A SURVEY ON VISUAL TRAFFIC SIMULATION: MODELS, EVALUATIONS, AND APPLICATIONS IN AUTONOMOUS DRIVING

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OUTLINE

INTRODUCTION

- Virtual traffic via various simulation models and animation techniques using real-world traffic data are promising approaches for reconstructing detailed traffic flows.
- Many applications such as video games, virtual reality, autonomous driving etc. can profit from virtual traffic simulation.
- In this survey, a comprehensive review on the state-of-the-art techniques for virtual traffic simulation and animation are given.

MODEL-BASED TRAFFIC SIMULATION

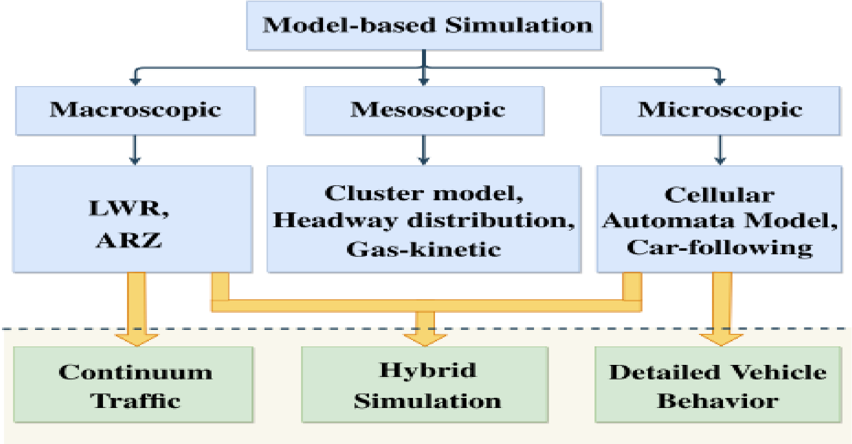

Figure: Classification of model based traffic simulation [1].

MACROSCOPIC METHODS

- Describe vehicle's behaviours and interactions at a low level of detail.
- A traffic stream is represented as a continuum in terms of speed, flow, density etc.
- Focuses on reproducing aggregated behaviours measured with collective quantities.

✓ Efficient tools to simulate large-scale traffic.

× Not suitable for simulating street-level traffic.

× They cannot model lane-changing behaviour of vehicles.

LWR Model

- Developed by Lighthill and Whitham [2] and Richards [3].
- Model builds a non-linear scalar conservation law for modelling traffic flows, based on similarities between one dimensional compressible gas dynamics and the evolving of traffic flows in a single lane.
- Model describes the motion of large-scale traffic flows with low resolution details.

× It cannot model the movements of a vehicle under non-equilibrium conditions.

PW Model

- Continuous second-order traffic model proposed by Payne [4] and Whitham [5].
- Introduces second order differential equation to describe traffic velocity dynamics.

× The model can introduce negative velocities.

× Information generated from vehicle dynamics can travel faster than vehicle velocity.

ARZ Model

- Aw and Rascle [6] and Zhang [7] modified PW model to eliminate its non-physical characteristics.
- Aw and Rascle [6] introduced a pressure term to guarantee that no information travels faster than the speed of the car.
- Zhang [7] modified the momentum equation of the PW model to handle backward-propagating traffic.

SEWALL et al.

- Macroscopic traffic simulation model to generate realistic traffic flows on large-scale road networks.
- Adapted single-lane ARZ model to handle multi-lane traffic by :
    1. introducing a novel model for lane-changing.
    2. using a discrete representation for each vehicle.

SEWALL et al.

