Reflective Gaussian Splatting

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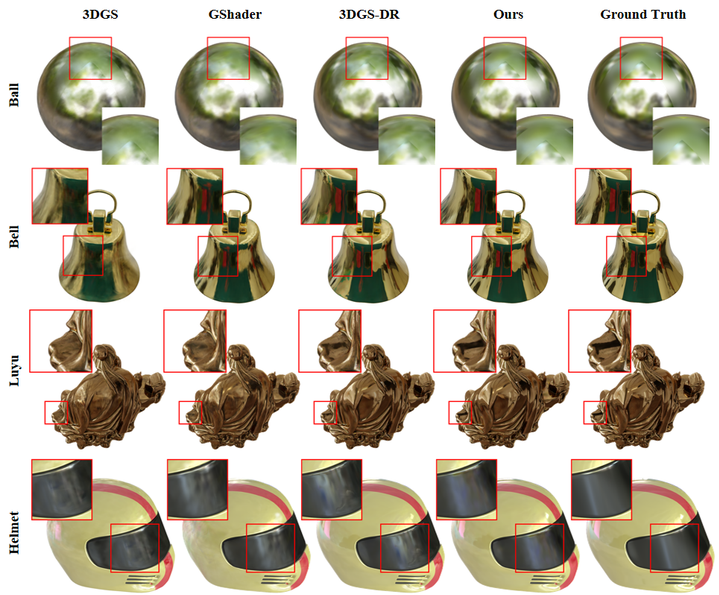
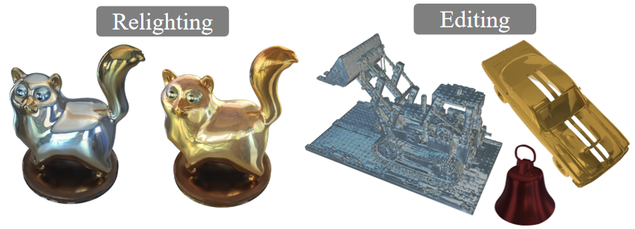
Project page

Ref-Gaussian



Qualitative comparisons on mutipul reflective scenes.



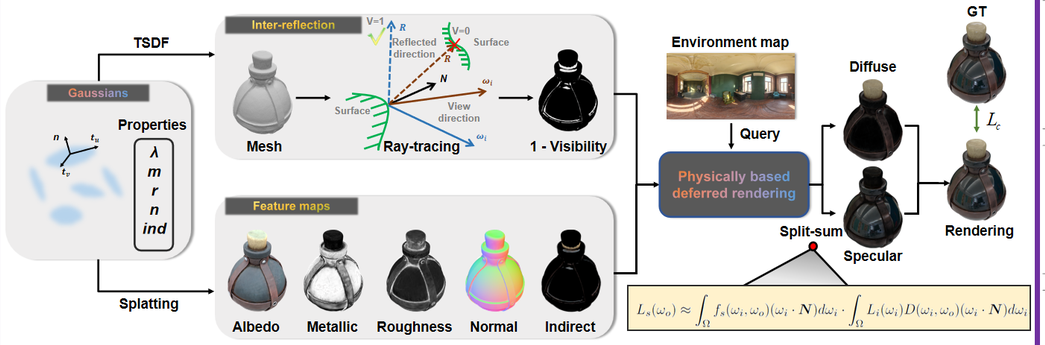
Downstream task like relighting and editing.

➢ ***Physically Based Deferred Rendering:*** Pixel-level material modeling (BRDF) with split-sum approximation, enabling stable optimization and photorealistic rendering.

➢ ***Gaussian-Grounded Inter-Reflection:*** First implementation of ray-traced visibility and indirect lighting.

➢ ***Geometry-Focused Optimization:*** Enhanced geometry via 2D Gaussian primitives, material-aware normal propagation, and a two-stage training pipeline.

Method



$$L_s(\omega_o) \approx \int_\Omega f_s(\omega_i,\omega_o)(\omega_i\cdot\boldsymbol{N})d\omega_i \cdot \int_\Omega L_i(\omega_i)D(\omega_i,\omega_o)(\omega_i\cdot\boldsymbol{N})d\omega_i$$

➢ Physically based deferred rendering:

1. Produce pixel-level feature maps with alpha-blending

$$\boldsymbol{X} = \sum_{i=1}^{N} \boldsymbol{x}_i\alpha_i\prod_{j=1}^{i-1}(1-\alpha_j), \quad \text{where} \quad \boldsymbol{X} = \begin{bmatrix}\boldsymbol{\Lambda}\\ M\\ R\\ \boldsymbol{N}\end{bmatrix}, \quad \boldsymbol{x}_i = \begin{bmatrix}\lambda_i\\ m_i\\ r_i\\ \boldsymbol{n}_i\end{bmatrix}.$$

