HDR-NeRF: High Dynamic Range Neural Radiance Fields

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Website: https://shsf0817.github.io/hdr-nerf/

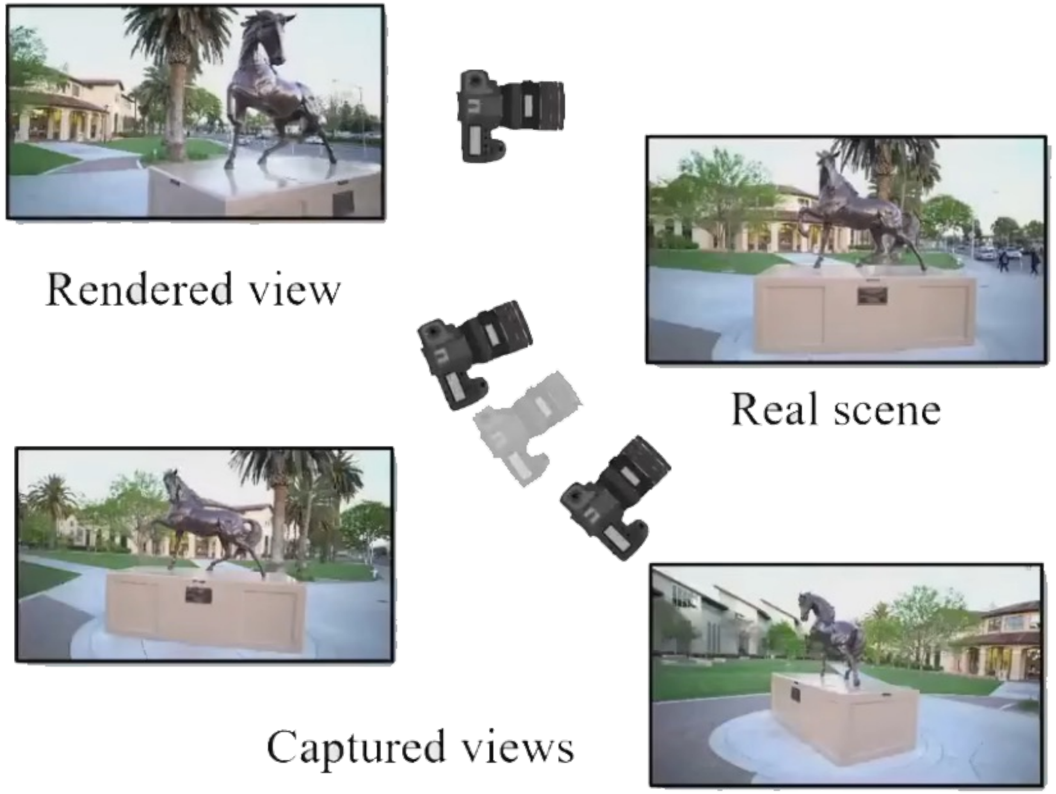
2022/10/16

Outline

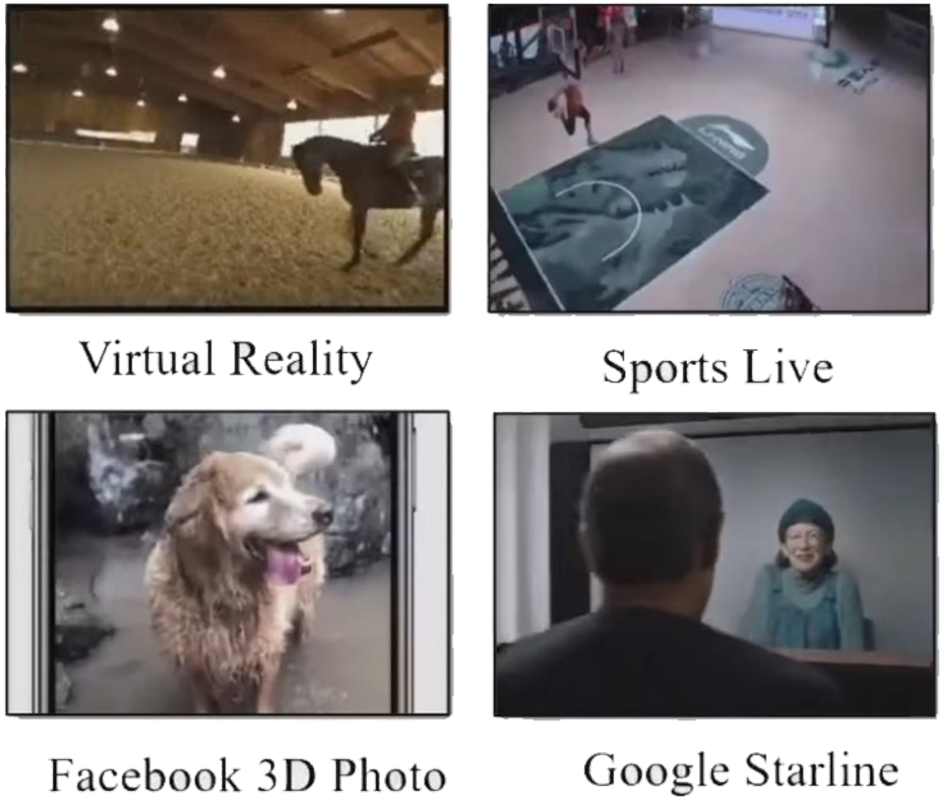
- Authorship
- Background
- Method
- Experiment
- Conclusion