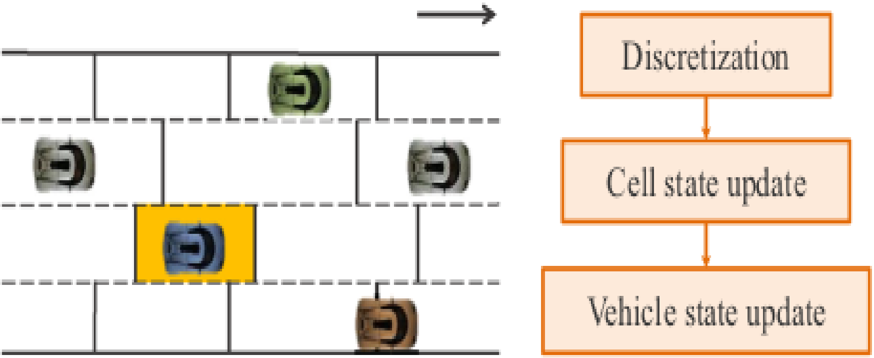

Figure: Illustration of macroscopic traffic simulation approach [8].

MICROSCOPIC METHODS

- Produce vehicle motion at a high level of detail.
- Each vehicle is treated as a discrete agent satisfying certain governing rules.
- Flexible in modelling:
  1. Heterogeneous behaviours of agents.
  2. Diverse road topologies.
  3. Interactions among surrounding vehicles.

✓ Used to simulate traffic in both continuous lanes and intersections.

× Computational cost is very large.

CELLULAR AUTOMATA MODEL

- Motions of vehicles are described by evolution rules in pre-specified time, space and state variables.
- The road is discretized into cells.
- Model determines when a vehicle moves from current cell to next cell.

✓ Can simulate a large group of vehicles on a large road network.

× Generated virtual traffic can only a limited number of real-world traffic behaviours.

CAR-FOLLOWING MODELS

- Introduced by Pipes and Reuschel.
- Assumed traffic flow consisted of scattered particles.
- Modelled detailed interactions among cars.
- Represented the position and speed of each car through continuous-time differential equations based on stimulus-response framework.

INTELLIGENT DRIVING MODEL

- The vehicle's acceleration or deceleration is computed according to its current speed and relative speed and position to its front vehicle.
- The vehicle-specific parameters enable the IDM model to simulate various vehicle types and driving styles.
- Shen and Jin [14] enhanced the IDM to incorporate lane-changing behaviours of vehicles.

SHEN AND JIN

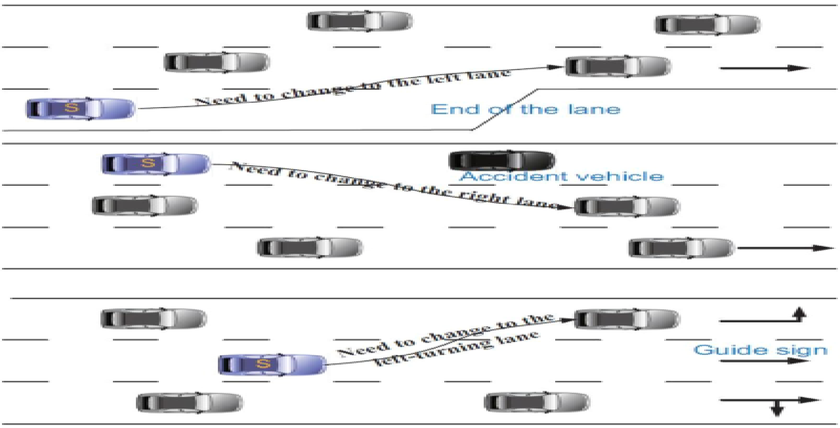

Figure: Situations where a vehicle must change its lane [14].

HYBRID METHOD

- Macroscopic models excel in large-scale traffic simulation and microscopic models excel in modelling of individual vehicles.
- Sewall et al. combined these two models and proposed a hybrid method.
- Their approach simulates traffic in the areas of interest using a microscopic model, while the rest areas using a macroscopic model.
- Their approach can simulate traffic by dynamically switching between the two models.

HYBRID METHOD

Figure: Illustration of a hybrid traffic simulation method [10].

