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Master's Thesis

Simplifying NeRF: Creating an Intuitive Web-Based 3D Scene Interface

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in

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by

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Abstract

The advent of Neural Radiance Fields (NeRF) has transformed the field of 3D scene modelling and rendering, offering photorealistic digital environments at relatively low effort and cost. Despite the technology's potential, the complexity of existing NeRF frameworks presents significant challenges to users without extensive technical expertise. This thesis presents the development of a web-based interface designed to simplify the creation of NeRFs, making them accessible to a broader audience, specifically targeting professionals from the film industry. The interface has been designed to facilitate the use of NeRFs by those without prior technical expertise, while still allowing users to leverage the full capabilities of the technology. The research employs a user-centred design approach, based on expert interviews to gauge user requirements and preferences. A subsequent user study evaluated the interface through qualitative and quantitative methods, in order to validate its effectiveness and accessibility. The contributions of this work not only enhance the user experience but also expand the creative possibilities for users across various use cases, thereby promoting broader adoption and innovation in NeRF-based content creation.

Abstract (German)

Neural Radiance Fields (NeRF) haben die Bereiche der 3D-Modellierung maßgeblich verändert. Sie ermöglichen die Erstellung fotorealistischer digitaler Szenen bei relativ geringem Aufwand und Kosten. Trotz des Potenzials der Technologie stellen die Komplexität der bestehenden NeRF-Frameworks sowie die erforderlichen technischen Kenntnisse für deren Nutzung eine Herausforderung für Benutzer:innen ohne entsprechende Vorkenntnisse dar. In dieser Arbeit wird die Entwicklung einer webbasierten Oberfläche vorgestellt, die die Erstellung von NeRFs vereinfachen soll, um sie einem breiteren Publikum zugänglich zu machen, insbesondere Fachleuten aus der Filmindustrie. Die Schnittstelle wurde so konzipiert, dass sie auch Personen ohne technische Vorkenntnisse die Verwendung von NeRFs erleichtert und es den Nutzenden dennoch ermöglicht, die Kapazitäten der Technologie voll auszuschöpfen. Die Forschungsarbeit folgt einem nutzerzentriertem Designansatz, basierend auf Experteninterviews um die Anforderungen und Präferenzen der Nutzer:innen zu ermitteln. In einer anschließenden Nutzerstudie wurde die Oberfläche mit Hilfe qualitativer und quantitativer Methoden bewertet, um ihre Wirksamkeit und Zugänglichkeit zu validieren. Die Beiträge dieser Arbeit verbessern nicht nur das Benutzererlebnis, sondern erweitern auch die kreativen Möglichkeiten für Nutzer:innen in verschiedenen Anwendungsfällen und fördern so eine Verbreitung und Innovation bei der Erstellung von NeRF-basierten Inhalten.

Contents

1 Introduction

1.1 Motivation

The potential of view synthesis to revolutionize visual content creation in the film industry has been recognized for some time. Nevertheless, it was not until recent advancements in machine learning that this technology began to fulfill its promise. The advent of Neural Radiance Fields (NeRF) has been pivotal, offering unprecedented realism and detail in 3D scene modeling and rendering. This has had a significant impact on various applications, including the enhancement of virtual reality experiences and the creation of photorealistic visual effects in movies.

Two prominent NeRF frameworks with user interfaces, namely Instant NGP [26] and Nerfstudio [39], have emerged as leaders in enabling users to explore and manipulate 3D scenes. These frameworks provide a number of features, including real-time scene rendering, adjustable training parameters, and the creation of camera trajectories for video rendering.

Despite these advancements, the technical complexity of these frameworks frequently acts as a barrier to broader accessibility, indicating a need for improvements in user experience. These interfaces usually require a high degree of technical knowledge, as they are intended to supplement, rather than substitute, command-line interfaces. For activities such as video data preprocessing, model training, and output rendering, users are required to navigate through terminal-based processes.

This complexity not only limits the potential user base to individuals with technical expertise but also hinders the creative and innovative application of NeRF technology across broader fields. Consequently, there exists a critical need to enhance the user experience and develop solutions that simplify the interaction with NeRF frameworks, making them more accessible and usable for a diverse range of users beyond the realm of technical specialists.

1.2 Research Objectives and Questions

This research aims to advance the capabilities and usability of NeRF frameworks, making them accessible to a broader audience and fostering innovation in 3D scene modeling and rendering. The study is guided by the following questions:

1. **Capabilities of Current NeRF Frameworks:** What are the existing interaction capabilities of NeRF frameworks, and how do they support various user groups in creating and manipulating 3D scenes?
2. **Enhancing Accessibility with a Web-Based Editor:** How can the development of a user-friendly web-based interface for NeRF improve its accessibility and simplify the creation and manipulation processes?
3. **Challenges in Developing Web-Based NeRF Tools:** What are the primary technical challenges and limitations associated with building a NeRF interface and how can these be overcome?

Scope of the Study. This research project is focused on the development and evaluation of a web-based interface for NeRF, with the objective of enhancing its accessibility and usability. The study will concentrate on interface design and user interaction, without delving into the underlying algorithms of NeRF technology itself. It is delimited by its emphasis on interface design over algorithmic advancements in NeRF processing.

Significance of the Study. This research addresses the usability challenges of current NeRF frameworks with the aim of making 3D scene modeling more accessible, fostering innovation and broadening the application of this technology across various fields. The development of a web-based interface could significantly lower the entry barrier to NeRF, enabling artists, designers, and educators to leverage this technology without requiring deep technical expertise.

1.3 Structure of the Thesis

This thesis is organized into several chapters, each focusing on a specific aspect of the research. The structure is outlined as follows:

2. **Background:** Provides a comprehensive overview of view synthesis, including traditional and neural approaches, and specifically introduces Neural Radiance Fields for view synthesis.

3. **Related Work:** Reviews existing solutions and technologies in the field, such as Instant NGP, Nerfstudio, Luma AI, and the Volinga Suite, discussing their features and limitations.
4. **Methodology:** Describes the methodological approach used to research and develop the web-based interface for NeRF.
5. **User Research:** Details the process and findings from user research, which informs the design and functionality of the developed interface.
6. **Application Design:** Covers the design process of the application, from initial sketches to the final design, emphasizing user interface and experience.
7. **Technical Implementation:** Explains the technical aspects of implementing the application, including system architecture and the integration of front-end and back-end components.
8. **User Study and Evaluation:** Discusses the setup, execution, and evaluation of user studies conducted to evaluate the usability and effectiveness of the interface.
9. **Results:** Presents the findings from the user studies, analyzing the data collected through both quantitative and qualitative methods.
10. **Discussion:** Reflects on the results, discussing implications for the film and VFX industry, and addressing the limitations encountered.
11. **Conclusion:** Summarizes the key findings, contributions to the field, and suggests directions for future work.

Background

2

2.1 View Synthesis

View synthesis is a computer graphics and computer vision process that involves the creation of new, synthetic images of a scene from viewpoints that were not originally captured by a camera. This technique leverages existing images and often incorporates geometric information about the scene, enabling the generation of perspective-correct views from desired locations. The objective of view synthesis is to generate realistic and accurate representations of a 3D scene from novel viewpoints, thereby enhancing applications such as virtual reality (VR), augmented reality (AR), 3D television, and film production. The following sections provide an overview of traditional view synthesis techniques.

Image-Based Rendering Techniques. Image-based rendering (IBR) techniques focus on synthesizing new views of a scene using pre-captured images, with minimal reliance on geometric models. The fundamental principle of IBR is to directly utilize radiance information captured in these images, manipulating it to generate new viewpoints without the necessity for detailed 3D reconstruction. IBR methods are distinguished by their capacity to generate photorealistic results, as they accurately capture lighting, shadows, and reflections in accordance with the original scene (see Fig. 2.1). These methods, such as those employing light fields or lumigraphs, are particularly suited to applications where visual realism is of critical importance, as they are able to efficiently simulate the complexity of real-world lighting and textures [6, 8, 11, 16, 21].

Volumetric Methods. Volumetric rendering techniques construct a 3D volume of the scene, often represented as a grid of voxels. Each voxel contains data such as color and opacity, which contribute to the final image through a process akin to 3D texturing (see Fig. 2.2). Unlike surface-based modeling, which requires explicit surfaces, volumetric methods fill the entire data space, allowing for the handling of complex phenomena like fog, clouds, and fire, which do not have clear boundaries. This approach is advantageous when the scene involves intricate details and volumetric phenomena that traditional polygon-based rendering might struggle to capture accurately. [9, 35].

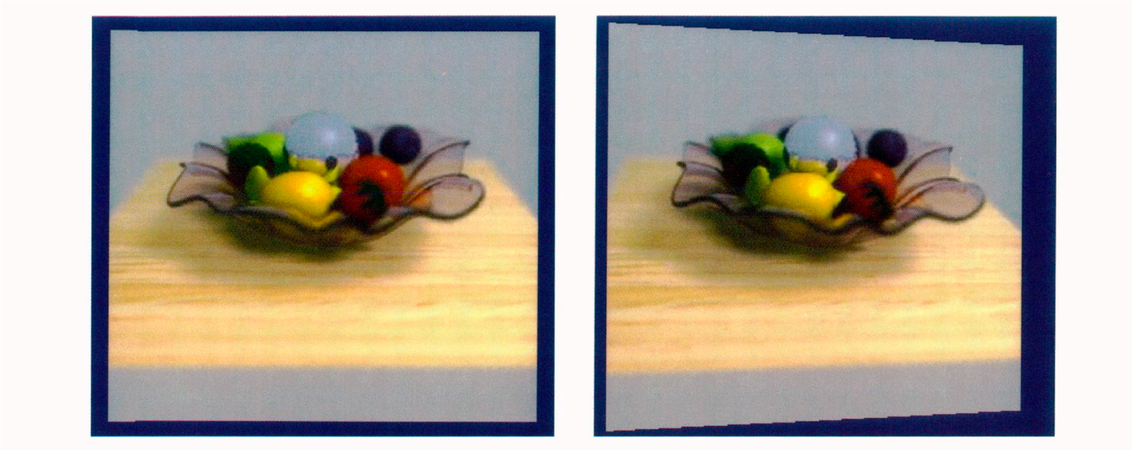


Fig. 2.1.: Stereo view generated by Lumigraph [16].

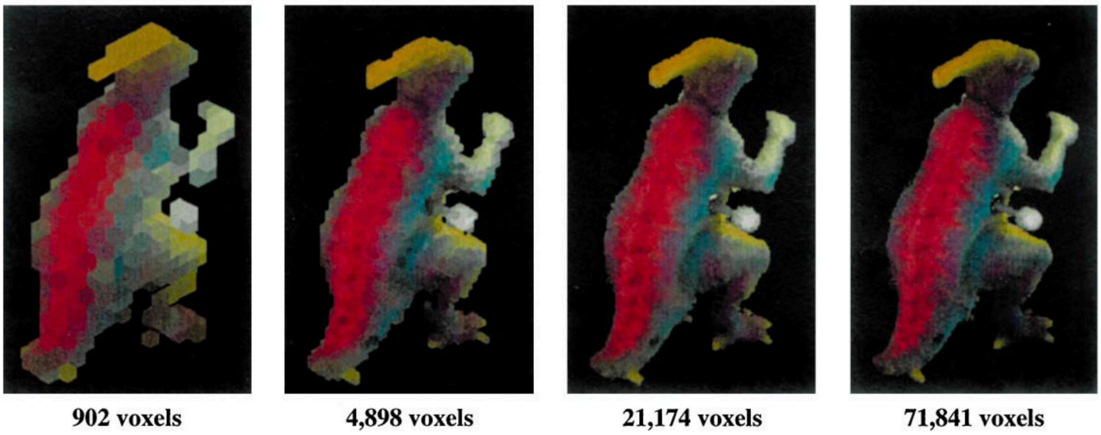


Fig. 2.2.: Voxel coloring of a toy dinosaur with increasing resolution [35].

2.2 Neural Approaches to View Synthesis

Neural approaches to view synthesis have significantly advanced the capabilities of generating realistic views from sparse data. These methods integrate deep learning techniques to enhance the synthesis process, offering substantial improvements over traditional geometric and image-based methods.

Deep Learning for View Synthesis. Deep learning models, particularly Convolutional Neural Networks (CNNs), are employed to predict depth and color information from sparse sets of images. These models facilitate the synthesis of intermediate views by interpolating between captured viewpoints, efficiently handling scenarios with incomplete data where traditional methods would struggle [19, 30].

Learning Volumetric Representations. Recent advances in neural view synthesis have explored volumetric representations as a means of effectively encoding 3D scene information. This approach employs deep learning to construct volumetric grids or embeddings that capture both color and spatial data, thereby enabling dynamic and realistic rendering of new views (see Fig. 2.3). Such techniques represent a significant departure from traditional modeling, as they provide a framework where 3D features are embedded directly into the network. This enables sophisticated scene understanding and rendering without the need for explicit geometric reconstruction [22, 36].

Fig. 2.3.: Rendering of objects captured and modeled using volumetric representation based on a neural network [22].

Multiplane Images and Scene Representation. Multiplane Images (MPIs) represent a neural approach to view synthesis, whereby scenes are decomposed into layers at different depths (see Fig. 2.4). Neural networks are capable of creating these layered representations from a limited number of views. Subsequently, the learned MPIs can be efficiently re-rendered from new perspectives using traditional graphics techniques. This method provides a robust solution for generating photorealistic and geometrically coherent views by accommodating variations in scene complexity and effectively handling occlusions. [24, 29, 32, 40].

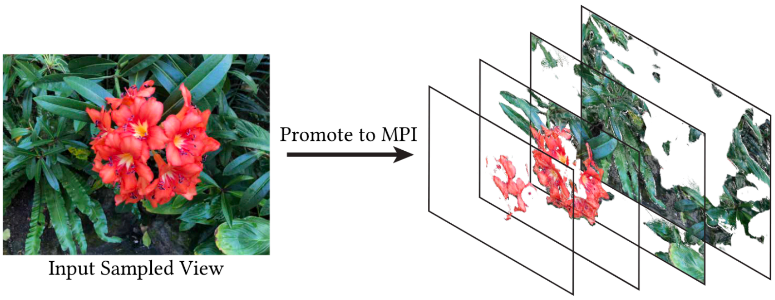


Fig. 2.4.: Local Light Field Fusion [24] promotes every input view into a MPI scene representation which are then blended into each other to create novel views.