Background-Novel View Synthesis

Task description

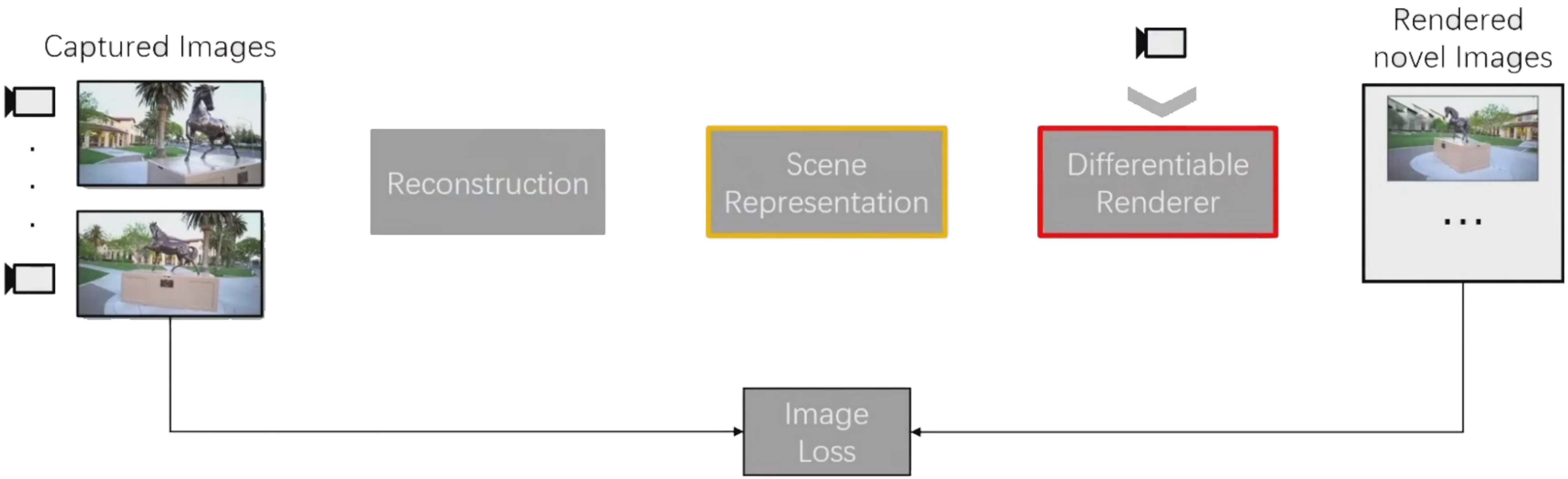


Application



Background-Novel View Synthesis

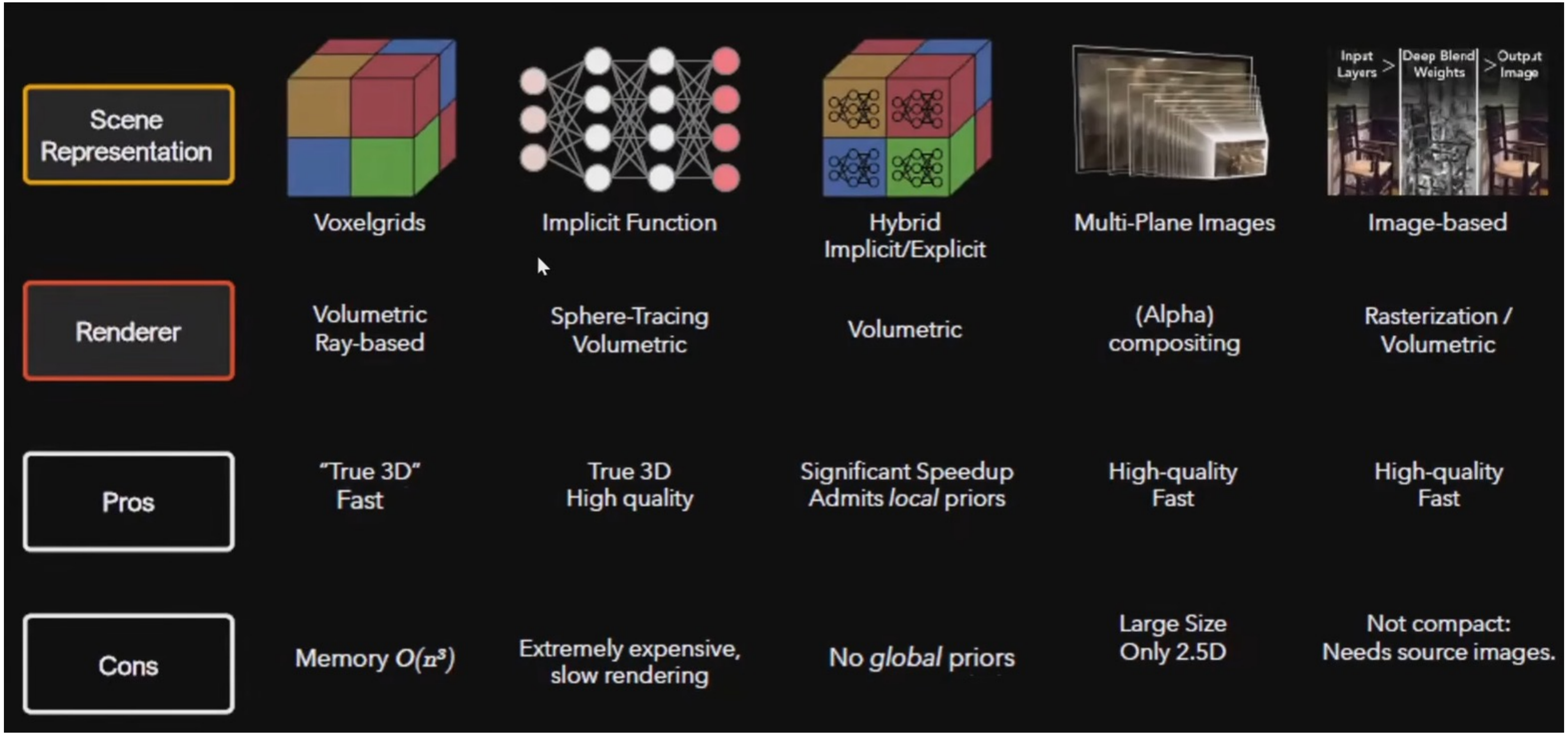
General pipeline



Scene pepresentation + Differentiable renderer

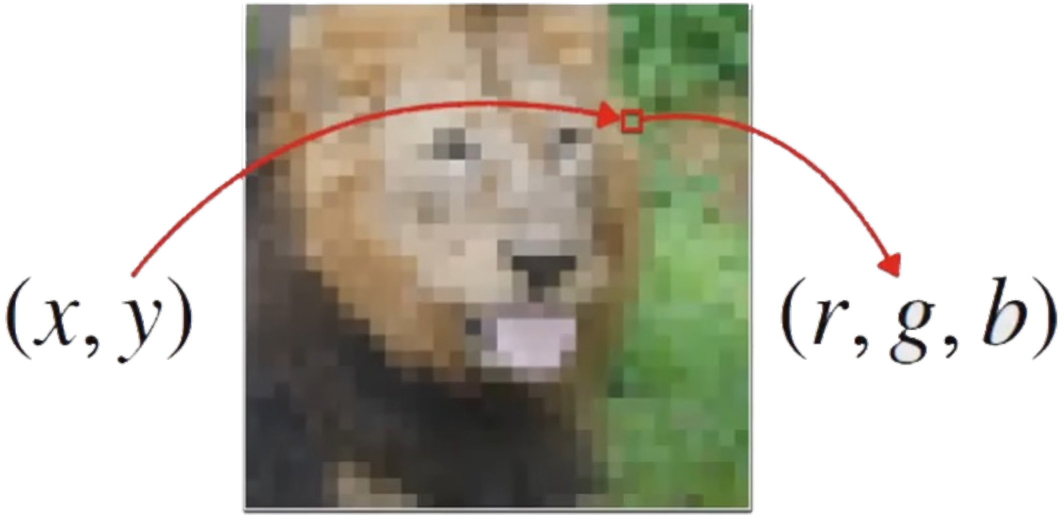
Background-Novel View Synthesis

Overview of Representations



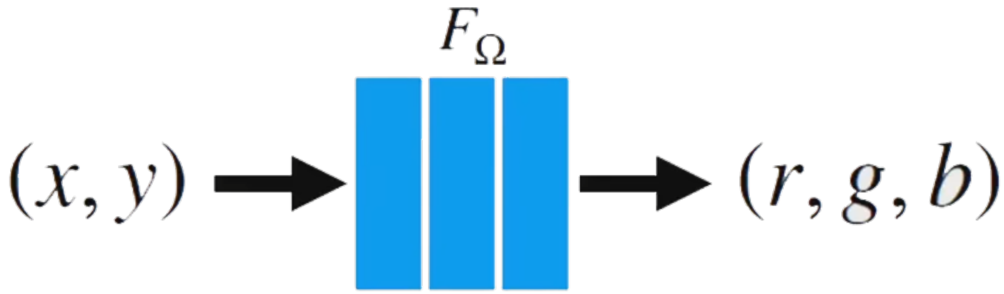
Background-Neural Radiance Fields (NeRF)

