媒体智能实验室
Media Intelligence Lab

Intelligent Agent Group @ HDU

End-to-end Deep Models For Self-driving Car

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Intelligent Agent Group

26 November, 2017

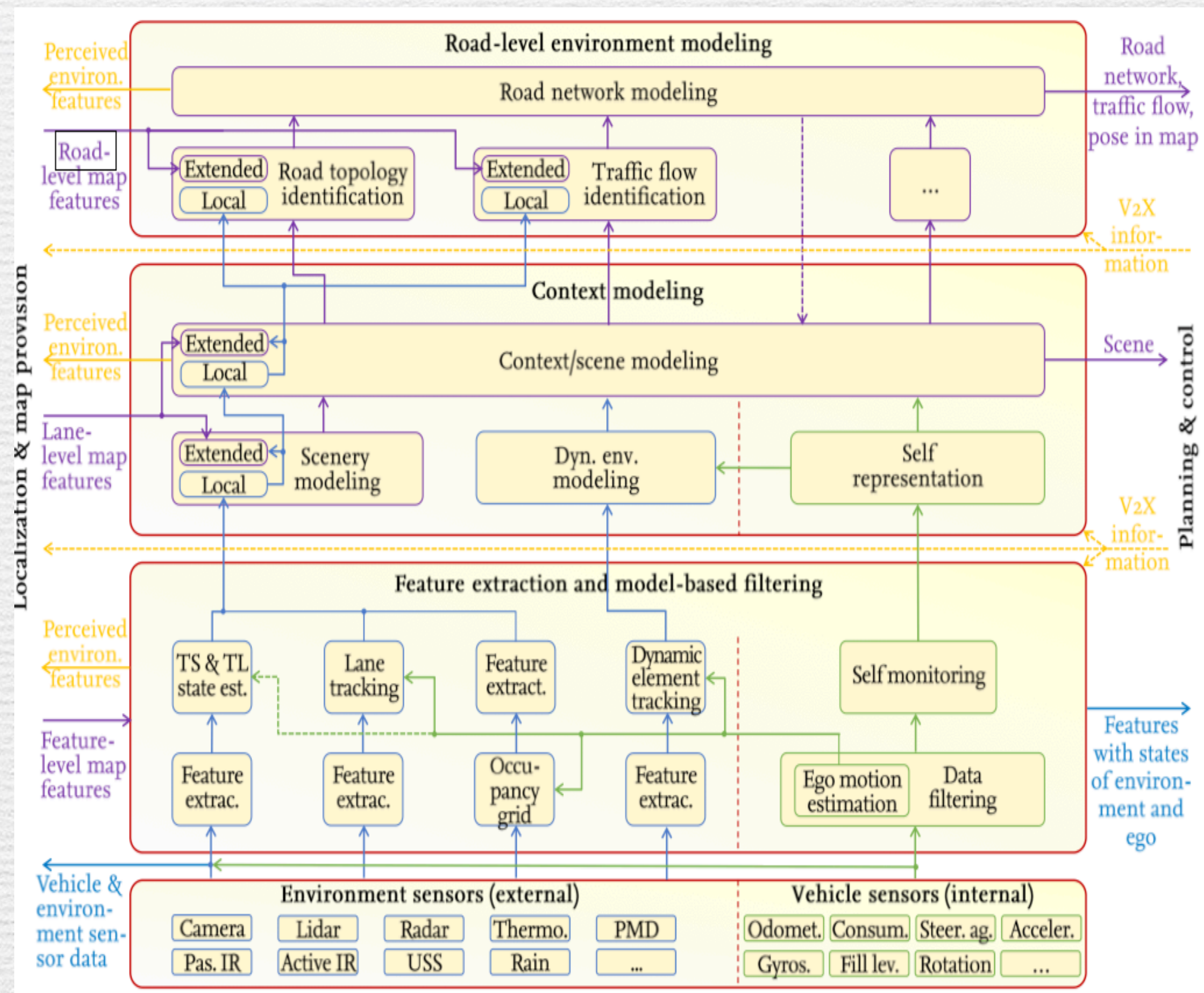
Categories of driving systems

Rule based

End-to-end

Rule based

Huval, Brody, et al. "An empirical evaluation of deep learning on highway driving." arXiv preprint arXiv:1504.01716 (2015).