End-to-End Learning. The advent of end-to-end learning with deep neural networks has significantly simplified the view synthesis process. This is due to the fact that a single network is now capable of handling multiple synthesis tasks concurrently. This approach reduces the complexity and potential failure points associated with multi-stage synthesis methods. The training of these networks on large datasets of posed imagery enables them to learn complex mappings from input images to synthesized views, efficiently handling challenging scenarios [7, 14].

2.3 Neural Radiance Fields for View Synthesis

Neural Radiance Fields (NeRF) offer a novel approach to view synthesis that significantly advances previous techniques. Utilizing a fully connected deep neural network, NeRF optimizes a continuous volumetric scene function from a sparse set of input views [25]. This method diverges from traditional discrete representations like voxel grids or mesh geometries, employing a more fluid and detailed scene representation.

Implementation. NeRF synthesizes views by querying a five-dimensional coordinate space comprising spatial locations (x, y, z) and viewing directions (θ, ϕ) along camera rays (see Fig. 2.5 a). Classic volume rendering techniques are then applied to convert the output densities and colors into images. At the core of this process lies a Multilayer Perceptron (MLP), a type of neural network characterized by layers of interconnected nodes processing input data sequentially from input to output. The MLP in NeRF takes sampled 3D points and corresponding viewing directions as input and outputs the color and volume density (see Fig. 2.5 b). This output is then composited into a 2D image using volume rendering techniques (see Fig. 2.5 c). As the rendering function is differentiable, NeRF uses gradient descent to minimize the difference between synthesized images and observed ground truth, optimizing the neural representation of the scene (see Fig. 2.5 d).

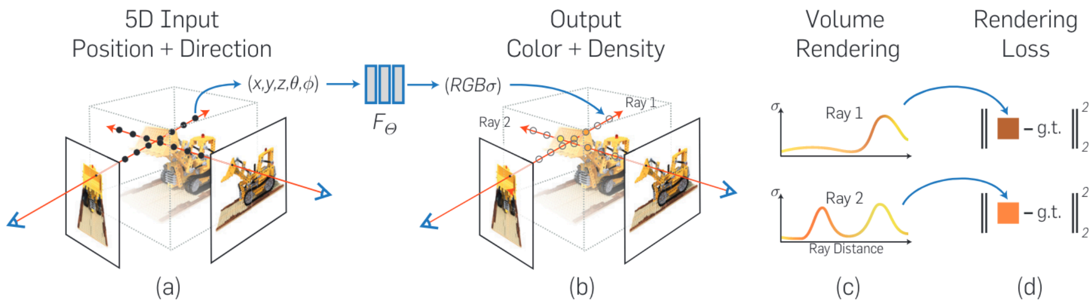


Fig. 2.5.: Overview of the NeRF scene representation and rendering procedure, illustrating the stages of sampling, neural processing, and image composition [25].

Advantages of NeRF. In comparison to the methodologies previously discussed, NeRF offers a number of advantages. It is capable of rendering high-resolution details and handling intricate geometries and material properties more effectively than mesh and voxel-based methods. The continuous volumetric representation is not only capable of producing more photorealistic images but also remains highly efficient in memory usage. This efficiency allows for the handling of complex real-world scenes without the storage and computation costs associated with traditional 3D representations.

Extensions and Applications of NeRF. The landscape of NeRF has been expanded by several innovative extensions that enhance the utility and interactivity of NeRF models. NeRF frameworks with user interfaces have emerged, enabling users to explore and manipulate 3D scenes [26, 39]. These frameworks provide features such as real-time scene rendering, adjustable training parameters, and the creation of camera trajectories for video rendering. Recent advancements have introduced text-based manipulation, allowing users to edit and transform scenes through natural language descriptions [1, 2, 17, 18, 46]. Another area of development is color and appearance editing, where new methods enable adjustments of scene colors, consistent across varying views [47]. Additionally, some tools have integrated mesh editing capabilities, enhancing the geometric manipulation within NeRF-generated scenes [49]. These enhancements not only extend the functional range of NeRF but also significantly improve their application in creative industries.

In conclusion, NeRF's innovative use of neural networks for scene representation sets a new standard for photorealistic view synthesis, delivering high-quality results that are both computationally efficient and visually impressive.

Related Work

3

3.1 Instant NGP

Instant Neural Graphics Primitives (Instant NGP) [26], developed by NVIDIA, utilizes a multiresolution hash encoding that simplifies models while maintaining high performance and quality. Its graphical user interface (GUI) plays a crucial role in enhancing accessibility and functionality, making it an important advancement in neural graphics technology.

Simplified User Interaction. The user interface of Instant NGP facilitates training and visualization of NeRFs (see Fig. 3.1). The user is able to interactively explore 3D scenes in real-time and adjust parameters in order to achieve the desired results.

Fig. 3.1.: Instant NGP's GUI rendering a NeRF scene, showing the 3D scene, camera path editor, and training parameters. [26].

VR Mode. The virtual reality (VR) mode of Instant NGP enhances user interaction by enabling immersive exploration of 3D environments in real-time. This feature is especially beneficial for professionals like architects and game developers, who can benefit from experiencing their virtual spaces as if they were real.

Camera Path Editor. Instant NGP's camera path editor allows users to intuitively create and adjust camera trajectories, enhancing the creation of animations. This tool is essential to professionals in visualization and animation, providing precise control over camera movements for detailed and smooth outputs.

Limitations. Despite advancements, Instant NGP's technical complexity and reliance on command-line interfaces for key operations remain significant barriers. These aspects limit its accessibility to those with specific technical skills and deter broader creative applications. The user experience still requires technical expertise, underscoring the need for more intuitive interfaces that simplify interaction and expand the user base beyond that of technical specialists.

3.2 Nerfstudio

Nerfstudio [39] represents a significant advance in the accessibility of Neural Radiance Fields to non-technical users. Its design focuses on modularity, ease of use, and integration capabilities, which are crucial for practical applications and academic research.

Modularity. Nerfstudio is built on a modular framework that allows users to easily customize and extend their NeRF implementations. This modularity enables the use of a variety of input data formats, making it versatile for different real-world scenarios and setting it apart from Instant NGP. A wide range of existing methods are already well integrated into Nerfstudio, including Instant-GPT [26], their own Nerfacto [@27] method that combines various existing techniques, and several of the previously mentioned extensions [17, 18].

Real-Time Web Viewer. One of the standout features of Nerfstudio is its real-time web viewer, which enables visualization of NeRF training progress and outputs directly through a web browser (see Fig. 3.2). This eliminates the need for high-end local GPU setups, such as in the case of Instant NGP, through remote sessions, broadening the tool's accessibility [@28].

Flexibility of Data Handling. Nerfstudio simplifies importing and exporting data, supporting a wide range of formats to accommodate various use cases. Users can easily import images and videos, including data from mobile capture apps such as Polycam [@31] and Record3D [@34]. Additionally, the framework supports exporting results in various formats such as videos, point clouds, and meshes. This flexibility allows users to integrate NeRF outputs into diverse creative and technical applications.

Fig. 3.2.: Nerfstudio's web viewer connected to a remote server running the training [39].

Community and Open-Source Contribution. As an open-source project, Nerfstudio encourages community-driven development and continuous improvement, facilitating updates that keep pace with the latest research and technological advances. This openness also allows users to adapt the tool to their specific needs.

Limitations. Nerfstudio is a welcome advancement improving on much of the features of Instant NGP. However, it still requires a certain level of technical knowledge to operate effectively, limiting accessibility to non-technical users. The tool's primary interactions are still command-line based, which presents a barrier to users who may prefer more intuitive graphical interfaces.

3.3 Luma AI

Luma AI [@23] is making Neural Radiance Fields accessible to non-technical users in a commercial space. This platform leverages augmented reality (AR) to guide users through the capture process, greatly simplifying the creation of NeRFs from everyday smartphones.

Guided Capture Process. Luma AI utilizes AR to assist users in capturing images from optimal angles and distances, ensuring that the collected data is suitable for NeRF generation. This guided process reduces the complexities involved in capturing the necessary footage for effective and streamlined NeRF creation.

Cloud-Based NeRF Generation. Once the footage is captured, it is automatically processed in Luma AIs cloud-based system to generate a NeRF, requiring no user input for configuration. This automation not only simplifies the user experience but also makes powerful 3D reconstruction technology readily accessible to a broad audience.

Viewing and Editing. Created scenes can be viewed directly within the app or through a web browser (see Fig. 3.3). While the editing capabilities are limited, users can make basic adjustments, reshoot parts of the scene, and interact with the generated NeRF in an intuitive manner. The features here are similar to those offered in Nerfstudio's viewer, but with a more modern user-interface.

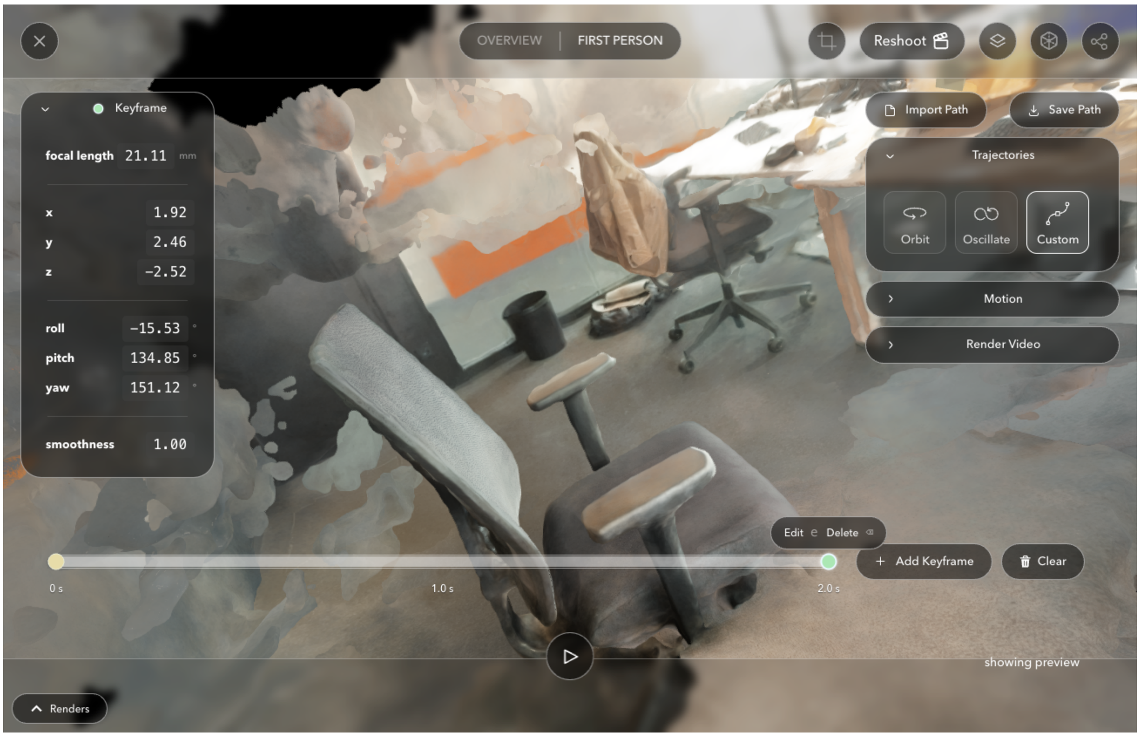


Fig. 3.3.: Luma AI Web Viewer in the camera path editor.

Export Capabilities. Luma AI offers a variety of export formats for the generated scenes, allowing users to utilize these outputs in different applications or platforms, enhancing the utility of the captured NeRFs. Additionally, they provide a social platform for the sharing and viewing of NeRFs, fostering a community of users around the technology.

Limitations. Despite its innovative approach, Luma AI's primary limitation lies in the lack of user control over the NeRF training process. The automated system is designed to be user-friendly, yet it lacks the capacity to permit adjustments to the training parameters or the refinement of the final model. This lack of control can result in suboptimal NeRF outputs for users who may require more precise or customized 3D representations. Additionally, the proprietary nature of Luma AI may be a concern for users who prefer the flexibility and transparency offered by open-source solutions, as it limits the ability to understand and modify the underlying processes.

3.4 Volinga Suite

The Volinga Suite [@45] aims to integrate Neural Radiance Fields into professional workflows. It facilitates the adoption of NeRF by leveraging familiar platforms, thereby broadening the accessibility of NeRF to a wider range of users.

Unreal Engine Integration. Volinga's integration as a plugin for Unreal Engine [@43] is a core feature that allows users to adopt NeRF seamlessly into existing pipelines (see Fig. 3.4). This integration is valuable for professionals already familiar with Unreal Engine, as it enables them to utilize advanced NeRF functionalities without additional training or significant adjustments to their current workflows.

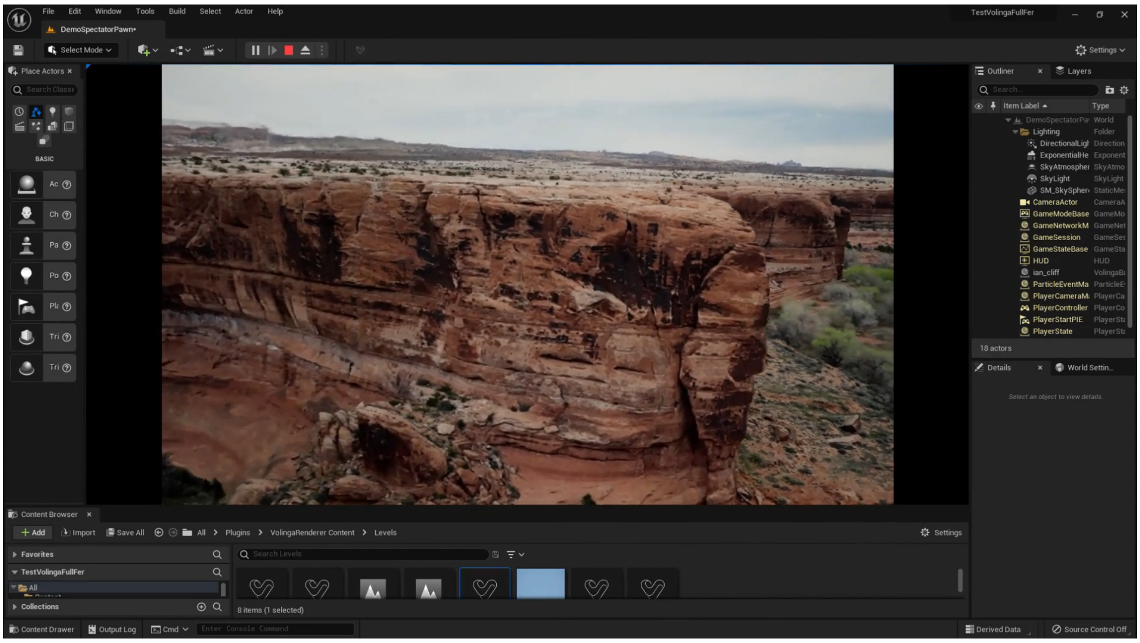


Fig. 3.4.: Volinga Suite's integrated viewer in Unreal Engine [@45].