2. Perform physically based rendering using rendering equation and split-sum approximation

$$L(\omega_o) = \int_\Omega L_i(\omega_i)f(\omega_i,\omega_o)(\omega_i\cdot\boldsymbol{N})\,d\omega_i = L_d(\omega_o) + L_s(\omega_o)$$

$$f_s(\omega_i,\omega_o) = \frac{D\,G\,F}{4(\omega_o\cdot\boldsymbol{N})(\omega_i\cdot\boldsymbol{N})},\ L_s(\omega_o) \approx \int_\Omega f_s(\omega_i,\omega_o)(\omega_i\cdot\boldsymbol{N})d\omega_i\cdot\left(\int_\Omega L_i(\omega_i)D(\omega_i,\omega_o)(\omega_i\cdot\boldsymbol{N})d\omega_i\right)_{L_{\text{dir}}}$$

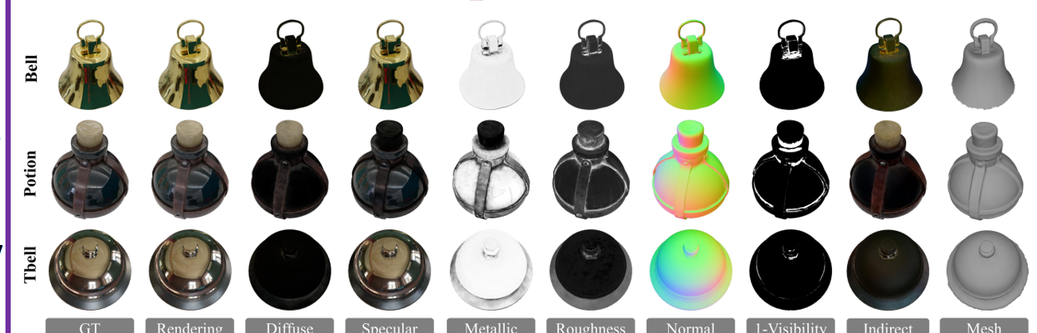
➢ Gaussian-grounded inter-reflection:

$$L'_s(\omega_o) \approx \left(\int_\Omega f_s(\omega_i,\omega_o)(\omega_i\cdot\boldsymbol{N})d\omega_i\right)\cdot[L_{\text{dir}}\cdot V + L_{\text{ind}}\cdot(1-V)] \quad L_{\text{ind}} = \sum_{i=1}^{N}\boldsymbol{l}_{\text{ind}}\alpha_i\prod_{j=1}^{i-1}(1-\alpha_j).$$

➢ Geometry-focused model optimization:

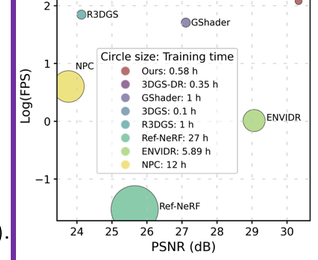
- Initial per-Gaussian shading stage
- Material-aware normal propagation