MESOSCOPIC METHODS

- Intermediate approach between macroscopic and microscopic methods.
- Describe traffic flow dynamics in an aggregate manner while representing the behaviours of individual drivers using probability distribution functions.
- Can be divided into three classes:
    1. Cluster models
    2. Headway-distribution models
    3. Gas-kinetic Models

MESOSCOPIC METHODS

- The cluster models represent the dynamics of traffic flows by describing groups of vehicles with the same properties.
- The headway distribution models focus on the statistical properties of time headways.
- The gas-kinetic models draws analogy between the gas-dynamics and the traffic dynamics.

ROAD NETWORK GENERATION

- Traffic simulation is a form of interplay between the vehicles and the road-network.
- Digital representations of road networks are increasingly available, but cannot be directly used for traffic simulation.
- A road network contains many features such as lanes, intersections, ramps etc.
- Road network generation is an important yet challenging aspect.

ROAD NETWORK GENERATION

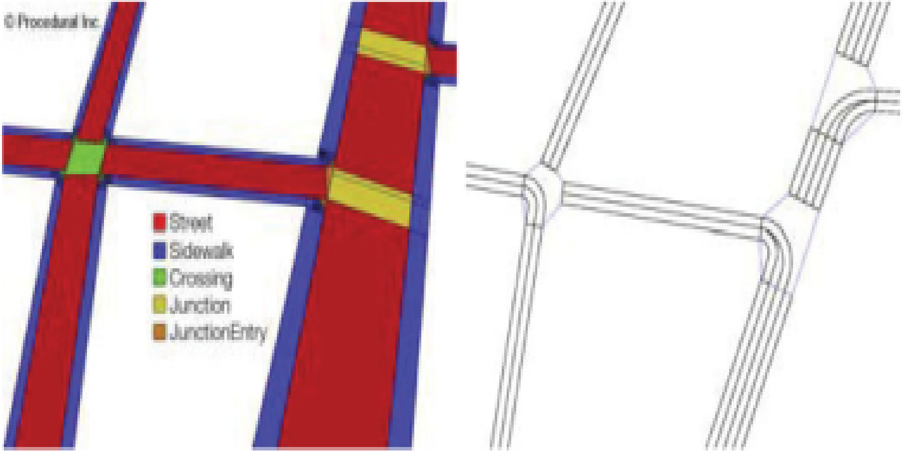

Figure: A road network created using (a) CityEngine [18] (b) Wilkie et al. [9] [19].

DATA-DRIVEN TRAFFIC SIMULATION

- The resulting animations from the above mentioned traffic models usually do not resemble real-world traffic at street level.
- This problem is solved using data-driven traffic animation techniques.
- Nowadays, empirical traffic flow data sets in the forms of video, LiDAR and GPS sensors are increasingly available.

TRAFFIC DATA ACQUISITION

- Traffic data is acquired using traffic sensors.
- Sensors can be categorised as:
    1. Fixed Sensors → Inductive-loop detector, video camera
    2. Mobile Sensors → Cellphones, GPS devices
- Video camera as an over-roadway sensor has been employed in Next Generation Simulation (NGSIM).

NGSIM DATASET

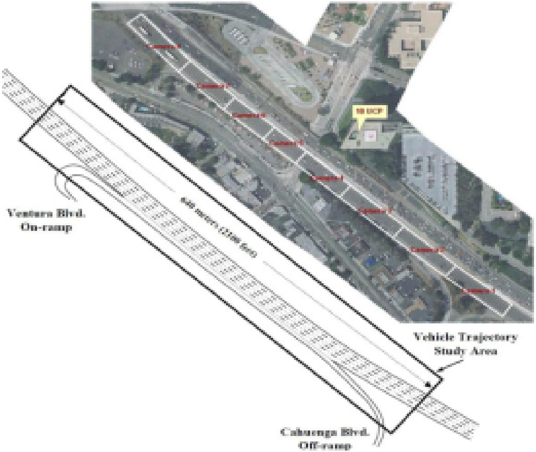

Figure: Next Generation Simulation [17]