Enhanced Control Over Training. Volinga distinguishes itself from LumaAI by offering enhanced control over the NeRF training process. Users have the ability to locally adjust numerous parameters, which enables precise tuning of the model's performance to meet specific project requirements. This level of control is beneficial for projects where the quality of the NeRF output is critical.

Local and Remote Training Capabilities. The Volinga Creator component supports both local and remote training of NeRF models. While remote training offers convenience and ease of access, local training provides advanced users with extensive configuration options and the ability to leverage powerful hardware, thereby maximizing the potential of NeRF technology under various usage scenarios.

Limitations. Volinga Suite's reliance on Unreal Engine for its integrated viewer may limit users who are unfamiliar with or do not wish to use this specific platform. The web based viewer of Nerfstudio and Luma AI is more accessible in this regard. Although Volinga is actively contributing to the open-source project Nerfstudio, its proprietary nature may also deter users or organizations that prefer open-source solutions.

4 Methodology

The research was structured into three distinct phases: initial user research, prototype development, and user testing. Each phase was designed to inform and refine the subsequent stages, ensuring a systematic approach to developing a user-friendly NeRF interface. The iterative process was designed to align closely with user needs and feedback, with the objective of creating a design that is both accessible and functional.

Initial User Research. The initial phase of this research involved conducting a series of in-depth interviews with users of NeRF technology, with the objective to gain insight into their user experience. The interviews were conducted with users of varying levels of expertise in NeRF model creation, including those with experience in the film industry. This exploratory phase was crucial for identifying the key features and improvements necessary for a more accessible and efficient NeRF interface. (see Chapter 5)

Design and Development Process. The transition from the initial findings of user research to the creation of a functional prototype was a multi-step process focused on the capture of user needs and their subsequent translation into a tangible design. This phase involved the creation of a user flow diagram, site map, wireframes, and a working prototype, each of which was informed by the insights gained from the previous stage. (see Section 6.1)

User Study and Evaluation. To assess the usability and overall utility of the developed prototype, a comprehensive user study was conducted. The primary objective of this study was to gather feedback on the prototype's user experience, identify any challenges participants encountered, and assess their levels of satisfaction with the interface. The use of a mixed-methods approach permitted the collection and analysis of both quantitative and qualitative data, providing a multifaceted view of the prototype's performance in real-world tasks. (see Chapter 8)

User Research

5

5.1 Participant Selection Criteria

Participants were selected with care, taking into account their previous experience with NeRF technology and their connection to the film industry. This resulted in a group of four experts. The selection of participants ensured a diversity of perspectives, encompassing a broad spectrum of technical proficiency and practical applications of NeRF. The study aimed to uncover both the shared challenges faced by all users and the unique requirements of distinct user groups within the film industry by including individuals who have utilized NeRF in various capacities.

5.2 Interview Methodology

The interviews were designed as semi-structured conversations, following a core set of prepared questions (see Appendix A.1). However they also allowed for spontaneous discussions and additional queries. The interviews were conducted in a one-on-one format (three online, one in person), facilitating a personalized dialogue with each participant. This approach allowed for the collection of insights into individual experiences and perspectives. Although the interviews were prepared in English, all conversations were held in German to ensure comfort and clarity for participants, potentially leading to more candid and informative discussions. The interviews took approximately 30 minutes to an hour, depending on the depth of the participants' responses and the extent of the discussions.

The structured flow of questions began with learning about the participants' backgrounds and experiences with NeRF technology, gradually moving towards more detailed questions about their specific needs, challenges, and desired improvements in NeRF interfaces. Additionally, participants were encouraged to suggest potential enhancements to the NeRF interface that they believed would enhance its usability and effectiveness for their professional or academic projects.

To ensure comprehensive analysis, interviews were recorded and transcribed with the participants' consent, allowing for a detailed review and coding of the responses. This process enabled the identification of recurring themes, challenges, and preferences across the participant group, providing a solid foundation for the subsequent phases of prototype development and user testing. The insights gained from this initial research phase were instrumental in shaping the direction and focus of the interface design, ensuring that it would effectively address the real-world needs of NeRF users.

5.3 Key Findings

NeRF in the Film Industry. NeRF technology is being explored for various applications in the film industry, including visual effects, virtual production, and pre-production location scouting. Despite its potential to simplify the creation of 3D scenes, current limitations in model quality, lack of editable models, and insufficient detail hinder its professional use. However, its capability for rapid 3D scene captures offers significant benefits for pre-visualization and planning in the pre-production phase, although concerns about model scale accuracy for export remain. [**P2**, **P4**]

> *So in the planning phase I think [NeRF] was pretty well received, the set visit, the planning of the actual shoot, but the quality wasn't that convincing yet.*[1]
>
> — **Participant 4**

Optimizing Parameters and Workflow. Creating NeRFs typically involves three main steps: pre-processing input data, training models, and exporting outputs. Technical users emphasize the importance of parameter optimization in improving NeRF quality, with iterative training and results analysis being crucial parts of their workflow. Tools such as TensorBoard [@41] are utilized for quantifying variations in training outcomes. [**P1**, **P3**]

> *Problems? Optimization, i.e. data sets. In training, I would say a big thing is optimization and parameterization, especially in Nerfstudio.*[2]
>
> — **Participant 1**

User Interface and Accessibility. A consensus among users indicates a clear need for an intuitive, comprehensive user interface that minimizes reliance on console commands. Features that allow users to visually navigate and control the NeRF creation pipeline, including real-time progress feedback and the ability to pause and adjust processes at any stage, are highly valued. [**P1**, **P2**, **P3**]

[1] Also in der Planungsphase kam [NeRF] glaube ich ziemlich gut an, Setbegehung, Planung vorne vom eigentlichen Dreh, aber die Qualität war halt noch nicht so überzeugend.

[2] Probleme? Optimisierung, also Datensätze. Beim Training würde ich sagen, eine große Sache ist die Optimierung und die Parameterisierung, vor allem in Nerfstudio.

The most important thing for me would be that I don't have to do anything in the console. In other words, that I can simply start the program and then do everything in the UI, upload it and then it will be executed somehow.[3]

— **Participant 2**

Comprehensive Error Handling and Visualization. Effective error feedback and clear, informative visualization tools are critical for user satisfaction. Users have expressed frustration with vague error messages and cumbersome command-line interactions for troubleshooting and adjustments. [**P2**, **P3**]

So if there is an error message, then it would be cool if they would somehow tell you more precisely what the error is, and not just any log.[4]

— **Participant 2**

File Management and Project Structure. Efficient file and project management, with clear distinctions between different stages and support for various input formats, is essential. Users discuss challenges with current tools regarding data organization, suggesting improvements for handling input data and managing projects. [**P1**, **P3**]

Integration and Export Options. Strong integration capabilities with popular 3D and VFX software and flexible export options are desired. Users discuss the importance of being able to easily import NeRF-generated scenes into tools like Unreal Engine [@43] or Blender [@3] for further processing and use in production-quality projects. [**P1**, **P2**, **P4**]

Multi-Mode Operation. The necessity for multi-mode operation in NeRF tool interfaces emerges as a significant insight, underscoring the importance of accommodating a broad spectrum of users, from novices to experts. A simplified mode is proposed to cater to beginners, offering an intuitive and streamlined workflow. In contrast, an advanced mode is tailored for experienced users requiring detailed control over the NeRF creation process. [**P1**, **P2**, **P3**, **P4**]

It just has to be understandable enough that film students aren't afraid of it. But still, not limit how much you adjust your parameters.[5]

— **Participant 1**

[3] Das Wichtigste wäre für mich, dass ich halt nichts in der Konsole machen muss. Also, dass ich einfach das Programm starte und dann alles in der UI machen kann, hochladen und dann auch irgendwie durchgeführt werde.

[4] Also wenn eine Fehlermeldung ist, dann wäre es halt cool, wenn die einem das irgendwie genauer sagen würden, was der Fehler ist, und dann nicht einfach so irgendein Log.

[5] Es muss halt verständlich genug sein, dass Filmstudenten davon keine Angst haben. Aber trotzdem, [das Maß] wie sehr du deine Parameter ansetzen kannst [nicht] zu limitieren

Summary

These findings highlight the demand for a NeRF tool interface that is user-friendly, versatile, and capable of supporting a wide range of workflows and user expertise levels. The optimal tool would integrate intuitive project management and visualization features with robust customization options, effective error handling and feedback mechanisms, and efficient performance management capabilities.

Application Design

6

6.1 Design Process

The transition from the initial findings of user research to the creation of a functional prototype was a multi-step process focused on the capture of user needs and their translation into a tangible design. This section outlines the process of transforming abstract requirements into a functional prototype, with particular emphasis on the methodologies employed at each stage of the process.

From User Research to User Flow Diagram

Following the completion of initial user research, the first step involved modeling the key findings into a user flow diagram (Figure 6.1). This diagram served as a visual representation of the user's journey through the prototype, highlighting the key interactions users would have with the system.

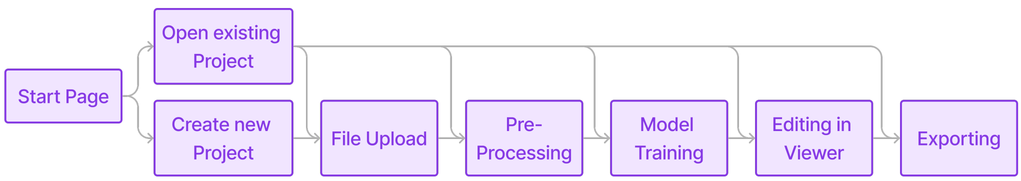


Fig. 6.1.: User flow diagram illustrating the key interactions for creating a NeRF model

The objective of the user flow diagram was twofold: firstly, to map out the envisioned user experience, and secondly, to identify any potential bottlenecks or usability issues at an early stage of the design process.

Developing the Site Map

Building upon the foundation established by the user flow diagram, the next stage involved the expansion of this outline into a detailed site map. The site map offered a more comprehensive view of the prototype's structure, delineating the relationships between different pages and features. This excerpt from the site map (Figure 6.2) illustrates the level of detail and complexity involved in mapping out the prototype's user interactions.

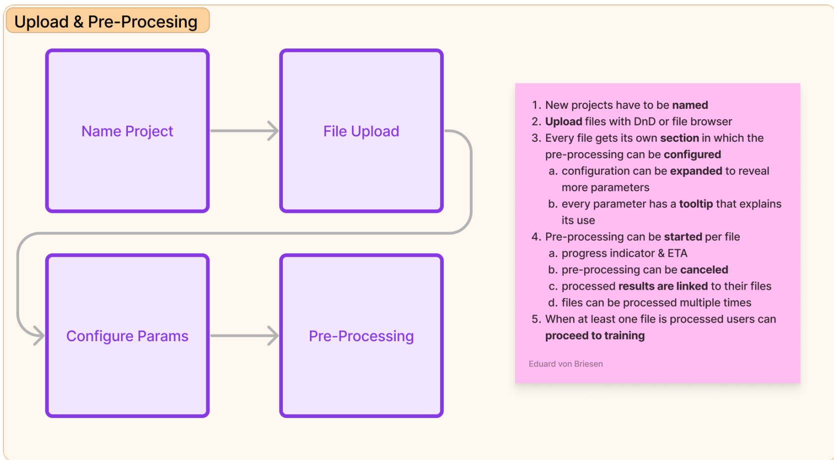


Fig. 6.2.: Excerpt of a view from the flow diagram with detailed interactions.

This expanded view was instrumental in ensuring that the user flow remained structured across the broader system, facilitating easy navigation and a cohesive user experience.

Wireframing

With a firm grasp on the user flow and site structure, the focus shifted to wireframing. The initial wireframes were created to model the overall layout of the interface, providing a skeletal framework for the visual design. These wireframes were intentionally kept simple to prioritize structural and functional decisions over aesthetic considerations (see Fig. 6.3). At this stage, emphasis was placed on the placement of key elements, usability, and adherence to the user flow and site map.

