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Improved Tracking of Articulated Vehicles in Self-Driving Applications Using Phantom Observations

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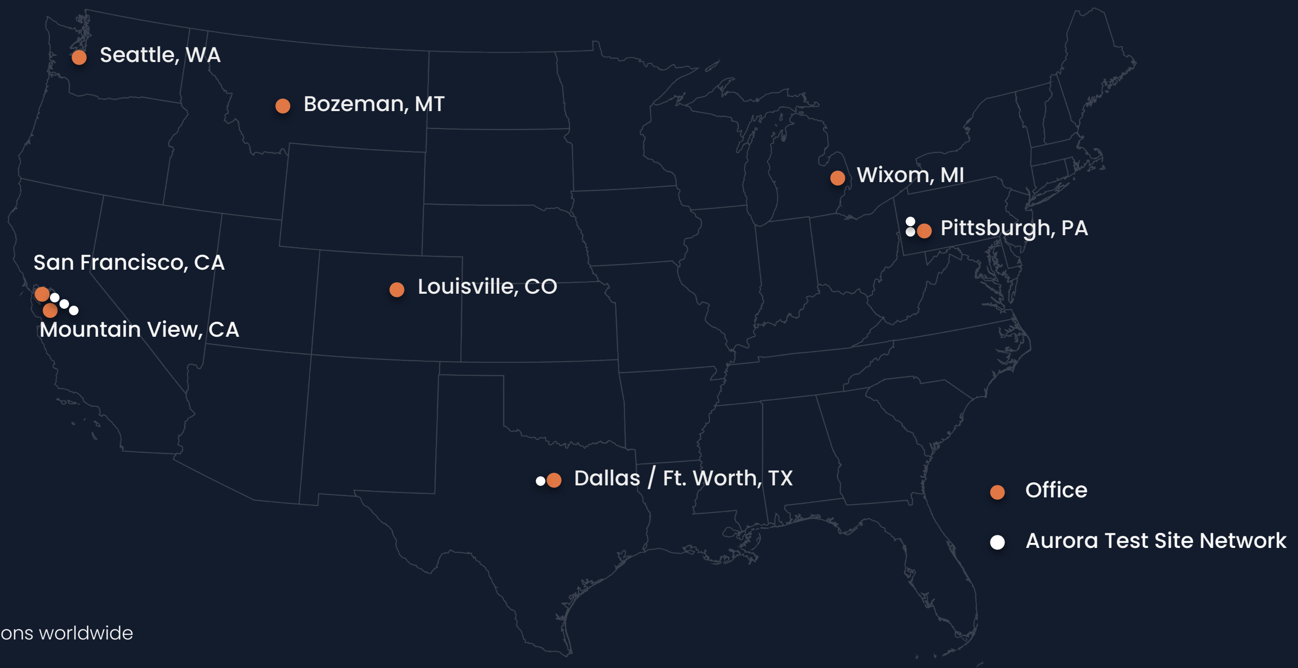

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Articulated vehicles

An articulated vehicle is a vehicle which has a permanent or semi-permanent pivot joint in its construction, allowing it to turn more sharply

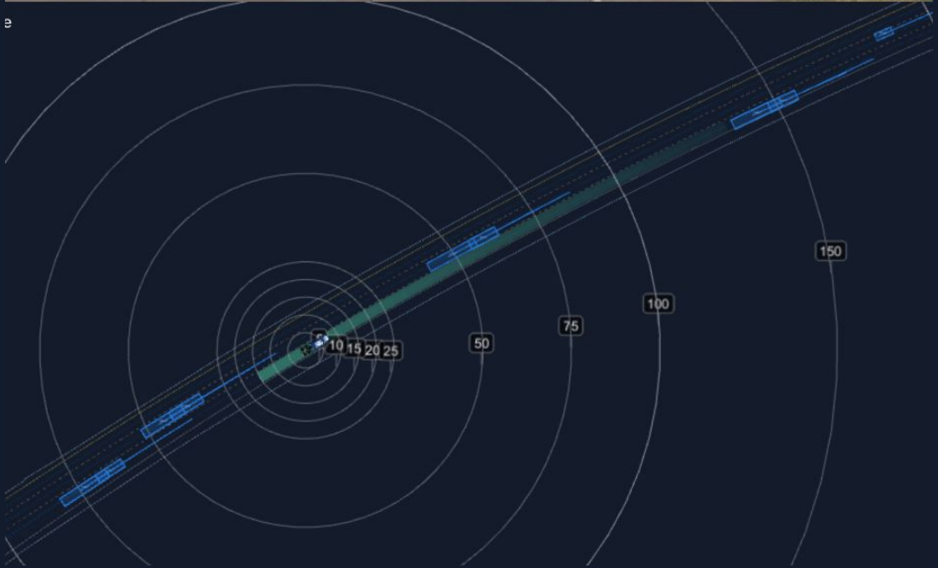
Because of the connection through “joint”, each part can not freely move. For example:

