Initial Plan: Simulating Instruments on the GPU

Daniel Sussmann - c21029111 - SussmannD@cardiff.ac.uk
Supervisor: Kirill Sidorov - SidorovK@cardiff.ac.uk

Project Description

In principle, high-fidelity simulation of all mechanical processes within a drum would give the most accurate results. However, since this is computationally expensive, this project will investigate ways to approximate accurate simulation with cheaper approaches. One NESS [1] project demonstrated a simulation of a timpani [2], where both the membrane and shell were modeled using physics-based techniques. CUDA [3] acceleration was used to improve efficiency. This approach provided accurate sound synthesis while reducing computational cost, making it a promising method for realistic percussion modeling; however, despite these optimizations, the computation time remained significant, with one example requiring four minutes to simulate just three seconds of sound. Inspired by this work, this project aims to investigate approximate methods for physics-based percussion modeling, focusing on drums. Instead of fully simulating the interactions of all instrument components, the focus will be on efficient approximations that retain realistic sound synthesis while reducing computational overhead.

The challenge is to balance realistic percussive sound simulation with computational feasibility. One approach has been successfully applied to string instruments, where high-fidelity string vibrations were modeled separately from body resonance [4]. This project aims to apply a similar method to drums. The membrane is the primary source of a drum's sound, undergoing complex vibrations when struck. These vibrations define the instrument's tonal characteristics and decay patterns. To accurately capture these dynamics, this project will use high-fidelity physics-based modeling to simulate membrane vibrations. Beyond the membrane, the drum body influences the overall sound by acting as a resonating structure, modifying both the tonal quality and sustain of the membrane's vibrations. A key question is the extent of this influence—how much does the body contribute to the final sound, and can it be effectively modeled without a full simulation? To investigate this, the drum body's response will be simulated as a simple resonator rather than fully modeled using physics-based methods. This approach aims to reduce computational complexity while preserving essential acoustic characteristics.

The interface for this task will be a program with the following operation pipeline:

- **3D Model Import:** Users design (and export as a mesh) a drum in Blender [5] or similar 3D modelling software, assigning materials to the different instrument parts (membrane, shell). The mesh is imported into the software.
- **Drum View:** The drum mesh is displayed in the software.
- **Mallet Programmer:** Users can script mallet hits on the drum.
- **Physics-Based Modeling of Membrane:** Use GPU-accelerated physics-based modeling to simulate membrane vibrations.
- **Approximation of the Body Response:** Use resonance models to approximate the effect of the body on the response created from the membrane.
- **Sound Rendering:** Convert the mechanical vibrations generated from the mallet hits into audio signals, and either play or export the sound.

Aims and Objectives

The primary aim for this project is to develop a physics-based simulator of 3D modeled drums, leveraging the computational power provided by the GPU.

- **Objective 1**: Create a literature review on the methods that could be used for simulating the membrane, as well as for modeling the body as a resonator.

- **Objective 2**: Develop a 3D model import pipeline, importing blender meshes and converting them into simulation ready meshes.

- **Objective 3**: Implement physics-based modeling for membrane vibrations, simulating how drumheads respond to mallet strikes.

- **Objective 4**: Approximate the response of the drum body to the vibrations created at the drumhead, to replace the full physics-based modeling of drum shells.

- **Objective 5**: Implement sound rendering and exporting, converting mechanical vibrations into audio signals.

- **Optional Objective**: Physics based simulation of other types of percussion instruments e.g. cymbals. This optional objective can be achieved given enough time at the completion of the core objectives.

One risk is my currently limited knowledge of the physics and methods behind percussion instrument simulation. While I have referenced some relevant techniques in this plan, I will need to conduct further research beyond these sources to ensure my understanding is sufficient for this project. Although I do not have a strong background in physics, I have successfully learned the content of mathematically intensive modules throughout my degree. Given sufficient time, I am confident in my ability to develop a solid understanding of the necessary concepts.

Another risk involves selecting the appropriate tech stack and adapting to GPU acceleration. However, I believe this should be manageable, as I have considerable experience evaluating and working with new technologies. Over the past few years, I have frequently chosen tech stacks and integrated unfamiliar developer toolkits, both within and outside of my degree, which should help mitigate this challenge.

Finally, a potential risk is iteration time during sound generation, as this step provides essential feedback on whether the simulation is functioning correctly. However, this may not be as significant an issue as I anticipate. My current GPU is significantly more powerful than the one used in the timpani simulation [2], and my project is less computationally demanding. These factors should contribute to faster processing times and a more efficient development cycle.

Feasibility

Ethical and Legal Considerations:

- No ethical concerns as no human data is used.
- Intellectual property: Blender models must be open-source or user-created.

Work Plan

Spring Week 1-2

Deliverable: Complete initial project plan.
Milestone: Familiarize with relevant physics-based modeling techniques, GPU solvers, and NESS project methods.
Conduct literature review on efficient physics-based modeling approaches for percussion instruments.

Spring Week 3-4

Deliverable: 3D model imported and a basic physics-based modeling vibration simulation for a simple drum membrane.
Milestone: First functional membrane vibration simulation achieved.
Ensure correct meshing of models and implement initial simulation of membrane dynamics.

Spring Week 5-6

Incorporate GPU acceleration with membrane simulation.
Ensure different models work.

Spring Week 7-8

Deliverable: Approximation of drum shell response implemented.
Develop and refine approximation for drum body response.
Begin sound rendering implementation.

Spring Week 9-10

Deliverable: Full mallet hit programmer and sound rendering implemented.

Spring Week 11-Easter Break

Begin final report.

Spring Week 12

Deliverable: Final Report.

References

[1] The University of Edinburgh
NESS / Next Generation Sound Synthesis [online]
Available at: https://www.ness.music.ed.ac.uk/

[2] Stefan Bilbao, Craig Webb (2012)
Timpani Drum Synthesis in 3D on GPGPUS [online]
Available at: https://www.ness.music.ed.ac.uk/wp-content/uploads/2012/06/timpani.pdf

[3] NVIDIA
CUDA [online]
Available at: https://developer.nvidia.com/cuda-toolkit

[4] Enda Zhang, Gopal Gupta, Charles Greif, Andrew Paplinski (2019)
An Efficient Modal-Based Approach Towards Guzheng Sound Synthesis [online]
Available at: https://arxiv.org/pdf/1910.05447

[5] Blender (1994) [online] Available at: https://www.blender.org/