LiDAR-in-the-loop Hyperparameter Optimization

Felix Goudreault[1] Dominik Scheuble[2] Mario Bijelic[3] Nicolas Robidoux[1] Felix Heide[1,3]

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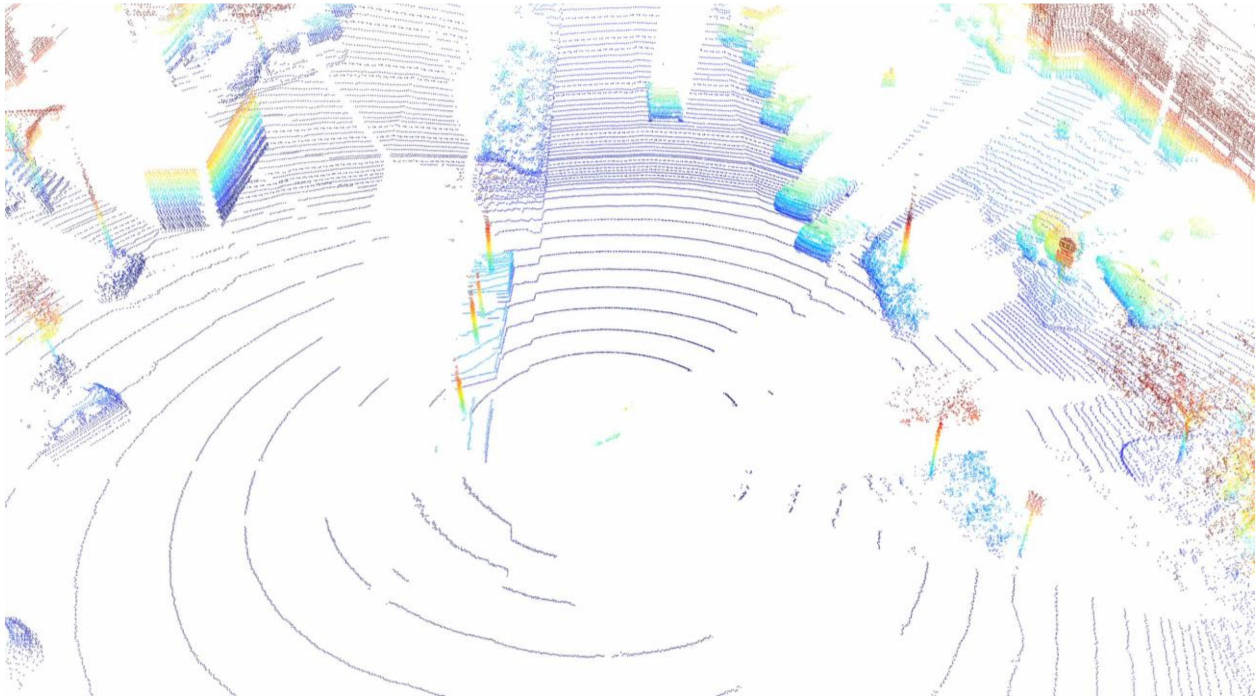
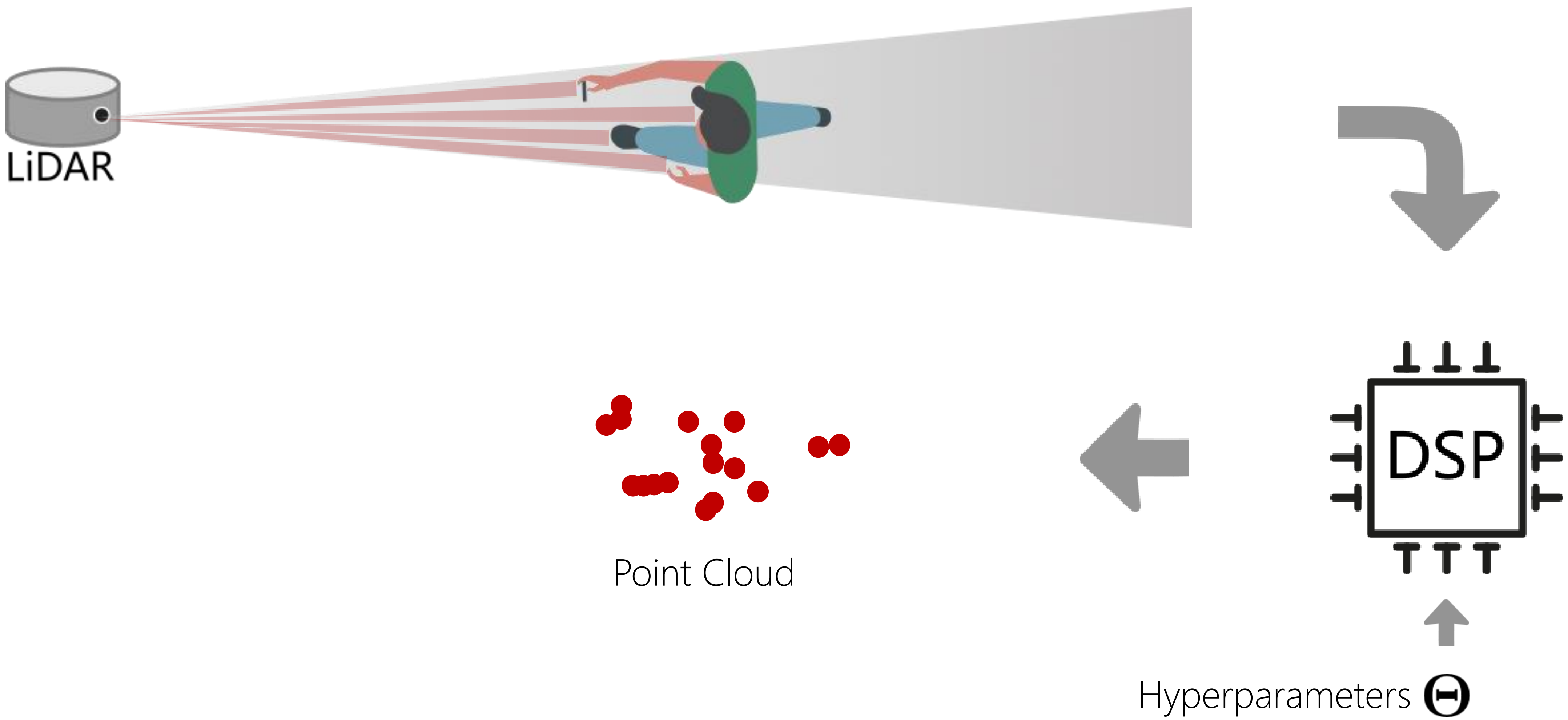
Website and Code:

https://light.princeton.edu/lidar-in-the-loop-hyperparameter-optimization/

LiDAR as a Cornerstone Sensor Modality



LiDAR Working Principles

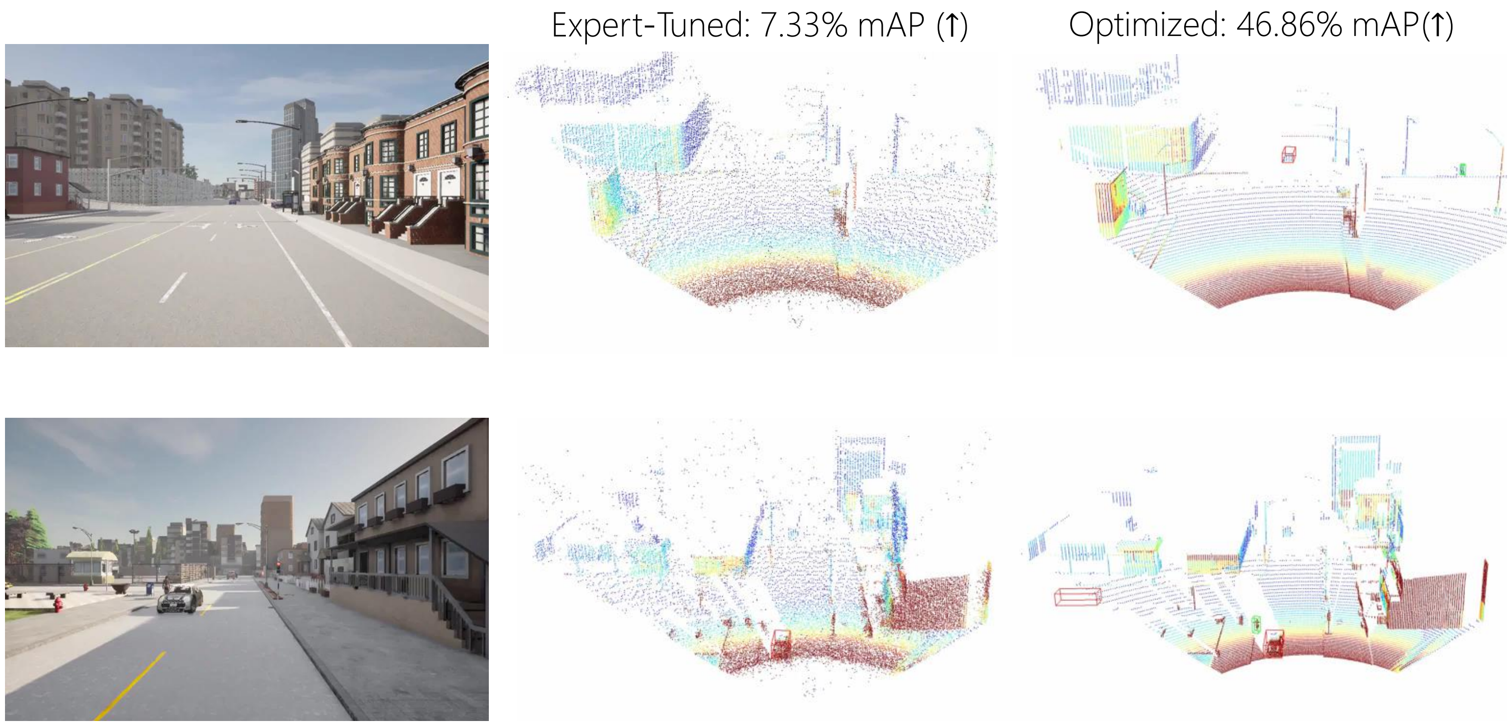


Learn LiDAR Hyperparameters

LiDAR-in-the-loop optimization for 3D object detection, depth and intensity estimation

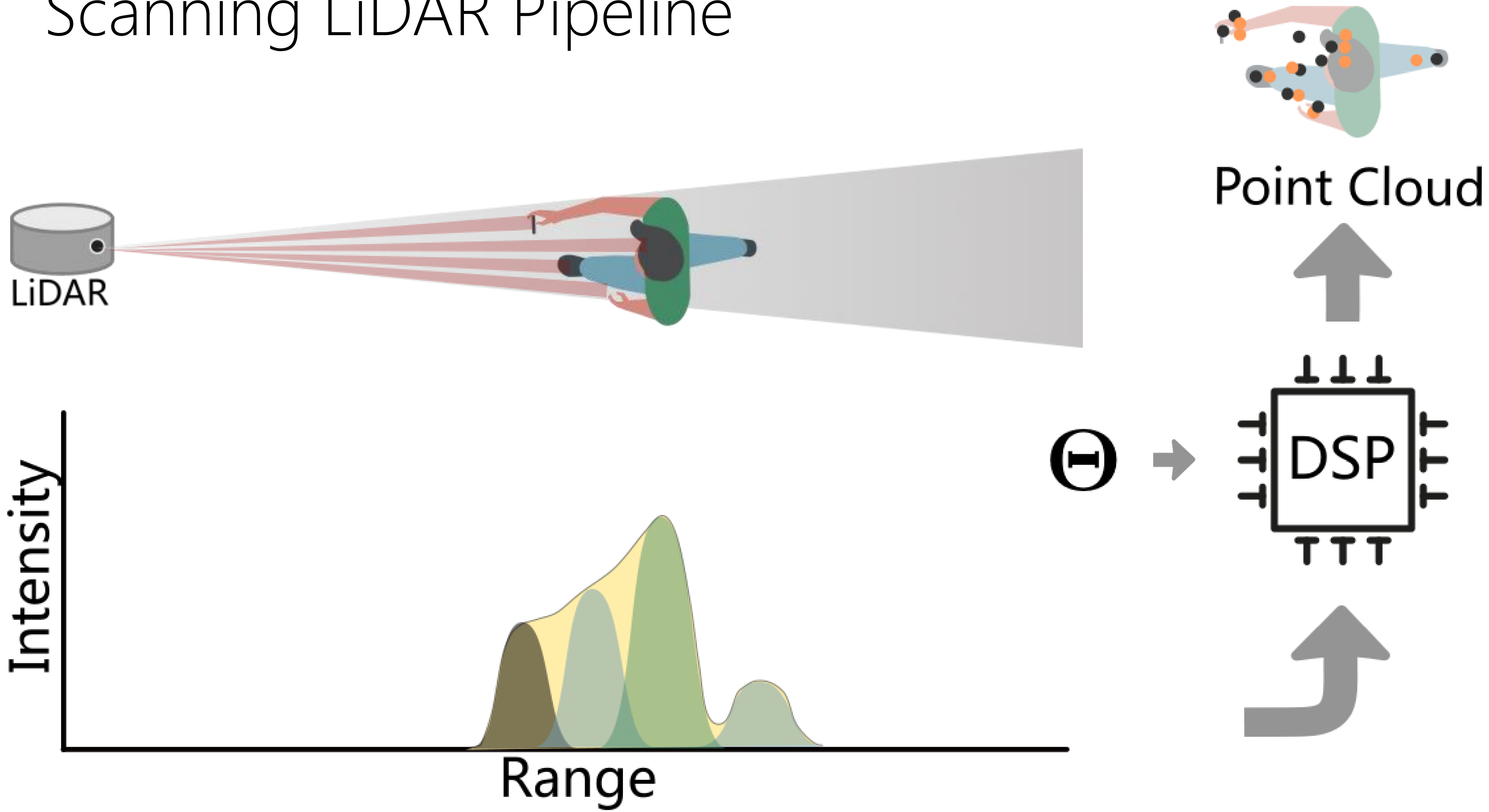
0th-order solver for optimal LiDAR hyperparameters

