# Digital Twinning and Predictive Modeling of Traffic for Safe, Efficient, and Reliable Intersections

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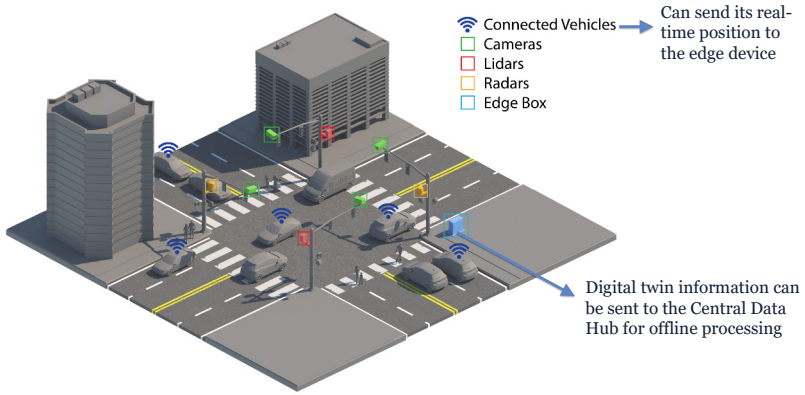
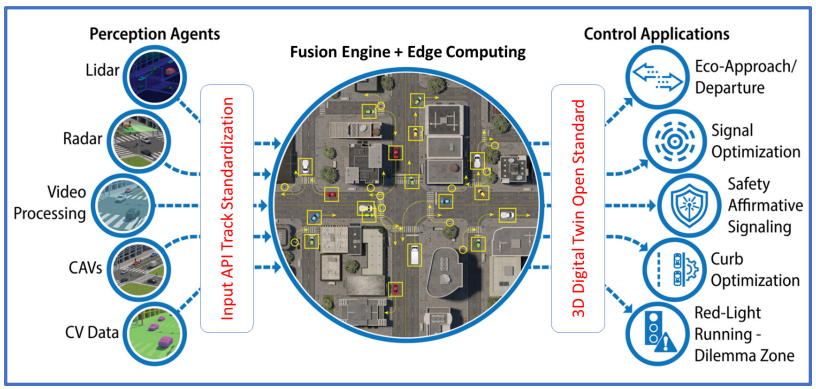
## Vision: Infrastructure Perception and Control (IPC)

Advances in connected and autonomous vehicles (CAVs) have far surpassed the technological realm of transportation infrastructure. The concept of Infrastructure Perception and Control (IPC) is aimed at bridging this technological gap by building a real-time digital twin of traffic by fusing detections from sensors installed at the intersection.




## Opportunity

- "50 percent of the combined total of fatal and injury crashes occur at or near intersections" – US DOT
- The recent White House Summit lists one of the key goals of the newly formed Advanced Research Projects Agency - Infrastructure (ARPA-I) agency as "Traffic lights sensors that can see a child trying to cross the street and reroute cars to keep them safe."




## Technology

OEM sensors have different characteristics:

- Type of object level information
- Data format
- Time resolution
- Range of detection
- Reliability
- Confidence/uncertainty levels
- Calibration settings

Fusing object lists from such a diverse set of sensors is a challenging mathematical and numerical endeavor.

| | |
|---|---|
| Transformation | Transform sensor input into the same coordinate system |
| Data Association | Associate sensor detections to existing/new objects |
| Track fusion | Fuse multiple detections about a given object |
| Lifespan management | Determine if detected object conforms to the intersection-level constraints |

## Bayesian Filtering

Making sense of noisy and incomplete sensor data requires balancing between what is plausible and what is consistent with the observations.

Bayesian filtering algorithms such as Kalman filter, Unscented Kalman filter and particle filter provides a robust probabilistic framework to assimilate multiple noisy sensor detections to obtain smooth tracks of vehicles and pedestrians.

The state-space framework is powered through a stochastic motion model and an observation model pertaining to sensor the detection.

## Innovation

Using multi-sensor data fusion to build a digital twin of traffic at an intersection which is

- Sensor-agnostic
- OEM-agnostic
- Scalable
- Real-time
- Resilient
- Equitable
- Connected (I2X)
- Predictive (through generative AI)

## Generative Artificial Intelligence (AI)

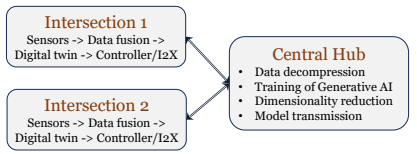
Generative AI can help predict/simulate the behavior of vehicles once they are detected by the digital twin.

Using the historical vehicle tracking data, a generative AI model can be trained to produce reliable real-time traffic predictions within or across intersections.

Generative AI models have gained significant attention in the recent years, in part due to large-language models such as ChatGPT in creating a human-like text for a given context. A similar idea could be applied to traffic...

Techniques such as generative adversarial networks (GANs) and variational encoders (VAEs) can help in predicting traffic scenarios, which can then be conveyed to connected vehicles through I2V communications.

The availability of real-time and predicted traffic scenarios can help guide connected and autonomous vehicles in optimizing their route and minimizing traffic congestion, which can help in significant energy savings.




## Challenges and Extensions

Several challenges exist in the deployment of generative AI for traffic applications:

- Uncertainty in digital twin output needs to be included in the trained AI model
- Time-varying intersection-level constraints should be respected during training and prediction
- Data compression required for wireless data transmission of predicted traffic scenario to connected vehicles in real-time
- Integrating multiple intersections requires dimensionality reduction and optimized object list data structure of digital twin to ensure real-time data communication to the central hub

Such a technology can be extended to any application that involves tracking and predicting dynamical agents under given constraints based on its surroundings.

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