Refinement Through Development

The transition from wireframes to a functioning prototype was achieved through a process of iterative refinement during the development phase. As the prototype developed, the initial designs were subjected to continuous evaluation and adjustment based on practical considerations and technical constraints. This phase permitted a deeper exploration

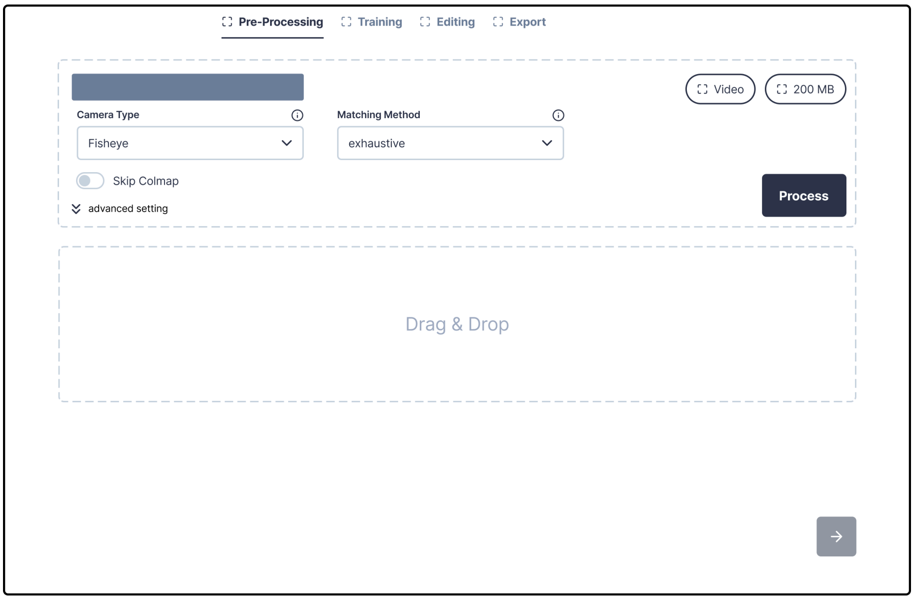


Fig. 6.3.: Wireframe of the pre-processing section, showing the layout and key elements.

of interactions, animations, and the overall look and feel of the interface. During this period, the wireframes underwent a transformation into a more detailed and user-friendly interface, with adjustments made as necessary to enhance usability and ensure a seamless user experience.

6.2 User Interface Design

The user interface was designed to be as simple as possible while still providing all necessary functionality. The design of the prototype can be divided into two primary sections: a dashboard that provides an overview of all projects and a project section that provides users with the necessary tools to create and edit NeRF models.

Dashboard

The dashboard is the initial view that users encounter when launching the application. It displays all previously created projects and enables users to create new ones. Each project is represented as a card, which includes the project name, a preview of the provided input images (if present), and tags that indicate the current status of the project (see Fig. 6.4 1). Additionally, a separate card is available through which users can create a new project by providing a name (see Fig. 6.4 2). To open a project, one must simply click on the respective card. When creating a new project, users are redirected to the project section.

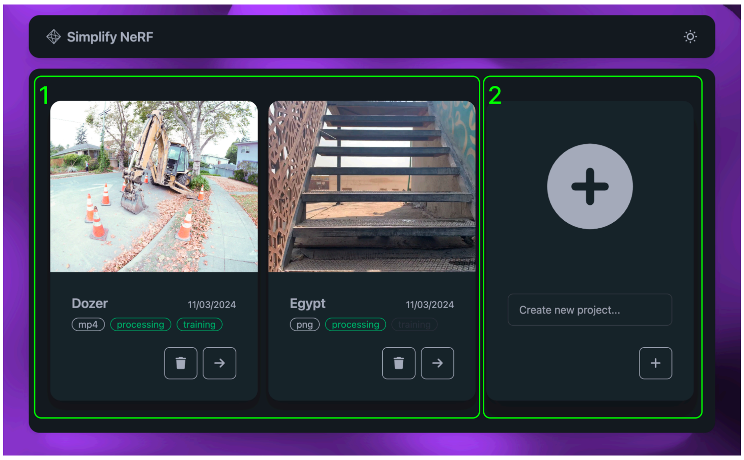


Fig. 6.4.: Dashboard overview, showing existing projects (1) and the option to create a new project (2).

Project Section

The project section represents the core of the application, through which users can create and edit NeRF models. The section is divided into three distinct sections: the input section, the training section, and the rendering section. In all sections, users can monitor their progress through a progress indicator located at the top of the screen, which also facilitates straightforward navigation between the various sections (see Fig. 6.5 1).

Input Section

The input section combines the first few interactions, as mapped out in the user flow diagram. Initially, users are prompted to upload their input data, which can be done by either dragging and dropping files into the browser window or by clicking a button to open a file dialog (see Fig. 6.5 2). Files may be either a set of images, a video or archives used for Polycam or Record3D. To ensure the input data is valid, certain guardrails are in place, such as file type restrictions. Once the input data has been uploaded, it must be processed before it can be used for training purposes.

The pre-processing can be configured by the user, which includes parameters such as the lens type or matching method (see Fig. 6.5 3). The parameter input fields vary based on the type of input data and are only shown when relevant. Additionally, a tooltip is provided for each parameter, explaining its purpose. Furthermore, advanced settings can

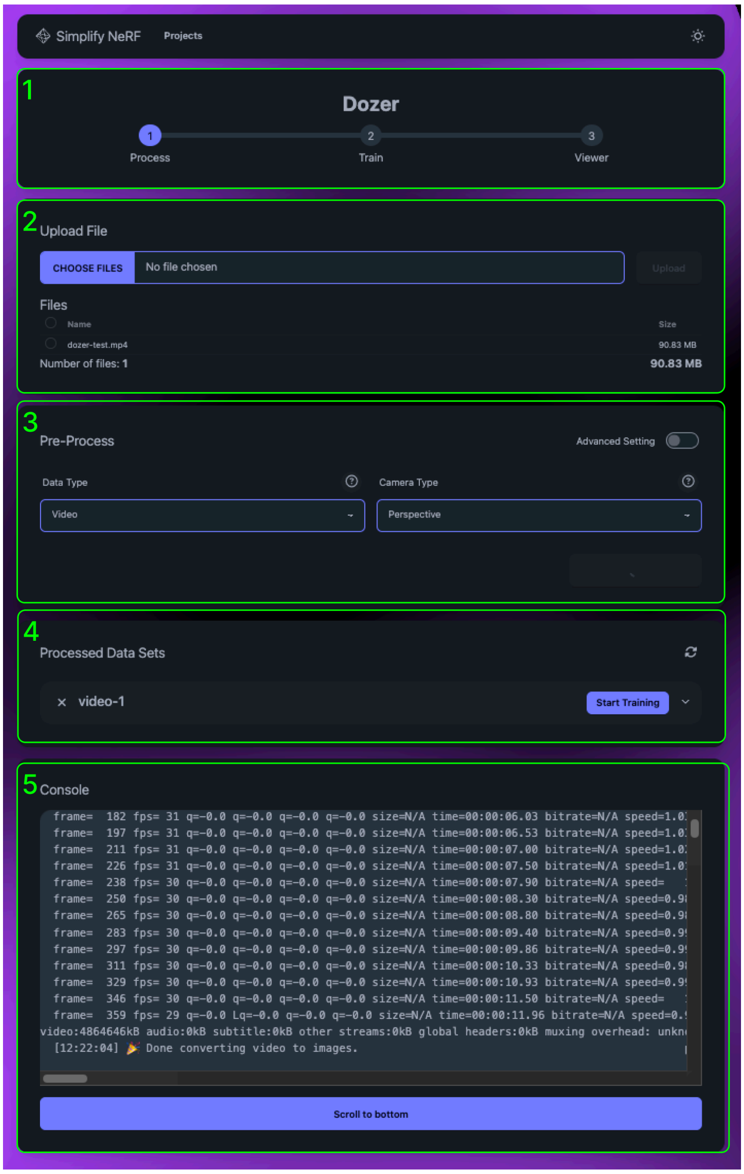


Fig. 6.5.: Pre-processing section, showing the progress bar (1), input data upload (2), parameter options (3), pre-processed data list (4), and console output (5).

be accessed by hovering over the question mark next to the parameter name. For advanced users, the settings can be further customized by activating the advanced settings using the toggle in the top right (see Fig. 6.6). Once the user is satisfied with the settings, they can initiate the pre-processing. The user will then be able to observe the progress of the pre-processing through a console that displays the output of the process running on the server (see Fig. 6.5 5). Upon completion of the pre-processing stage, the user may then proceed to the training section.

In case the data was already pre-processed, a list is visible that shows all available pre-processed data, and the user can select one to use for training (see Fig. 6.5 4). Users

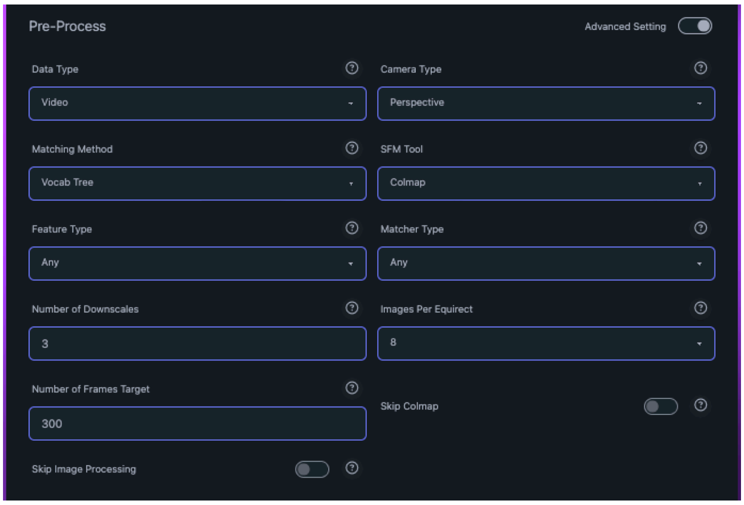


Fig. 6.6.: Advanced settings for pre-processing, showing additional parameters and options.

can also inspect the configuration with which the data was pre-processed, and delete it if necessary.

Training Section

The training section is structured similarly to the input section, with a form that allows users to configure the training process (see Fig. 6.7 1), and a console that displays the output of the training process running on the server. Once the user is satisfied with the configuration, they can start the training process.

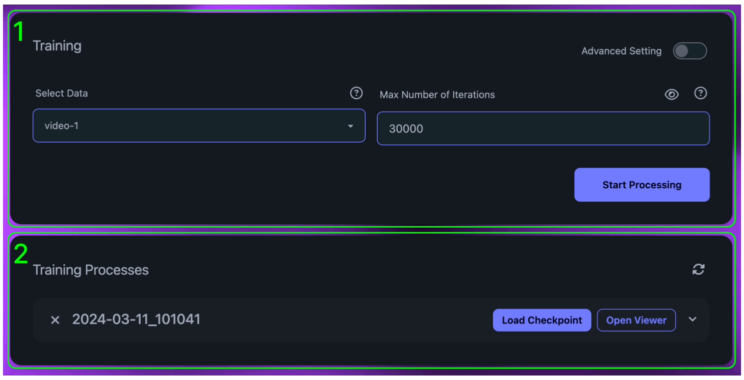


Fig. 6.7.: Training section, showing the training configuration form (1), and previous training runs (2).

Previous training runs are listed, and users can inspect the configuration with which the training was run, and delete it if necessary (see Fig. 6.5 2). The viewer can be opened to inspect the results of the training run, or an existing checkpoint can be selected to resume training from that point.

Viewer Section

The final step in the process is the viewer section, which allows users to inspect their NeRF model while it is still training or after the training has finished (see Fig. 6.8 1). At its core is the Nerfstudio Viewer, which is integrated into the application. The integrated version provides users with all the functionality available in the standalone version, with a few integrations that simplify the rendering process. Instead of providing commands that have to be executed in the terminal, the rendering is started by clicking a button. The renders are listed below the viewer, and once they finish processing, they can be downloaded to the user's machine (see Fig. 6.8 2). Due to the narrow layout of the page, the viewer can be conveniently opened in a new tab to provide a better viewing experience.

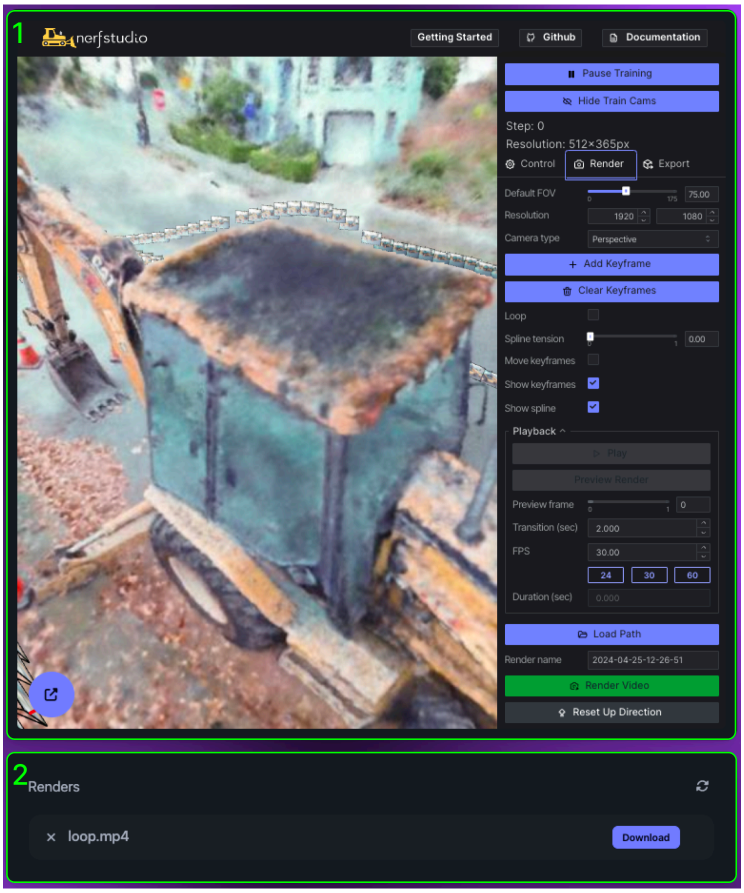


Fig. 6.8.: Viewer section, showing the Nerfstudio viewer (1) and list of rendered outputs (2).

7 Technical Implementation

7.1 System Architecture

The architectural design adheres to the conventional client-server paradigm, with the server acting as a wrapper for the Nerfstudio Command Line Interface (CLI) and the client as a web application. The service is responsible for handling incoming requests from the client and translating them into commands that the Nerfstudio CLI could understand. Requests from the client are transmitted to the service via HTTP. In the event of an asynchronous operation, the server updates the client via WebSockets. (see Fig. 7.1).