Realistic LiDAR waveform simulation for CARLA



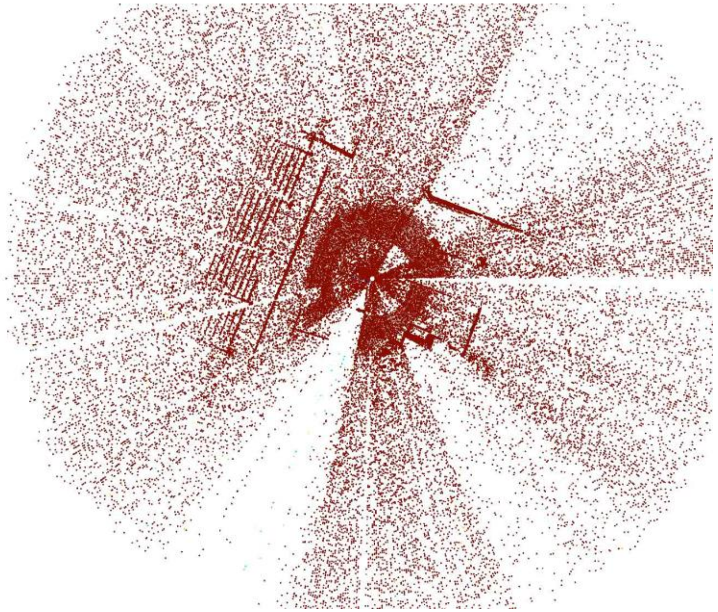
Webpage and Code at https://light.princeton.edu/publication/lidar-in-the-loop-hyperparameter-optimization/

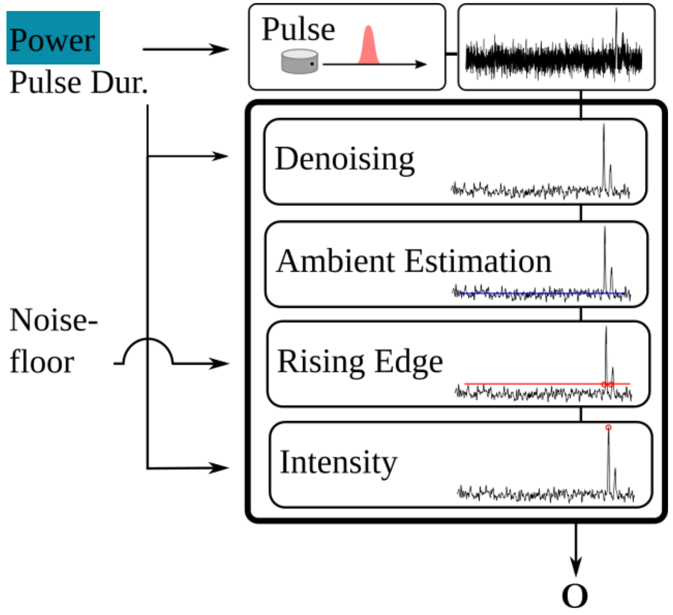
Scanning LiDAR Pipeline



LiDAR Sensing Hyperparameters

Power
Pulse Dur.
Noise floor





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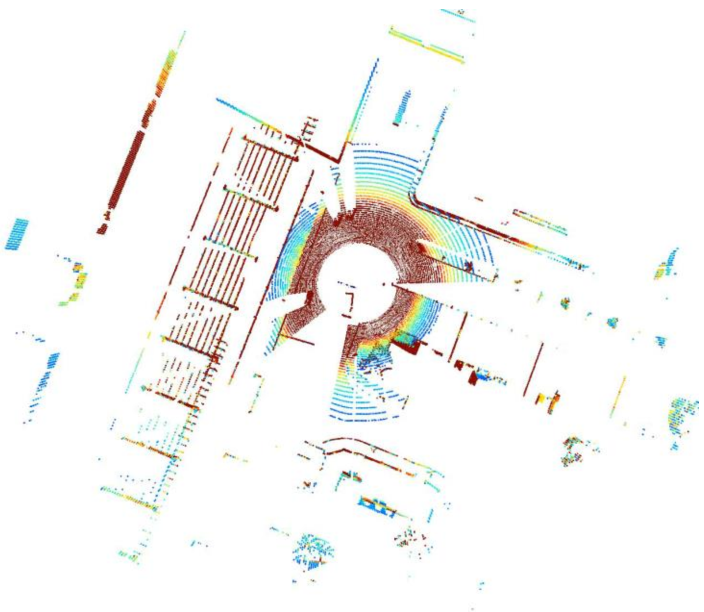

