NeRF: Representing Scenes as Neural Radiance Fields for View Synthesis

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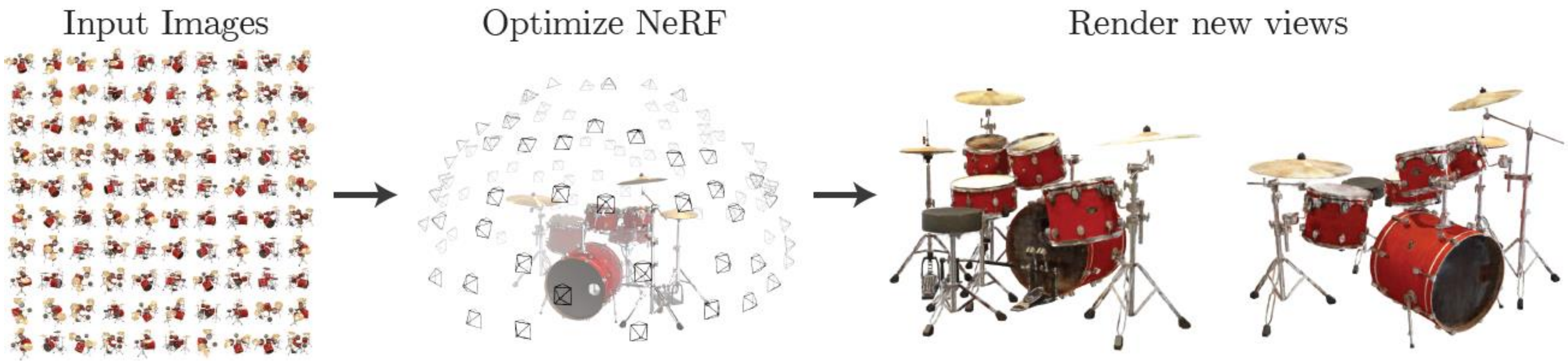
NeRF

B. Mildenhall, P. Srinivasan, and M. Tancik, “NeRF: Representing Scenes as Neural Radiance Fields for View Synthesis,” in Proceedings of European Conference on Computer Vision, (Springer, 2020).



- Neural radiance fields (NeRF): scene representation using neural network
- Input images rendered from discretized viewpoint
  → Rendering new views which is not included in training dataset