Explicit representation of 2D scene



Store an image as
a 2D grid of RGB color values

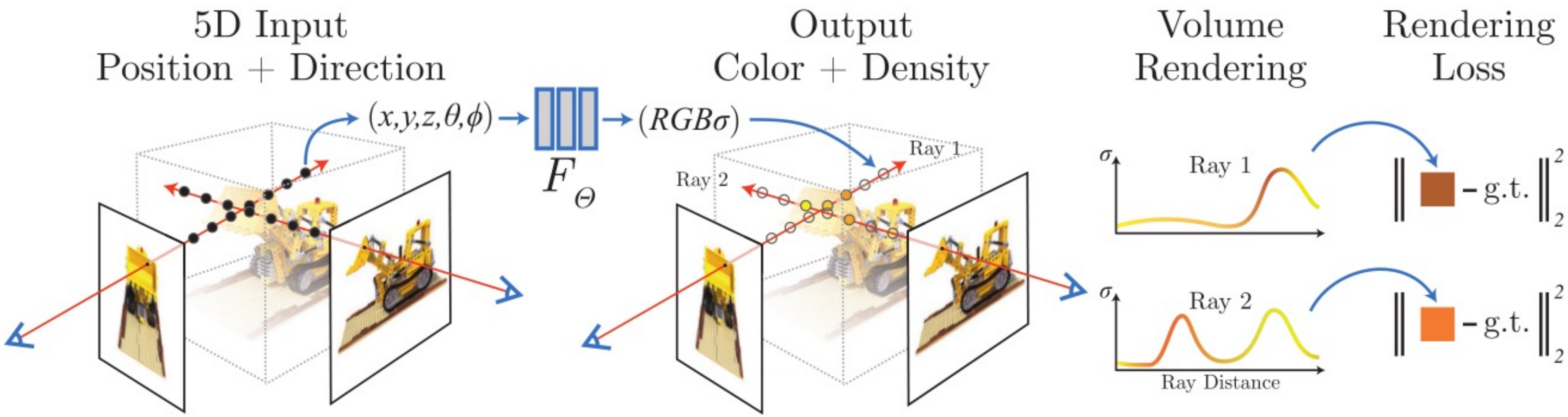
Implicit representation of 2D scene



Training a simple MLP to do this instead.

Background-Neural Radiance Fields (NeRF)

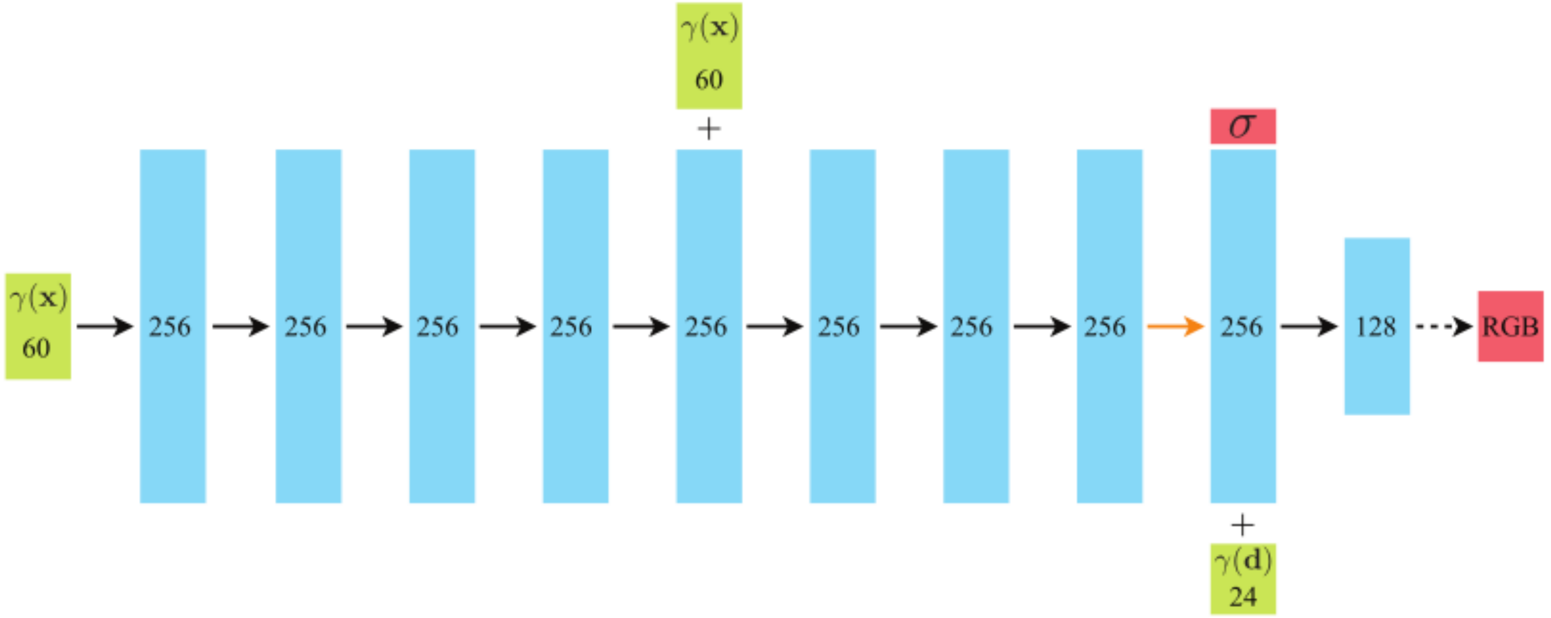
Build implicit representations of 3D scenes via MLP



Background-Neural Radiance Fields (NeRF)