Ulbrich, Simon, et al. "Towards a Functional System Architecture for Automated Vehicles." arXiv preprint arXiv:1703.08557 (2017).

Rule based

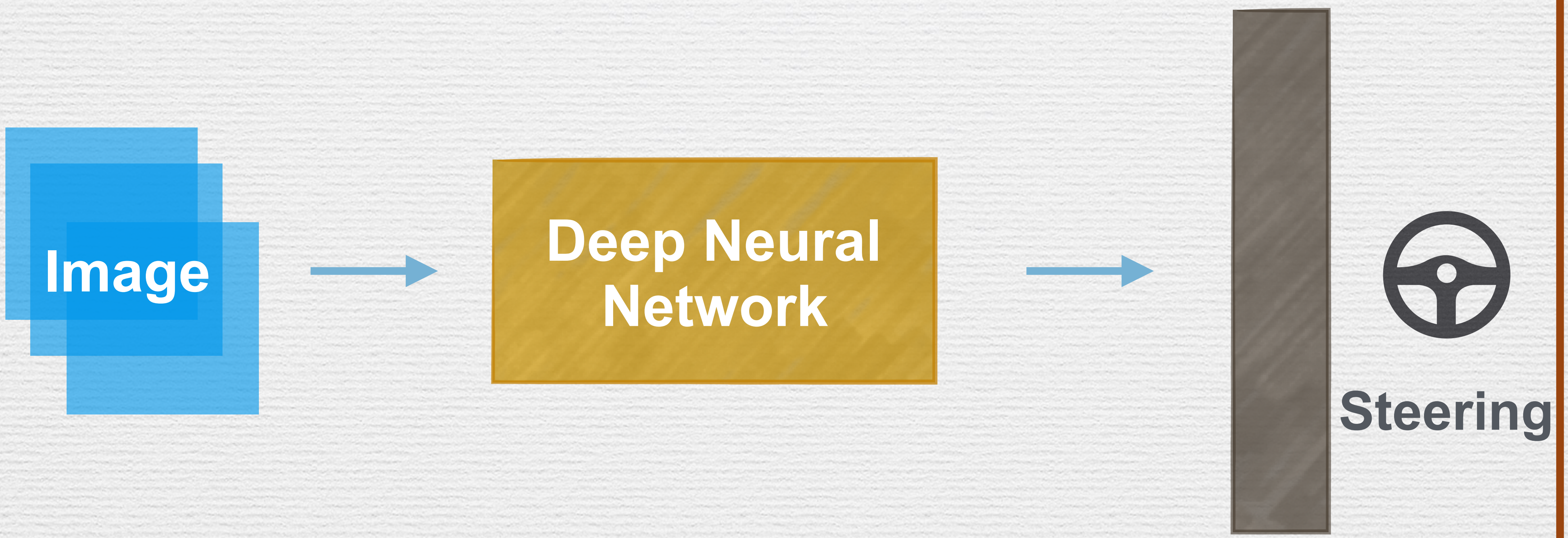
Road-level localization	Road-level modeling	Navigation
Lan-level localization	Context modeling	Guidance
Feature-level localization	Feature extraction	Stabilization

Rule based vs End-to-end

		Rule based	End-to-end
function	reactive control （边打电话边开车）	✅	✅
	proactive planning (思考判断怎么开)	✅	❌
system complexity		very high	very low
interpretability		high	low
scale costs		high (HD Map)	low
sensor costs		very high	low
computing power (on board)		very high	low

