# SPC-3DGS: Pose-Free 3D Gaussian Splatting with Single Photon Camera

## Overview

This project investigates the integration of Single Photon Camera (SPC) data into the **3D Gaussian Splatting (3DGS)** framework for scene reconstruction. SPCs capture binary photon arrival frames with extremely fine temporal resolution, which can be used for reconstructing scenes in low-light conditions. Building upon *PhotonSplat* (ICCP 2025), which introduced SPC data into 3DGS for grayscale image reconstruction, this project extends the pipeline by exploring trajectory-aware accumulation strategies and pose-free optimization methods. The work is structured into three tasks: reproducing PhotonSplat as a baseline, improving supervision through trajectory accumulation, and developing a pose-free SPC-3DGS system without COLMAP initialization.

## Motivation

Traditional 3DGS pipelines rely on RGB inputs and accurate pose estimates from COLMAP or similar SfM methods. SPCs offer a unique sensing modality by recording photon arrivals directly, enabling simulation of extremely short exposures and operation in photon-limited environments. However, the existing *PhotonSplat* approach applies a binary cross-entropy loss directly to noisy binary SPC frames, which is suboptimal. By modeling photon trajectories and accumulating evidence across frames, more robust loss functions can be designed, leading to improved reconstructions. Furthermore, removing dependence on COLMAP initialization through a SLAM-inspired optimization framework would make SPC-3DGS fully self-contained, extending its applicability to real-world low-light or textureless scenes.

## Project Tasks

### Task 1: Baseline — PhotonSplat in 3DGS

- Objective: Implement PhotonSplat using SPC binary frames in the 3DGS framework.

- Method: Use either real SPC datasets (from PhotonSplat) or simulate binary frames from RGB sequences via Poisson sampling. Employ binary cross-entropy loss for grayscale reconstruction.

- Expected Outcome: Baseline SPC-3DGS results comparable to PhotonSplat.

### Task 2: Trajectory-Aware SPC Accumulation

- Objective: Improve reconstruction robustness by accumulating SPC frames along photon trajectories.

- Method: Inspired by BAD-Gaussians, estimate trajectories during exposure and accumulate binary frames along them. Formulate exposure-scale losses applied on accumulated reconstructions rather than raw frames. Jointly optimize Gaussian parameters and trajectory parameters.

- Expected Outcome: More robust reconstructions under noise compared to direct BCE loss.

**Task 3: Pose-Free SPC-3DGS**

- Objective: Remove reliance on COLMAP by jointly optimizing camera poses and Gaussian parameters.

- Method: Adapt ideas from IncEventGS by designing a SLAM-style framework for SPC data, where both poses and scene representation are optimized directly from photon arrivals. Compare performance with COLMAP-initialized variants.

- Expected Outcome: Prototype of a pose-free SPC-3DGS pipeline operating solely on SPC frames.

## Key Deliverables

- Baseline SPC-3DGS results reproducing PhotonSplat.

- Trajectory-accumulation based SPC-3DGS with improved loss functions.

- Pose-free SPC-3DGS pipeline jointly optimizing poses and Gaussians.

- Comparative evaluations on simulated and real SPC datasets.

## Timeline

- **Task 1: 1 week** — Implement and validate PhotonSplat baseline in 3DGS.

- **Task 2: 2 weeks** — Develop trajectory accumulation losses and evaluate improvements.

- **Task 3: 2 weeks** — Implement and test pose-free SPC-3DGS framework.

## Conclusion

This project aims to extend 3D Gaussian Splatting to Single Photon Camera data by building upon PhotonSplat and introducing two major innovations: trajectory-aware accumulation for robust supervision and a pose-free optimization framework. The outcome will be a research-grade SPC-3DGS pipeline capable of robust scene reconstruction in photon-limited settings.

## References

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