Build implicit representations of 3D scenes via MLP

MLP structure



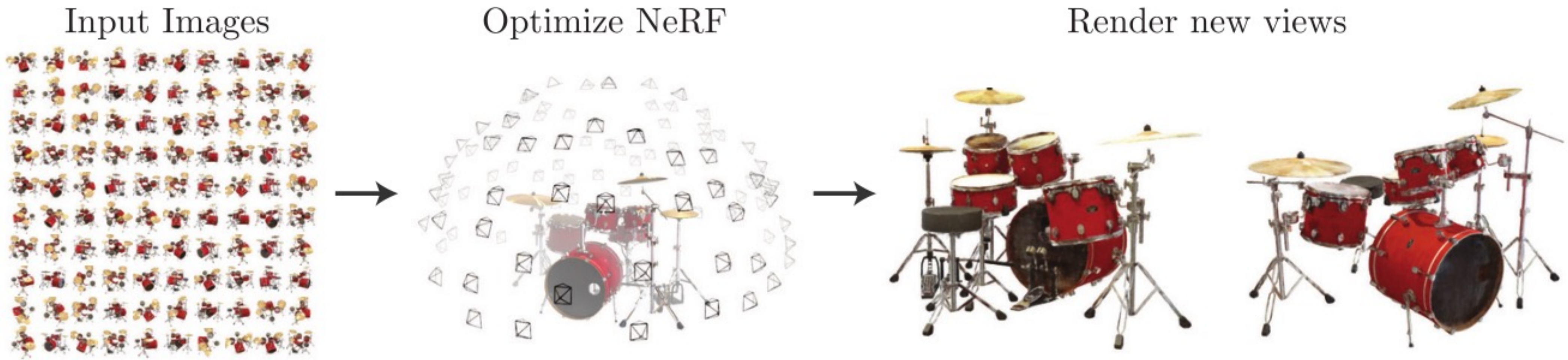
volume rendering

$$C(\mathbf{r}) = \int_{t_n}^{t_f} T(t)\sigma(\mathbf{r}(t))\mathbf{c}(\mathbf{r}(t), \mathbf{d})dt\,, \text{ where } T(t) = \exp\left(-\int_{t_n}^{t} \sigma(\mathbf{r}(s))ds\right)$$

Kajiya et al. Ray tracing volume densities, SIGGRAPH 1984

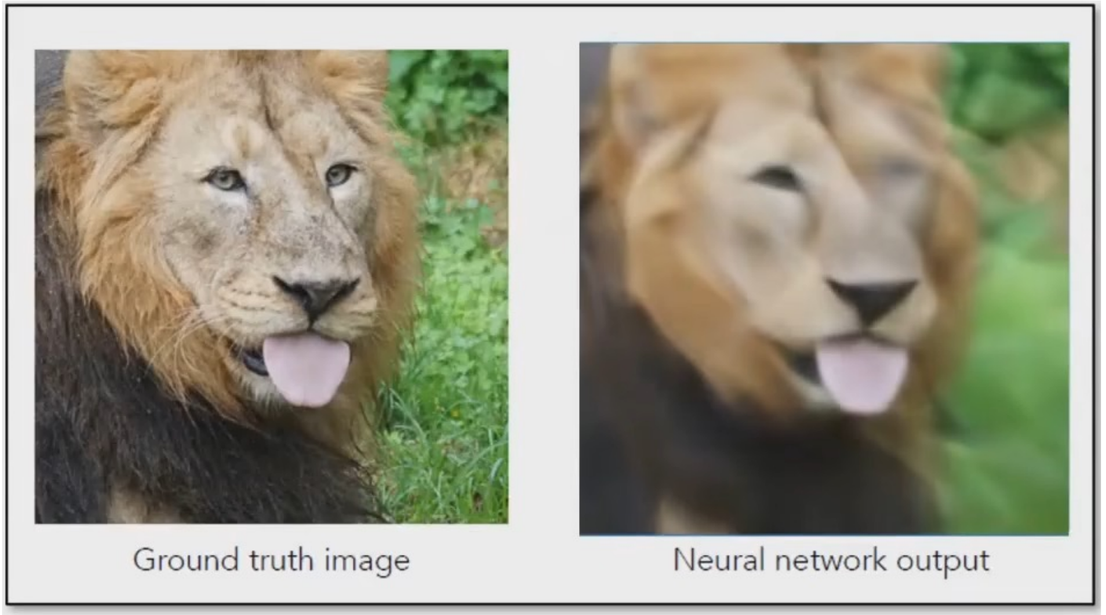
Background-Neural Radiance Fields (NeRF)

Overall pipeline

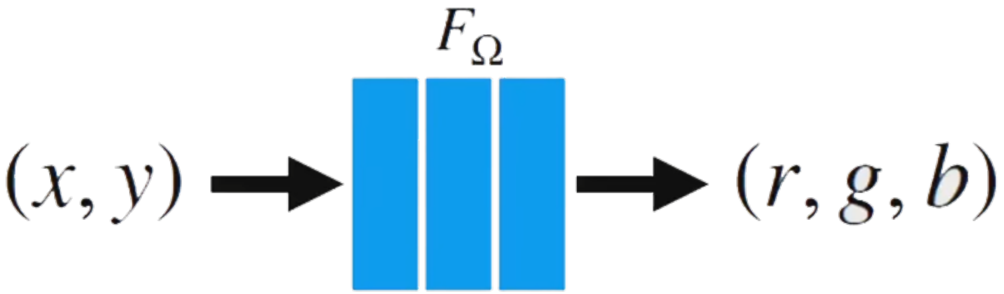


Background-Neural Radiance Fields (NeRF)

Optimizing the NerF: Positional encoding



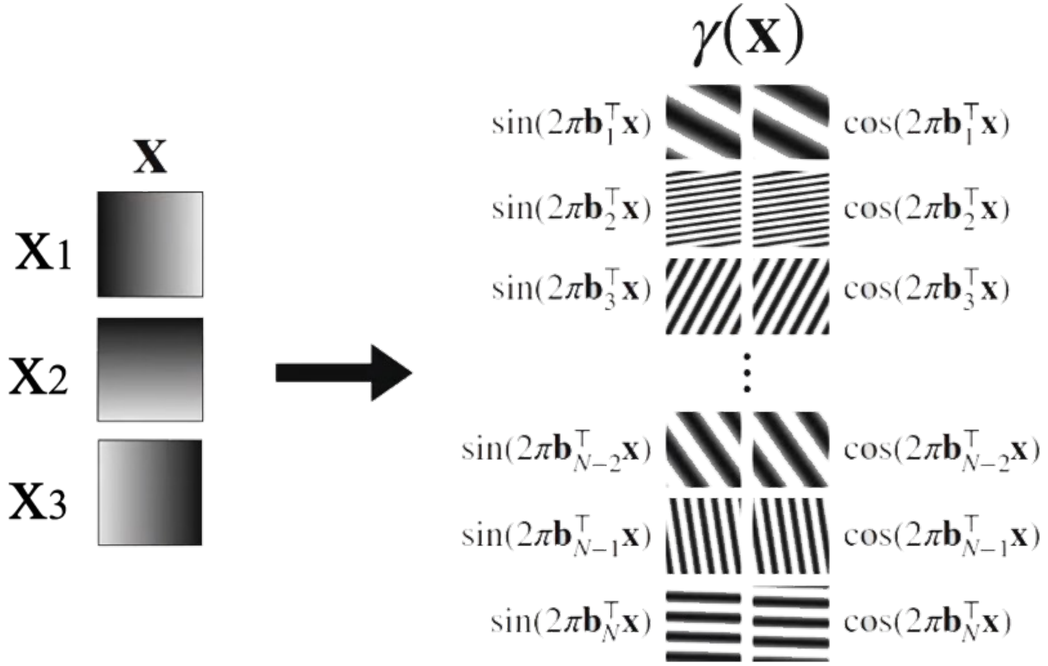
Ground truth image | Neural network output



How to learn high freguency information?