From Baidu Apollo open course

End-to-end



Mariusz et .al 2016

End-to-end

ALVINN - 1989

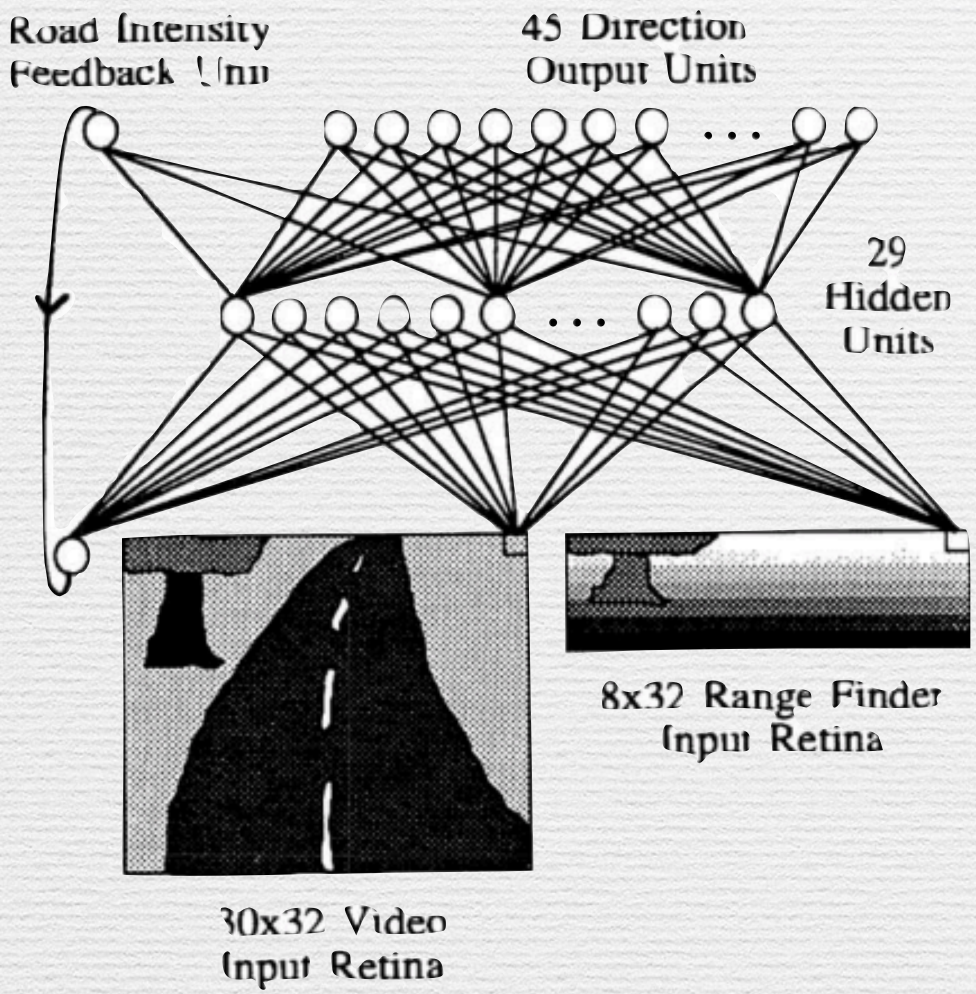


Figure . ALVINN Architecture

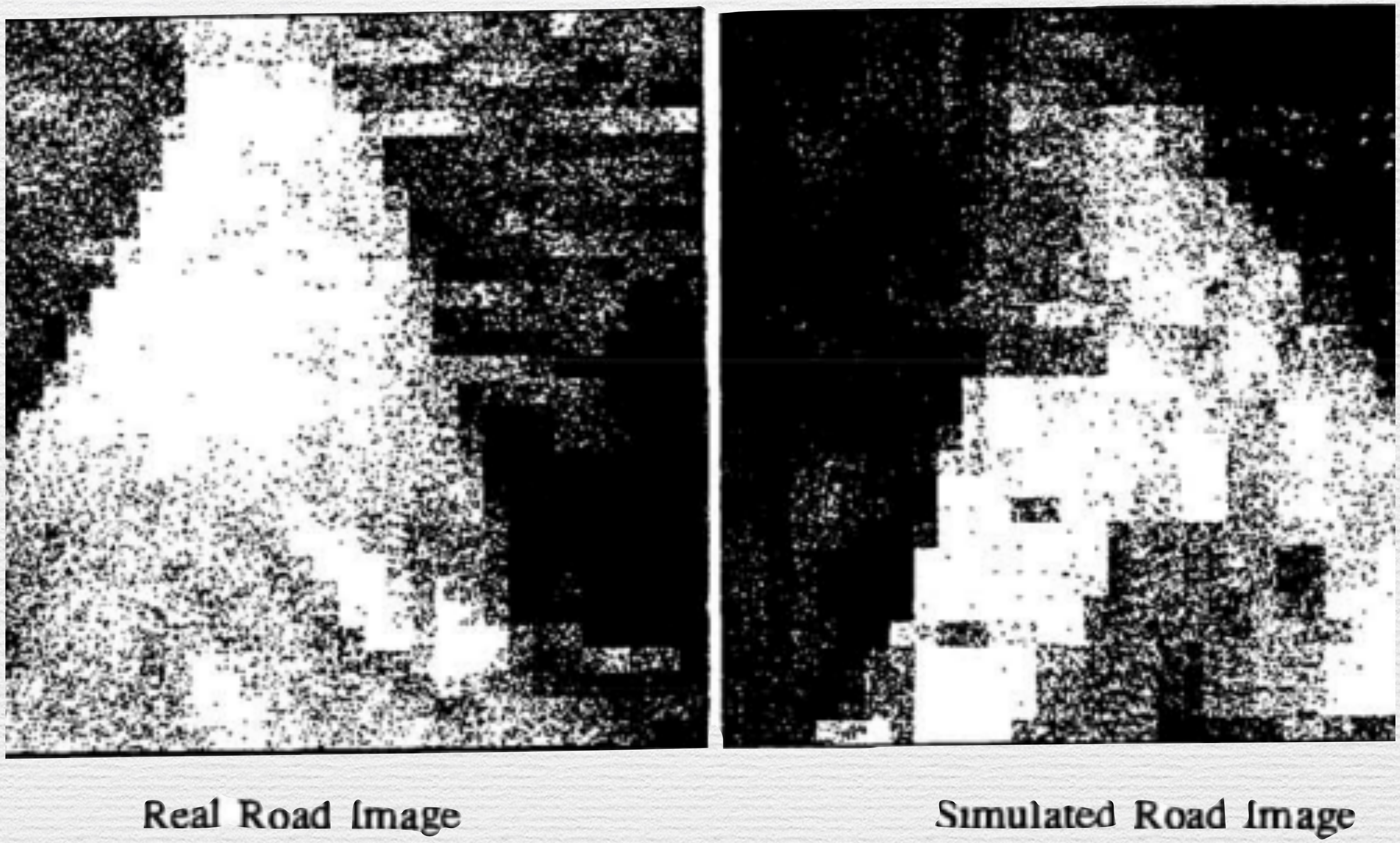


Figure 2. Real and simulated road images

Pomerleau, Dean A. "Alvinn: An autonomous land vehicle in a neural network." Advances in neural information processing systems. 1989.

