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Uncertainty-Aware Initialization for 3D Gaussian Splatting

Proposal for a Master thesis topic (DE/EN)

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3D Gaussian Splatting has emerged as a powerful approach for novel view synthesis and 3D scene reconstruction, enabling real-time rendering capabilities. The initialization of this representation is commonly based on sparse 3D point clouds obtained from Structure-from-Motion (SfM) reconstruction pipelines, such as COLMAP. However, the uncertainty inherent in these initial reconstructions due to factors such as limited viewpoint coverage, ambiguous correspondences, or challenging scene properties, is typically discarded during the initialization process. Each 3D point is treated as equally reliable, regardless of the number of observations, triangulation quality, or reprojection error statistics. Disregarding this uncertainty can result in suboptimal initialization, particularly in challenging regions, subsequently degrading both the geometric accuracy and visual quality of the final reconstruction.

The objective of this master thesis is to develop a methodology for incorporating reconstruction uncertainty into the initialization of 3D Gaussian Splatting. For this purpose, first, suitable measures for quantifying the uncertainty of reconstructed 3D points are to be identified and extracted from SfM reconstruction pipelines. These measures may include bundle adjustment statistics, reprojection errors, track lengths, and triangulation geometry. Subsequently, an uncertainty-aware initialization strategy for 3D Gaussian Splatting is to be developed that utilizes these uncertainty measures to inform the initialization of Gaussian parameters, including their scale, opacity, and potentially their covariance structure. The developed approach is to be evaluated with respect to novel view synthesis quality and convergence behavior for different scene types.

Optional extensions beyond the core thesis scope may include (i) evaluating the geometric representation of the perceived Gaussians, (ii) incorporating uncertainty information from multi-view stereo reconstruction pipelines or (ii) propagating uncertainty through the Gaussian Splatting optimization process and quantifying the final reconstruction uncertainty, enabling the method to not only leverage input uncertainty but also provide confidence estimates for the rendered output.

In addition to the conceptual elaboration, this master thesis includes a practical implementation of the developed methodology. As basis for this implementation, existing 3D Gaussian Splatting frameworks and COLMAP reconstruction software are to be utilized and extended as necessary. The optional uncertainty extraction from MVS reconstruction pipelines may build upon methodologies developed earlier at the Institute. For the purpose of evaluation, the developed approach is to be tested on publicly available datasets such as DTU, Tanks and Temples, or Mip-NeRF 360. The acquisition of own data is not necessary within the scope of this work.

This thesis will be supervised by Christian Grannemann.