Projects: Real-time Sound Simulations for Interactive Scenes

DTU - Acoustic Technology Group

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About

The project proposals are all centered around the topic 'Real-time sound simulations for interactive scenes' with applications in computer games and mixed reality. In interactive scenes, sources and receivers are allowed to move freely, and scene changes should be possible, for example, opening and closing doors, and moving obstacles around. For a good introduction see [Microsoft, 2021a]. The project proposals are divided into four parts:

- A) modeling interactive scenes (requires good math/programming skills)
- B) material modeling (requires good math/programming skills, knowledge in acoustics)
- C) efficient implementations (requires excellent programming skills)
- D) method evaluation (requires good knowledge in acoustics)

All referenced papers can be accessed here: `https://www.mendeley.com/community/virtual-acoustics-research-projects/` [1]

Our research group

We are concerned with developing accurate and efficient methods for simulating room acoustics. Applications are in building design, computer games, and mixed reality. The focus is centered around numerical methods solving the underlying physics, implicitly taking wave phenomena into account. Still, it comes with the price of being computationally expensive, especially for larger rooms and for higher frequencies. Therefore, an offline pre-processing step is done to calculate the room impulse responses in a grid, which are then convolved with the source signal at runtime.

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[1]Mendeley app: `www.mendeley.com/download-desktop-new/`

A - Modeling interactive scenes

Requirements: good math/programming skills

Project 1a: Modeling flexible geometries at runtime

The impulse responses are calculated offline for fixed positions, restricting the flexibility of the scene at runtime. However, in most real-time environments, some modification to the scene should be possible, for example, opening and closing doors, and moving obstacles around. This project should investigate efficient methods for allowing (some) geometrical flexibility at runtime without pre-computing all possible settings, but instead learning to adapt to changes from few pre-processed settings. The methods should be computation efficient and require low storage, yet still exhibiting physically correct results.

Methods/literature

- Machine Learning methods [Umetani and Bickel, 2018, Bianco et al., 2019, Brunton et al., 2019]
- Reduced Order Modeling

Project 2a: Impulse response interpolations

The impulse responses are calculated offline for fixed positions in the scene. At runtime, the receivers are allowed to move freely, also at locations where no impulse responses have been calculated. Simple linear interpolations have shown degraded accuracy and therefore more advanced methods should be investigated. A coarser grid means less storage (which can be hundreds of gigabytes in complex scenes) but requires better reconstruction methods. The goal of this project is to develop methods for reconstructing the sound field between the fixed impulse responses.

Methods/literature

- Machine Learning methods [Caviedes-nozal, 2020, Lluís et al., 2020, Fernandez-Grande et al., 2019, Brunton et al., 2019]
- Reduced Order Modeling
- Wave expansions [Fernandez-Grande, 2016]
- Other: [Chaitanya et al., 2019, Raghuvanshi and Snyder, 2014]

Project 3a: Impulse response compression

The impulse responses for the scenes are pre-calculated for fixed grid position and the storage requirements can be huge in large, complex scenes (up to hundreds of gigabytes). The goal of this project is to compress the impulse responses, taking human perception into account by considering early and late reflections.

Methods/literature

- Auto-encoders (Machine learning): [Deb, 2018, Martínez, 2019, Yildirim et al., 2018, Sunilkumar et al., 2021]
- Other: [Raghuvanshi et al., 2010, Raghuvanshi and Snyder, 2014]

Project 4a: Aesthetic modification of room acoustics for interactive auralization

On the contrary to architectural acoustics where the goal is to accurately simulate the real-world, games and mixed reality require aesthetic adjustments to the simulated acoustic properties, still requiring realistic acoustics. Room conditions should be adjusted e.g. to increase the intelligibility of important scripted dialogs, or to enhance the perception of a large room by increasing the reverberation time. This project aims to modify the accurately simulated impulse responses to match some required aesthetics in a simple, efficient, and automized manner.

Methods/literature

- Machine learning methods
- Other: [Godin et al., 2019]

B) Boundary modeling

Requirements: good math/programming skills, knowledge in acoustics

Project 1b: Modeling sound transmission

It is important to be able to model sound transmission through materials - such as walls - for realistic, immersive scenes. Sound transmissions can be divided into two types: airborne and structure-borne/impact sound transmission. Airborne transmission is concerned with sound sources in one room inducing vibrations from air pressure waves on one side of a separating wall impacting the structure to transmit the waves through the material. The other face of the structure starts vibrating, transferring the sound into the new domain. Structure-borne/impact transmission is concerned with a sound source in one room resulting from an object impacting a separating surface transmitting the sound to an adjacent room. An example could be footsteps on the floor being transmitted to a room below. This project is concerned with coming up with efficient methods for modeling sound transmission methods for efficient real-time, interactive scenes.