NGSIM DATASET

Location	Road Length (ft)	Road Type	Record Time	Number of vehicles
I-80, Emeryville, California	1650	Freeway, one on-ramp	4:00 pm-5:30 pm	3200+
US 101, Los Angeles, California	2100	Freeway, one on-ramp & off-ramp	7:50 am-8:35 am	3000+
Lankershim Blvd, Universal City, California	1600	Arterial, four intersections	8:30 am-9:00 am	1500+
Peachtree Street, Atlanta, Georgia	2100	Arterial, five intersections	12:45 pm-1:00 pm 4:00 pm-4:15 pm	1500+

Table: Four selected NGSIM data sets [17].

TRAFFIC RECONSTRUCTION AND SYNTHESIS

- Virtualized Traffic refers to the creation of a digital representation of traffic that corresponds to the real-world traffic scenario.
- The term virtualized traffic was first introduced by van den Berg et al. [11].
- In van den Berg et al., a continuous traffic flow is reconstructed and visualized from spatio-temporal data provided by traffic sensors.

VAN DER BERG et al.

- For a given vehicle i, the sensors provide a tuple $(t_i^A, l_i^A, v_i^A, t_i^B, l_i^B, v_i^B, t_i^C, l_i^C, v_i^C)$ as data input.
- The task is to compute trajectories for the vehicle i on the road.
- The approach first discretizes possible state-time space and constrains the motion of a vehicle to a pre-computed roadmap.
- Then, it searches for an optimal trajectory for each vehicle in the roadmap that minimizes the number of lane-changing and the amount of acceleration/deceleration, and maximizes the distance to other vehicles.

VAN DEN BERG et al.

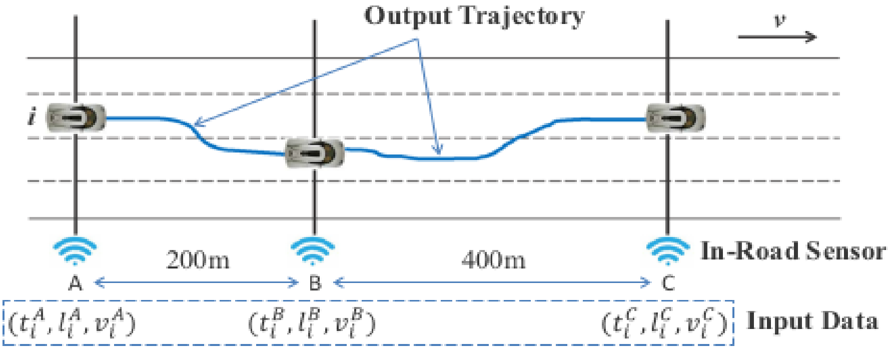

Figure: Illustration of traffic reconstruction from temporal-spatial data acquired from in-road sensors [11].

VALIDATION AND EVALUATION

- Virtual traffic evaluation is categorised into two:
  1. Visual Validation
     → Graphical representations of the real-world traffic and the simulated traffic are displayed side by side to determine whether they can be differentiated.
  2. Statistical Validation
     → Different traffic simulation methods are compared on the basis of other features such as average velocities and traffic volumes over time.

SEWALL et al.

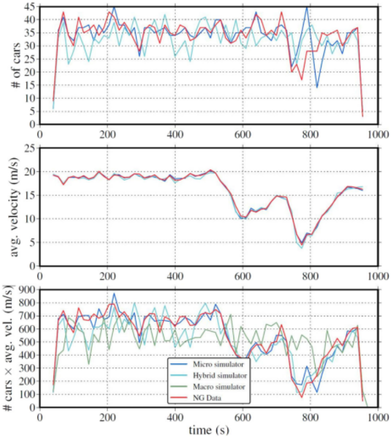

Figure: Comparison between micro, macro, hybrid simulation and real-world data [10].