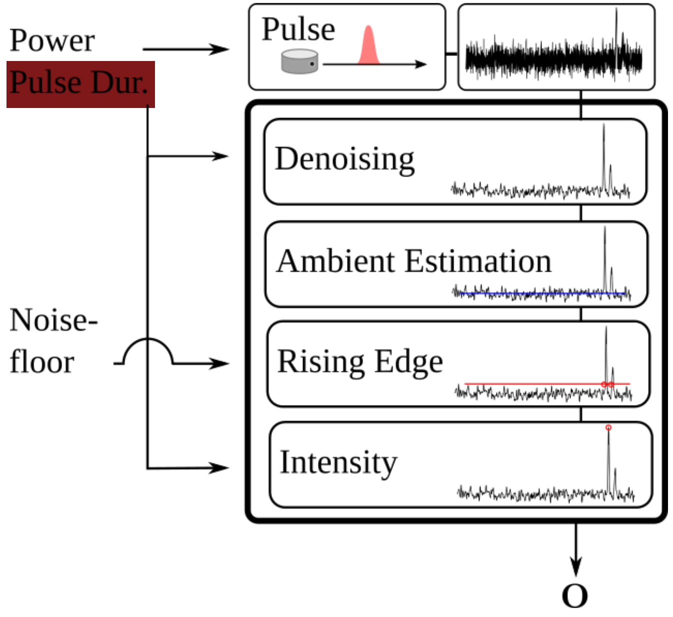

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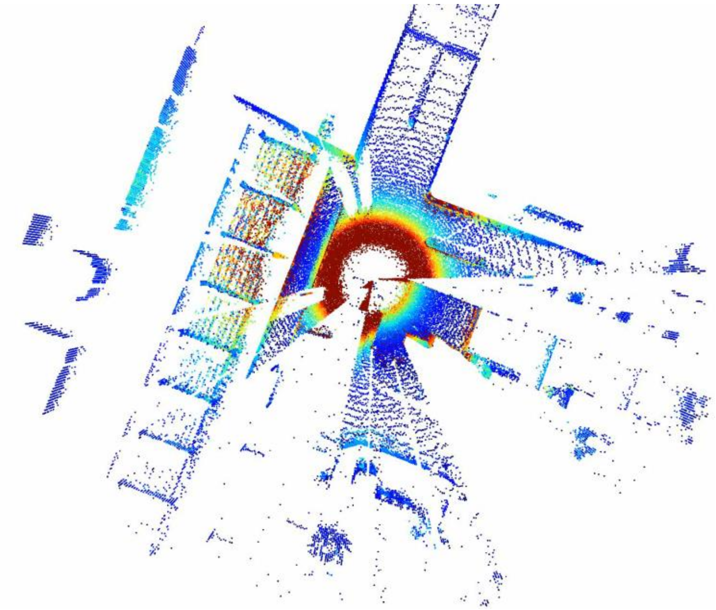
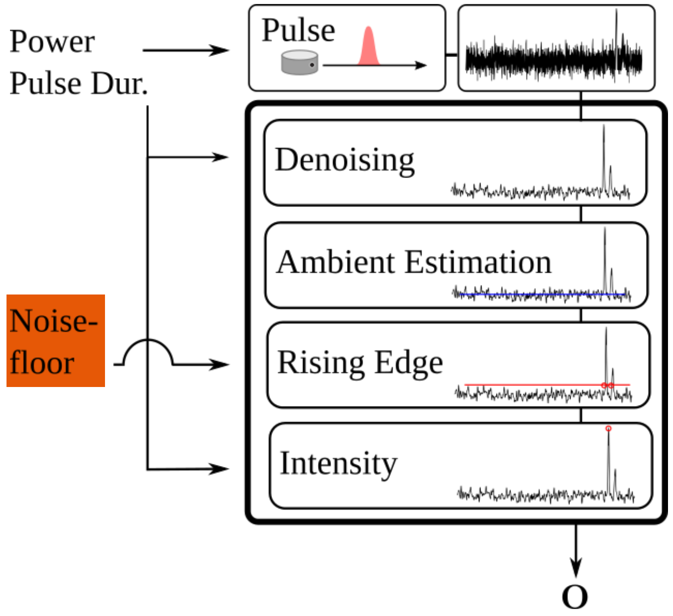
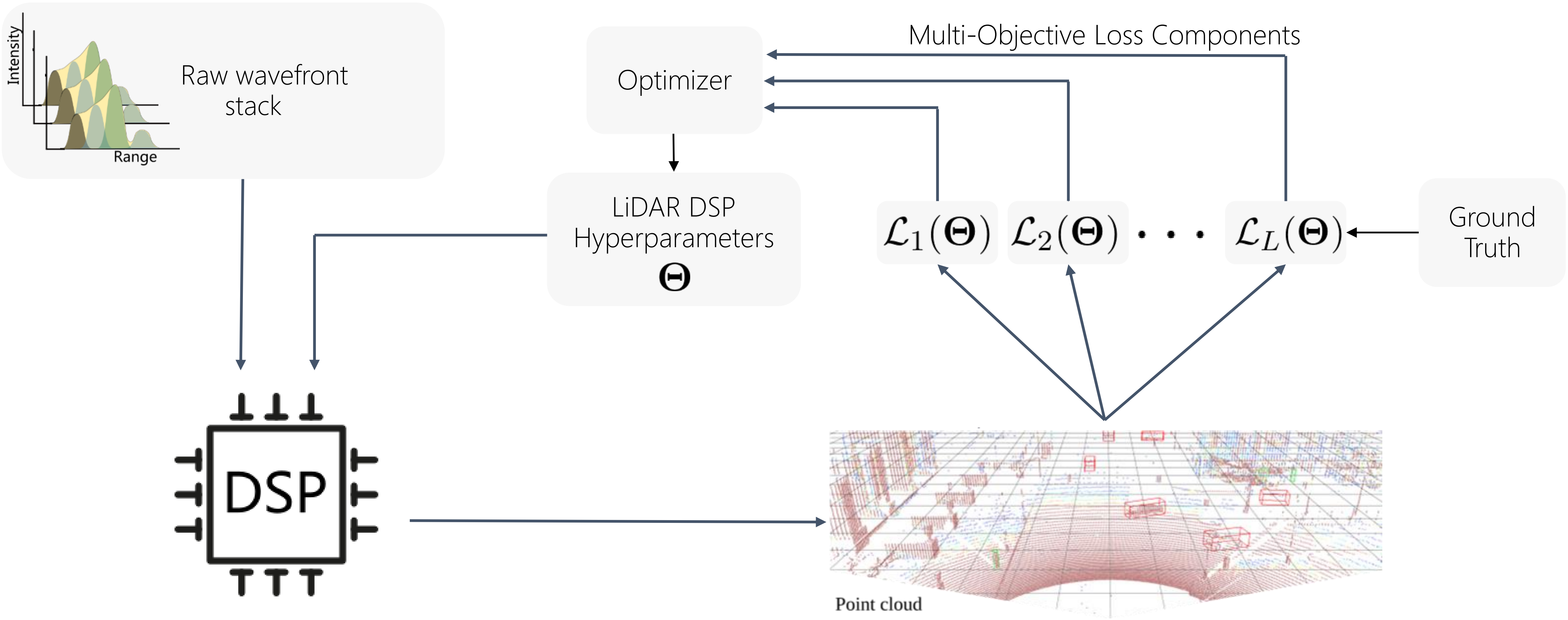
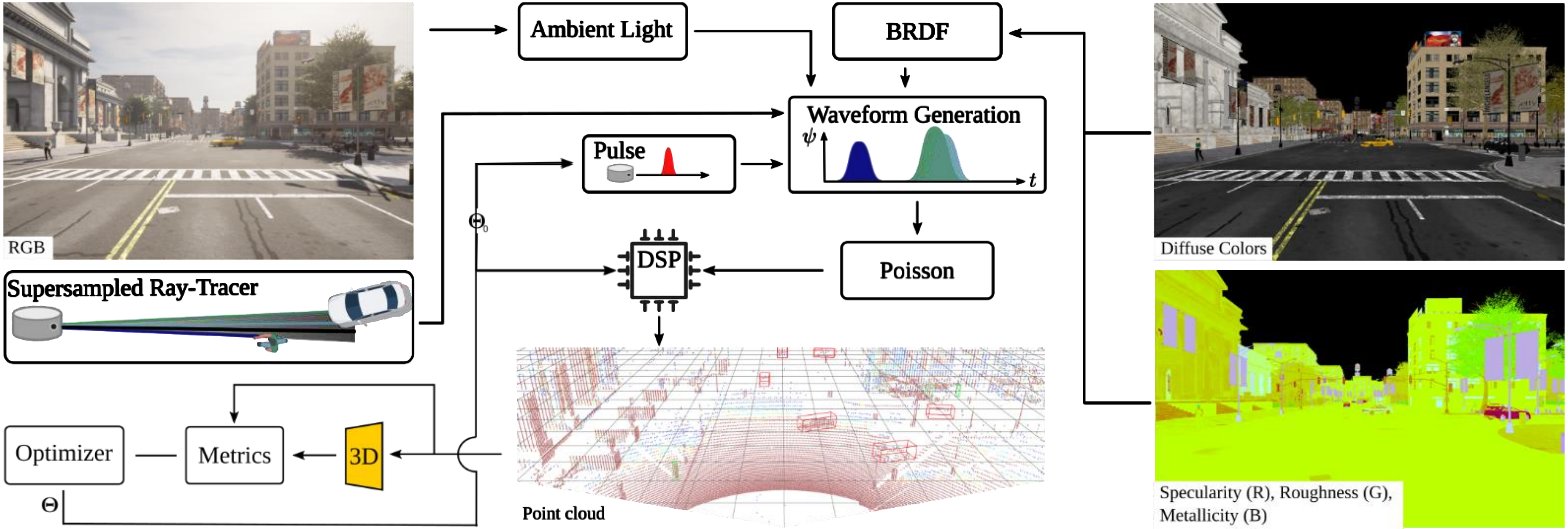