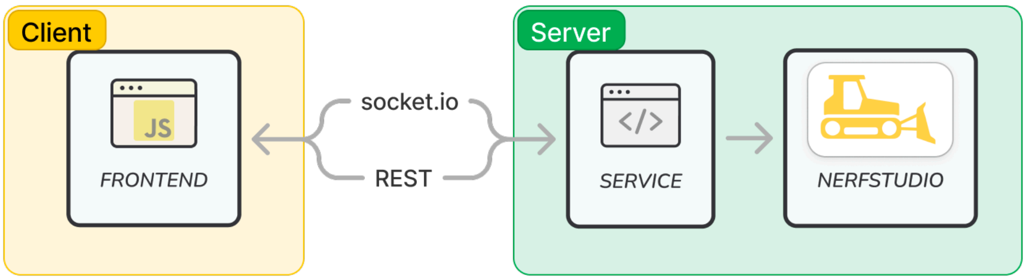


Fig. 7.1.: System Architecture Overview. The client communicates with the server, which in turn interacts with the nerfstudio CLI.

In case of the prototype, all components were integrated into a single Docker [@12] container and deployed as a single unit. This approach made use of the pre-configured container provided by Nerfstudio, facilitating a rapid and straightforward deployment. All source code is available in the project's GitHub repository [@5] and pre-built Docker images are hosted on Docker Hub [@4].

7.2 Frontend Development

The frontend is built with React [@33], chosen for its popularity and strong support in web application development. Vite [@44] serves as the build tool, offering a fast and efficient development experience. For styling, Tailwind CSS [@38], a utility-first CSS framework, provides a set of predefined classes to style components efficiently. Additionally, the daisyUI [@10] component library supplies pre-styled components, facilitating rapid UI construction.

Extensibility

Extensibility was a key consideration during the development of the frontend, given that the underlying Nerfstudio CLI is in itself extensible. All parameters for processing and training a NeRF model are configurable using JSON or strongly typed TypeScript objects (see Listing 7.1).

```
const stepsPerSave: NumberInput = {
  name: "stepsPerSave",
  label: "Steps Per Save",
  tooltip: "Number of steps between each save of the model.",
  inputType: "number",
  defaultValue: 1000,
};
```

Listing 7.1: Minimal parameter configuration for ’Steps Per Save’ input.

The current input types supported are `number`, `select`, and `boolean`. This covers all relevant parameters, but new types can be added by extending the configuration object. It is also possible to define dependent parameters that are only shown when a certain condition is met. Furthermore, images can be added to illustrate the effect of a parameter, providing additional context to the user.

Additionally, filters and presets may be configured by specifying an array of the names of the parameters that should be included in the filter or preset. This is currently employed to narrow down the displayed options and expand them when activating advanced settings. The complete configuration may be found in the `frontend/src/config` folder within the codebase.

Nerfstudio Viewer Integration

The Nerfstudio viewer is constructed using Viser [@28], a Python library for developing 3D visualizations. This approach presented certain limitations in integrating it into the frontend, as it is not straightforward to embed a Python application directly into a web application. To circumvent this issue, the viewer is hosted by Nerfstudio and embedded into the frontend using an iframe. This included some simple styling changes to enhance the viewer’s integration into the frontend. Additionally, modifications were implemented to enhance the user experience. The viewer contained several interactions where it was necessary for the user to copy console commands, which were to be used in the CLI. These interactions are replaced with buttons that send a request to the server to execute the command instead. These modifications are applied at the build-time of the container by applying a patch to the Nerfstudio source code of the base image.

The main shortcoming of this approach is that the frontend is unaware of the state of the viewer, and cannot update the UI based on actions triggered in the viewer. Instead, it must rely on periodic polling of the server to obtain the current status of rendering processes, which is then used to provide feedback to the user.

7.3 Backend Development

The backend was constructed using tRPC [@42], a framework for developing type-safe APIs in TypeScript. This type-safety proved beneficial in the construction of the API, as Nerfstudio endpoints necessitate a specific set of parameters of various types, which could be readily defined using TypeScript and reused in the frontend.

It is often the case that processes can take several minutes to complete. In such instances, it is important that the user is able to see the progress of these operations. tRPC implements subscriptions, which allows the client to subscribe to an event and receive updates when that event occurs. This is used for any long-running operations such as pre-processing or training a NeRF model (see Listing 7.2).

Some additional endpoints were implemented using Express [@13], including the file upload and render endpoints, due to limitations in tRPC discussed in Section 7.4.

All project related data is stored in a workspace directory, which is mounted as a volume in the Docker container. This allows for the data to persist between container restarts, and for the user to access the data outside of the container.

7.4 Challenges and Solutions

Limitations of tRPC

Although tRPC is a highly effective tool for developing APIs, with seamless integration into the frontend, it is not without its limitations. It lacks support for `multipart/form-data`

```
export const nerfstudioRouter = router({
  process: publicProcedure
    .input(
      z.object({
        project: z.string(),
        dataType: z.enum(["images", "video"]),
        ...
      }),
    )
    .subscription(({ input }) => {
      return observable<{message: string}>((emit) => {
        const args = ...
        const process = spawn("ns-process-data", args, {
          cwd: path.join(WORKSPACE, input.project),
        })
        process.stdout.on("data", (data: any) => {
          emit.next({message: data.toString()});
        });
      });
    })
});
```

Listing 7.2: Example tRPC endpoint for Pre-Processing returning a subscription.

file uploads, which are necessary for uploading images and videos. This issue was addressed by implementing a distinct endpoint utilizing Express, which is employed for the purpose of uploading files to the server.

Additionally, the manner in which tRPC handles subscriptions is not optimal for the execution of lengthy processes. In the event of a client disconnect, the subscription is lost, and the client will lose the context for incoming events. An improved solution would utilize a standard WebSocket connection, with the events containing the state necessary for the client to properly update the UI.

tRPC lacks a client for Python, which is required when processes are initiated from the Nerfstudio viewer. This necessitated the implementation of an additional distinct endpoint utilizing Express, which is invoked by the viewer to render the NeRF model. These limitations could be mitigated by the use of a more general-purpose framework, such as Express.

Working with the nerfstudio CLI

The implementation of the prototype using the nerfstudio CLI offered a useful layer of abstraction, enabling rapid development without the necessity to concern oneself with the underlying implementation details of a vast codebase. However, this abstraction comes at the cost of flexibility and the overall complexity of the system.

The CLI is constructed using tyro [@48], a tool for the creation of command line interfaces in Python utilising configuration objects. Efforts were made to translate the configuration objects into TypeScript objects that could be employed throughout the project. This would facilitate a more seamless integration of the CLI. Regrettably, this was not feasible, as the configuration objects are not readily serializable and would necessitate a significant amount of additional work to implement. Consequently, the implemented solution is reliant on manually constructing the commands based on documentation, which is error-prone and not particularly maintainable.

7.5 Future Directions

Improved CLI Integration

As outlined above, the approach of wrapping the Nerfstudio CLI with a custom API has some limitations. A more integrated and robust solution would be to built within the Nerfstudio codebase itself. It is conceivable that the existing configuration object, utilized for the CLI, could be repurposed to construct a REST API. This would facilitate a more seamless integration of the CLI into the frontend, and would allow for greater flexibility in the future. Furthermore, this approach would reduce the overall complexity of the system, as it would not require the use of a separate server to handle requests.

Improved Viewer Integration

The current approach of embedding the viewer in an iframe is not optimal. The Nerfstudio viewer in versions 0.3.4 and earlier was constructed using React with a direct integration of Viser. In its first major release, nerfstudio rewrote the viewer in Python, thereby eliminating the React integration.

The reconstruction of this project's frontend with a framework such as Viser would be severely constrained in terms of features and flexibility. A more optimal solution would be to integrate Viser into the frontend, analogous to the original nerfstudio viewer. Such an integration would facilitate a more seamless interaction between the frontend and the viewer, thereby enhancing the overall user experience. The re-use of UI elements would ensure a consistent look and feel, while the frontend could react to events triggered in the viewer.

8 User Study and Evaluation

To assess the usability and overall utility of the NeRF interface prototype, a comprehensive user study was conducted, which included a variety of tasks to evaluate different aspects of the interface. The primary objective of this study was to gather feedback on the prototype's user experience, identify any usability challenges participants encountered, and assess their satisfaction with the interface. The use of a mixed-methods approach allowed for the collection and analysis of both quantitative and qualitative data, providing a multifaceted view of the prototype's performance in real-world tasks.

The subjects were then presented with a series of tasks to be completed within the prototype. Following this, they were asked to complete a User Experience Questionnaire (UEQ) and then participate in a follow-up interview, during which they were encouraged to provide detailed feedback on their experiences. Of the ten participants, eight studies were conducted in person, while two were conducted remotely due to logistical constraints.

8.1 Participant Selection Criteria

The participants were selected in a manner analogous to the initial user research phase, with an emphasis on individuals engaged in the film industry and exhibiting a range of experience with NeRF technology, from novices to experts. The resulting sample was diverse, with participants ranging in experience from those with no prior exposure to NeRF to those with expert-level proficiency (see Fig. 8.1).

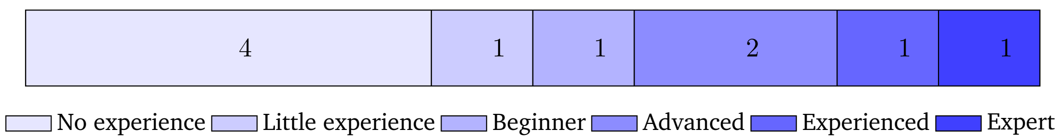


Fig. 8.1.: Level of experience with NeRF technology among participants.

Four of the participants have backgrounds in filmmaking, including directors, camera operators, and post-production specialists. The remaining six participants were selected for their expertise in software development and human-computer interaction, as well as their familiarity with NeRF.

8.2 Tasks Based Usability Test

The usability test was conducted in a controlled environment, where participants were asked to complete a series of tasks with the prototype. The tasks were designed to cover a range of functionalities and features of the prototype, representing a typical workflow for creating NeRF models. The tasks included:

1. Creating a new project.
2. Uploading a prepared video file.
3. Pre-processing the uploaded file to prepare it for training.
4. Switching to an existing project with pre-processed data.
5. Starting a NeRF training.
6. Creating a camera path in the viewer.
7. Exporting a video.

To maintain an appropriate time frame, none of the tasks required completion of a training process. Instead, pre-processed data and pre-trained models were provided. On average, participants required approximately 30 minutes to complete the tasks.

The participants were observed passively while working on their tasks in order to identify any problems or operational errors they encountered and to determine their overall performance. Furthermore, the screen was recorded to document the participants' interactions with the prototype, thus enabling a more comprehensive analysis of their behavior at a later stage.

8.3 User Experience Questionnaire

Once the participants had completed their assigned tasks, they were asked to complete the User Experience Questionnaire (UEQ) [20], a standardized tool for assessing user experience. The UEQ was administered immediately after the tasks to capture the participants' immediate impressions while the experience was still fresh in their minds, and before any influence from the follow-up interview. Due to an oversight, the UEQ was not administered before the tasks for the studies conducted remotely.

The UEQ measures user experience across six dimensions:

- **Attractiveness** - the overall impression of the product.
- **Perspicuity** - the clarity and understandability of the product.
- **Efficiency** - the perceived effort required to use the product.
- **Dependability** - the perceived reliability and trustworthiness of the product.
- **Novelty** - the perceived originality and innovation of the product.
- **Stimulation** - the perceived level of excitement and engagement with the product.

This tool covers both classical usability goals (Efficiency, Perspicuity, Dependability) and user experience qualities (Novelty, Stimulation), with Attractiveness serving as a valence dimension not directly related to usability or user experience.

The questionnaire comprises 26 items, each represented by two terms of opposite meaning. The order of the terms is randomized for each item to avoid bias. Participants are asked to rate each item on a seven-point scale, with values ranging from -3 to +3. The value of 0 represents a neutral response. An illustrative example of the scale is as follows:

boring o o o o o o o *exciting*

The participants completed the questionnaire digitally via using a web-based survey tool [@37], which also included additional questions to gather demographic information and capture prior experience with NeRF and other 3D modeling tools.

8.4 Follow-up Interview

Following the completion of the usability test, participants were invited to engage in a brief follow-up interview, during which they were encouraged to provide more detailed feedback on their experience with the prototype. The interviews were semi-structured, following a predefined set of questions, with the option for participants to share their own thoughts and suggestions. The questions were designed to elicit participants' overall impressions of the prototype, any usability challenges they encountered, and suggestions for improvement. The interview template is included in the Appendix A.2.

8.5 Data Analysis

Both the video recordings of the usability test and the audio recordings of the follow-up interviews were analyzed to identify common themes and patterns in participant feedback. The videos were coded to identify usability issues or challenges encountered during tasks, while the interview transcripts were coded to extract detailed feedback and suggestions.

The UEQ data was analyzed using the standard procedure outlined by the questionnaire's authors, which involved the use of a spreadsheet tool for the calculation of all necessary values and the visualization of the results.

In summary, this user study and evaluation served to validate the effectiveness of the NeRF interface prototype, uncover valuable insights into its usability, and identify opportunities for further refinement. The mixed-methods approach ensured a comprehensive assessment, capturing both the tangible aspects of interface interaction and the subjective experiences of users. This provided a solid foundation for subsequent development stages.

9 Results

This section presents the findings of the user study conducted to assess the usability of the application. First, the results of the quantitative user experience questionnaire are presented, which allows for an evaluation of the user experience as a whole. Subsequently, the results of the qualitative user testing are analysed in order to provide more detailed insights into the usability of the application. Finally, the results are integrated and discussed in detail.

9.1 User Experience Questionnaire

Despite the relatively small sample size of 10 participants, the results of the User Experience Questionnaire (UEQ) provide a good overview of the overall user experience. The scores for the different scales of the UEQ are presented in Figure 9.1.