CHAO et al.

- In the work of Chao et al. [13], researchers conducted user studies using pairwise comparison on the generated traffic flows with three different methods:
  1. NGSIM traffic flow data
  2. Texture based traffic synthesis method by Chao et al. [13].
  3. One of the latest developments of IDM model [14].

CHAO et al.

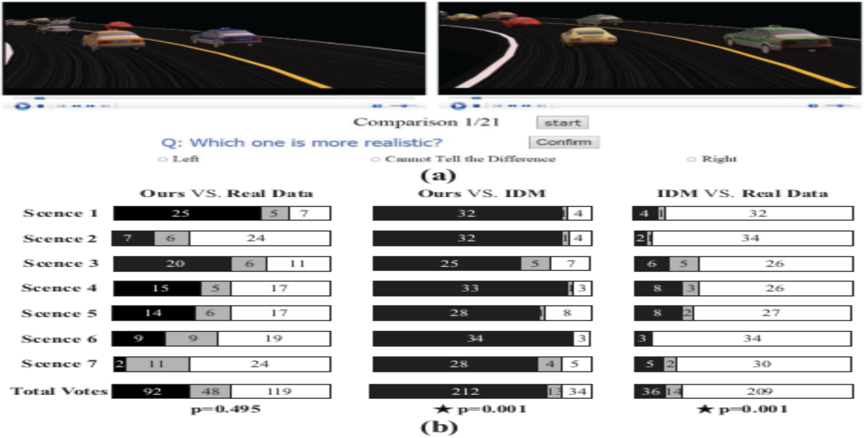

Figure: Visual validation [13] [14].

CHAO et al.

- Recently, Chao et al. [15] introduced a general, dictionary-based learning method to quantitatively and objectively measure the fidelity of traffic trajectory data.

(a) Data from real world (b) Fidelity score: 0.73 (c) Fidelity score: 5.41 (d) Fidelity score: 8.99

Figure: Fidelity measure comparisons among three virtual traffic flows [15].

CHAO et al.

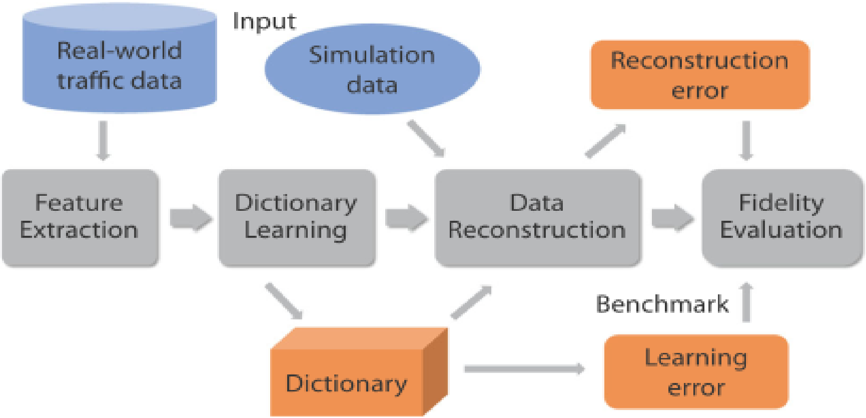

Figure: The pipeline of the dictionary-based fidelity measure for virtual traffic [15].

APPLICATIONS IN AUTONOMOUS DRIVING

- One major application of virtual traffic simulation is the development of autonomous vehicles.
- They have the potential to increase the safety and efficiency of current transportation systems.
- Autonomous vehicles can transform the current transportation system into a utility available to anyone at any time.