- If the tractor or “predecessor” is moving at 30 mps, the trailer or “successor” can’t be moving at 10 mps
- If the tractor or “predecessor” is turning left, , the trailer can’t turn right

Importance to autonomous trucking

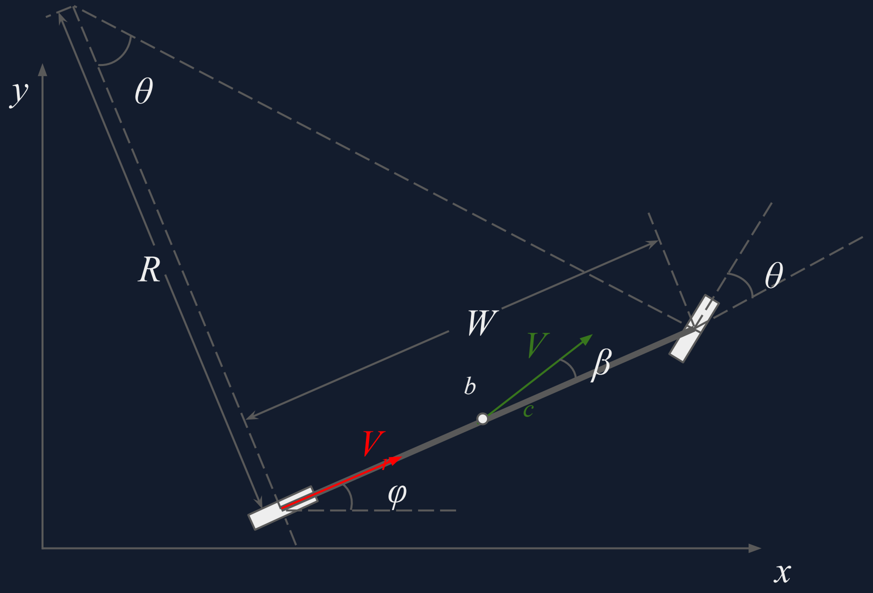
Accurate perception of trucks and articulated vehicles are important for autonomous truck system:

- In US in 2011 there were more than 164k miles of highways that were used to transport 16.1 billion tons of freight, with more than 70% being carried by trucks
- In 2020, nearly 47% of fatal and 43% injury-related highway accidents involving trucks



Tracking of traffic actors

- Assume the track state being a 12-D vector:
  - $[x, y, z, \theta_x, \theta_y, \theta_z, v, a, c, l, w, h]^T$
- **Association step**: match new detections to tracks
  - E.g., using smallest Mahalanobis distance
- **Update step**: update track state using the matched detection
  - Typical algorithm: Extended Kalman filter
  - Typical kinematic model: Bicycle model



Typical bicycle kinematic model

Tracking articulated vehicles: Existing approaches

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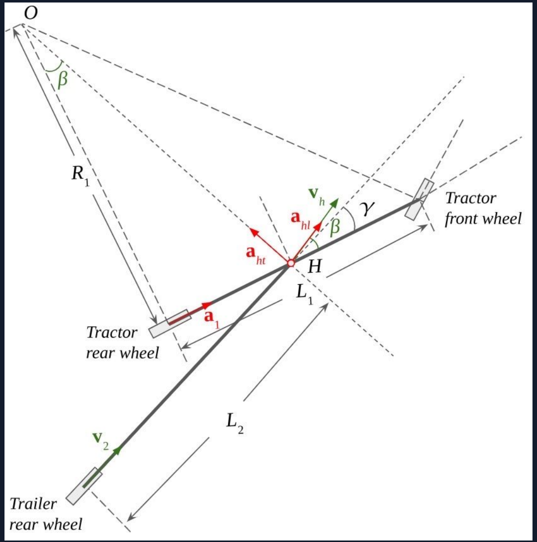
- **Single update**:
  - Treat the tractor and the trailer as a single large vehicle, using 12-D state
- **Independent update**:
  - Track the tractor and the trailer as two completely independent actors, each with 12-D state
- **Full update**:
  - Augment track state to include both tractor and trailer state, resulting in 24-D state vector
  - Update the state with either the tractor or trailer detections, or both



