Reinforcement Learning and Neural Radiance Fields for Real-time Ray Tracing

Advisors: Piotr Didyk, Jorge Condor
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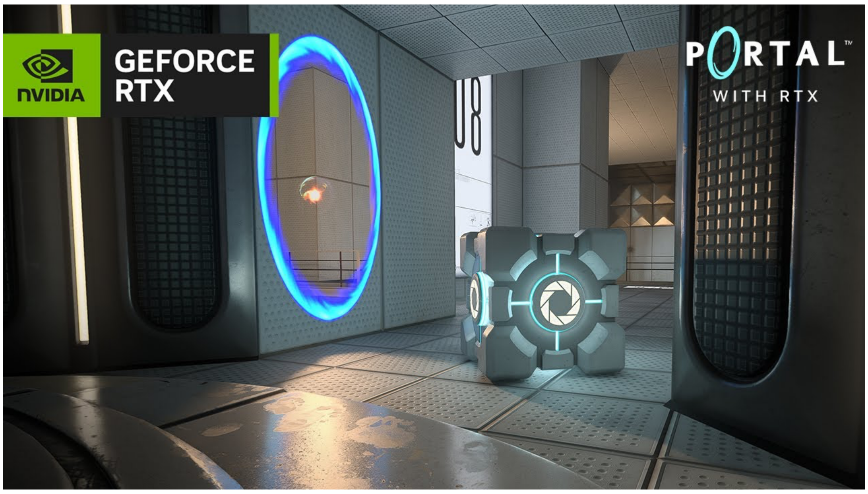
Motivation



Path tracing and ray tracing techniques are the holy grail of computer graphics. They are simple, elegant solutions to the physical problem of light transport, how light flows from its source and bounces around a scene to reach our eyes. However, the nature of the algorithm, namely its immense computational cost, has limited its adoption to high-budget cinematic productions and offline simulations, while real-time applications like videogames had to resort to the cheaper but far less realistic rasterization, where light behavior is "baked", or rather, placed by artists, instead of resembling an actual physical simulation. As of the last few years though, the paradigm is changing: hardware accelerators are being included in GPUs to accelerate some of the costlier parts of the ray tracing algorithm (NVIDIA's RTX cores are just ray-triangle intersection checkers). Thus, the advent of real-time raytracing is upon us, which will dramatically change the way we design GPUs and videogames, delivering unprecedented levels of realism.

Problem Statement

We present a longstanding problem of ray tracing (RT): the rendering of complex luminaires and grand chandeliers. Due to the nature of RT, every change of medium will generate a new bounce, with the goal of all rays (which in RT, come from the camera) being to reach sources of light on the other end. But, the more bounces we have (i.e. several layers of crystal), and the smaller the light sources are (small wires of incandescent bulbs), the smaller the chance of hitting the light source. In practice, this means that scenes containing these super-complex light sources will require a lot more computation to be rendered, and thus they are completely out of reach for real time applications like modern videogames. Our solution to the problem is to abstract the final scene of all the internal complexity of these grand chandeliers by encoding them using Neural Radiance Fields (NeRFs) which allow us to consider them as a single view-dependent source of light. However, knowing where to direct our rays when all we have is a black-box neural network is impossible, and results in many rays being wasted, falling into areas of the luminaire where no light is being emitted (i.e. the brass handles, or empty spaces within the different branches). We propose to use reinforcement learning to train a model that learns the emission profile of the luminaire and is thus able to predict the most energetic paths, enabling what in computer graphics is known as importance sampling (simply, sending rays in the directions that matter).

Your Task

Your task will be to develop and train a model using reinforcement learning so that it learns where most energy is coming from a view-independent octree structure that encodes our NeRFs. Upon completion, we will integrate it within our NeRF-driven path tracing pipeline to significantly accelerate it.

Why You Should Choose This Project

If you have interest in computer graphics or AI, this project combines both in a very practical and potentially impactful way. By the end of this project, you will have learned about state of the art techniques in computer vision (NeRF), computer graphics (path tracing) and AI (reinforcement learning), which are key technologies for the future and some of the main drivers of innovation in top tech companies right now (Google, Microsoft, NVIDIA, Meta, among others). Furthermore, this is a research-oriented project. If successful, we envision it to become a part of a submission to one of the top-tier computer graphics conferences such as ACM SIGGRAPH.

