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From Light to Muons: Towards a Unified Framework for Physics-based 3D Scene Reconstruction

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Inverse problems like magnetic resonance imaging, computer tomography, optical inverse rendering or muon tomography, amongst others, occur in a vast range of scientific, medical and security applications and are usually solved with highly specific algorithms depending on the task.
Approaching these problems from a physical perspective and reformulating them as a function of particle interactions, enables 3D scene reconstruction in a physically consistent manner across different types of electromagnetic radiation and particles.
Recent developments in differentiable volumetric rendering and optical optimization techniques, such as Neural Radiance Fields, Gaussian Splatting and Scene Representations Networks (SRN), have been used to demonstrate the feasibility of jointly estimating unknown geometry and material parameters of a 3D scene.
Some works also show the feasibility of modeling refraction and multiple scattering of light using differentiable optimization.

In this work, we approach the formulation of a physically based 3D reconstruction method for the visible light spectrum, serving as a representative case to demonstrate the applicability of generalized and physics-based 3D scene reconstruction.
By directly incorporating these interactions into a differentiable pipeline captured by a parameterized observer, we decouple the optimization procedure from both, the specific type of interaction and the capture mechanism.
We perform a first experimental validation of our method using simulated and experimental optical scans from different sensing devices.
Lastly, we explore the inter-domain capability of the new reconstruction method to other inverse problems, including muon tomography imaging.

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