Background-Neural Radiance Fields (NeRF)

Optimizing the NerF: Positional encoding



$$\gamma(p) = \left(\sin\left(2^0 \pi p\right), \cos\left(2^0 \pi p\right), \cdots, \sin\left(2^{L-1} \pi p\right), \cos\left(2^{L-1} \pi p\right) \right)$$

Background-Neural Radiance Fields (NeRF)

Optimizing the NerF: Hierarchical volume sampling

“coarse” network

$$\hat{C}_c(\mathbf{r}) = \sum_{i=1}^{N_c} w_i c_i \,, \qquad w_i = T_i(1 - \exp(-\sigma_i \delta_i))$$

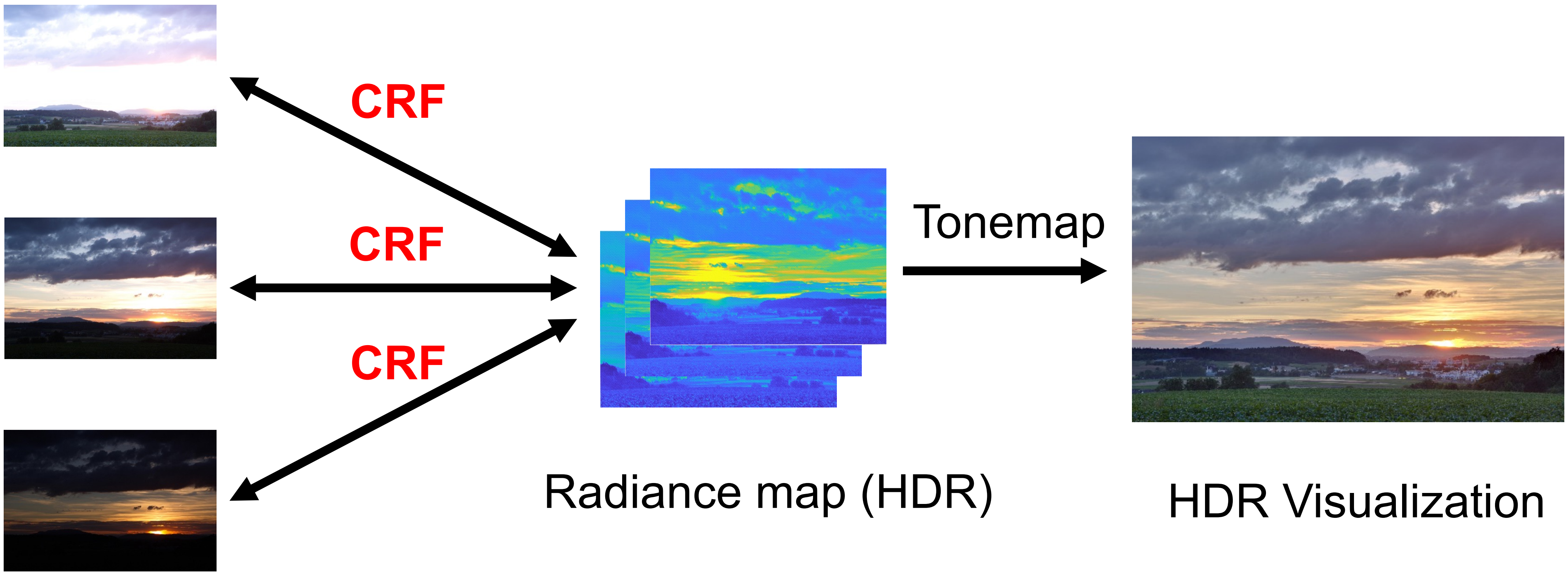
Speed up training

“coarse” network + “fine” network

$$\mathcal{L} = \sum_{\mathbf{r} \in \mathcal{R}} \left[\left\| \hat{C}_c(\mathbf{r}) - C(\mathbf{r}) \right\|_2^2 + \left\| \hat{C}_f(\mathbf{r}) - C(\mathbf{r}) \right\|_2^2 \right]$$

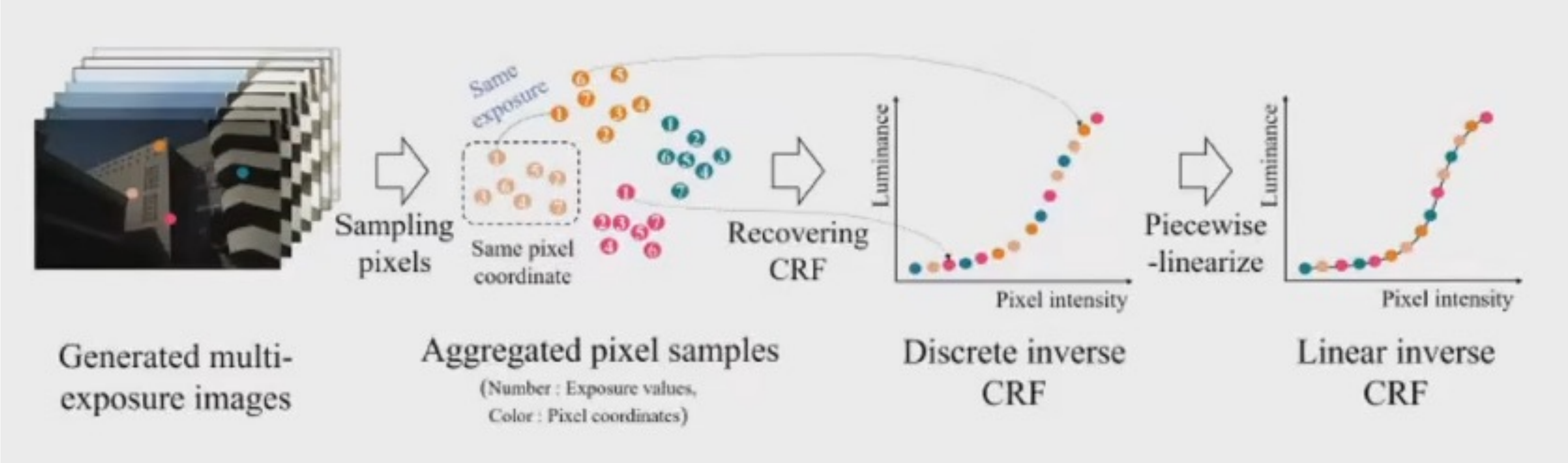
Background-High dynamic range imaging (HDRI)

A typical pipeline



Background-High dynamic range imaging (HDRI)