LiDAR-in-the-Loop Optimization



Raw LiDAR Simulation



Black Box Multi-Objective Solver

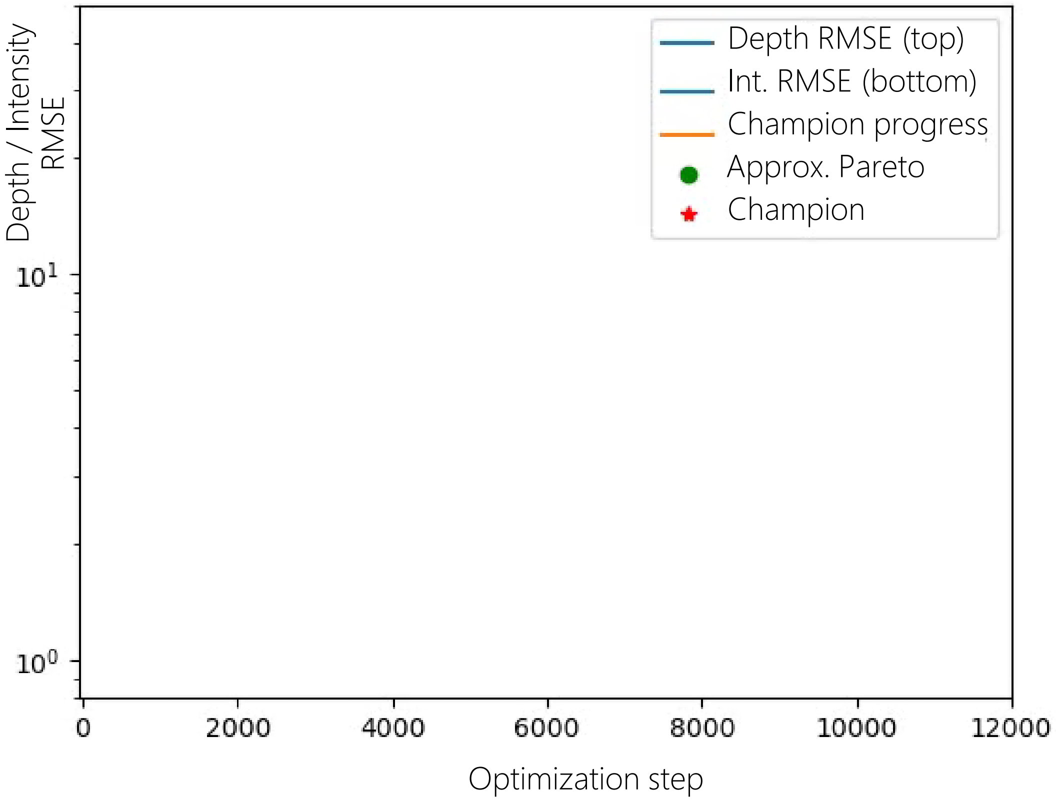
Algorithm 1 LiDAR Hyperparameter Optimization.

Require: LiDAR $\mathbf{\Phi}$, $\mathbf{\Theta} \in [0,1]^{\mathrm{P}}$ (initial hyperparameter vector), $\mathrm{N} \in \mathbb{N}^*$ (number of generations), $\varepsilon \in \left(0, \frac{1}{3}\right)$ (small bound), $\mathbf{C} \in \mathbb{R}^{\mathrm{P} \times \mathrm{P}}$ (CMA-ES "directional" covariance matrix factor), $\sigma \in \left[\varepsilon, \frac{1}{3}\right]$ (square root of covariance matrix "scale" factor)

```
p ← 0, c ← 0 (CMA-ES path vectors), Θ_center ← Θ
for n = 1 to N do
    Θ^{0,n} ← Θ
    L^{0,n} ← losses for LiDAR Φ modulated by Θ^{0,n}
    for p = 1 to 4P do
        Θ^{p,n} ← random draw from Gaussian distribution with
            covariance matrix σ^2 C centered at Θ_center
        Θ^{p,n} ← Θ^{p,n} + Gaussian distribution with diagonal cov.
            matrix proportional to square of quantization grain [48]
        Θ^{p,n} ← Θ^{p,n} reflected back into [0,1]^P
        L^{p,n} ← losses for LiDAR Φ modulated by Θ^{p,n}
    end for
    Compute {M^{q,m,n}}_{q∈{0,...,4P},m∈{1,...,n}} by including
        {L^{p,n}}_{p∈{0,...,4P}} in rank computations
    Use "eager" [36] centroid weights with λ = 4P, μ = 3P
    if n is odd then
        Use "stable" [48] centroid weights with λ = μ = 4P
    end if
    Standard CMA-ES update [21] of Θ, σ, C, p, c based on
        {Θ^{p,n}}_{p∈{1,...,4P}} and {M^{p,n,n}}_{p∈{1,...,4P}}
    Θ_center ← Θ
    if min_{p∈{0,...,4P}} M^{p,n,n} < min_{q∈{0,...,4P},m∈{1,...,n}} M^{q,m,n}
    then
        Θ_center ← minimizer closest to centroid of minimizers
    end if
end for
return Θ^{p,n} in the (guaranteed nonempty) intersection of
    the Pareto front and the set of minimizers of M^{q,m,N}, with
    ties resolved by choosing the one closest to their centroid and
    remaining ties resolved by maximizing n, then p
```

Optimization Process

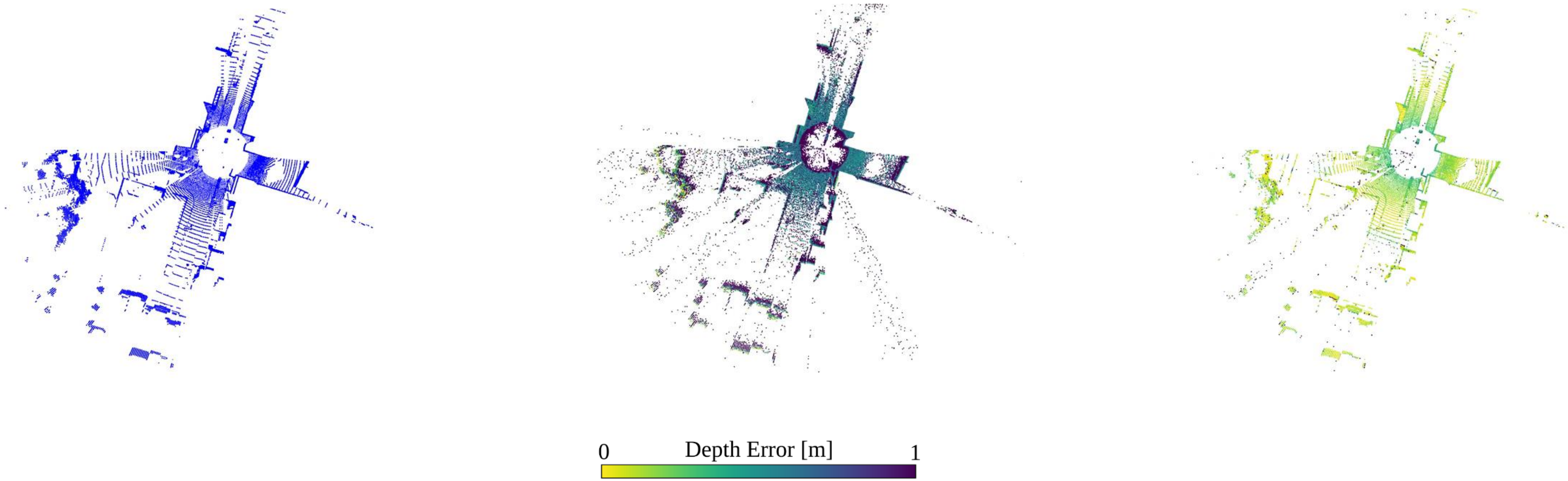
Point cloud depth error for every optimization step