AUTONOMOUS DRIVING DATASETS

Dataset	Intention	Driving Behaviours	Driving Time (hours)	Areas	Camera View	Sensors and Videos			Conditions
						Video Image	LiDAR	GPS IMU	
KITTI [20]	Semantic & geometric understanding	-	1.4	City, highway	Front-View	✓	✓	✓	One weather condition, daytime
Cityscape [21]	Visual Semantic & geometric understanding	-	<100	City	Front-view	✓	-	✓	Multiple weather conditions, daytime
Comma.ai [22]	Driving behaviour learning	✓	7.25	Highway	Front-view	✓	-	✓	Night, daytime
BDDV [23]	Semantic & geometric understanding, driving behaviour learning	✓	10k	City, highway	Front-view	✓	-	✓	Multiple weather conditions, daytime
Oxford [24]	Long-term localization & Mapping	-	214	City	360-degree view	✓	-	✓	Multiple weather conditions, daytime

Table: Comparison of various autonomous driving datasets [1]

AUTONOMOUS DRIVING DATASETS

Dataset	Intention	Driving Behaviours	Driving Time (hours)	Areas	Camera View	Sensors and Videos			Conditions
						Video Image	LiDAR	GPS IMU	
Udacity [25]	Semantic & geometric understanding, driving behaviour learning	-	8	City, highway	Front-View, left-view, right-view	✓	✓	✓	Multiple weather conditions
HDD [26]	Driving behavioural learning, casual reasoning	✓	104	City, highway	Front-View, left-view, right-view	✓	✓	✓	Multiple weather conditions, daytime
LiVi-Set [27]	Driving behaviour learning	✓	20	City, highway	Front-View	✓	✓	✓	Multiple weather conditions, daytime
Drive360 [28]	Driving behaviour learning	✓	60	City, highway	360-degree view	✓	-	✓	Multiple weather conditions, daytime

Table: Comparison of various autonomous driving datasets [1]

MOTION PLANNING AND DECISION-MAKING

- Motion planning and decision-making are critical for autonomous agents to navigate in their environments.
- With an increasing number of driving data sets collected, the resulting accurate traffic simulation can enrich the motion planning and decision-making of autonomous vehicles in terms of more accurate traffic semantics.
- Some examples for autonomous driving systems using motion planning and decision-making are ALVINN, Du-Drive, etc.

SIMULATION FOR AUTONOMOUS DRIVING

- For safe autonomous driving, a high-fidelity driving simulator, which incorporates realistic traffic flows and complex traffic conditions, is necessary.
- Such a simulator can produce critical training environments in an efficient and reproducible manner.

CARLA SIMULATOR

- It is an open-source simulator developed to support development, training and validation of autonomous urban driving models.
- Supports flexible setup of sensor suites and provides signals that can be used to train driving strategies.
- A wide range of environmental factors can be specified, including weather and time of day.

CARLA SIMULATOR

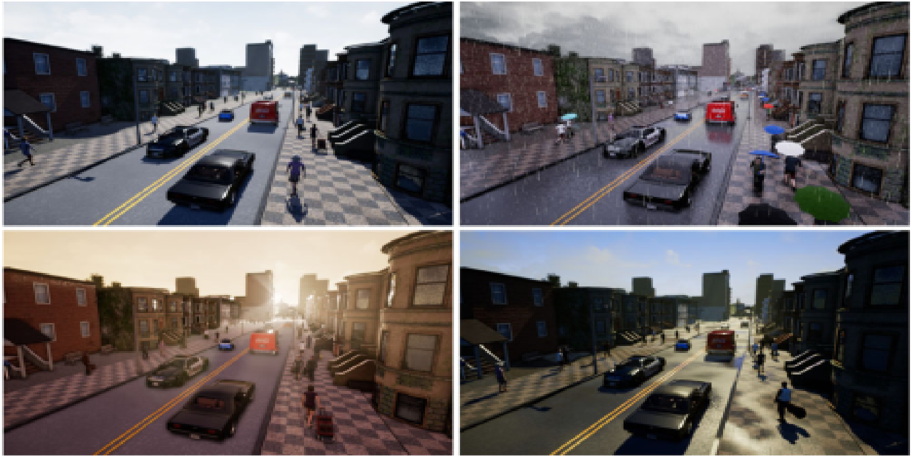

Figure: A street traffic in CARLA simulator [16].