Traditional CRF Estimation Algorithms



Limitation：Requires aligned multi-exposure images as input

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Method

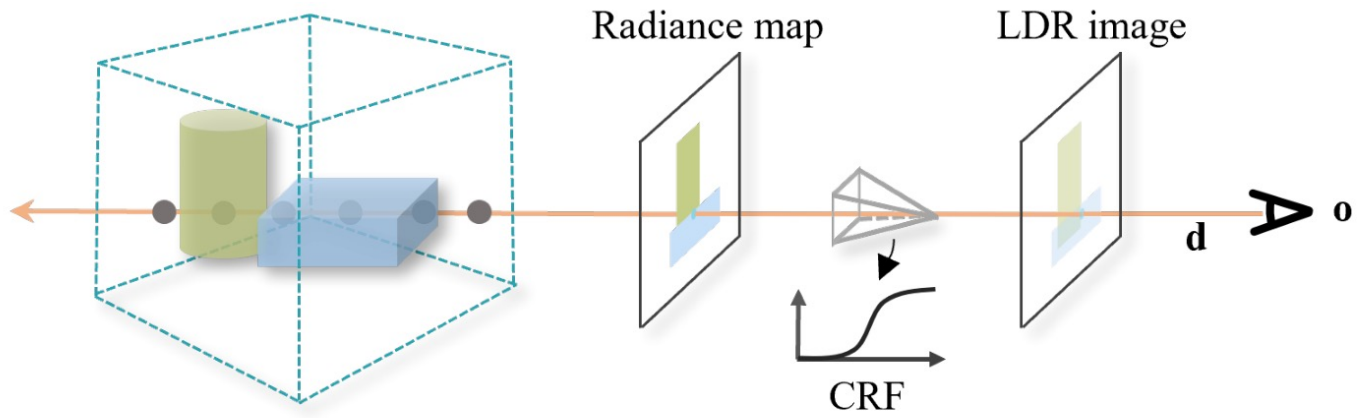
Task description

(a) Input views (b) Novel LDR views (c) One of the novel HDR views

Recover HDR radiance fields from LDR views with different exposure

Method

Radiance to color



Combinie volume rendering and tone-mapping

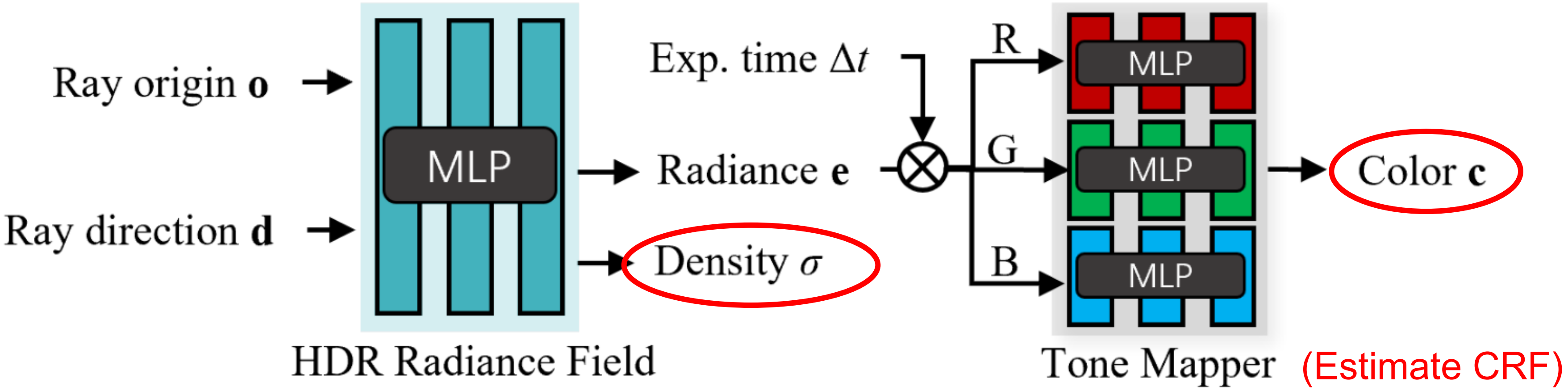
$$\widehat{C}(\mathbf{r}) = \int_{s_n}^{s_f} T(s)\sigma(\mathbf{r}(s))\mathbf{c}(\mathbf{r}(s), \mathbf{d})\, ds$$

$$\mathbf{c}(\mathbf{r}, \Delta t) = g\left(\ln \mathbf{e}(\mathbf{r}) + \ln \Delta t(\mathbf{r})\right)$$

$$\hat{C}(\mathbf{r}, \Delta t) = \int_{s_n}^{s_f} T(s)\sigma\big(\mathbf{r}(s)\big) g\big(\ln \mathbf{e}\big(\mathbf{r}(s)\big) + \ln \Delta t(\mathbf{r})\big)\, ds$$

Method

Pipeline

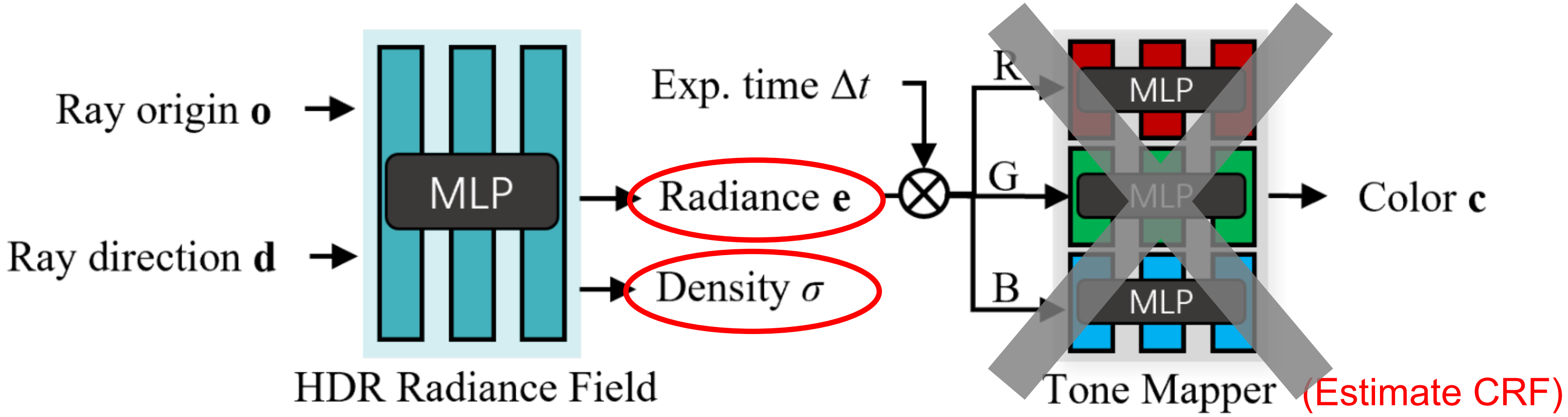


LDR Views Rendering

$$\hat{C}(\mathbf{r}, \Delta t) = \int_{s_n}^{s_f} T(s)\sigma\big(\mathbf{r}(s)\big) g\big(\ln \mathbf{e}(\mathbf{r}(s)) + \ln \Delta t(\mathbf{r})\big)\, \mathrm{d}s$$

Method

Pipeline



HDR Views Rendering

$$\hat{E}(\mathbf{r}) = \int_{s_n}^{s_f} T(s)\sigma(\mathbf{r}(s))\mathbf{e}(\mathbf{r}(s))\,\mathrm{d}s$$

Method

Loss Function

Color reconstruction loss

$$\mathcal{L}_c = \sum_{\mathbf{r} \in \mathcal{R}(\mathbf{P})} \|\widehat{C}_c(\mathbf{r}, \Delta t) - C(\mathbf{r}, \Delta t)\|_2^2 + \|\widehat{C}_f(\mathbf{r}, \Delta t) - C(\mathbf{r}, \Delta t)\|_2^2$$