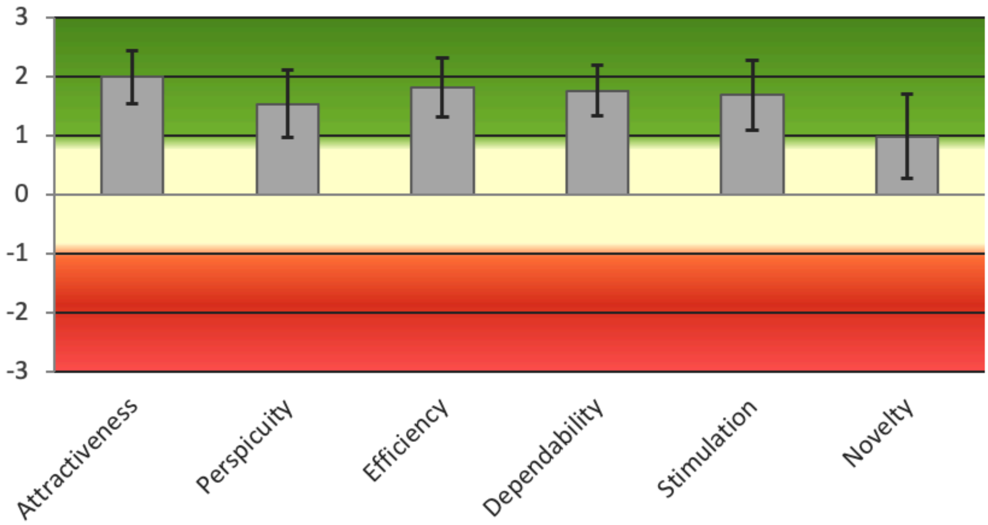


Fig. 9.1.: Results of the User Experience Questionnaire, showing the average scores for each scale and their 95 % confidence interval.

The *Novelty* scale scores the lowest with a value just below 1, while the *Attractiveness* scale has the highest score with 1.98. The other scales score between 1.5 and 1.8, indicating a generally positive user experience.

The UEQ scores can be benchmarked against the results of 452 other studies provided by the UEQ benchmark. The benchmarking results are shown in Figure 9.2, where *Attractiveness* and *Dependability* classify as *Excellent*, placing them in the top 10% of all studies. *Stimulation* and *Efficiency* are classified as *Good*, while *Novelty* and *Perspicuity* only classify as *Above Average*.

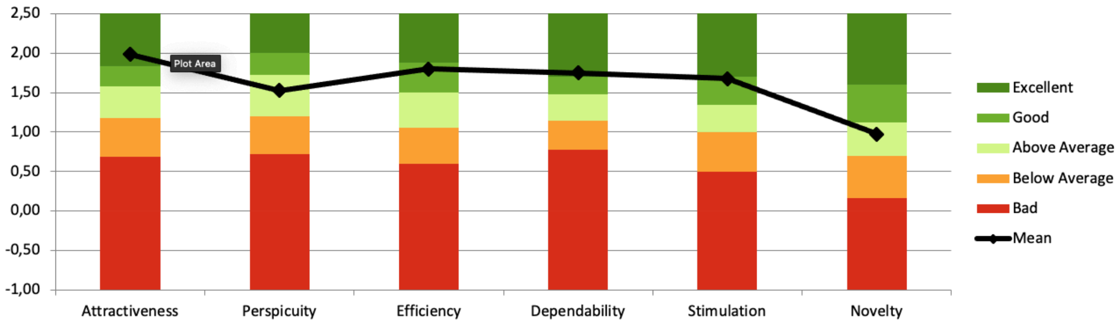


Fig. 9.2.: Benchmarking results of the User Experience Questionnaire, comparing the results of the study to a benchmark of 452 other studies.

The variance of the scores is relatively high, which may be attributed to the limited sample size. The variance across the first five scales ranges from 0.49 to 0.92, only exceeding 1 for the *Novelty* scale with a value of 1.31.

Table 9.1 provides a summary of the UEQ results, including mean values, confidence intervals, and standard deviation. The standard deviation is a measure of the degree of agreement among participants, with lower values indicating higher level of agreement. Any value below 0.83 is considered to indicate *high agreement*, while values between 0.83 and 1.01 are considered *medium agreement* and values above 1.01 are considered *low agreement*. Of the six scales, three exhibit high agreement, two have a medium agreement and one has a low agreement.

Scale	Mean	Conf.	Conf. Int.	Std. Dev.	Agreement
Attractiveness	1.983	0.445	1.538 - 2.428	0.718	high
Perspicuity	1.525	0.573	0.952 - 2.098	0.924	medium
Efficiency	1.800	0.500	1.300 - 2.300	0.806	high
Dependability	1.750	0.432	1.318 - 2.182	0.691	high
Stimulation	1.675	0.594	1.081 - 2.269	0.958	medium
Novelty	0.975	0.710	0.265 - 1.685	1.145	low

Tab. 9.1.: Summary of the User Experience Questionnaire results, including mean values, confidence intervals, standard deviation, and agreement among participants.

Summary

The analysis of the UEQ results provides insights into the application's user experience. High scores in *Attractiveness* and *Efficiency* scales, accompanied by high agreement among participants, suggest that these aspects of the application are both effective and appealing. The consistency of these scores suggests that such attributes can be rapidly gauged by users, even within the limited timeframe of the user study, leading to a uniformly positive perception.

The lower score and agreement on the *Novelty* scale indicate that the perceptions of the application's innovativeness are varied. This could be interpreted to suggest that while the application may not introduce new features or functionalities, it effectively repackages existing ones within an intuitive user interface. The moderate *Novelty* score may be indicative of the application's use of familiar concepts and interactions, which could reduce the learning curve by leveraging well-understood mechanisms.

However, it is important to note that these findings are based on a relatively small sample size of 10 participants. While the results provide valuable insights, they should not be overvalued or considered definitive. It is advisable to exercise caution in generalizing these findings without further validation from a larger, more diverse sample.

9.2 Findings from Qualitative User Testing

This section presents the findings from the user study conducted to evaluate the user interface of the application. The results are organized into categories reflecting overall impressions, learning curve and accessibility, identified issues, and recommendations for improvement, which now include feature requests.

Overall Impressions

Users generally find the interface user-friendly, effective, and aesthetically pleasing, enhancing the user experience across various functionalities.

User-Friendly. Participants highlighted the intuitive layout and ease of navigation within the interface, appreciating how straightforward it was to perform tasks without prior training or extensive help [**P1**, **P2**, **P4**, **P5**, **P7**, **P8**, **P10**].

> *So it's definitely a very nice tool, so it's pleasant to use.*[1]
>
> — **Participant 2**

Effective. The effectiveness of the interface was noted in terms of its responsiveness and reliability. Users were satisfied with the speed at which the interface responded to commands and the consistency of its performance during tasks, which helped in building trust and reducing frustration during interactions [**P2**, **P4**, **P7**, **P8**, **P10**].

> *Otherwise I thought it was super precise. I had the feeling that there wasn't much room for error.*[2]
>
> — **Participant 4**

Aesthetically Pleasing. Many users commented on the visual appeal of the interface, mentioning the modern and clean aesthetic that made the experience more engaging [**P7**, **P8**, **P10**].

> *In terms of design, I thought it was really cool, the way the colors are designed, even the animated background, I'm personally in favor of something like that.*[3]
>
> — **Participant 10**

These aspects collectively contribute to a positive user experience, making the application not only a tool that meets functional needs but also a pleasure to use, thereby encouraging repeated and prolonged engagement.

Learning Curve and Accessibility

Accessibility and ease of use are the main concerns of the application, driven to reduce the technical knowledge required to enable a broader user base. This section elaborates on the specific feedback received regarding the short comings and successes of the application in this regard.

Ease of Use. As mentioned above, the overall user-friendliness was well received by participants across the board. Feedback from users indicates that the layout and workflow of the application facilitate quick learning and ease of use [**P4**, **P5**, **P7**, **P8**, **P10**]. The progress indicator, as shown in Figure 6.7, was particularly appreciated, as it helped users understand the current state of the application and what steps were required to complete a task [**P5**, **P7**, **P8**, **P9**].

[1] Also es ist auf jeden Fall sehr schönes Tool, also angenehm zum Nutzen.
[2] Sonst fand ich super präzise. Also ich hatte das Gefühl, da war nicht so super viel Raum für Fehler.
[3] Designtechnisch fand ich es echt cool, also wie die Farben gestaltet sind, auch das mit dem animierten Hintergrund, bin ich persönlich auch für sowas.

> *I thought it was nice that it was split into three parts, so to speak, that this overview at the top said, okay, you're currently at Step 1 and then you know, okay, there are two more to go, so you can categorize it a bit.*[4]
>
> — **Participant 8**

Overwhelming Aspects. Despite the general ease of use, some users expressed concerns about overwhelming aspects of the interface. The parameter settings often require a deep understanding of NeRF to understand their effects, but this did not hinder the overall usability of the application [**P5**, **P7**]. The viewer component, while powerful, presents a steep learning curve due to its complexity and the dense presentation of information and controls. New users, unfamiliar with NeRF and, in particular, Nerfstudio, might find this part of the application challenging to navigate initially [**P2**].

> *But the [Nerfstudio Viewer] is quite complicated in itself, I think. It would be good to have some kind of explanation next to it about what you have to do or what you can do.*[5]
>
> — **Participant 2**

Technical Complexity. Reducing the technical complexity inherent in NeRF applications is crucial for making the application more accessible to a broader audience. Based on the feedback received from users, who were previously unfamiliar with NeRF, the application requires users to have some level of prior knowledge. The guided experience and the reduced number of options to configure were appreciated by certain participants. It enabled them to quickly get started with the application without feeling overwhelmed. Most users felt confident that after a short learning phase, they would be able to use the application effectively [**P2**, **P3**, **P4**, **P5**, **P6**, **P7**, **P8**].

However, the feedback indicates a need for an onboarding process or tutorials to help new users overcome initial hurdles and gain confidence in using advanced features. In contrast, advanced users appreciated the depth of control and customization available [**P9**, **P10**].

> *I think I'll need a bit more time to get used to it, but I think that will happen quite quickly.*[6]
>
> — **Participant 2**

---

[4] Ich fand es schön, dass es quasi dreigeteilt war, dass diese Übersicht oben, dass da stand, okay, du befindest dich gerade bei Step 1 und dann weißt du, okay, es folgen noch zwei weitere, dann kann man es ein bisschen einordnen.

[5] Der [Nerfstudio Viewer] ist aber an sich recht kompliziert, finde ich. [Es wäre gut] daneben irgendwie eine Erklärung [zu haben], was man machen muss oder was man da machen kann.

[6] Ich glaube, ich bräuchte schon noch ein bisschen um mich rein zu arbeiten, aber ich glaube, dass das recht schnell gehen wird.

Project Management. Novice users appreciated the similarities to existing project management of an already familiar tool from the film industry [**P5**]. For experienced users, the abstraction of tedious project management tasks, like file uploads and data organization, was well received [**P1**]. This allowed them to focus on the core tasks of training and rendering, without getting bogged down by administrative overhead.

> *Yes, it's definitely very self-explanatory, so how to manage projects, how to create projects, and so on. I'm familiar with this from almost all software that has something to do with film, video editing and Photoshop.*[7]
>
> — **Participant 5**

Technical Language. One particularly insightful point of concern was the unfamiliar terminology used, as there exist differences between some terms in the context of NeRF and the film industry [**P5**]. This can lead to confusion and hinder the learning process, as users struggle to understand the meaning and implications of certain terms. Adjusting the language used in the application to specifically target the intended audience can help bridge this gap and further reduce the learning curve.

> *I think sometimes it could be less technical and a bit more translated, if you make it movie-specific.*[8]
>
> — **Participant 5**

In summary, the application succeeds in providing new users with access to advanced NeRF tools, while also catering to the needs of experienced users by offering advanced options for customization.

Identified Issues

The following issues were identified during the user testing sessions, based on feedback from participants. Most of these issues became apparent while participants were performing tasks, and were then further discussed during the post-task interviews.

Unclear Navigation. Users experienced confusion about navigating through tasks and understanding their progression within the application. This was particularly evident when having to switch to a different project. The intended way to navigate to the dashboard was to click on the logo, which was not immediately clear to all users. Some users succeeded

[7] Ja, ist auf jeden Fall sehr selbsterklärend, wie man also das Projektmanagement, wie man Projekte anlegt usw. Das kenne ich aus ungefähr allen Softwares, die jetzt was mit Film, mit Video Editing, Photoshop zu tun haben.

[8] Ich [finde] teilweise könnte es weniger technisch und ein bisschen mehr Übersetzter sein, wenn man das filmspezifisch macht.

in finding the dashboard after some exploration, while others used browser navigation to return to the dashboard [**P1**, **P4**, **P5**, **P6**, **P8**, **P10**]. Some participants also mentioned uncertainties about navigating between the different sections of a project. The progress indicator can be used to navigate between the different sections, but some users took some time to discover this feature [**P9**].

> *What I would also like is for the home button to be marked with a little box when I went back, so that I know how to get back to Home.*[9]
>
> — **Participant 4**

Inconsistent Wording. An issue that many participants stumbled upon was the inconsistent wording used specifically on the button to start the training process. In the version of the application used during the user study, the button was labeled "*Start Processing*", which was confusing to most users [**P2**, **P3**, **P6**, **P7**, **P8**].

> *Then I would have looked somewhere on the button for 'Nerf Training' and it says 'Start Processing'.*[10]
>
> — **Participant 8**

Project Creation. Similar to the wording issue, the process of creating a new project was not as intuitive as intended. Many participants encountered a small annoyance when they tried to click on the big plus icon placed in the center of the card, which was not clickable. (see Fig. 6.4) Although everyone quickly discovered the intended way to create a new project, this issue was mentioned by almost all participants [**P3**, **P4**, **P5**, **P6**, **P7**, **P8**].

> *If [...] I have to create a new project and there is a big plus at the top and a small plus at the bottom, I would also tend to press the big plus at first.*[11]
>
> — **Participant 3**

File Upload. A few participants experienced issues with the file upload process [**P1**, **P4**, **P6**]. The system model is quite complex, as it involves multiple steps and the feedback provided was lacking in some cases. Before pre-processing can start, the user has to select the input data to use, upload it to the server, wait for the upload to complete before continuing. Users were not always aware of the progress, and would sometimes continue to the next step before the upload was complete.

[9] Was ich noch gerne hätte, wäre, dass der Homebutton, als ich zurückgegangen bin, also mit einem kleinen Häuschen markiert ist, damit ich weiß, wie ich zurück zu Home komme.

[10] [Dann] hätte ich halt irgendwo auf dem Button nach 'Nerf Training' gesucht und da steht 'Start Processing'.

[11] Wenn [...] ich ein Projekt neu erstell[en] soll und oben ist ein großes Plus und unten ist ein kleines Plus, würde jetzt erst mal auch dazu neigen, auf das große Plus zu drücken.