CONCLUSION

- Virtual traffic simulation and animation will continue to be researched.
- Many exciting angles for traffic modelling remain to be explored.
- In terms of autonomous driving research, the various models and applications summarised, would encourage fascinating research topics to come forward in the coming years.

FUTURE SCOPE

- A traffic simulation model must be able to model as many complex situations as possible, while maintaining computational efficiency.
- Current data-driven traffic animation approaches cannot handle non-trivial interactions between vehicles and other moving objects.
- Fidelity metrics have to be developed that can measure traffic flows in an aggregate fashion.
- For autonomous driving addressing the interactions between autonomous vehicles and other road users remain a challenge.

REFERENCES

[1] Chao Q., Bi H., Li W., Mao T., Wang Z., Lin M.C., Deng Z.: A survey on visual traffic simulation: models, evaluations, and applications in autonomous driving. Computer Graphics Forum (2019).

[2] Lighthill M.J., Whitam G.B.: On kinematic waves ii. a theory of traffic flow on long crowded roads. Proceedings of the Royal Society London (1955).

[3] Richards P.I.: Shock waves on the highway. Operations Research (1956).

[4] Payne H.: Models of Freeway Traffic and Control. Mathematical Models of Public Systems. Simulation Councils (1971).

REFERENCES

[5] Whitham G.B.: Linear and Nonlinear Waves (1974).

[6] Aw A., Rascle M.: Resurrection of "second order" models of traffic flow. SIAM Journal on Applied Mathematics (2000).

[7] Zhang H.M.: A non-equilibrium traffic model devoid of gas-like behavior. Transportation Research Part B: Methodological (2002).

[8] Sewall J., Wilkie D., Merrell P., Lin M.C.: Continuum traffic simulation. Computer Graphics Forum (2010).

[9] Wilkie D., Sewall J., Lin M.C.: Transforming GIS data into functional road models for large-scale traffic simulation. IEEE Transactions on Visualization & Computer Graphics (2012).

REFERENCES

[10] Sewall J., Wilkie D., Lin M. C.: Interactive hybrid simulation of large-scale traffic. ACM Transactions on Graphics (TOG) (2011).

[11] Sewall J., Van Den Berg J., Lin M., Manocha D.: Virtualized traffic: Reconstructing traffic flows from discrete spatio-temporal data. IEEE Transactions on Visualization Computer Graphics (2011).

[12] Wilkie D., Sewall J., Lin M.: Flow reconstruction for data-driven traffic animation. ACM Transactions on Graphics (TOG) (2013).

[13] Chao Q., Deng Z., Ren J., Ye Q., Jin X.: Realistic data-driven traffic flow animation using texture synthesis. IEEE Transactions on Visualization Computer Graphics (2018).

REFERENCES

[14] Shen J., Jin X.: Detailed traffic animation for urban road networks. Graphical Models (2012).

[15] Chao Q., Deng Z., Xiao Y., He D., Miao Q., Jin X.: Dictionary-based fidelity measure for virtual traffic. IEEE Transactions on Visualization Computer Graphics (2018).

[16] Dosovitskiy A., Ros G., Coevilla F., Lopez A., Koltun V.: CARLA: An open urban driving simulator. In Proceedings of the 1st Annual Conference on Robot Learning (2017).

LINKS TO DATASETS

[17] Next generation simulation fact sheet (2018).

[18] Cityengine manual (2018).

[19] Road network library (Wilkie et al.) (2015)

[20] KITTI Dataset

[21] Cityscape Dataset

[22] Comma.ai Dataset

LINKS TO DATASETS

[23] Berkeley DeepDrive dataset

[24] Oxford robotcar dataset

[25] Udacity self driving car

[26] Honda research institute Driving Dataset

[27] LiDAR Video Driving dataset

[28] Drive360 dataset