Seminar topics

Advanced Computer Graphics, 2020/21

1 Introduction

The document describes the seminar topics for the Advanced Computer Graphics course given in 2020/21. The seminar work must be completed during the spring semester and defended prior to the final deadline. Students must defend the seminar at the laboratory exercises and present it at the final presentation session in front of the class.

Upon successful completion, the seminar may contribute up to 30 % to the final grade. It must be graded with more than 15 % for a positive grade. The defense of the seminar after the deadline lowers its maximum contribution: 1-week extension: 22.5 %, 2-week extension 17.5 %. Seminars can also be completed and defended prior to the given deadline.

When the topics are assigned, the students must report their GitHub username and initialize the repository. During the semester the students must present their progress every two weeks through git commits at the laboratory exercises.

The expected outputs of each seminar are the seminar report and code repository published on GitHub under the CC-BY, BSD or MIT license. The report must be submitted through the FRI Učilnica. It must be written as a research paper in accordance with the Eurographics LaTeX template[1].

2 Seminar Topics

2.1 Procedural generation of volumetric fluid environments

The goal of the seminar is to create a procedural model of a fluid environment which can be used in the VPT framework [1]. The initial fluid model should be generated using 3D Perlin noise where noise values represent pressure levels in the volume. Furthermore, the model should be physically simulated by applying a suitable fluid simulation method. In this seminar you will be using Stam's real-time fluid dynamics [2, 3]. The resulting volume should be rendered in the VPT framework. For even better results try to implement refraction based on [4]. The final goal is to generate a static volume containing fluid environment with non-transparent ground material and wavy surface.

References:

[1] Ž. Lesar, C. Bohak, and M. Marolt, "*Real-time interactive platform-agnostic volumetric path tracing in WebGL 2.0*", Web3D 2018: proceedings, 2018.

[2] J. Stam, "*Stable Fluids*", ACM Transactions on Graphics, 1999.

[3] J. Stam, "*Real-Time Fluid Dynamics for Games",* Game Developers Conference, 2003.

[4] J. G. Magnus; S. Bruckner, "*Interactive Dynamic Volume Illumination with Refraction and Caustics*", IEEE Transactions on Visualization and Computer Graphics, 2018.

2.2 Procedural cell shape model

The goal of this seminar is to create a procedural model of call membrane shape extracted from real-life cell data. The cell data can be obtained from Allan Cell institute database [1], where thousands of cells are labeled, and their shape can be extracted and used for defining the membrane model parameters. Use statistical shape modeling (e.g. [3]) to define a cell shape. The model must allow users to customize the basic cell shape parameters while retaining the randomness of shape through model seed parameter. You can get a basic idea of what cells look like in [2].

References:

[1] Membrane (CAAX). url: https://www.allencell.org/data-downloading.html

[2] A. Kessel, "*The Living Cell Gallery*". url: https://amit1b.wordpress.com/the-molecules-of-life/10-the-living-cell-gallery/

[3] T. Vrtovec, D. Tomaževič, B. Likar, L. Travnik, F. Pernuš, "*Automated Construction Of 3D Statistical Shape Models*", Image Analysis & Stereology, 2004.

2.3 Transfer function design gallery

Creating and adjusting a transfer function for good visualization in volume rendering can be quite demanding. To ease the process and bring the transfer function closer to the everyday user, your task is to develop an exploratory tool which will allow users to easily create and adjust the transfer function for a specific dataset. The tool should allow "browsing" through variations of the currently applied transfer function in a similar fashion to design galleries

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[1] https://www.overleaf.com/gallery/tagged/eurographics

[4]. The transfer function recommendations should be presented to the user in the form of small low-resolution previews. The user should be able to adjust and fine-tune the resulting transfer function.

References:

[1] C. R. Salama, M. Keller, P. Kohlmann, "*High-Level User Interfaces for Transfer Function Design with Semantics*", IEEE Transactions on Visualization and Computer Graphics 2006, doi: 10.1109/TVCG.2006.148.

[2] R. Maciejewski, I. Woo, W. Chen, D. Ebert, "Structuring Feature Space: A Non-Parametric Method for Volumetric Transfer Function Generation", IEEE Transactions on Visualization and Computer Graphics 2009, doi: 10.1109/TVCG.2009.185.

[3] Y. Liu, C. Lisle and J. Collins, "*Quick2Insight: A user-friendly framework for interactive rendering of biological image volumes,*" 2011 IEEE Symposium on Biological Data Visualization (BioVis)., 2011, doi: 10.1109/BioVis.2011.6094041.

[4] J. Marks, B. Andalman, P. A. Beardsley, W. Freeman, S. Gibson, J. Hodgins, T. Kang, B. Mirtich, H. Pfister, W. Ruml, K. Ryall, J. Seims, and S. Shieber, "*Design galleries: a general approach to setting parameters for computer graphics and animation,*" Proceedings of the 24th annual conference on Computer graphics and interactive techniques (SIGGRAPH '97), 1997, doi: 10.1145/258734.258887.