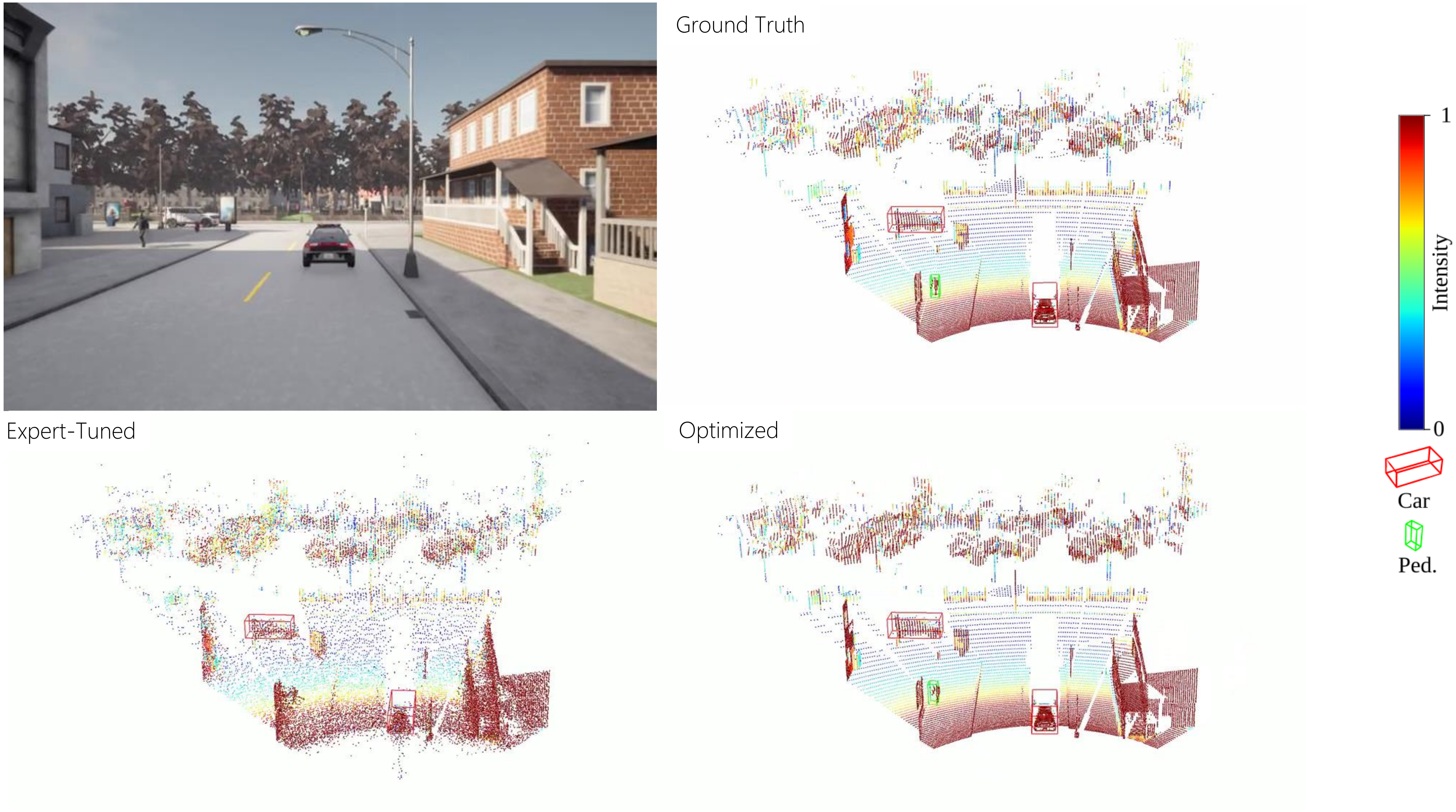
Convergence of depth and intensity RMSE showing current champion and approximate Pareto points