Further Information

Please feel free to contact us for more information at piotr.didyk@usi.ch and jorge.condor@usi.ch.

Perceptual Compression of Neural Radiance Fields

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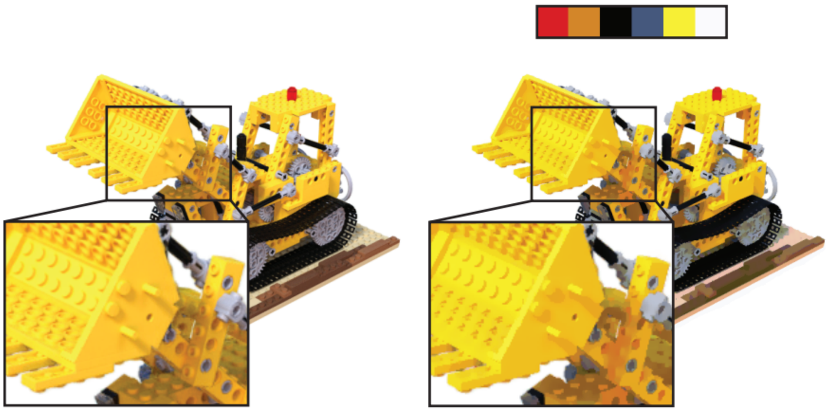
Motivation



Neural Radiance Fields or NeRFs for short are one of the most interesting technologies to come up in the past 3 years. They enable impressive reconstructions of real scenes with just a few images, through the use of basic computer graphics algorithms and machine learning. These reconstructions are behind some of the biggest advances in the last few years in computer graphics (real time path tracing), computational photography (next denoising for phone cameras) and even autonomous driving (improved SLAM algorithms), among many others.

Problem Statement

However, reconstructing novel views from this latent space is very expensive, or requires dedicated hardware (new GPUs with large amounts of cache). Nevertheless, there are ways to circumvent this by extracting the latent space into an octree, which is orders of magnitude faster. The side of effect of this is that, while the latent model occupies around 10Mb, an octree with good quality can weight several gigabytes, which is not feasible for most mobile applications.

Your Task

Your task will be to research ways of compressing this octree by means of exploiting the human visual system. For example, due to perceptual effects, humans are more sensitive to certain colors and less to others. By exploiting this it is possible to use less data to map certain areas of the color space, while maintaining the same perceived quality. This trick is normally used in video compression algorithms, but it has not yet been applied to 3D reconstructions of this kind.

Why You Should Choose This Project

If you have interest in computer graphics or AI, this project combines both in a very practical and potentially impactful way. By the end of this project, you will have learned about state of the art techniques in computer vision (NeRF), and understood basic notions of human perception. Furthermore, this is a research-oriented project. If successful, we envision it to become a part of a submission to one of the top-tier computer graphics conferences such as ACM SIGGRAPH.

Further Information

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Complex Camera Models for Neural Radiance Fields

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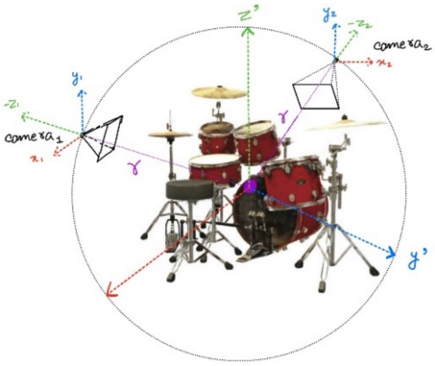
Motivation

Neural Radiance Fields or NeRFs for short are one of the most interesting technologies to come up in the past 3 years. They enable impressive reconstructions of real scenes with just a few images, through the use of basic computer graphics algorithms and machine learning. These reconstructions are behind some of the biggest advances in the last few years in computer graphics (real time path tracing), computational photography (next-gen denoising for phone cameras) and even autonomous driving (improved SLAM algorithms), among many others.



Problem Statement

While NeRF works incredibly well with cameras where the pin-hole assumption holds (i.e. phones), it is not capable of modelling more complex camera systems, where blur from de-focused areas created by using big focal distances or very fast lenses can create too much ambiguity for NeRF to work properly. However, unlike pin-hole cameras, where everything is in focus, these blurred areas can provide depth information, which if modelled correctly would notably increase the performance of the reconstruction, both for rendering and for the quality of the reconstruction itself.