Kinematic model for articulated vehicle

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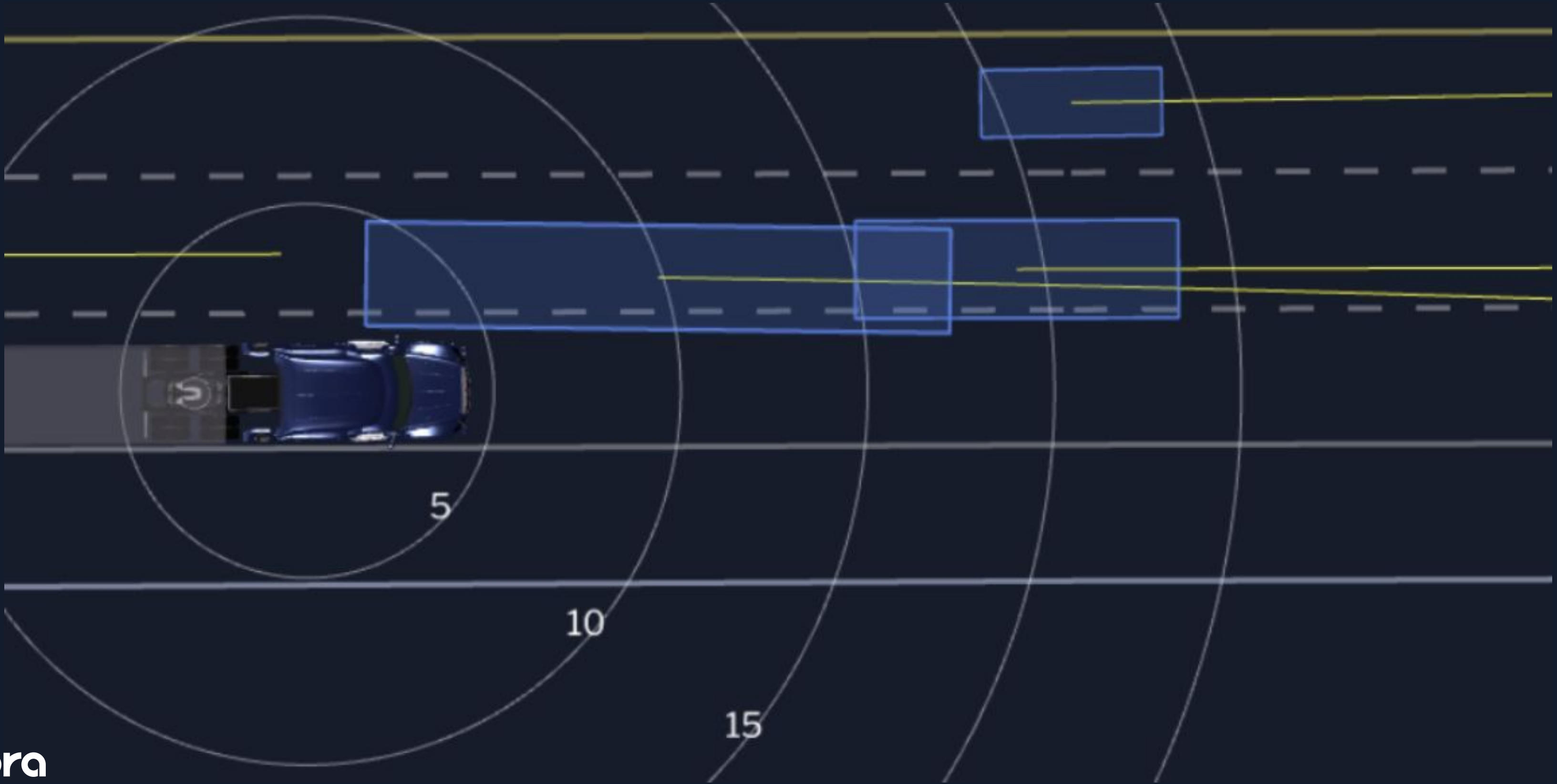
Mismatching states in the case of independent updates



