PairGate3D: Score-Independent Geometric Gating for Online 3D Multi-Object Tracking

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Introduction

Abstract

Online 3D multi-object tracking maintains vehicle identities through frame-wise detection association. In score-weighted association, track scores affect both candidate ranking and, under a fixed matching threshold, the spatial acceptance region, admitting distant and weakly overlapping pairs to assignment. We present PairGate3D, a complete online tracking system with a score-independent geometric gate. Before assignment, the gate rejects a candidate edge when its 3D center distance is large and BEV overlap is low, while retaining the original costs and ranking of all other candidates. The thresholds can adapt to prediction uncertainty or be calibrated on target scenes. Gating improves HOTA across five KITTI Car detector streams, including a +5.757-point gain on PointRCNN. Evaluations on V2V4Real and nuScenes further show how geometric eligibility supports tracking accuracy and identity continuity across datasets.

Contribution

The main contributions are as follows:

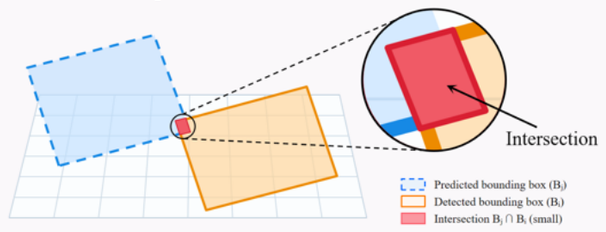
- We analyze the relationship between a score-normalized association cost and its geometric acceptance region, making explicit the score-dependent spatial boundary induced by a fixed matching threshold.
- We propose PairGate3D for online 3D multi-object tracking, with a score-independent joint distance–overlap gate that constrains candidate admissibility before assignment while preserving the original costs and ranking of the remaining edges.
- We assess geometric gating through paired comparisons across five KITTI detector streams, component ablation, per-sequence analysis, and cross-dataset transfer.

