EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

Universität Tübingen · Prof. H. Lensch · Maria-von-Linden-Str. 6 · 72076 Tübingen

Fachbereich Informatik
(Wilhelm-Schickard-Institut)

Computergrafik
Prof. Dr. Hendrik Lensch

Maria-von-Linden-Str. 6
72076 Tübingen, Germany

Telefon +49 7071 29-76356
Telefax +49 7071 29-35324
hendrik.lensch@uni-tuebingen.de

Office of Student Affairs
Charles University
Ke Karlovu 3, 121 16 Paha 2
Czech Republic

Tübingen, 13.09.2023

Review of the dissertation handed in by Mr. Tobias Rittig with the title
”Optimization Techniques in Computer Graphics and Appearance Fabrication“

In his thesis, Tobias Rittig investigates and develops numerous approaches for introducing optimization in computer graphics applications, e.g. to estimate material parameters for truthful appearance reproduction in 3D printing or for generative modeling of sky-dome images.
In colored 3D printing, due to the nature of the employed materials, scattering within the volume is unavoidable. Reproducing an intended colored 3D model with given textures therefore is not a trivial task as the appearance would be rather different. Even if one intends to print a translucent object it is not clear where to deposit colored ink and how to control the scattering appearance. Already modeling a proper simulation of these effects is not trivial. One would need the scattering and absorption parameters of all involved materials and then run a scattering simulation to predict the volumetric light transport. Inverting this process accordingly to optimize the material parameters for the intended look is even more involved. Based on Monte Carlo rendering and heuristic optimization Tobias Rittig makes several contributions to make the estimation process more robust and more efficient. He proposes the first optimization framework that predicts optimal material distributions for arbitrarily shaped objects where the scattering behavior particularly in thin geometric features makes appearance reproduction even tougher. As the predefined shape might limit the possible space of representable colors a novel gamut mapping scheme is proposed. He further introduces a fast neural rendering predictor. Operating orders of magnitude faster it can achieve the same or better quality as before. While the previous optimization involves some heuristics in the material deposition novel differential rendering approaches for volumetric scattering allowed him to also address the material optimization problem with MC-based differentiable rendering and gradient descent optimization. Similarly, the estimation of scattering parameters when measuring the properties of a given material probe can now be addressed by differentiable rendering.
The second part of the thesis looks at optimization for generative modeling of the sky such that the representation can be used as a realistic environment map for rendering outdoor scenes. In this context, Mr. Rittig worked on fitting models to brute-force atmosphere simulations, contributed to realistic image-based lighting with cloudy sky imagery, and developed a generative neural network with automatic differentiation and stochastic gradient descent.

The dissertation is written in English. It is structured into four main chapters as well as a conclusion and a future work section. The introduction starts quite generally and then gives a rough outline of the two parts of the thesis and a list of the main contributions of the candidate in these projects.

The background chapter gives a short but concise and informative overview of various optimization schemes from global to local optimization, gradient descent, and automated differentiation. The chapter further describes the current challenges and existing solutions for differentiable rendering that lays the ground for gradient-based optimization on photometric content. Similarly, the related work chapter covers current approaches for 3D printing including translucency fabrication, forward and inverse volume rendering, and differentiable path tracing, as well as neural rending techniques. The chapter further addresses the related approaches that are needed to represent and render using atmospheric sky models. Mr. Rittig discusses machine learning for image-based lighting as well as generative adversarial networks (GANs) for generative modeling. These two chapters equip the reader with sufficient information to properly follow the two main contributions and anchor them in the current research landscape.

Chapter 3 gathers all proposed techniques for optimizing 3D appearance fabrication with the goal of compensating or at least controlling the immanent scattering in 3D printing. In Section 3.1. the focus is on the appearance modeling of complex shapes. It starts by verifying that known material depositing heuristics are in agreement with conjugate-gradient-based solutions on the full volume. Those heuristics are then extended to general shapes. They are further augmented by novel gamut mapping approaches which map the intended appearance to a close-by solution in case the given shape simply does not allow for an exact appearance reproduction.
The acceleration method based on neural rendering is presented in Section 3.2. The proposed neural model speeds up the material distribution optimization by up to 300 times while still converging to a similar or better quality as before, which is demonstrated in a thorough evaluation study. To train the neural network an exhaustive data set of synthetic scattering volumes with a wide range of material composites has been created. The approach can even be extended to spectral rendering of the scattering effects.
Section 3.3. approaches the scattering compensation problem using advanced differentiable volumetric rending and stochastic gradient descent, and Section 3.4. describes how a similar framework can be used to recover the scattering parameters for measured probes.
Besides a clear description of the presented contribution each section also lists an almost overwhelming set of challenges that had to be solved on the way as well as further interesting details. In each part, a well-designed set of experiments demonstrates the effect on the final quality and the runtime for each proposed step.

The second half of the contributions on modeling and rending with realistic sky models is covered in Chapter 4. At first, a realistic, comprehensive clear-sky model is presented that can predict hemispherical radiance patterns for varying altitudes. By simulating the environment maps for a large range of parameter settings a complex data set is assembled which is converted and compressed using tensor decomposition. In addition to the radiance, the transmission function is modeled. Section 4.2 focuses on more realistic sky representations including clouds for image-based lighting. Based on a vast set of captured HDR sky-dome images both the previous clear-sky model as well as a conditional GAN-based neural network (StyleGAN3) for the cloudy sky are optimized. Special attention had to be paid to properly recover the sun's position in all images and to model its intensity as the HDR images might not properly report it.

The thesis ends with a short conclusion on the main findings and some outlook on promising future directions for the use of optimization methods in both fields.

The text is overall very well structured. Due to the complexity of the problems and the corresponding solutions, it takes sometimes some effort to fully follow the thesis in the first read. The wealth of provided detailed insights and performed rigorous experiments is remarkable. With his thesis, Tobias

Rittig has demonstrated profound expertise in the field of optimization in computer graphics and demonstrated extraordinary skills to implement and apply various optimization schemes in different application scenarios which are already highly complex when just considering the forward model. The quality of his contributions is manifested also a list of six strong top-tier publications (e.g. ACM SIGGRAPH, ACM Transactions on Graphics and Computer Graphics Forum) and one submission currently under review.

To summarize, I recommend accepting this remarkable thesis by Mr. Tobias Rittig. The thesis clearly shows the strong capability of Tobias Rittig to conduct excellent creative scientific work and deserves to be defended on September 19th.

(Prof. Dr.-Ing. Hendrik Lensch) Tübingen, 13.09.2023