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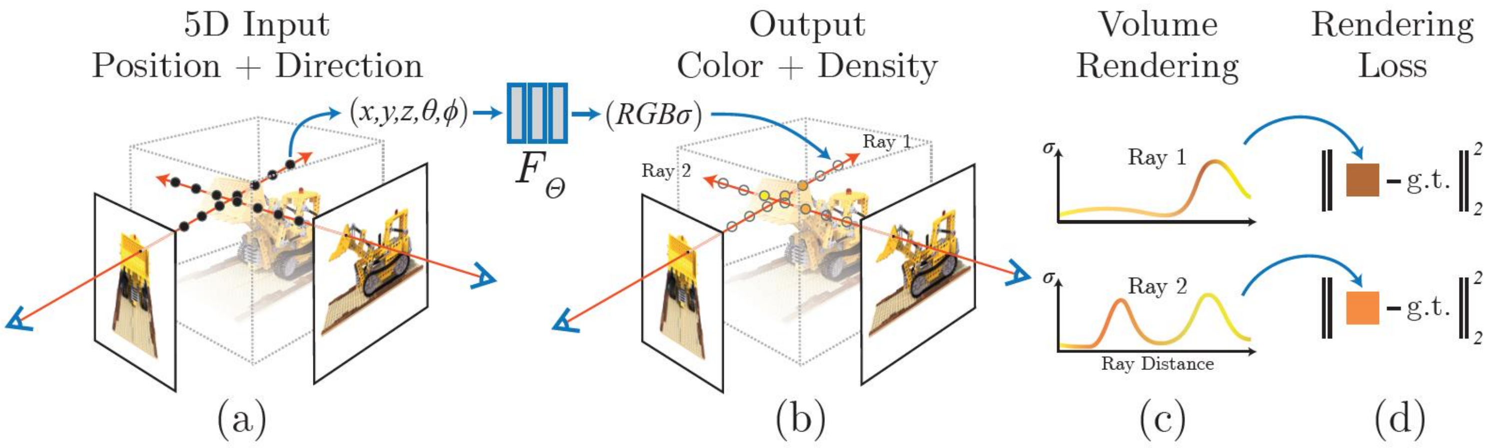
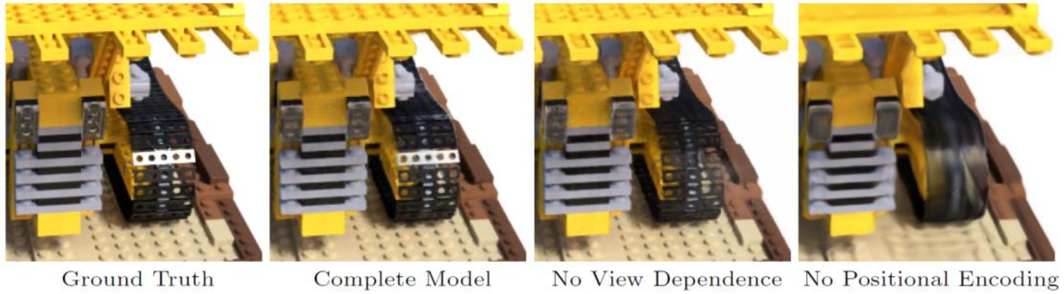
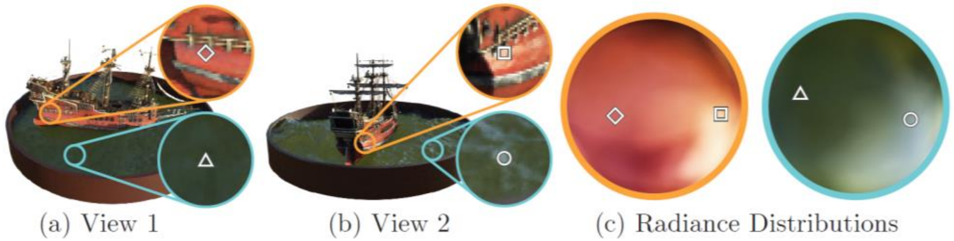


- N of 2D image → Synthesizing random view image
- $F_\Theta : (\mathbf{x}, \mathbf{d}) \rightarrow (\mathbf{c}, \sigma)$
  Replacing with deep neural network
- **c** : with respect to location **x** and viewing direction **d**
  $\boldsymbol{\sigma}$: with respect to location **x**
- Continuous radiance field is synthesized for the changing in viewing direction.





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N. Max, "Optical models for direct volume rendering," IEEE Trans. Vis. Comp. Graph. 1, 99–108 (1995).

Volume rendering

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

$$t_i \sim \mathcal{U}\left[t_n + \frac{i-1}{N}(t_f - t_n),\; t_n + \frac{i}{N}(t_f - t_n)\right].$$

$$\hat{C}(\mathbf{r}) = \sum_{i=1}^{N} T_i(1 - \exp(-\sigma_i\delta_i))\mathbf{c}_i\,, \text{ where } T_i = \exp\left(-\sum_{j=1}^{i-1}\sigma_j\delta_j\right), \delta_i = t_{i+1} - t_i$$

- $\mathbf{r}(t) = \mathbf{o} + t\mathbf{d}$ → ray
- $\sigma(\mathbf{r}(t))$ → the differential probability of a ray terminating at an infinitesimal particle at location $\mathbf{x}$
- T(t) → accumulated transmittance, the probability that the ray travels from t_n to t without hitting any other particle.
- Deterministic quadrature limit resolution of NeRF → stratified sampling