Unit exposure loss $\mathcal{L}_u = \|g(0) - C_0\|_2^2$ C_0 : the midway of the pixel value

(a) with $\mathcal{L}_u$ (b) w/o $\mathcal{L}_u$ (c) GT (d) CRFs

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Experiment

Novel Views Randering

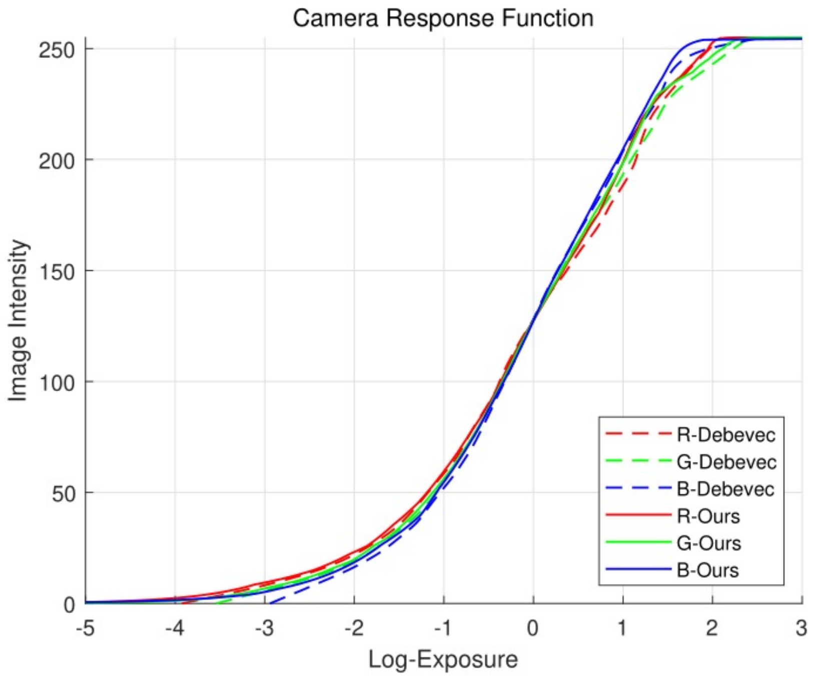
LDR GT

LDR output

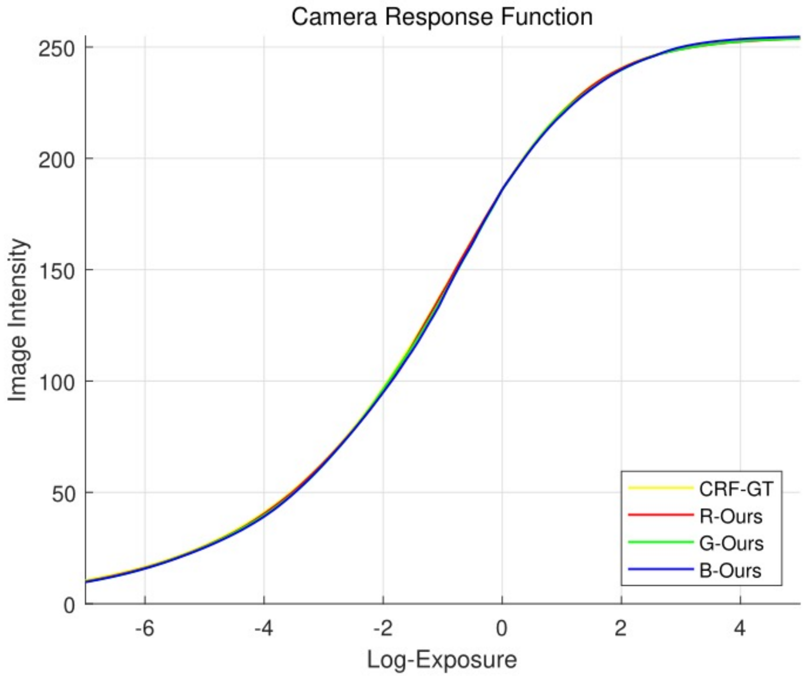
HDR output

Experiment

Estimated CRF by MLP



Comparisons with Debevec's method
in real scene



Comparisons with GT CRF
in synthetic scene

Experiment

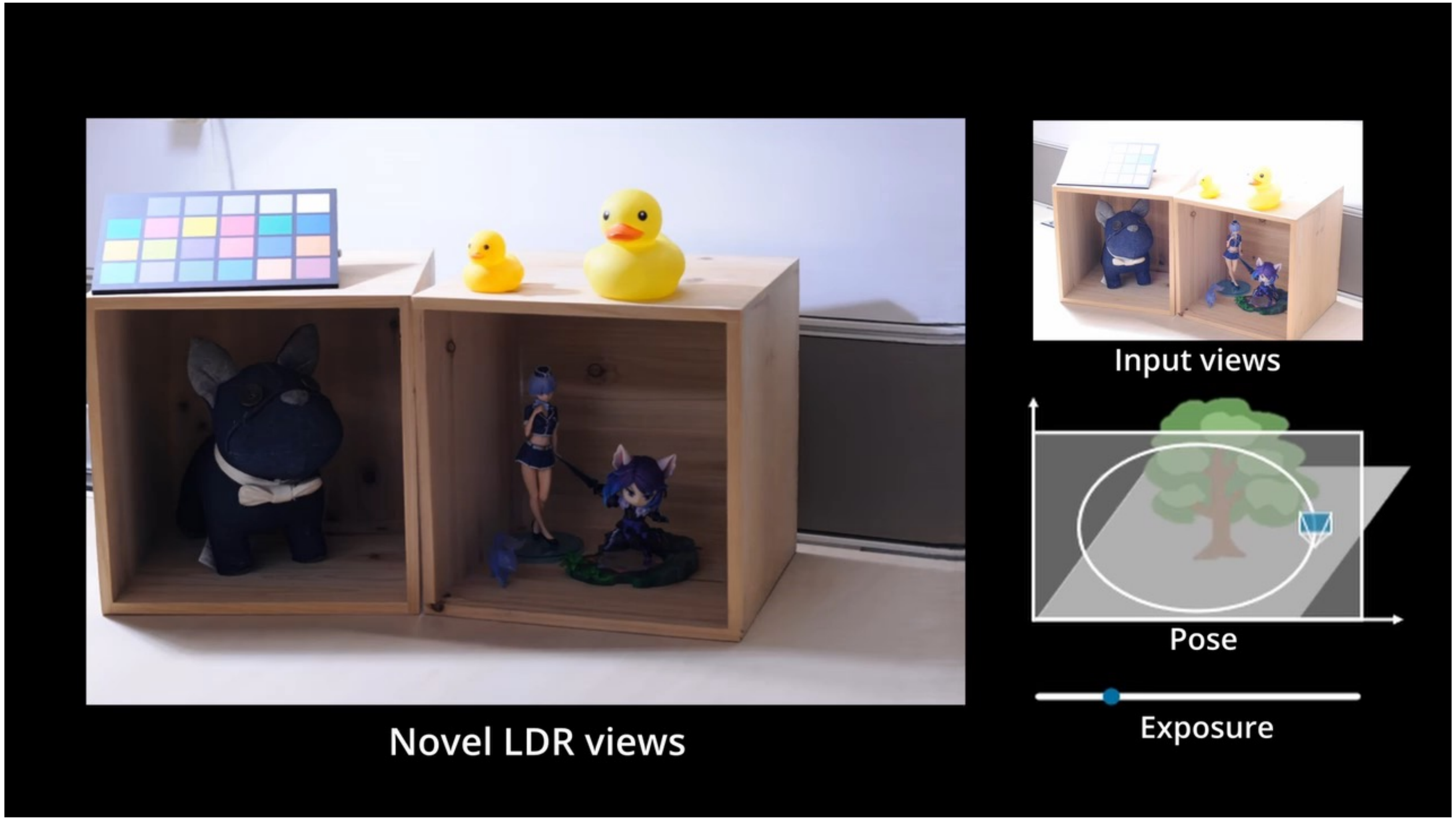
Quantitative comparisons with baseline methods
on synthetic and real scenes