Methods/literature

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- Acoustic transmission [Kuttruff, 2001, ACT, 2019, Hartmann et al., 2016, Rabold et al., 2008, Park, 2019]
- Other: [Pind et al., 2020, Lamancusa, 2009, Ángel and Bermúdez, 2017, Godin et al., 2019]

Project 2b: Open-space sound propagation

Our methods for sound propagation have been implemented for room acoustics only, but a typical scenario in interactive scenes includes open-spaces - such as outdoor and semi-outdoor scenes. Possible factors to include could be air attenuations and wind impacting the sound field. The goal of this project is to efficiently and realistically simulate outdoor spaces including factors such as air attenuations and wind.

Methods/literature

- See [Ángel and Bermúdez, 2017, Lamancusa, 2009, Godin et al., 2019]

C) Efficient implementation of the Wave-Based Method

Requirements: excellent programming skills

Project 1c: Implementation of the Wave-Based Method on Massively Parallel Systems

The Wave-Based Method has been implemented by the group for simulating wave propagation in rooms and is a numerical method for solving the steady-state Helmholtz equation w.r.t. sound pressure. The method is computationally expensive especially for large rooms and high frequencies and therefore an efficient and high-performant implementation is needed for off-line calculations. The goal is to implement the existing method on massively parallel hardware, scalable to many cluster nodes and GPUs in a low-level language as C/C++/Rust and CUDA/AMD ROCm for GPU capabilities. Middle-layer languages for GPU programming, such as Futhark or OCCA can be considered.

Methods/literature

- Wave-based method (WBM) [Deckers et al., 2014]
- Technologies: Futhark [Futhark, 2020], OCCA [OCCA, 2020], CUDA [CUDA, 2020], AMD ROCm [ROCm, 2020], RUST [Rust, 2020]
- Other: [Strøm and Melander, 2020]

D) Method evaluation

Requirements: good knowledge in acoustics

Project 1d: Evaluate Project Triton: a tool for immersive sound propagation for games and mixed reality

Microsoft has created "Project Triton" for immersive sound propagation for games and mixed reality and a plugin for Unity is available. This project should investigate how well Triton performs concerning some parameters, e.g.

1. Obstruction/occlusion (diffraction), reverberance/decay time
2. Source/receiver directivity
3. Compare Triton with geometrical acoustics (GA) in interactive scenes: when does GA break down? Investigate smooth transitions moving around occlusion/obstacles (GA has problems here due to the abrupt change of the direct path)
4. Ease of use: UI/UX, compare with the usual way of designing sound in games (using e.g. Wwise from Audiokinetic)
5. Computational efforts

3) is particularly interesting: The additional accuracy gained from wave physics might not be needed in computer games, so why use wave physics instead of GA? One reason is the smooth transitions when moving around the scene, where it is claimed that GA cannot ensure this.

Methods/literature

- Project Triton [Microsoft, 2021a], What is Acoustics? [Microsoft, 2021b]
- Gears of War 4, Project Triton 2017 [video]: `https://www.youtube.com/watch?v=qCUEGvIgco8`
- Project Acoustics, GDC 2019 [video]: `https://www.youtube.com/watch?v=uY4G-GUAQIE`

References

[ACT, 2019] ACT, D. (2019). Structure-borne sound. https://www.act.elektro.dtu.dk/Research/Research_fields/Structure-borne-Sound.

[Ángel and Bermúdez, 2017] Ángel, M. and Bermúdez, M. (2017). *Sound propagation modelling in urban areas : from the street scale to the neighbourhood scale*. Université du Maine, 2012.

[Bianco et al., 2019] Bianco, M. J., Gerstoft, P., Traer, J., Ozanich, E., Roch, M. A., Gannot, S., and Deledalle, C.-A. (2019). Machine learning in acoustics: theory and applications. (May).

[Brunton et al., 2019] Brunton, S. L., Noack, B. R., and Koumoutsakos, P. (2019). Machine Learning for Fluid Mechanics. *Annual Review of Fluid Mechanics*, 52(1):1–31.

[Caviedes-nozal, 2020] Caviedes-nozal, D. (2020). Sound field reconstruction for outdoor sound field control applications.

[Chaitanya et al., 2019] Chaitanya, C. R., Snyder, J. M., Godin, K., Nowrouzezahrai, D., and Raghuvanshi, N. (2019). Adaptive Sampling for Sound Propagation. *IEEE Transactions on Visualization and Computer Graphics*, 25(5):1846–1854.

[CUDA, 2020] CUDA (2020). Cuda. https://developer.nvidia.com/cuda-toolkit.

[Deb, 2018] Deb, S. (Oct. 12 2018). How to perform data compression using autoencoders? https://medium.com/edureka/autoencoders-tutorial-cfdcebdefe37.