Author's WeChat

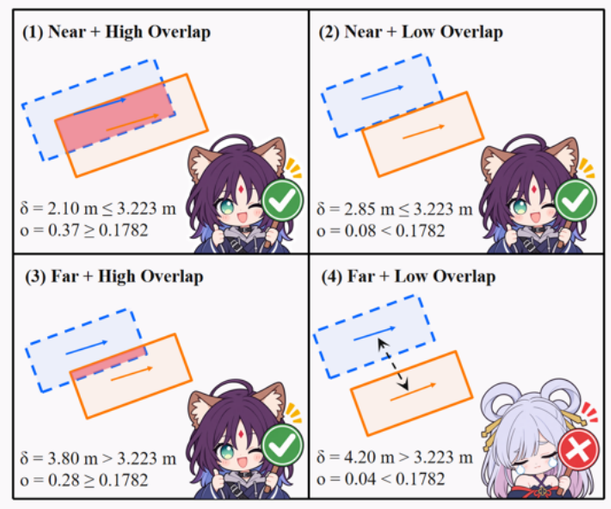
Author's Academic Blog

Geometric Gating

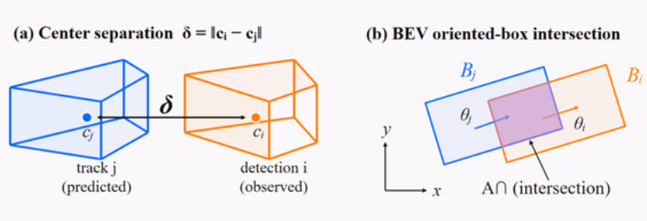
BEV Overlap



Four Gate Outcomes

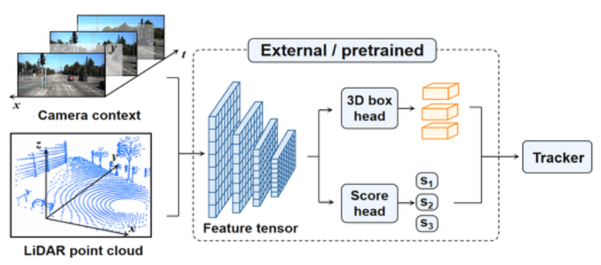


Association Geometry

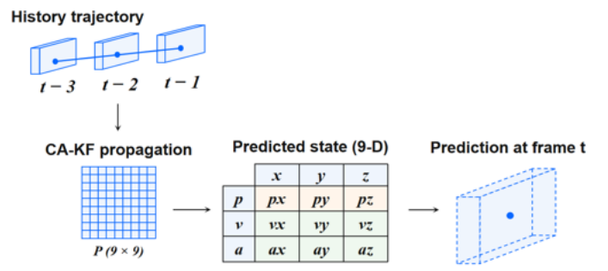


PairGate3D Framework

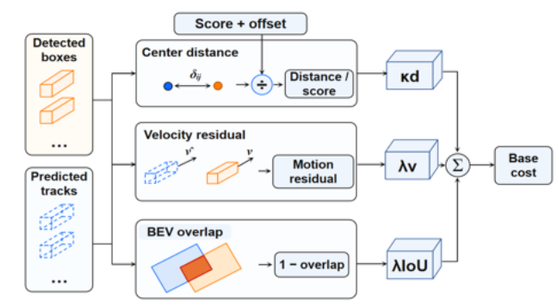
(a) External 3D Detection



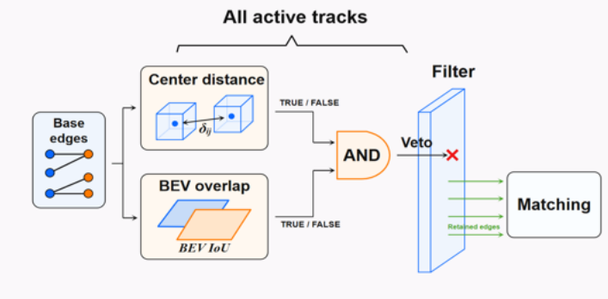
(b) Motion Prediction



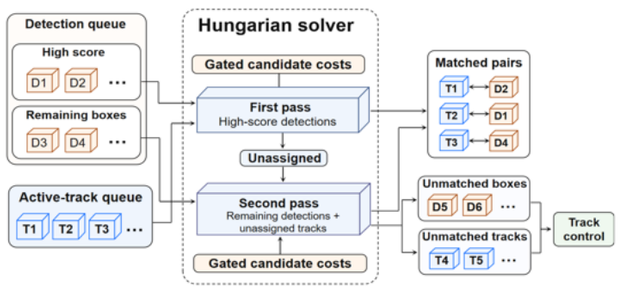
(c) Candidate Ranking



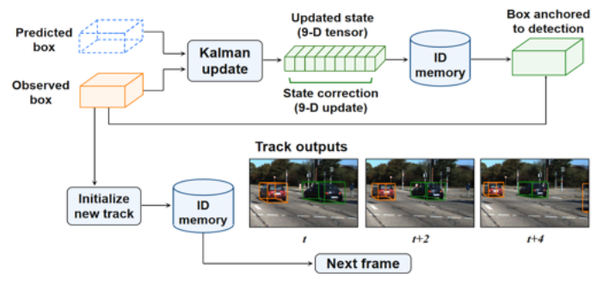
(d) Geometric Gate



(e) Two-Stage Assignment



(f) Track Update and Output



Results

Table 1 · KITTI Car results

Detector stream	τ_u	τ_i	Gate	HOTA↑	DetA↑	AssA↑	LocA↑	MOTA↑	Rcl.↑	Prc.↑	FP↓	FN↓	IDSW↓
CasA	0.75	1.00	off	80.436	78.978	82.097	90.654	86.979	94.558	92.819	613	456	22
			on	**81.467**	**79.354**	**83.814**	**90.672**	**87.457**	**94.677**	**93.067**	**591**	**446**	**14**
PointRCNN	0.75	3.00	off	68.626	67.909	69.655	**87.625**	74.973	91.467	85.336	1,317	715	65
			on	**74.382**	**70.333**	**78.945**	87.613	**79.735**	**92.314**	**88.138**	**1,041**	**644**	**13**
PV-RCNN	0.25	1.35	off	73.410	70.738	76.442	89.398	76.930	92.302	86.125	1,246	645	42
			on	**76.648**	**72.992**	**80.746**	**89.422**	**80.690**	**92.672**	**88.804**	**979**	**614**	**25**
SECOND-IoU	0.00	0.00	off	75.000	72.586	77.797	89.022	81.704	87.123	94.560	420	1,079	**34**
			on	**75.842**	**72.954**	**79.154**	**89.030**	**82.194**	**87.397**	**94.821**	**400**	**1,056**	36
VirConv	-1.00	0.00	off	82.291	81.390	83.323	92.290	87.290	95.405	92.320	665	385	15
			on	**83.128**	**81.900**	**84.493**	**92.306**	**87.946**	**95.441**	**92.826**	**618**	**382**	**10**

Table 2 · Comparison of gating rules

Gate rule	HOTA	ΔHOTA	IDSW
No gate	75.952	–	178
Joint distance–overlap	**78.293**	**+2.007 [0.990, 3.124]**	**98**
Scale-normalized dist.	78.278	+1.979 [0.946, 3.176]	108
Corrected heading	76.949	+0.829 [0.307, 1.471]	142
Naive heading†	76.607	+0.357 [−0.301, 1.165]	481
Relative-cost gate	76.897	+0.553 [0.121, 1.123]	121
BEV Mahalanobis†	68.338	−8.256 [−18.477, −0.229]	2,031

Figure · Sequence wins and edge vetoes