2.4 Unbiased emission-absorption model in VPT

The goal of this seminar is to develop an unbiased emission-absorption model [2] for rendering volumetric data in the VPT framework [1]. The VPT framework is a tool for interactive visualization of volumetric data in a web browser. There are several techniques that are already implemented in the framework, including a biased emission-absorption model; however, the task of this seminar is to employ a Monte Carlo approach to bypass the shortcomings of the existing implementation. The existing implementation should also be updated with the two most common bias mitigation strategies – sampling offset and jitter. The resulting methods should be compared to one another in terms of output quality, accuracy and computational complexity.

References:

[1] Ž. Lesar, C. Bohak, and M. Marolt, *"Real-time interactive platform-agnostic volumetric path tracing in WebGL 2.0",* Web3D 2018: proceedings, 2018.

[2] N. Max, "*Optical models for direct volume rendering,*" in IEEE Transactions on Visualization and Computer Graphics, vol. 1, no. 2, pp. 99-108, June 1995, doi: 10.1109/2945.468400.

2.5 Comparison of transmittance and distance estimators in light transport

There are numerous approaches to sample distances and estimating transmittance in heterogeneous media. In 2013, Galtier et al. [1] published a general integral formulation of the light transport problem, postulating an infinite family of estimators. Some of them have been studied and understood, each having their own pros and cons. The goal of this seminar is to study, implement and compare different estimators, preferably in an existing volume rendering framework such as VPT.

References:

[1] M. Galtier, S. Blanco, C. Caliot, C. Coustet, J. Dauchet, M. El Hafi, V. Eymet, R. Fournier, J. Gautrais, A. Khuong, B. Piaud, and G. Terrée, "*Integral formulation of null-collision Monte Carlo algorithms*", Journal of Quantitative Spectroscopy and Radiative Transfer, 2013, doi: 10.1016/j.jqsrt.2013.04.001

[2] J. Novák, I. Georgiev, J. Hanika, J. Křivánek, and W. Jarosz, "*Monte Carlo methods for physically-based volume rendering*", ACM SIGGRAPH 2018 Courses, ACM Press, 2018, doi: 10.1145/3214834.3214880

[3] J. Novák, I. Georgiev, J. Hanika, J. Křivánek, and W. Jarosz, "*Monte Carlo methods for volumetric light transport simulation*", Computer Graphics Forum, 2018, doi: 10.1111/cgf.13383

2.6 Removing shadows from ortho-photo images

The goal of this seminar is to implement algorithm that will take an aerial ortho-photo image as an input and output an image with removed shading/shadows. To achieve this, you may apply one of the algorithms presented in [1, 2] or some other state-of-the art shadow removing algorithm. The developed algorithm should be able to read images in different formats (at least JPG and PNG) and output the image in same format. The application should support piping so it can be used in some image processing pipeline.

References:

[1] S. H. Khan, M. Bennamoun, F. Sohel and R. Togneri, *"Automatic Shadow Detection and Removal from a Single Image",* IEEE Transactions on Pattern Analysis and Machine Intelligence, 2016, doi: 10.1109/TPAMI.2015.2462355.

[2] G. D. Finlayson, S. D. Hordley, M. S. Drew, *"Removing Shadows from Images"*, Proceedings of the 7th European Conference on Computer Vision, 2002, url: https://dl.acm.org/doi/10.5555/645318.649239

2.7 Scattered data approximation with multigrid relaxation

In many cases in computer graphics, we are faced with unstructured data samples, such as point clouds or path tracing rays. Given a finite set of scattered samples, your task is to guess the function values in the entire domain. Many methods exist for this task, taking significantly different approaches. One of them involves solving the Laplacian equation on a grid (e.g., pixels in an image). However, just straightforwardly discretizing the equation results in extremely slow convergence. The goal of this seminar is to explore and implement the multigrid method on the GPU. The multigrid method effectively accelerates the convergence of low-frequency signals by discretizing and solving the equation in different resolutions and then systematically distributing the residual error.

References:

[1] K. Anjyo, J. P. Lewis, and F. Pighin, "*Scattered data interpolation for computer graphics*", ACM SIGGRAPH 2014 Courses, ACM Press, 2014, doi: 10.1145/2614028.2615425

2.8 Mixed surface and volume shading support in VPT

In volume rendering the notion of surfaces is not strictly defined, as a volume is only a scalar field of values. One may define a surface as a large difference in material density, which can be estimated to some degree with a gradient of the scalar field. The goal of this seminar is to add support for mixed surface and volume shading to the VPT framework [1]. As a basis you can use the mixed Henyey-Greenstein/Blinn-Phong phase function, as defined by Kroes et al. [2], but also explore other possible solutions.

References:

[1] Ž. Lesar, C. Bohak, and M. Marolt, *"Real-time interactive platform-agnostic volumetric path tracing in WebGL 2.0",* Web3D 2018: proceedings, 2018.