[Deckers et al., 2014] Deckers, E., Atak, O., Coox, L., D'Amico, R., Devriendt, H., Jonckheere, S., Koo, K., Pluymers, B., Vandepitte, D., and Desmet, W. (2014). The wave based method: An overview of 15 years of research. *Wave Motion*, 51(4):550–565.

[Fernandez-Grande, 2016] Fernandez-Grande, E. (2016). Sound field reconstruction using a spherical microphone array. *The Journal of the Acoustical Society of America*, 139(3):1168–1178.

[Fernandez-Grande et al., 2019] Fernandez-Grande, E., Hahmann, M., and Verburg, S. A. (2019). Sparse representation of the sound field in a room with dictionary learning. *The Journal of the Acoustical Society of America*, 146(4):2762–2762.

[Futhark, 2020] Futhark (2020). Futhark. https://futhark-lang.org.

[Godin et al., 2019] Godin, K. W., Gamper, H., and Raghuvanshi, N. (2019). Aesthetic modification of room impulse responses for interactive auralization. *Proceedings of the AES International Conference*, 2019-March(March).

[Hartmann et al., 2016] Hartmann, T., Tanner, G., Xie, G., Chappell, D., and Bajars, J. (2016). Modelling of high-frequency structure-borne sound transmission on FEM grids using the Discrete Flow Mapping technique. *Journal of Physics: Conference Series*, 744(1).

[Kuttruff, 2001] Kuttruff, H. (2001). *Room Acoustics, Fourth edition.*

[Lamancusa, 2009] Lamancusa, J. S. (2009). Outdoor Sound Propagation. *Building Acoustics and Vibration*, pages 620–665.

[Lluís et al., 2020] Lluís, F., Martínez-Nuevo, P., Møller, M. B., and Shepstone, S. E. (2020). Sound field reconstruction in rooms: Inpainting meets superresolution. *arXiv*, 649.

[Martínez, 2019] Martínez, G. (Jan 18, 2019). Autoencoders for the compression of stock market time series. https://towardsdatascience.com/autoencoders-for-the-compression-of-stock-market-data-28e8c1a2da3e.

[Microsoft, 2021a] Microsoft (2021a). Project triton.

[Microsoft, 2021b] Microsoft (2021b). What is acoustics?

[OCCA, 2020] OCCA (2020). Occa. https://libocca.org/.

[Park, 2019] Park, S. (2019). Vibro-acoustic numerical simulation for analyzing floor noise of a multi-unit residential structure. *Applied Sciences (Switzerland)*, 9(20).

[Pind et al., 2020] Pind, F., Jeong, C.-H., Engsig-Karup, A. P., Hesthaven, J. S., and Strømann-Andersen, J. (2020). Time-domain room acoustic simulations with extended-reacting porous absorbers using the discontinuous Galerkin method. *The Journal of the Acoustical Society of America*, 148(5):2851–2863.

[Rabold et al., 2008] Rabold, A., Düster, A., and Rank, E. (2008). FEM based prediction model for the impact sound level of floors. *Proceedings - European Conference on Noise Control*, (December 2013):2993–2998.

[Raghuvanshi and Snyder, 2014] Raghuvanshi, N. and Snyder, J. (2014). Parametric wave field coding for precomputed sound propagation. *ACM Transactions on Graphics*, 33(4).

[Raghuvanshi et al., 2010] Raghuvanshi, N., Snyder, J., Mehra, R., Lin, M., and Govindaraju, N. (2010). Precomputed wave simulation for real-time sound propagation of dynamic sources in complex scenes. *ACM SIGGRAPH 2010 Papers, SIGGRAPH 2010.*

[ROCm, 2020] ROCm, A. (2020). Amd rocm. https://www.amd.com/en/graphics/servers-solutions-rocm.

[Rust, 2020] Rust (2020). Rust. https://www.rust-lang.org.

[Strøm and Melander, 2020] Strøm, E. N. and Melander, A. D. (2020). Massively Parallel Nodal Discontinous Galerkin Finite Element Method Simulator for 3D Room Acoustics. (April).

[Sunilkumar et al., 2021] Sunilkumar, K. N., Shivashankar, and Keshavamurthy (2021). Bio-signals compression using auto-encoder. *International Journal of Electrical and Computer Engineering*, 11(1):424–433.

[Umetani and Bickel, 2018] Umetani, N. and Bickel, B. (2018). Learning three-dimensional flow for interactive aerodynamic design. *ACM Transactions on Graphics*, 37(4).

[Yildirim et al., 2018] Yildirim, O., Tan, R. S., and Acharya, U. R. (2018). An efficient compression of ECG signals using deep convolutional autoencoders. *Cognitive Systems Research*, 52:198–211.