Proposed approach: Phantom updates

- Track the tractor and trailer as two independent actors
- Perform the usual steps of detection association and track update
- **Then perform the newly proposed steps**
  - Create phantom detection of part A based on articulated vehicle kinematic model and part B's state
  - Update track A with the phantom detection
  - Do vice versa for part B

E.g., given tractor state, trailer angle, and hitch displacement, compute trailer phantom speed as:

$$v_h = \sqrt{v_1^2 + \left(\omega_1 L_h\right)^2}$$
$$\beta = arctan\left(c_1 L_h\right)$$
$$v_2 = v_h cos(\beta - \gamma)$$

Trailer phantom speed can be computed as:

$$c_2 = tan(\beta - \gamma)/L_2$$

Phantom update: Pros and cons

- Pros
  - As phantom detections are computed using a kinematic model, trailer/tractor phantom updates make them more kinematically consistent
  - Simpler equations than for full-update baseline, using 12-D state vector
  - Very flexible approach, a modeler can use phantom detections of any form (e.g., just speed, or just speed and accel., or just curvature, or …)
  - Can choose to update part A, part B, or both (e.g., just update a less visible part)
- Cons
  - Constrained to compute phantom update allowed by the used kinematic model
  - Extra update step

Experiments

- Used internal labeled data of large vehicles collected on Texas highways between 2021 to 2023, comprising around 100,000 actor samples
- Three situations considered, in each case phantom-updating the less visible part
  a. An articulated actor is passing the autonomous vehicle (AV)
     - Apply phantom updates to the trailer
  b. An articulated actor is turning in front of the AV (encountered on surface roads before and after the highway portion of the AV's route)
     - Apply phantom updates to the trailer
  c. The AV is following a lead articulated vehicle
     - Apply phantom updates to the tractor

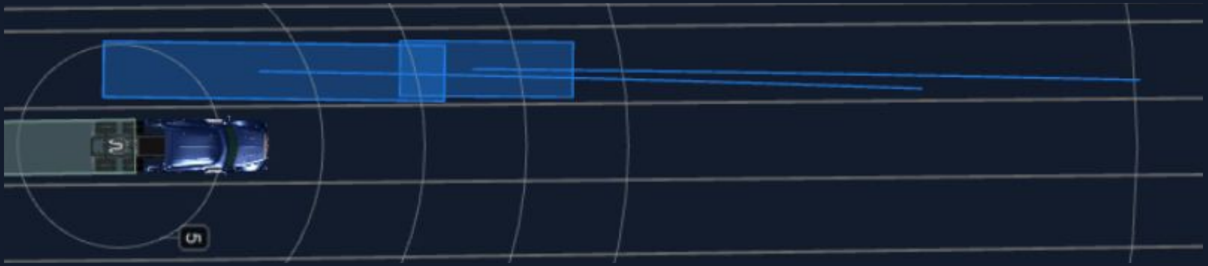
Comparison of competing approaches (lower is better)

	Passing trailer				**Turning trailer**				**Lead tractor**			
Method	loc.	orien.	velo.	accel.	loc.	orien.	velo.	accel.	loc.	orien.	velo.	accel.
Single update	0.96	1.01	0.72	0.90	3.74	6.62	0.82	**0.61**	1.31	1.07	1.05	1.04
Independent update	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**1.00**	1.00	1.00
Full update	0.93	1.04	1.12	1.53	**0.78**	**0.93**	0.81	0.75	**0.93**	1.14	1.22	1.30
Phantom update	**0.83**	**0.98**	**0.71**	**0.82**	0.96	1.23	**0.72**	0.63	**0.93**	1.16	**0.81**	**0.97**

Experiments

- Qualitative result on the earlier example with mismatched states

Independent update:



Phantom update:

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Thank you for your attention!
Questions?