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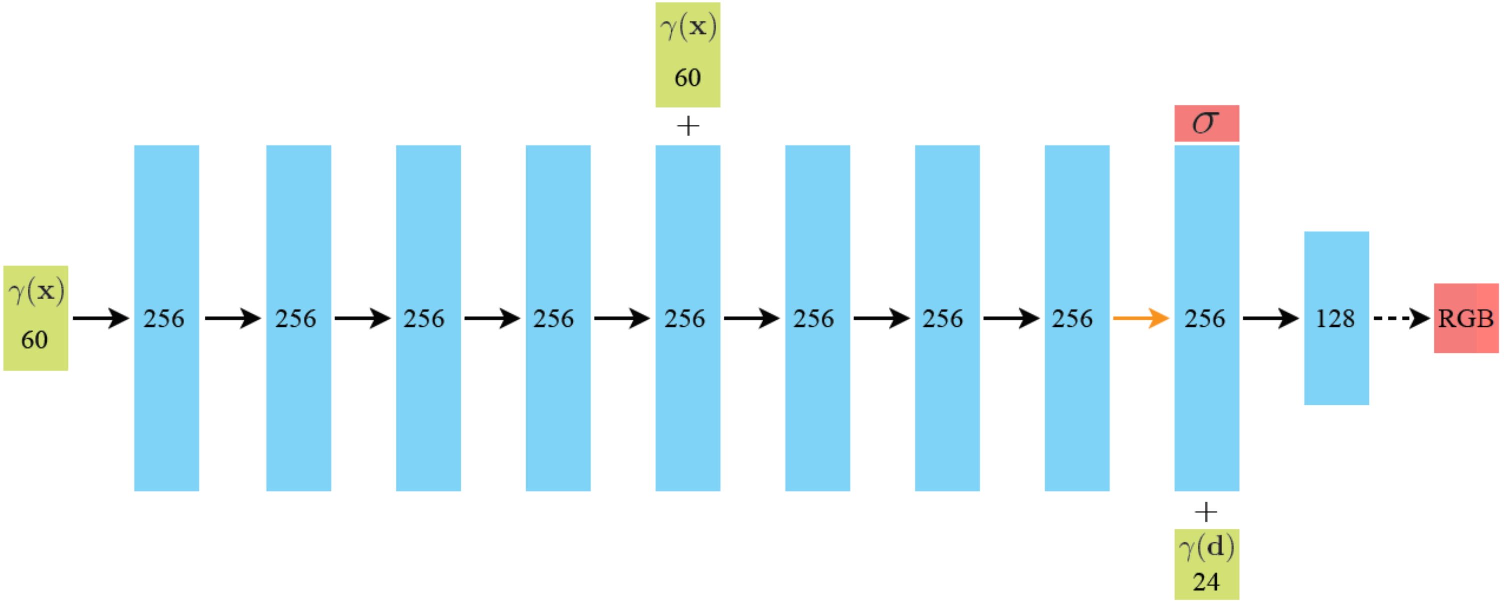
Implementation – positional encoding and network architecture

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



- Mapping the inputs to a higher dimensional space using high frequency functions before passing them to the network → better fitting of data that contains high frequency variation
- This paper set $L = 10$ for $\gamma(\mathbf{x})$ and $L = 4$ for $\gamma(\mathbf{d})$.

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Hierarchical volume sampling

- Sample N_c locations using stratified sampling → evaluate **"coarse"** network
- Given "coarse" network, producing a more informed sampling of points N_f → evaluate **"fine"** network
- Final rendered color of the ray $\hat{C}_f(\mathbf{r})$ is computed using $N_c + N_f$ samples.

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

Implementation details

- At each optimization iteration,
  randomly sampling camera rays → hierarchical sampling $N_c + N_f$ → volume rendering → computing loss
- $\mathcal{L} = \sum_{r \in \mathcal{R}} \left[\left\| \hat{C}_c(\mathbf{r}) - C(\mathbf{r}) \right\|_2^2 + \left\| \hat{C}_f(\mathbf{r}) - C(\mathbf{r}) \right\|_2^2 \right]$
- 4096 rays, $N_c = 64, N_f = 128$.
- The optimization for a single scene typically takes around 100-300k iterations to converge on a single Nvidia V100 GPU (about 1-2 days)

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Results