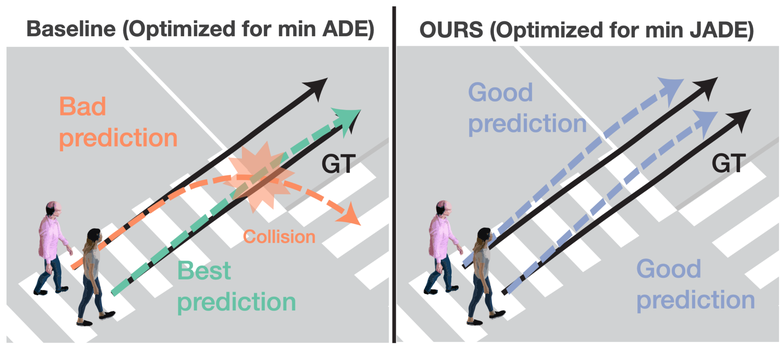
Joint Metrics Matter: A Better Standard for Trajectory Forecasting

Erica Weng, Hana Hoshino, Deva Ramanan, and Kris Kitani

Motivation



- SOTA trajectory forecasting methods optimize wrt ***marginal*** metrics, resulting in optimal *per-agent* predictions but suboptimal ***joint*** *multi-agent* predictions
- We introduce a loss function addition based on *joint metrics* that can be applied to many forecasting methods, achieving ***better multi-agent performance*** and ***lower collision rate***

Marginal vs. Joint Metrics

Sum over agents · Min over multi-modal predictions · Sum over timesteps · L2 displacement error

$$ADE(\mathbf{y}, \mathbf{y}^*) = \frac{1}{TN} \sum_{n=1}^{N} \min_{k=1}^{K} \sum_{t=1}^{T} \left\| y_{t,n}^{(k)} - y_{t,n}^* \right\|_2^2 \quad \text{(marginal)}$$

$$JADE(\mathbf{y}, \mathbf{y}^*) = \frac{1}{TN} \min_{k=1}^{K} \sum_{n=1}^{N} \sum_{t=1}^{T} \left\| y_{t,n}^{(k)} - y_{t,n}^* \right\|_2^2 \quad \text{(joint)}$$

$$FDE(\mathbf{y}, \mathbf{y}^*) = \frac{1}{N} \sum_{n=1}^{N} \min_{k=1}^{K} \left\| y_{T,n}^{(k)} - y_{T,n}^* \right\|_2^2 \quad \text{(marginal)}$$

$$JFDE(\mathbf{y}, \mathbf{y}^*) = \frac{1}{N} \min_{k=1}^{K} \sum_{n=1}^{N} \left\| y_{T,n}^{(k)} - y_{T,n}^* \right\|_2^2 \quad \text{(joint)}$$

Loss Modification

AgentFormer

$$\mathcal{L}_{elbo} = \sum_n ||\mathbf{y}_n^{(0)} - \mathbf{y}^*||^2 + \sum_n \min_{k=1}^{K} ||\mathbf{y}_n^{(k)} - \mathbf{y}_n^*||^2$$

$$+ \mathrm{KL}(q_\phi(\mathbf{z}|\mathbf{y}, \mathbf{x}) \,||\, p_\theta(\mathbf{z}|\mathbf{x})) + \min_{k=1}^{K} \sum_n ||\mathbf{y}_n^{(k)} - \mathbf{y}_n^*||^2$$

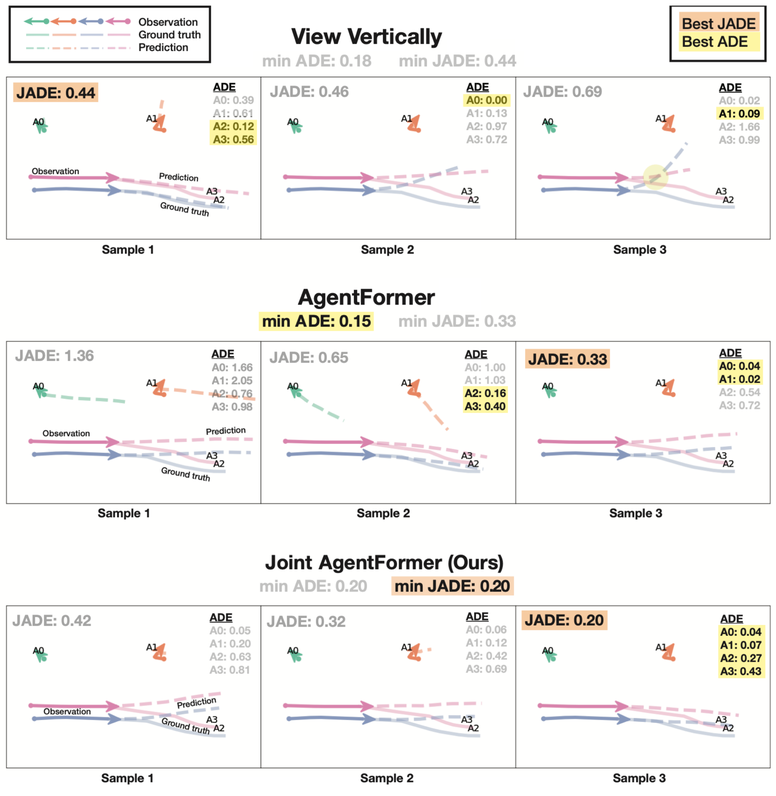
View Vertically

$$\mathcal{L}_{coarse} = \frac{1}{N_{way} N_{agents}} \sum_n \min_{k=1}^{K} \sum_{m=1}^{N_{way}} ||\mathbf{y}_{m,n}^{(k)} - \mathbf{y}_{m,n}^*||^2$$