Experimental Results – Depth and Intensity

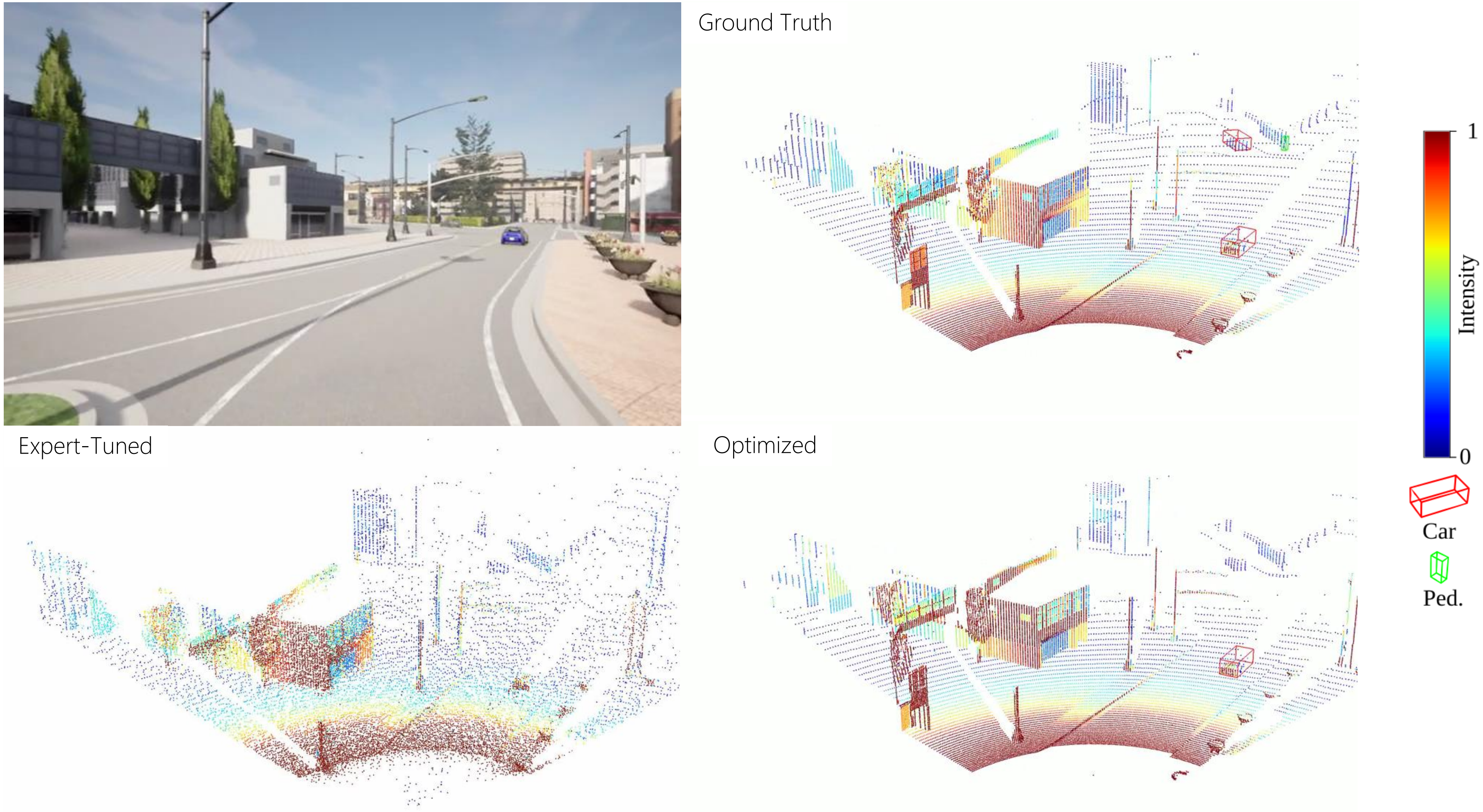
Ground Truth Expert-Tuned Optimized



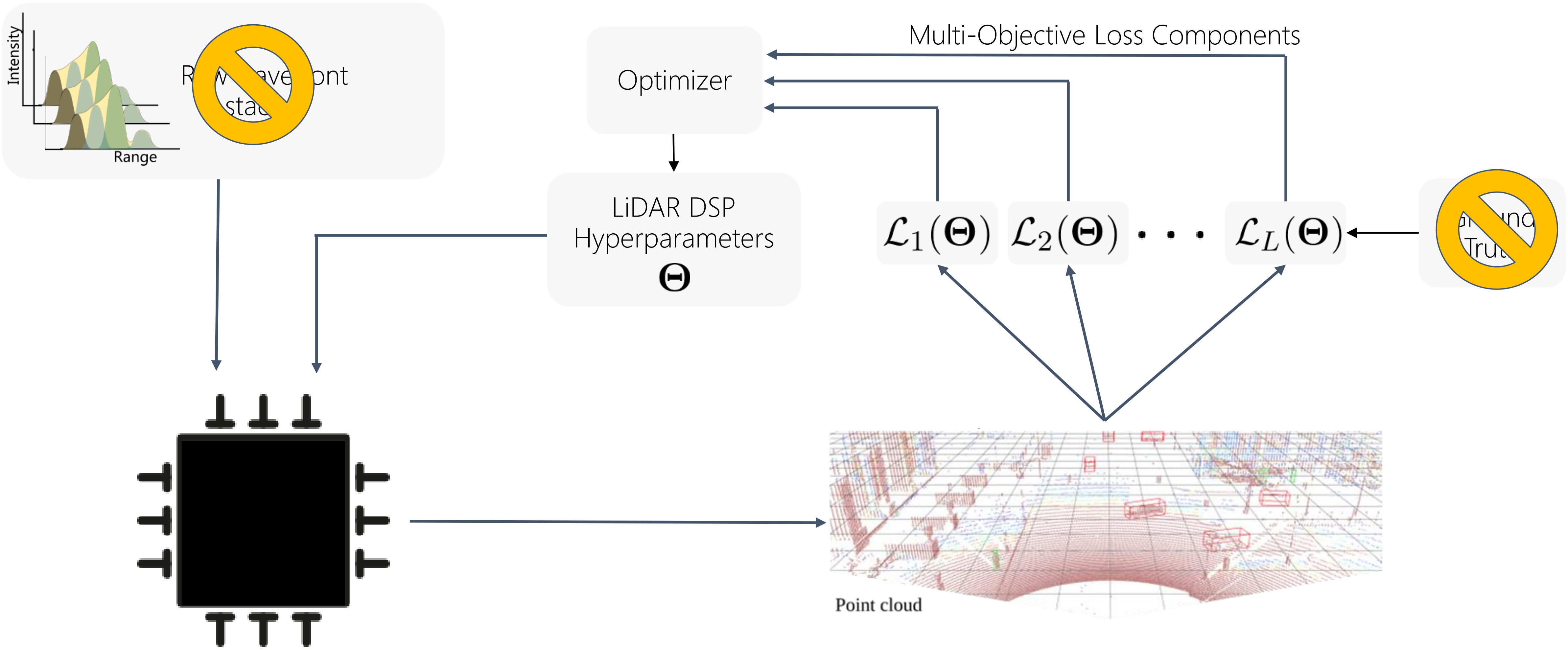
Experimental Results – Object Detection



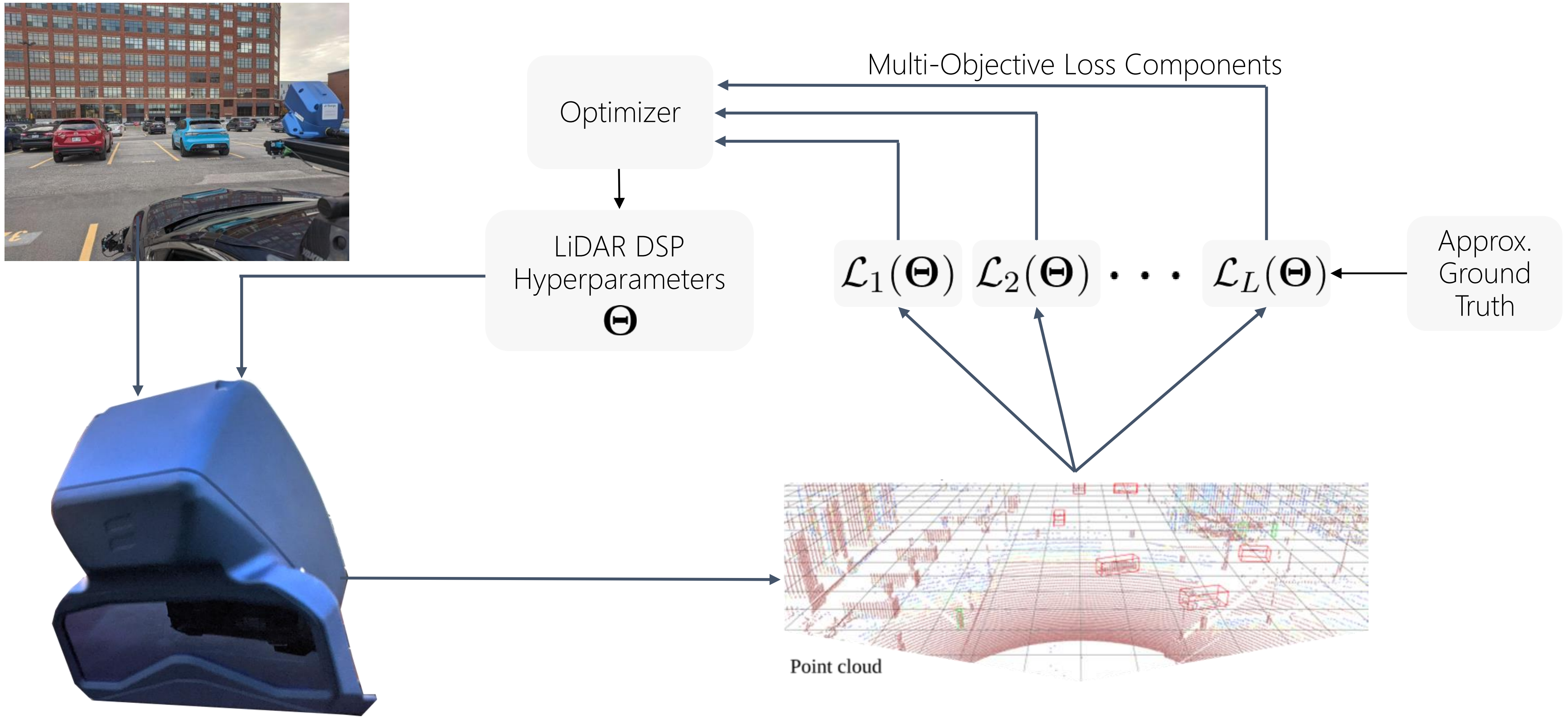
Experimental Results - Object Detection



Blackbox LiDAR-in-the-Loop Optimization

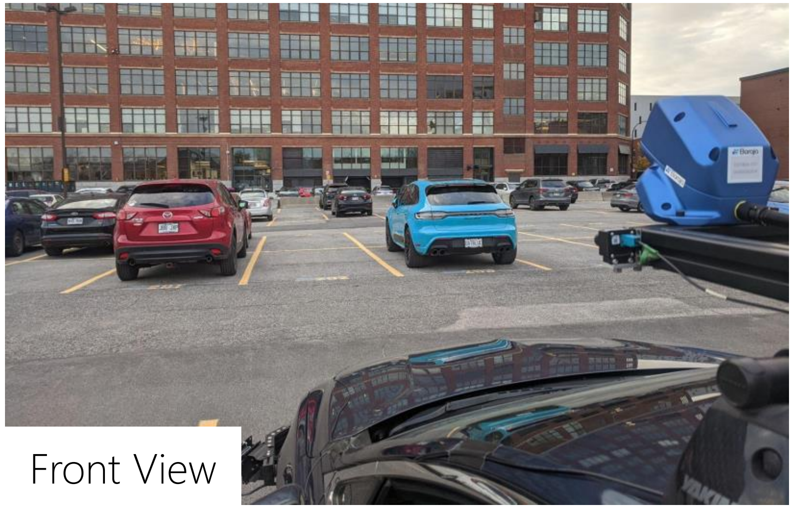


Hardware-in-the-Loop Optimization



Experimental Results – Hardware-in-the-Loop

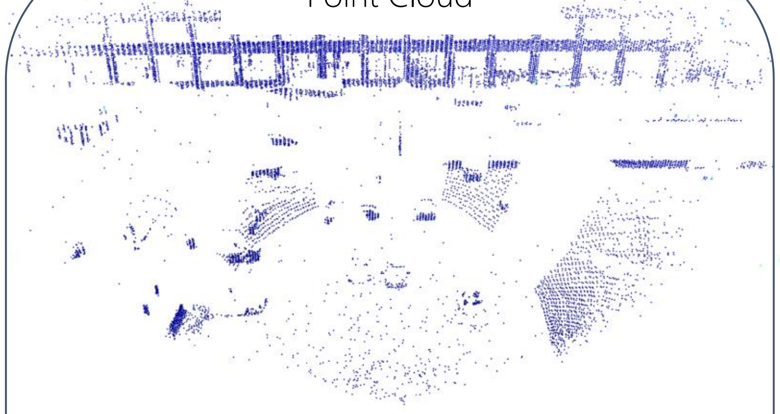
Ground Truth



Front View

Expert-Tuned