		LDR-OE (t_1, t_3, t_5)			LDR-NE (t_2, t_4)			HDR		
		PSNR↑	SSIM↑	LPIPS↓	PSNR↑	SSIM↑	LPIPS↓	PSNR↑	SSIM↑	LPIPS↓
NeRF [42]	Syn.	13.97	0.555	0.376	—	—	—	—	—	—
	Real	14.95	0.661	0.308	—	—	—	—	—	—
NeRF-W[1][37]	Syn.	29.83	0.936	0.047	29.22	0.927	0.050	—	—	—
	Real	28.55	0.927	0.094	28.64	0.923	0.089	—	—	—
NeRF-GT[2][42]	Syn.	37.66	0.965	0.028	35.87	0.955	0.032	37.80	0.964	0.029
	Real	34.55	0.958	0.057	34.59	0.956	0.051	—	—	—
Ours†	Syn.	—	—	—	—	—	—	—	—	—
	Real	30.37	0.944	0.075	29.37	0.938	0.078	—	—	—
Ours	Syn.	39.07	0.973	0.026	37.53	0.966	0.024	36.40	0.936	0.018
	Real	31.63	0.948	0.069	31.43	0.943	0.069	—	—	—

[1] The exposures of input views for NeRF-W are randomly selected from all five exposures to learn five appearance vectors for testing.
[2] A version of NeRF (as the upper bound of our method) that is trained from LDR images with consistent exposures or HDR images.
† An ablation study of our method that models the tone-mapping operations of RGB channels with a single MLP.

Experiment

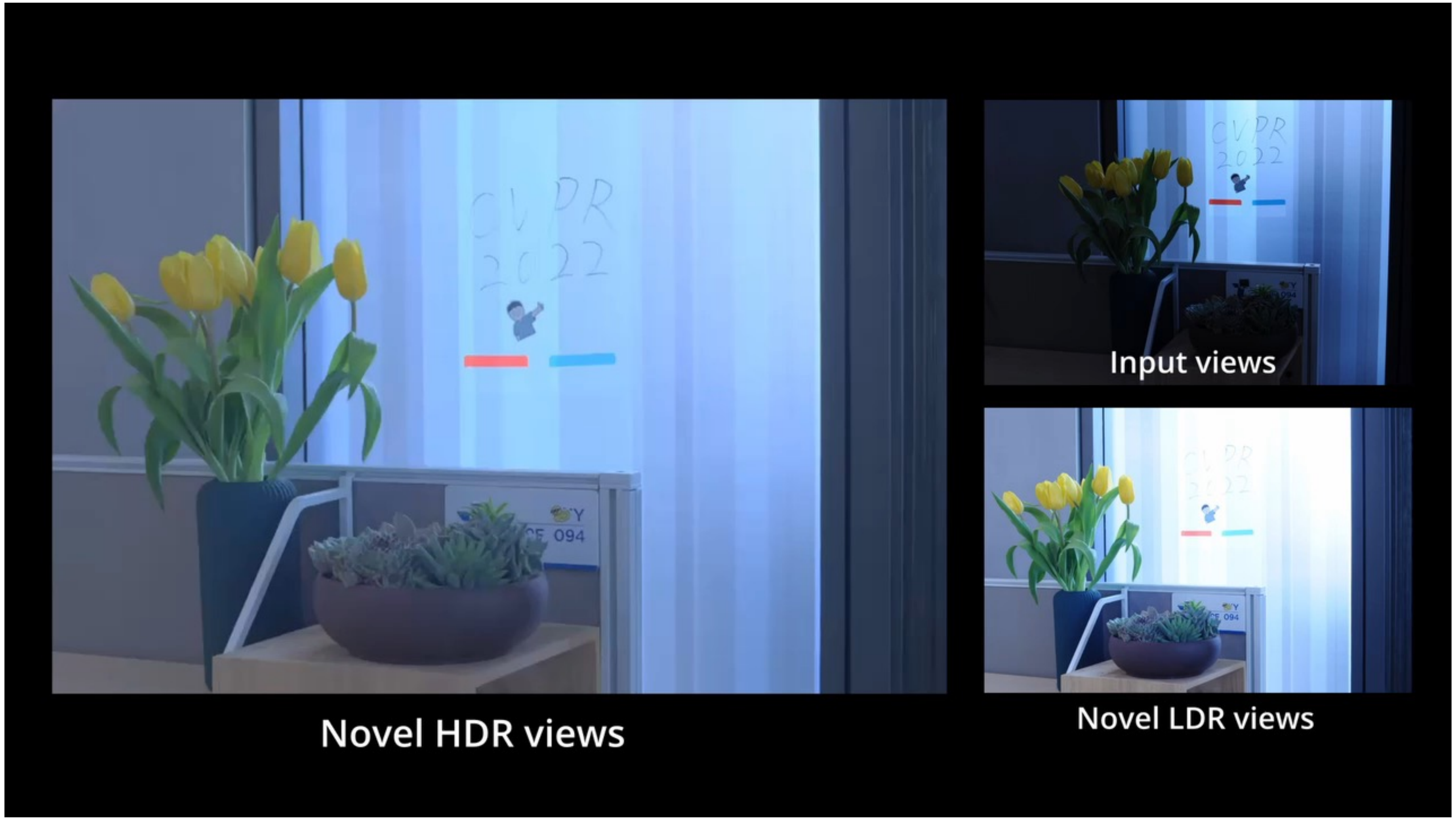
Novel LDR views



Video website: https://shsf0817.github.io/hdr-nerf/images/ldr1.mp4

Experiment

Novel HDR views (Tone-mapped)



Video website: https://shsf0817.github.io/hdr-nerf/images/hdr1.mp4

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Conclusion

Contribution:

- Proposing a novel method to recover the high dynamic range neural radiance field from a set of LDR views with different exposures.
- Rendering novel HDR views without ground-truth HDR supervision.
- Producing high-fidelity LDR views with specified exposures.

Future work:

- Dynamic 3D scene
- HDR Video
- Joint with denoise in raw data

Thanks for watching.

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