$$+ \omega \cdot \frac{1}{N_{way} N_{agents}} \min_{k=1}^{K} \sum_n \sum_{m=1}^{N_{way}} ||\mathbf{y}_{m,n}^{(k)} - \mathbf{y}_{m,n}^*||^2$$

Better Joint Predictions

Dataset (mean # peds) →	min JADE$_{20}$/JFDE$_{20}$ ↓ (m), $K = 20$ samples						
	ETH (1.4)	HOTEL (2.7)	UNIV (25.7)	ZARA1 (3.3)	ZARA2 (5.9)	ETH / UCY Avg.	SDD TrajNet (1.5)
S-GAN	0.919 / 1.742	0.480 / 0.950	0.744 / 1.573	0.438 / 1.001	0.362 / 0.794	0.589 / 1.212	13.76 / 24.84
Trajectron++	0.726 / 1.299	0.237 / 0.418	0.609 / 1.316	0.359 / 0.712	0.294 / 0.625	0.445 / 0.874	11.36 / 18.21
PECNet	0.618 / 1.097	0.291 / 0.587	0.666 / 1.417	0.408 / 0.896	0.372 / 0.840	0.471 / 0.967	10.82 / 19.48
Y-Net	0.495 / 0.781	0.205 / 0.386	0.695 / 1.559	0.487 / 1.045	0.492 / 1.101	0.475 / 0.974	9.67 / **16.01**
MemoNet	0.499 / 0.859	0.222 / 0.416	0.686 / 1.466	0.349 / 0.723	0.385 / 0.864	0.428 / 0.866	9.59 / 16.43
View Vertically	0.561 / **0.776**	0.196 / 0.332	0.654 / 1.307	0.328 / 0.654	0.298 / 0.602	0.408 / 0.734	10.75 / 17.45
Joint View Vertically (Ours)	0.652 / 0.839	**0.186 / 0.309**	**0.523 / 1.091**	0.331 / 0.634	0.267 / 0.547	0.392 / 0.684	10.92 / 17.70
AgentFormer	**0.482** / 0.794	0.237 / 0.456	0.622 / 1.310	0.285 / 0.564	0.296 / 0.624	0.384 / 0.749	9.67 / 16.92
Joint AgentFormer (Ours)	0.485 / 0.798	0.186 / 0.320	0.590 / 1.219	**0.271 / 0.513**	**0.252 / 0.509**	**0.357 / 0.672**	**9.56** / 16.59



Fewer Predicted Collisions

Dataset (mean # peds) →	CR$_{mean}$/CR$_{JADE}$ ↓ (m), $K = 20$ samples						
	ETH (1.4)	HOTEL (2.7)	UNIV (25.7)	ZARA1 (3.3)	ZARA2 (5.9)	ETH / UCY Avg.	SDD TrajNet (1.5)
S-GAN	0.015 / **0.045**	0.031 / 0.090	0.165 / **0.251**	0.060 / 0.185	0.083 / 0.195	0.071 / 0.153	0.00 / 0.00
Trajectron++	0.025 / 0.137	0.044 / 0.271	0.281 / 0.489	0.088 / 0.466	0.126 / 0.456	0.113 / 0.364	0.00 / 0.00
PECNet	0.014 / 0.115	0.043 / 0.269	0.218 / 0.409	0.059 / 0.396	0.128 / 0.455	0.092 / 0.329	0.00 / 0.03
Y-Net	0.016 / 0.141	0.039 / 0.250	0.265 / 0.482	0.100 / 0.513	0.134 / 0.480	0.111 / 0.373	0.00 / 0.00
MemoNet	0.014 / 0.160	0.040 / 0.301	0.206 / 0.415	0.065 / 0.445	0.136 / 0.483	0.092 / 0.361	0.00 / 0.00
View Vertically	0.014 / 0.090	0.029 / 0.203	0.212 / 0.428	0.045 / 0.233	0.082 / 0.316	0.077 / 0.254	0.00 / 0.00
Joint View Vertically (Ours)	**0.011** / 0.076	0.026 / 0.168	0.276 / 0.484	0.045 / 0.262	0.081 / 0.349	0.088 / 0.268	0.00 / 0.00
AgentFormer	0.016 / 0.068	0.022 / **0.084**	0.204 / 0.362	0.021 / **0.088**	**0.054 / 0.139**	0.063 / **0.148**	**0.00 / 0.00**
Joint AgentFormer (Ours)	0.013 / 0.064	**0.019** / 0.094	**0.163** / 0.333	**0.021** / 0.100	0.055 / 0.203	**0.054** / 0.159	0.00 / 0.00
Ground Truth	0.000	0.001	0.021	0.000	0.002	0.005	0.00