[2] T. Kroes, F. H. Post and C. P. Botha, "*Exposure Render: An Interactive Photo-Realistic Volume Rendering Framework,"* PLoS ONE, vol. 7, no. 7, 2011, doi: 10.1371/journal.pone.0038586.

2.9 Temporal volume rendering support in VPT

The goal of this seminar is to extend the functionality of VPT [1] with support for rendering temporal volumetric data. The added temporal support must support two use cases: (1) fixed-time rendering of individual frame, where system spends equal rendering time for each frame and stores the final render in image sequence, and (2) fixed error rate rendering of individual frame, where each frame is rendered for as long as the difference between the consecutive rendering epochs is below the defined error threshold. As part of this seminar also create 4D temporal volumetric data, e.g., smoke simulation or fluid simulation which or use appropriate 4D radiological data e.g. [3].

References:

[1] Ž. Lesar, C. Bohak, and M. Marolt, *"Real-time interactive platform-agnostic volumetric path tracing in WebGL 2.0",* Web3D 2018: proceedings, 2018.

[2] B. She, P. Boulanger, M. L. Noga, "*Real-Time Rendering of Temporal Volumetric Data on a GPU*", International Conference on Information Visualisation, 2011.

[3] 4D Lungs dataset. url: https://wiki.cancerimagingarchive.net/display/Public/4D-Lung

2.10 Spectral rendering support in VPT

Path tracing applications usually ignore the effects of wave optics and wavelength dependency, such as diffraction, interference, and chromatic aberration. Depending on the scene, these effects may be more or less pronounced. The goal of this seminar is to implement spectral rendering support for volumetric path tracing in the VPT framework in order to reproduce some of the effects of wave optics. In addition, the application should support realistic light sources and their spectral distributions.

References:

[1] H. J. Noordmans, H. T. M. van der Voort and A. W. M. Smeulders, "*Spectral volume rendering,*" in IEEE Transactions on Visualization and Computer Graphics, vol. 6, no. 3, pp. 196-207, July-Sept. 2000, doi: 10.1109/2945.879782.

[2] S. Bergner, T. Moller, M. S. Drew and G. D. Finlayson, "*Interactive spectral volume rendering,*" IEEE Visualization, 2002. VIS 2002., Boston, MA, USA, 2002, pp. 101-108, doi: 10.1109/VISUAL.2002.1183763.

2.11 Focused rendering

In path tracing, casting a large number of rays into a homogeneous part of an image is rather wasteful. In this seminar you will develop a method that can estimate the complexity of different parts of an image. You will then use the complexity map to guide the ray casting process towards the parts of the image that require more samples. The resulting method has to be robust, as it will be used in path tracing where we are faced with large amounts of noise. A few ideas on how to approach the problem: use the gradient of the luminance, use the gradient of the chroma, use a coarse maximum intensity projection.

References:

[1] R. Rosenholtz, Y. Li and L. Nakano, "*Measuring visual clutter,*" Journal of Vision, vol. 7, no. 17, Aug. 2007, doi: 10.1167/7.2.17.

[2] E. Saraee, M. Jalal and M. Betke, "*Visual complexity analysis using deep intermediate-layer features,*" Computer Vision and Image Understanding, vol. 195, 2020, doi: 10.1016/j.cviu.2020.102949.

2.12 Electrostatic field visualization

Proteins play a key role in most of the processes that take place in living organisms, from bacteria to trees and large mammals. This role is a function of their chemical composition, their physical structure, and the physico-chemical properties that result from that combination. Chief among these physico-chemical properties are the electrostatic fields they generate, for these determine a large portion of the attractive and repulsive forces that will emerge between a given protein and other molecules with which it may interact (other proteins, membranes, nucleic acids, etc.). Studying the electrostatic fields of proteins is therefore very important in structural biology, and thus to the understanding of fundamental biological processes, as well as to the design of new drugs. And studying such complex shapes requires appropriate visualization techniques. The goal of this seminar is to develop a volume rendering technique that could convey a sense of the value taken by the electrostatic field at every point surrounding the protein, without occluding its structure. An example of such a rendering technique is provided in [1]; however, this technique was shown to work for volumetric grids of about 100×100×100, but failed to produce smooth results with larger grids. The goal of this seminar is therefore to develop a technique that can scale to larger grids.

References:

[1] M. Chavent, A. Vanel, A. Tek, B. Levy, S. Robert, B. Raffin and M. Baaden, "*GPU-accelerated atom and dynamic bond visualization using hyperballs: A unified algorithm for balls, sticks, and hyperboloids,*" Journal of Computational Chemistry, vol. 32, no. 13, pp. 2924-2935, 2011, doi: 10.1002/jcc.21861.

2.13 Special topic [with prior agreement]

If you have in mind a specific topic which is in line with the course syllabus and is not covered in any of above topics you may present your idea to the Professor or Teaching Assistant and discuss with them whether your idea can be defined as a seminar topic for this course. You must contact and discuss your topic prior to the deadline of topic selection and you have to get the agreement for the topic from the Professor or Teaching Assistant.