Point Cloud

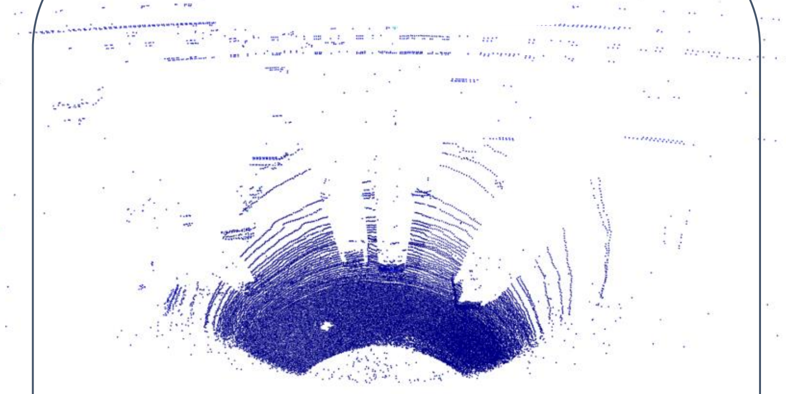


Hist. Contribution

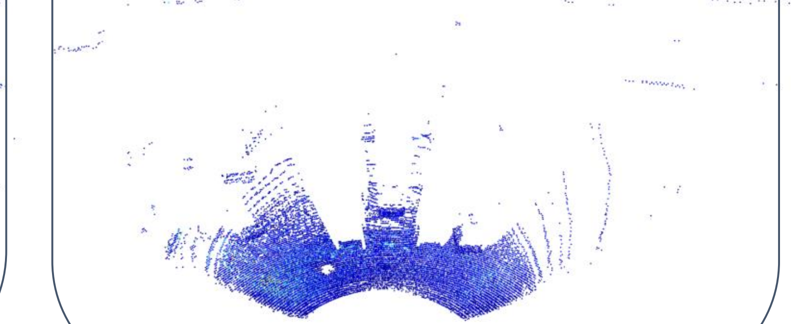
$\mathrm{RMSE}_{\mathrm{depth}} = 14.8\mathrm{cm}$

Optimized

Point Cloud



Hist. Contribution



$\mathrm{RMSE}_{\mathrm{depth}} = 5.9\mathrm{cm}$

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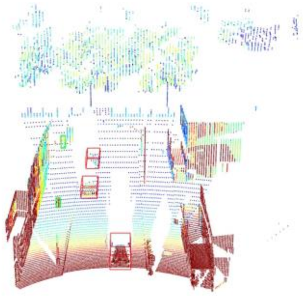
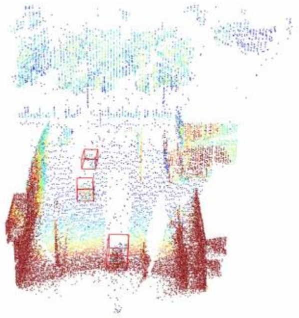
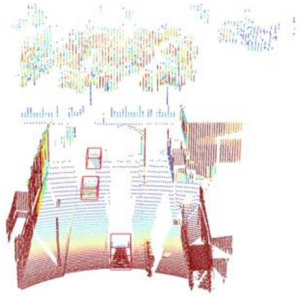
Ground Truth



Expert-Tuned



Optimized



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