> *During the upload, I didn't realise for a moment that it was still loading.*[12]
>
> — **Participant 6**

Viewer and Screen Layout. Feedback indicates a need for a more flexible UI that adjusts to different screen sizes and supports fullscreen modes [**P10**].

Awareness of Progress. In some cases, users were not aware of what stage of the creation process they were in. This was somewhat caused by the inconsistent wording (see 9.2), but also by the high degree of similarity between the pre-processing and training steps [**P2**].

> *It happened to me that I didn't really realize that I was already in the training step and not yet in this preprocessing step.*[13]
>
> — **Participant 2**

Console Output. The console output was perceived differently by users. Some users appreciated the detailed feedback and insights provided, even with no technical background [**P5**]. Others that could not interpret the output, found it useless and distracting [**P3**, **P4**].

> *That's quite exciting. When you see the console, you usually do not get to see that.*[14]
>
> — **Participant 5**

Recommendations for Improvement

This section outlines some of the recommendations for improving the application based on the feedback received from participants. In contrast to the identified issues, these recommendations are more general and focus on improving the overall user experience.

Enhance Interface Usability. To address the need for a more personalized and less distracting user interface, the animated background should be able to be disabled. Additionally, implementing a 'back-to-top' button would streamline navigation, enabling users to quickly return to the top of the page without manual scrolling [**P10**].

Viewer Customization and Usability Enhancements. Several enhancements to the viewer are recommended to improve its functionality and usability:

[12] Bei dem Upload, da habe ich ja auch, kurz nicht gecheckt, dass es noch lädt.
[13] Mir ist es passiert, dass ich ja nicht so richtig gecheckt habe, dass ich jetzt dann schon in dem Trainingsschritt war und noch nicht in diesem Preprocessing Schritt.
[14] Das ist ja ganz spannend. Wenn man [die Konsole] sieht, kriegt man ja sonst nie zu sehen.

- **Multiple Viewing Modes**: Incorporate the ability to view the cameras perspective, as well as the scene from different angles, providing users with a more comprehensive understanding of the scene [**P5**].
- **Advanced Camera Controls**: Introduce adjustable controls for camera speed, motion blur, and the ability to set up speed ramps, to provide users with greater creative control [**P5**].
- **Camera and Shot Management**: Develop a more structured approach to camera and shot management within the application to support complex productions. Allow users to label and organize different camera shots and paths, making it easier to manage multiple views or scenes within a single project [**P5**].
- **Measurement Tools**: Add tools that enable users to take precise measurements within the viewer, useful for detailed scene planning and analysis [**P7**].

The participants requesting these features were exclusively users with a background in film production who would include these features in their workflow.

Expand Advanced Settings and Benchmarks. Users with an academic background in NeRF requested the following features, when evaluating the application for their workflow:

- **Support for different NeRF implementations**: Allow users to select different NeRF implementations, providing flexibility and customization options based on their requirements [**P1**].
- **Advanced-Advanced Settings**: Provide deeper customization options for experienced users who require fine control over parameters, possibly allowing them to inject custom settings or scripts [**P9**].
- **Integration of Benchmarking Tools**: Integrate tools like TensorBoard or WandDB to allow users to perform benchmarks, providing insights into model performance [**P10**].

Tighter Integration of Viewer. One participant suggested a tighter integration of the viewer with the rest of the application. Building the viewer controls directly into the interface, instead of inserting the viewer as a separate component, to provide a more seamless experience [**P9**].

General Feedback concerning NeRF

The interview also provided insights into the participants' general perception of NeRF technology and its potential applications. This feedback is not directly related to the application but provides valuable insights into the participants' understanding and expectations of the technology. Especially participants with a background in film production and no prior experience with NeRF, provided valuable insights into the potential use cases and limitations of the technology.

Use Cases. One participants saw no potential use cases for the application or NeRF in general in their current workflow [**P3**]. Others cited the limitation to static scenes as a major drawback, as they require dynamic scenes for their projects [**P4**, **P5**]. But the possibility for stylized and 'impossible' camera movements was inspiring application in advertisement and music videos [**P4**]. Pre-visualization was also mentioned as a potential use case, as it allows for quick and easy scene creation that can be used for planning and storyboarding [**P4**].

> *So what pops into my head are some aestheticized commercials where you can do something with a cool idea and try out your camera technique and make shots that would not be possible.*[15]
>
> — **Participant 4**

Summary

The qualitative user testing indicated that users generally perceive the interface of the application as user-friendly, effective, and aesthetically pleasing. The intuitive layout and straightforward navigation were highlighted, indicating that users can perform tasks efficiently without prior training.

Nevertheless, certain aspects of the interface were perceived as overwhelming, particularly the complex parameter settings and the viewer component, which present a significant learning curve. The aforementioned elements require a more profound understanding of NeRF technology, which may present a barrier to entry for newcomers. Furthermore, issues such as unclear navigation and inconsistent wording were identified, indicating that minor improvements in interface design could significantly enhance usability and user satisfaction.

[15] Also das was mir rein ploppt, sind irgendwelche ästhetisierten Werbungen, wo du mit einer coolen Idee was machen kannst und kameratechnisch sich ausprobieren kannst und Shots möglich machst, die du eigentlich nicht machen könntest.

9.3 Integration and Findings

This section integrates the results from the quantitative user experience questionnaire and the qualitative user testing to provide a comprehensive overview of the application's usability and user experience.

Detailed Insights from Integrated Data

Each UEQ dimension is discussed in the context of corresponding qualitative insights, providing a comprehensive understanding of the applications performance from the users' perspective.

Attractiveness. The high scores in the *Attractiveness* dimension of the UEQ were strongly supported by qualitative feedback, with users frequently noting the visual design and aesthetic appeal of the application. Comments indicated that the modern interface and engaging visuals not only made the application appealing but also enhanced the user experience. This correlation indicates that the visual design is one of the application's most significant strengths.

Perspicuity. The *Perspicuity* dimension received mixed reviews, with some users reporting that the application was straightforward to use from the start, while others encountered difficulties with specific features or perceived the learning curve to be steeper than anticipated. This indicates a discrepancy in user experience that could be addressed by examining how information and options are presented in the interface, with the objective of ensuring that they are accessible to all users regardless of their prior expertise.

Efficiency. The *Efficiency* scores were moderate but generally positive, which aligns with the mixed feedback from users about the application's performance. While the majority of users perceived the application as efficient in terms of task completion, a few noted instances where the interface could be streamlined to reduce points of confusion. A common theme among the suggestions for improving workflow efficiency was the potential for enhancing the user experience.

Dependability. The application received a high rating in the *Dependability* category, which is consistent with user remarks about the applications reliability and stability. Participants expressed confidence in the application, noting that it consistently performed well during tasks without errors or interruptions. This reliability is of vital importance for user trust and satisfaction, indicating that the applications design is effectively meeting user needs.

Novelty. The *Novelty* scores were the lowest of all the evaluated dimensions. This finding can be interpreted in several ways. One potential explanation is that the application employs familiar usability patterns, which while facilitating ease of use, may not be perceived as innovative by users. An alternative interpretation is that, particularly for expert users, the application does not enhance the underlying NeRF technology with new or distinctive features. Instead, it merely re-packages existing capabilities in a more accessible format. This indicates that although the application is effective and user-friendly, it may not offer users a significant degree of novelty or innovation.

Stimulation. The *Stimulation* dimension received moderate scores, which may be indicative of user feedback on the task format within the application. A number of users observed that while the tasks were clearly defined and structured, this rigidity often did not leave much room for exploration or personalization, which could dampen their enthusiasm and engagement. This indicates that the application's functionality, while efficient, may benefit from the integration of more flexible and explorative elements that would allow users to engage with the tasks in a more creative manner. Such modifications could potentially enhance user interest and satisfaction by rendering the experience not only functional but also more dynamically engaging.

Summary

The integration of quantitative and qualitative data provides a nuanced understanding of the user experience with the application. While high scores in dimensions like *Attractiveness*, *Efficiency*, and *Dependability* indicate positive user perceptions, caution is warranted in interpreting the findings, particularly regarding *Novelty* and *Stimulation*. The relatively lower score and agreement in the *Novelty* dimension suggest a potential lack of significant innovative features or the application's reliance on familiar usability patterns. Similarly, the moderate score in *Stimulation* could be attributed to the task format, potentially limiting user exploration. These insights underscore the complexity of user perceptions and the necessity for further investigation to identify and address the underlying reasons in a comprehensive manner.

10 Discussion

10.1 Interpretation of Results

This section presents a critical analysis of the key findings from the study in relation to the initially posed research questions. It explores the capabilities of current NeRF frameworks, the impact of a web-based editor on accessibility, and the challenges encountered in the development of such tools.

RQ1: Capabilities of Current NeRF Frameworks

What are the existing interaction capabilities of NeRF frameworks, and how do they support various user groups in creating and manipulating 3D scenes?

The current landscape of NeRF frameworks, notably Instant NGP and Nerfstudio, offers a diverse range of interaction capabilities, which are tailored to different user needs in the creation and manipulation of 3D scenes. Nerfstudio stands out with its modular design and real-time web viewer, which enables dynamic interaction with NeRF models. This design supports not only professionals who require robust tools for detailed manipulation but also provides a platform for future innovation and research (see Section 3.2).

However, findings from initial interviews indicate that these frameworks typically require substantial technical knowledge, which can limit their use to those with advanced skills, hindering broader adoption. In contrast, platforms like Luma AI prioritize accessibility through a more streamlined, user-friendly interface that automates numerous NeRF processes. This approach significantly lowers the entry barrier for non-technical users. However, this simplicity often comes at the cost of reduced control over the final outputs, which can be a critical drawback in professional settings where precise adjustments and customizations are crucial (see Section 5.3).

This analysis highlights a clear need for NeRF frameworks that not only simplify the user experience but also retain the advanced functionalities required by professionals. This informs much of the design and development of the web-based editor in this study.

RQ2: Enhancing Accessibility with a Web-Based Editor

How can the development of a user-friendly web-based interface for NeRF improve its accessibility and simplify the creation and manipulation processes?

The development of the web-based editor for NeRF was specifically designed to enhance accessibility by minimizing the need for extensive technical knowledge. This approach has proven effective in making NeRF technology more accessible, as evidenced by the positive feedback from the user study (see Section 9.2). Those with less experience found the interface intuitive and easy to navigate, enabling them to create and manipulate 3D scenes with minimal guidance. Professional users appreciated the streamlined workflow and the depth of control offered by the tool.

However, despite the initial success in improving accessibility, the testing phase also revealed several usability issues that could impede user efficiency and satisfaction (see Section 9.2). These included challenges with interface navigation, wording, and the responsiveness of the tool under various user actions. Such feedback underscores the importance of continuous user testing and iterative development to address these concerns.

This iterative approach is essential to refine the interface, ensuring that it not only meets the basic needs of non-technical users but also scales to support the complex demands of professional environments. By continuously improving the interface, the tool can better support a diverse range of users in efficiently working with NeRF.

RQ3: Challenges in Developing Web-Based NeRF Tools

What are the primary technical challenges and limitations associated with building a NeRF interface and how can these be overcome?

The technical development of a web-based NeRF editor introduces specific challenges related to remote operation, real-time feedback, and integration with existing frameworks:

Remote Operation. NeRF processing is a computationally intensive task, typically requiring the processing to be offloaded to a server. The prototype leverages a client-server architecture to enable users to manage NeRF-related tasks through a web browser efficiently (see Section 7.1).

Real-Time Feedback. To enhance the user experience, immediate feedback on user actions is crucial. The prototype employs WebSockets to establish a real-time connection between the client and server, facilitating instant updates on the status of the ongoing processes (see Section 5.3).

Integration with Existing Frameworks. Integrating the web-based editor with Nerfstudio presents significant technical challenges. Currently, the server-side interactions are constrained to command-line interface commands, which complicates maintainability and limits deeper integration. Direct integration could circumvent the need for makeshift solutions such as parsing log statements for progress tracking. On the client-side, Nerfstudio's viewer is hosted separately and embedded via an iframe in the web-based editor. This setup restricts direct communication between the interfaces, leading to a disjointed user experience. Additionally, the visual and functional disparities between the two interfaces can cause user confusion and inconsistency (see Section 7.4).

To overcome these challenges, a more integrated approach is necessary. Enhancing the server-side architecture to support direct API calls rather than relying on CLI can improve maintainability and functionality. On the client-side, integrating Nerfstudio's viewer directly into the web-based editor's framework would enable better synchronization and a unified user experience. Such an approach would not only streamline user interactions but also align the UI elements and workflow, reducing confusion and enhancing usability.

10.2 Implications for the Film and VFX Industry

The findings of this study indicate several implications for the film and VFX industry. They highlight the potential applications of NeRF technology in production workflows and the challenges that need to be addressed for wider adoption.

Pre-Visualization and Set Planning. One notable outcome of the study was the potential of NeRF technology in the field of pre-visualization and set planning. The capacity to rapidly generate 3D scenes from footage captured by a mobile phone or camera can be of significant benefit to filmmakers at the early stages of production. A NeRF model can be employed to explore different camera angles and lighting conditions, thus aiding the planning of shots and the general visual direction. This capability offers significant potential for time and resource savings, as it provides a more accurate representation of the final scene before actual production begins. Moreover, the generated scenes can be utilized for set planning purposes, thereby ensuring that the physical set allows for the desired camera angles and placements of actors, props, crew, and equipment.

Virtual Production. Another potential application for NeRF technology is in virtual production, where virtual environments are used to replace physical sets or backgrounds. The ability to easily scan and generate 3D scenes makes it possible for filmmakers to create virtual environments with much less effort than traditional methods. This makes NeRF a valuable tool for low-budget productions or independent filmmakers who may lack access to expensive equipment or large teams.

Innovative Applications. The potential of NeRF also inspired creative ideas among participants of the user study with a background in film. This included suggestions for virtual art exhibitions or highly stylized camera movements for advertisements. The enthusiasm of participants for exploring these new possibilities suggests that NeRF has the potential to drive innovation within the film and visual effects industry. Further exploration of this area is therefore warranted.

