corso: ING-IND/11 FISICA TECNICA AMBIENTALE
Tipologia di corso: Avanzato
Modalità di verifica dell'apprendimento: Progetto

Abstract

Physical modelling is a computational technique to render the sound of real-world objects. Models describing wave propagation in elastic media are usually in the form of Partial Differential Equations (PDEs), and it is, therefore, natural to turn to mainstream numerical applications for their solution. On the other hand, the same idea of synthesis poses strict constraints which must be respected in the numerical design, especially when aimed at real-time rendering. Most of all, the problem accuracy must be approached considering perceptual factors. Efficiency is also a requirement since typical music software must work using a fraction of the available CPU on a common machine. This course will review the cornerstones of physical modelling sound synthesis, including early developments such as FM synthesis and digital waveguides. Then, starting from the simple harmonic oscillator case, the course will cover all the relevant ideas needed to produce an effective sound synthesis of common acoustic objects such as bars and strings. While the course will cover some advanced methods in numerical simulation, there is no need for a lot of background knowledge: the method of finite differences will be reviewed in some detail, and other relevant methods (such as spectral elements) will also be explained thoroughly.

Course Outline

Here is a proposed outline for the five lectures, each lasting 2 hours, based on the provided abstract. These lectures are designed to be delivered to a cohort of PhD students in mathematics, focusing on physical modelling sound synthesis.

1 Lecture 1: Introduction to Physical Modelling Sound Synthesis

Duration: 2 hours

1. **Introduction to Physical Modelling**
   - Definition and significance in sound synthesis
   - Overview of the course and its objectives
2. **Wave Propagation in Elastic Media**
   - Basics of wave propagation
   - Mathematical models using Partial Differential Equations (PDEs)
3. **Numerical Applications for PDEs**
   - Mainstream numerical methods for solving PDEs
   - Introduction to Finite Difference Method (FDM)
4. **Constraints in Numerical Design for Sound Synthesis**
   - Accuracy and perceptual factors
   - Efficiency considerations for real-time rendering
5. **Early Developments in Physical Modelling**
   - FM synthesis (Frequency Modulation)
   - Digital waveguides

Activities:

- Discussion on historical context and early breakthroughs
- Introduction to key software tools used in the field

2 Lecture 2: Harmonic Oscillator and Basic Models

Duration: 2 hours

1. **Simple Harmonic Oscillator**
   - Mathematical formulation and physical interpretation
   - Numerical simulation of the harmonic oscillator
2. **Numerical Accuracy and Perceptual Factors**
   - Importance of accuracy in sound synthesis
   - Methods to ensure perceptual relevance

3. **Finite Difference Method (FDM)**
   - Detailed review of FDM
   - Practical implementation for sound synthesis
4. **Real-Time Rendering Constraints**
   - Computational efficiency
   - Techniques to optimize performance on common hardware

Activities:

- Hands-on implementation of a simple harmonic oscillator
- Real-time rendering exercises and performance analysis

3 Lecture 3: Sound Synthesis of Acoustic Objects (Bars and Strings)

Duration: 2 hours

1. **Modelling Bars and Strings**
   - Physical characteristics and mathematical models
   - PDEs for bars and strings
2. **Numerical Methods for Acoustic Objects**
   - Application of FDM to bars and strings
3. **Practical Sound Synthesis Techniques**
   - Effective synthesis methods for bars and strings
   - Real-world examples and case studies
4. **Advanced Topics in Numerical Simulation**
   - Handling boundary conditions
   - Stability and convergence of numerical methods

Activities:

- Simulation exercises for bars and strings
- Case studies on practical sound synthesis applications

4 Lecture 4: Advanced Methods in Numerical Simulation

Duration: 2 hours

1. **Introduction to Spectral Methods**
   - Basics of Spectral Element Method
   - Comparison with FDM and other methods
2. **Application of Spectral Methods in Sound Synthesis**
   - Practical examples and implementation
   - Advantages and challenges
3. **Hybrid Methods and Multiscale Modelling**
   - Combining different numerical methods
   - Applications in complex sound synthesis scenarios
4. **Perceptual Evaluation of Synthesized Sound**
   - Techniques for subjective and objective evaluation
   - Importance of perceptual factors in sound synthesis

Activities:

- Implementation of spectral element method for simple models
- Evaluation exercises for synthesized sound quality

5 Lecture 5: Integration and Advanced Topics

Duration: 2 hours

1. **Review of Key Concepts**
   - Summary of main topics covered in the course
   - Discussion on the interrelation of different methods
2. **Complex Acoustic Object Modelling**
   - Synthesis of complex objects beyond bars and strings
   - Case studies and advanced applications
3. **Current Trends and Future Directions**
   - Latest research and developments in the field
   - Emerging technologies and methodologies

4. **Project Discussion and Q&A**
    - Guidance on potential research projects
    - Open floor for questions and discussion

Activities:

- Group discussions on potential research projects
- Q&A session for course-related queries

These lectures provide a comprehensive overview of physical modelling sound synthesis, covering foundational and advanced topics. Activities are designed to reinforce learning through practical implementation and discussion.