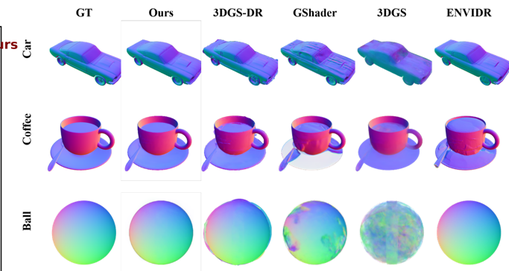
Experiment



Datasets	Shiny Blender (Verbin et al. 2022)						Glossy Synthetic (Liu et al. 2023)								Real (Verbin et al. 2022)		
Scenes	ball	car	coffee	helmet	teapot	toaster	angel	bell	cat	horse	luyu	potion	tbell	teapot	garden	sedan	toycar
PSNR ↑																	
Ref-NeRF	33.16	30.44	33.99	29.94	45.12	26.12	20.89	30.02	29.76	19.30	25.42	30.11	26.91	22.77	22.01	25.21	23.65
ENVIDR	41.02	27.81	30.57	32.71	42.62	26.03	29.02	30.88	31.04	25.99	28.03	32.11	28.64	26.77	21.47	24.61	22.92
3DGS	27.65	27.26	32.30	28.22	45.71	20.99	24.49	25.11	31.36	24.63	26.97	30.16	23.88	21.51	21.75	26.03	23.78
2DGS	25.97	26.38	32.31	27.42	44.97	20.42	26.95	24.79	30.65	25.18	26.89	29.50	23.28	21.29	22.53	26.23	23.70
GShader	30.99	27.96	32.39	28.32	45.86	26.28	25.08	28.07	31.81	26.56	27.18	30.09	24.48	23.58	21.74	24.89	23.76
R3DG	23.64	25.92	30.10	25.01	43.15	18.80	24.90	23.51	27.59	23.37	24.68	27.29	21.25	20.47	21.92	21.18	22.83
3DGS-DR	33.43	30.48	34.53	31.44	47.04	26.76	29.07	30.60	32.59	26.17	28.96	32.65	29.03	25.77	21.82	26.32	23.83
Ref-Gaussian	37.01	31.04	34.63	32.32	47.16	28.05	30.38	32.86	33.01	27.05	30.04	33.07	29.84	26.68	22.97	26.60	24.27
SSIM ↑																	
Ref-NeRF	0.971	0.950	0.972	0.954	0.995	0.921	0.853	0.941	0.944	0.820	0.901	0.933	0.947	0.897	0.584	0.720	0.633
ENVIDR	0.997	0.943	0.962	0.987	0.995	0.922	0.934	0.954	0.965	0.925	0.931	0.960	0.947	0.957	0.561	0.707	0.549
3DGS	0.937	0.931	0.972	0.951	0.996	0.894	0.792	0.908	0.959	0.797	0.916	0.938	0.900	0.881	0.571	0.771	0.637
2DGS	0.934	0.930	0.972	0.953	0.997	0.892	0.918	0.911	0.958	0.909	0.918	0.939	0.902	0.886	0.609	0.778	0.597
GShader	0.966	0.932	0.971	0.951	0.996	0.929	0.914	0.919	0.961	0.933	0.914	0.936	0.898	0.901	0.576	0.728	0.637
R3DG	0.888	0.922	0.963	0.931	0.995	0.858	0.894	0.888	0.934	0.878	0.889	0.911	0.875	0.869	0.556	0.643	0.657
3DGS-DR	0.979	0.963	0.976	0.971	0.997	0.942	0.942	0.959	0.973	0.933	0.943	0.959	0.958	0.942	0.581	0.773	0.639
Ref-Gaussian	0.981	0.964	0.976	0.971	0.998	0.948	0.954	0.969	0.973	0.944	0.952	0.963	0.962	0.947	0.617	0.777	0.660
LPIPS ↓																	
Ref-NeRF	0.166	0.050	0.082	0.086	0.012	0.083	0.144	0.102	0.104	0.155	0.098	0.084	0.114	0.098	0.251	0.234	0.231
ENVIDR	0.020	0.046	0.083	0.036	0.009	0.081	0.067	0.054	0.049	0.065	0.059	0.072	0.069	0.041	0.263	0.387	0.345
3DGS	0.162	0.047	0.079	0.081	0.008	0.125	0.088	0.104	0.062	0.077	0.064	0.093	0.102	0.125	0.248	0.206	0.237
2DGS	0.156	0.052	0.079	0.079	0.008	0.127	0.072	0.109	0.060	0.071	0.066	0.097	0.125	0.101	0.254	0.225	0.396
GShader	0.121	0.044	0.078	0.074	0.007	0.079	0.082	0.098	0.056	0.562	0.064	0.088	0.091	0.122	0.274	0.259	0.239
R3DG	0.214	0.058	0.090	0.125	0.013	0.170	0.085	0.125	0.089	0.081	0.080	0.117	0.156	0.115	0.354	0.380	0.312
3DGS-DR	0.105	0.033	0.076	0.050	0.006	0.082	0.052	0.050	0.042	0.057	0.048	0.068	0.059	0.060	0.247	0.208	0.231
Ref-Gaussian	0.098	0.033	0.076	0.049	0.006	0.074	0.042	0.040	0.040	0.048	0.043	0.064	0.058	0.058	0.256	0.245	0.256

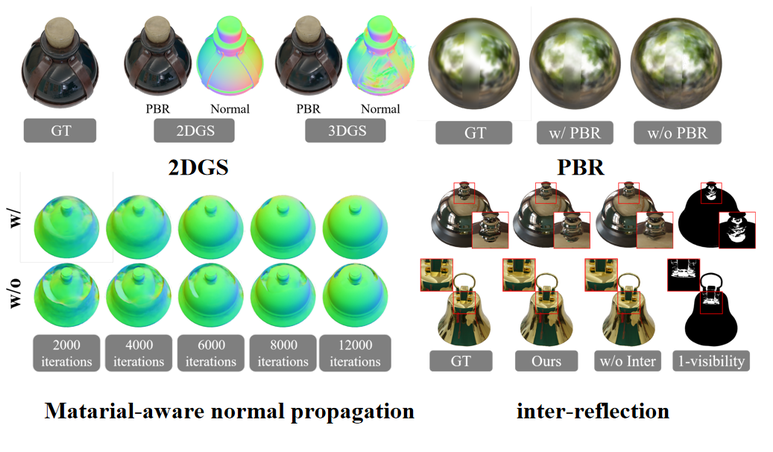
Per-scene image quality comparison on synthesized test views.





Per-scene qualitative comparisons of normals.

Ablation studies



Matarial-aware normal propagation

inter-reflection