Conerns and Limitations. One significant concern raised by professionals in the film industry is the quality of NeRF models. These models frequently contain artifacts and noise that can be challenging to remove, particularly in complex scenes, rendering them unsuitable for high-quality production. During the user study, other limitations became apparent, including the static nature of the generated images. The lack of a time dimension represents a significant limitation for the dynamic nature of film and video production. Although there have been some recent developments in the field of NeRF models that allow for the addition of motion [15], the results remain limited and do not match the fidelity of static NeRF models.

Accessibility and Adoption. Although the tool developed in this study was the initial point of contact for some filmmakers with NeRF technology, they were able to use it with confidence and saw potential for its use in production. Their feedback on the potential usage of NeRFs did not focus on the accessibility of the tool, but rather on the specific features that would be required for certain use cases. While accessibility and ease of use are not the primary concerns for professionals in the film industry, they are nevertheless important factors for the wider adoption of NeRF technology. Tools targeting the film and VFX industry should aim to slot right into existing workflows without overwhelming users with new concepts or technical jargon. Industry-specific language and workflows should be considered in the design of such tools to ensure they are intuitive and easy to use for professionals. In light of these considerations, the potential for NeRF technology in the film and VFX industry is promising. It could find a place in various stages of production, even with its current limitations.

10.3 Limitations

This study offers valuable insights into the usability and potential applications of a new NeRF web-based editor. However, it is important to note that the results are subject to several limitations that should be considered when interpreting them.

Size and Diversity of User Group. The user study was conducted with a small, diverse group of participants, which limits the generalizability of the quantitative results from the user experience questionnaire. The limited number of participants, their varied backgrounds, and different levels of NeRF expertise may have an impact on the findings and are not necessarily representative of all potential users. Future studies could enhance the validity of the results by including a larger, more homogeneous group of participants, focusing on filmmakers. This would enable the derivation of statistically significant insights and ensure broader applicability.

User Study Tasks. The tasks assigned to participants were designed to be straightforward and guided, focusing primarily on fundamental functionalities. The participants were not required to engage with advanced features or given the freedom to explore the tool independently. The limited scope of the study may not have fully tested the tool's capabilities, particularly in handling the complexity typical of real-world projects. Future research should incorporate a broader range of tasks, including those that engage with more advanced features and simulate real-world usage scenarios. This will provide a deeper understanding of the tools practical challenges and strengths.

Comparison with Existing Tools. The study did not include a direct comparison to existing NeRF frameworks, such as those presented in Section 3. Such a comparison would have provided a more comprehensive understanding of the relative strengths and limitations of existing tools, as well as a clearer picture of how the prototype developed in this study compares to them. A comparative analysis would have also revealed the distinctive features and functionalities of the web-based editor and how it addresses the shortcomings of current NeRF frameworks.

Design Iterations. The web-based editor was developed and evaluated within a single design cycle, which may have led to the oversight of some usability issues and user feedback integration. In order to refine the tool and address diverse user needs effectively, it is essential that continuous iterative design incorporates ongoing user feedback. Subsequent iterations must aim to expand the testing phases and include longer-term usage evaluations in order to thoroughly assess the performance and user satisfaction over time.

10.4 Integration of User Feedback

Following the identification of issues during user testing, several adjustments were implemented with the objective of enhancing the usability and intuitiveness of the application. Further testing and refinement are necessary to ensure that the changes address the primary concerns raised by users.

Improved Navigation. To address the confusion in navigation to the dashboard, a dedicated button was added to the navigation bar. This feature should improve the clarity of navigation to users significantly (see Fig. 10.1).

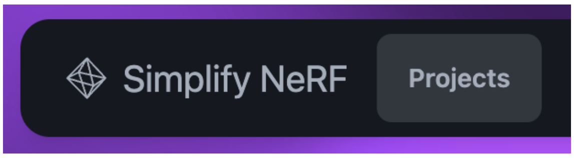


Fig. 10.1.: Dedicated Button for Dashboard Navigation.

Clarified Wording. The wording on the button to start the training process was changed from "*Start Processing*" to "*Start Training*", which aligns better with user expectations and reduces confusion.

Enhanced Project Creation. The project creation process was moved into a modal dialog, which not only eliminates a point of confusion but also clarified the need to name projects before creation (see Fig. 10.2).

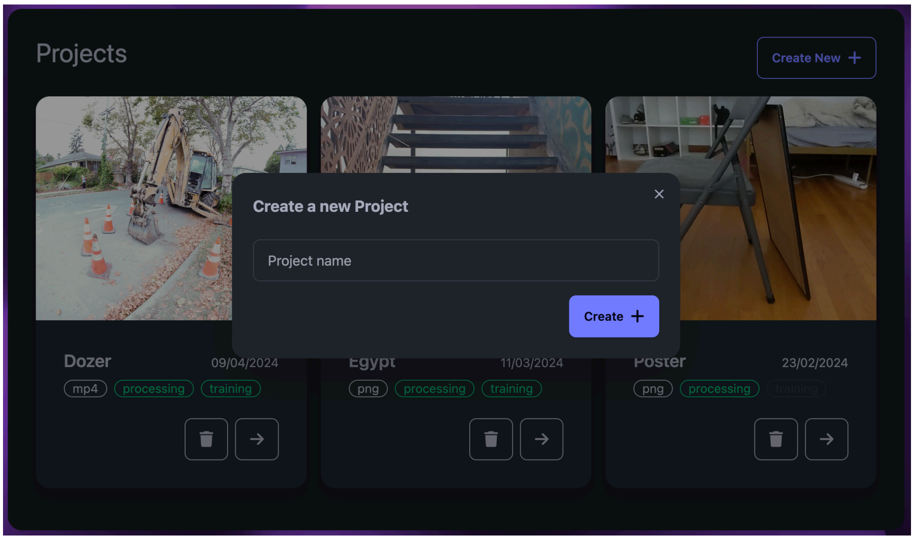
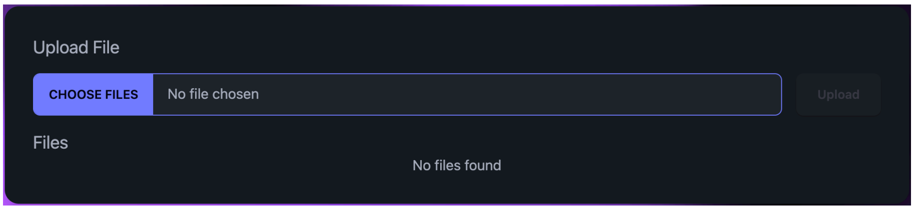
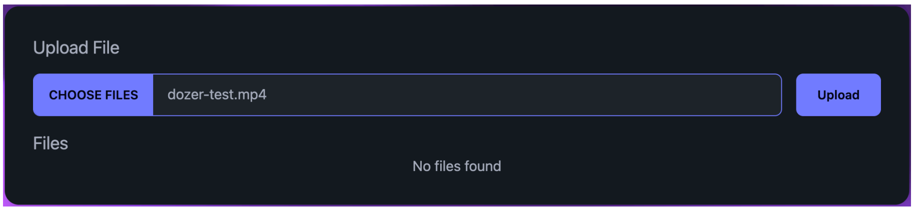


Fig. 10.2.: Modal Dialog for Project Creation.

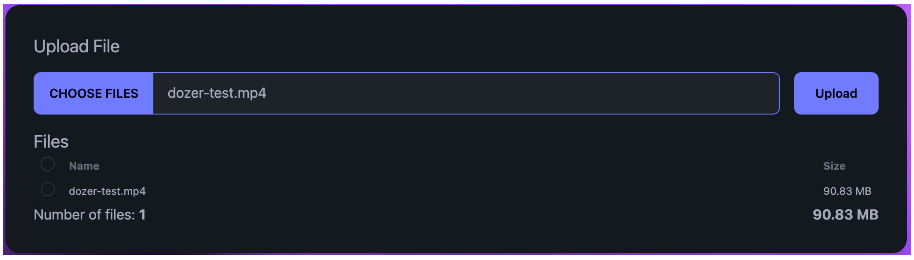
File Upload Improvements. The file upload process was improved by adding some guardrails, to ensure user would not accidentally skip a step. The upload button starts out disabled, so that the only interactive element is the file-input field. Once a file is selected, the button becomes active, indicating to the user that they can proceed to upload their selected file. Only once the file is uploaded, the UI elements related to pre-processing appear, guiding the user through the next steps. This solution is likely to prevent many of the issues users encountered when uploading files during testing (see Fig. 10.3).



(a) Initial State



(b) File Selected



(c) File Uploaded

Fig. 10.3.: Improved File Upload Process.

Disabling Background Animations. A potential concern for some participants was the presence of background animations, which could be distracting to some users. To address this, an option was added to disable background animations in a sub-menu accessible in the header (see Fig. 10.4).

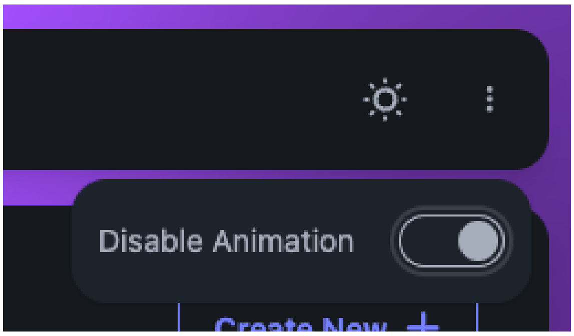


Fig. 10.4.: Option to Disable Background Animations.

11 Conclusion

11.1 Key Findings

Neural Radiance Fields have emerged as a powerful technology for view synthesis, particularly for its ability to render photorealistic scenes with significant applicability in the film industry. A review of existing NeRF interfaces has identified significant usability issues that are impeding the adoption of this technology by filmmakers. Tools that are accessible to non-experts often lack the necessary control features, while those designed for experts present a steep learning curve due to their complexity.

To address these issues, this research developed a new NeRF interface that strikes a balance between simplicity and functional depth. The graphical user interface streamlines the NeRF model creation process by consolidating essential controls. The user study conducted to evaluate this interface demonstrated that it was well received by both novice and expert users. The simplicity and guided process were appreciated by novices, while the extensive control options and workflow enhancements were appreciated by experts. Nevertheless, the study also identified areas for potential enhancement, suggesting refinements to the interface's usability and the incorporation of additional features.

11.2 Contributions to the Field

The thesis makes a significant contribution to the field by conducting a general evaluation of NeRF tools. This highlights the practical limitations and needs associated with current NeRF technologies. A novel interface has been developed, designed to effectively balance ease of use for newcomers with the depth required by advanced users. Furthermore, the interface has been subjected to a rigorous evaluation through a user study, which has confirmed its enhanced usability and functionality.

11.3 Future Work

Although the new NeRF interface has demonstrated promising results, there is considerable scope for further development. The interface could be enhanced to support a wider range of Nerfstudio features and plugins, thereby broadening the tool's capabilities. Furthermore, it is necessary to enhance the system's robustness and scalability in order to accommodate an expanding user base and increasingly complex application scenarios. It is imperative that the framework be more deeply integrated with Nerfstudio if its full capabilities are to be fully leveraged, thereby enhancing both usability and functionality (see 7.5). Finally, the continuous refinement of the interface, guided by ongoing user feedback and extended user testing, including comparative studies, will provide deeper insights and encourage continual improvements. These future directions are of pivotal importance for maintaining the interface's relevance and effectiveness in adapting to the evolving demands of filmmakers and other creative professionals.

Appendix A

A.1 Interview Questions

Introduction

- Thank the interviewee for their participation.
- Briefly explain the purpose of the interview, which is to gather insights for the development of a NeRF interface.
- Assure the interviewee that their responses will be kept confidential.

Background

- Can you briefly describe your experience with NeRF or 3D modeling in general?

Needs and Challenges

- What specific tasks or objectives do you typically aim to achieve when working with NeRF models or 3D scenes?
- What are the main challenges or pain points you encounter when using current NeRF frameworks or interfaces?

Usability and Features

- In your opinion, what features or functionalities would make a NeRF interface most useful for your work or research?
- Are there any specific editing or manipulation tools you find lacking in current NeRF interfaces?
- How important is real-time visualization and interactivity in a NeRF interface for your needs?

Ease of Use

- How do you envision the ideal user interface for NeRF? What elements would make it easy to use, even for those with limited technical expertise?

- What level of technical knowledge or familiarity with 3D modeling should the ideal NeRF interface require from its users?

Integration and Compatibility

- Are there any other software tools or workflows you typically use alongside NeRF, and how important is it for a NeRF interface to integrate with these tools?
- Do you have any preferences regarding the file formats or data compatibility that the NeRF interface should support?

Feedback and Suggestions

- Are there any additional thoughts, suggestions, or requirements you would like to share regarding the development of a NeRF interface?
- Is there anything else you believe is essential for us to understand about your needs and expectations?

Closing

- Thank the interviewee for their time and valuable input.
- Provide contact information for any follow-up questions or clarifications.

A.2 User Study Questionnaire

Usability Experience

- Can you share your overall impressions of using the Simplify NeRF application?
- Were there any specific features or functionalities of the application that stood out to you positively? If so, why?
- On the other hand, were there any aspects of the application that you found challenging or frustrating? Please elaborate.

Task-Specific Feedback

- Were there any particular steps or actions within the tasks that you found confusing or unclear? If yes, could you describe them?
- Were there any features or functionalities you expected to find in the application that were missing? If so, what were they?

Suggestions for Improvement

- Based on your experience using the Simplify NeRF application, do you have any suggestions for improving its usability or functionality?
- Are there any specific changes or enhancements you would like to see in future versions of the application?
- How do you think the application could better meet your needs or expectations as a user?

Closing

- Is there anything else you would like to add or share about your experience with the Simplify NeRF application?
- Thank the participant for their time and valuable feedback. Offer contact information for any follow-up questions or clarifications.

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I do solemnly declare that I prepared this thesis independently and that the thoughts taken directly or indirectly from other sources are indicated accordingly. The work has not been submitted to any other examination authority and also not yet been published.

Munich, May 14, 2024

Eduard von Briesen

Declaration of AI Usage

I declare that I have exclusively used ChatGPT 4[1], Whisper[2], DeepL Write[3] and MAXQDA's AI Assist[4] in my thesis for the purposes listed below:

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