Your Task

Your task will be to implement more complex camera models within the NeRF framework, allowing the method to exploit wider apertures, different exposures, focal lengths and obtain depth cues from defocus. Potentially, one could exploit NeRF this way to obtain full light fields from several takes from a single view point at different focus points.

Why You Should Choose This Project

If you have interest in computer graphics or AI, this project combines both in a very practical and potentially impactful way. By the end of this project, you will have learned about state of the art techniques in computer vision (NeRF), and computational photography (complex camera models and the digital processing pipeline). Furthermore, this is a research-oriented project. If successful, we envision it to become a part of a submission to one of the top-tier computer graphics conferences such as ACM SIGGRAPH.

Further Information

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Progressive Neural Radiance Fields for Robotic Path-Planning

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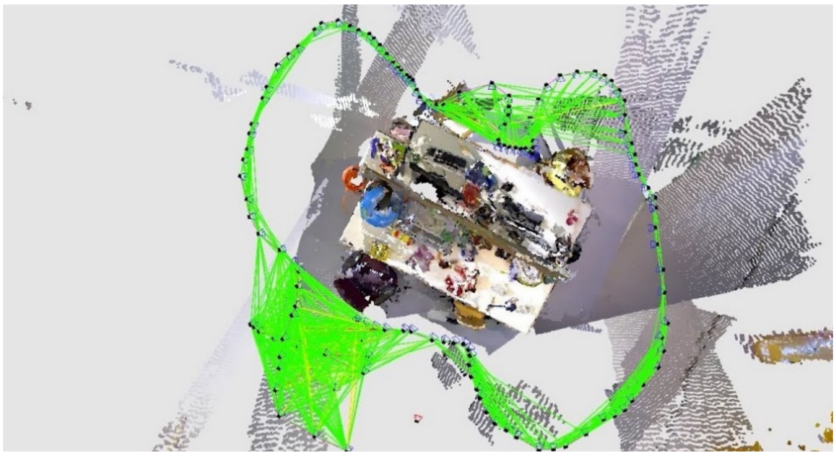
Motivation



Neural Radiance Fields or NeRFs for short are one of the most interesting technologies to come up in the past 3 years. They enable impressive reconstructions of real scenes with just a few images, using basic computer graphics algorithms and machine learning. These reconstructions are behind some of the biggest advances in the last few years in computer graphics (real time path tracing), computational photography (next-gen denoising for phone cameras) and even autonomous driving (improved SLAM algorithms), among many others.

Problem Statement

NeRF reconstructions are notorious for the amount of different viewpoints required to obtain high quality reconstructions; otherwise, uncertainty in the reconstruction manifests mainly in blur and non-smooth surfaces, and most notably in very long decays in the transmittance function. This problem is homonymous in traditional reconstructions based on feature extraction and bundle adjustment, while discovering views with high uncertainty is more expensive. Furthermore, in NeRF, solving the optimization for hundreds of views takes much longer to converge, which makes it particularly interesting to select only those that will make a big difference on reconstruction quality. With the advent of simultaneous localization and mapping (SLAM) algorithms based on NeRF for autonomous driving and NeRF-based UAV 3D mappings, there's an increasing need for a method to assess where uncertainty is highest in a NeRF model, to suggest which paths or views should be taken next to reconstruct a scene with the highest level of quality at the lowest number of views possible.

Your Task

Your task will be to develop a method that takes the uncertainty cues NeRF models provide and suggest which views should be added next to the optimization to maximize quality at the lowest number of views possible. Ideally, a progressive way of training NeRFs could be used or developed, in which case this could have impact in a wider range of applications, particularly those with unconstrained datasets and spaces, reducing the overall training time of NeRFs. If time allows, your method could be deployed and combined with existing robotic path planning systems for showcasing a real application.

Why You Should Choose This Project

If you have interest in computer graphics or AI, this project combines both in a very practical and potentially impactful way. By the end of this project, you will have learned about state-of-the-art techniques in computer vision (NeRF), and computational photography (complex camera models and the digital processing pipeline). Furthermore, this is a research-oriented project. If successful, we envision it to become a part of a submission to one of the top-tier computer graphics conferences such as ACM SIGGRAPH or robotics conferences such as IROS.

Further Information

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