End-to-end

DAVE - 2006

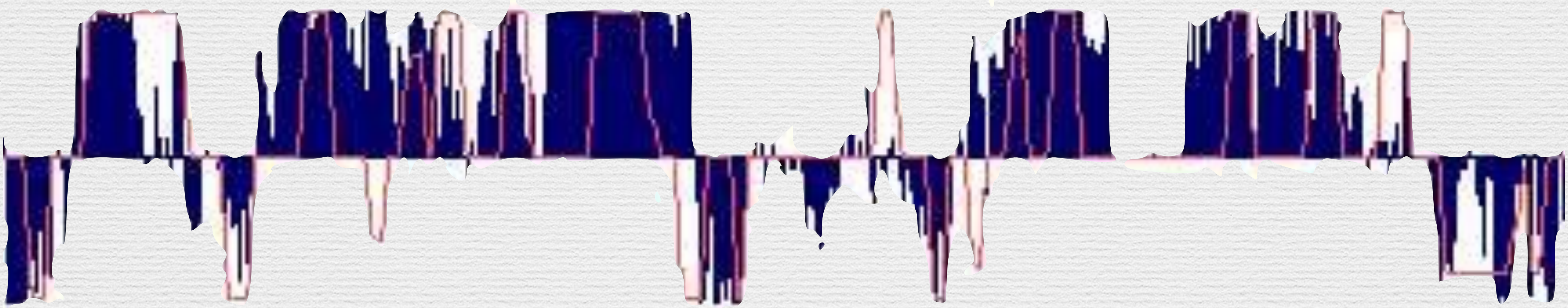
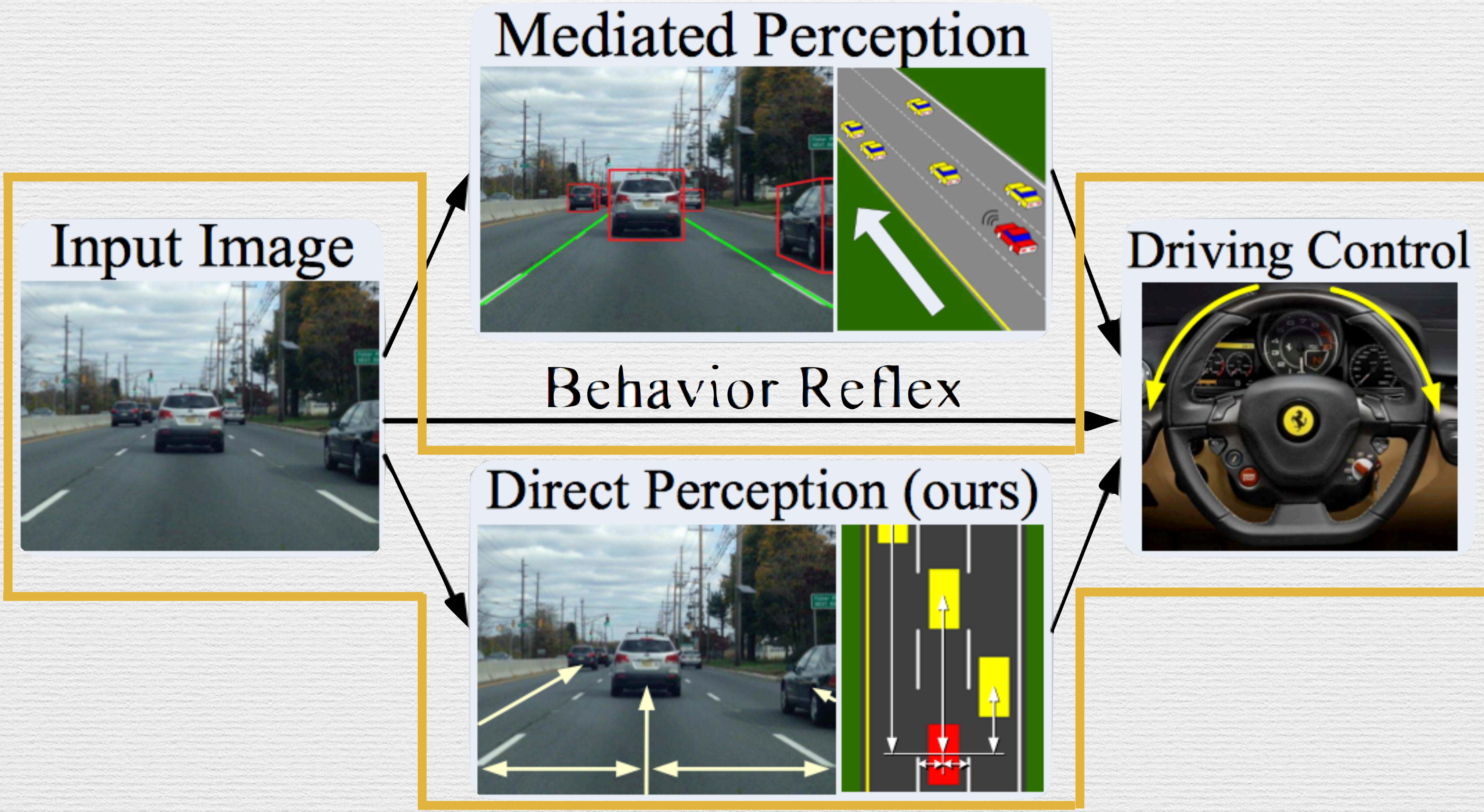


Figure: The steering angle produced by the system (black) compared to the steering angle provided by the human operator (red line) for 8000 frames from the test set. Very few obstacles would not have been avoided by the system.

Muller, Urs, et al. "Off-road obstacle avoidance through end-to-end learning.
“ Advances in neural information processing systems. 2006.APA

End-to-end (Intermediate Approach)

DeepDriving - 2015

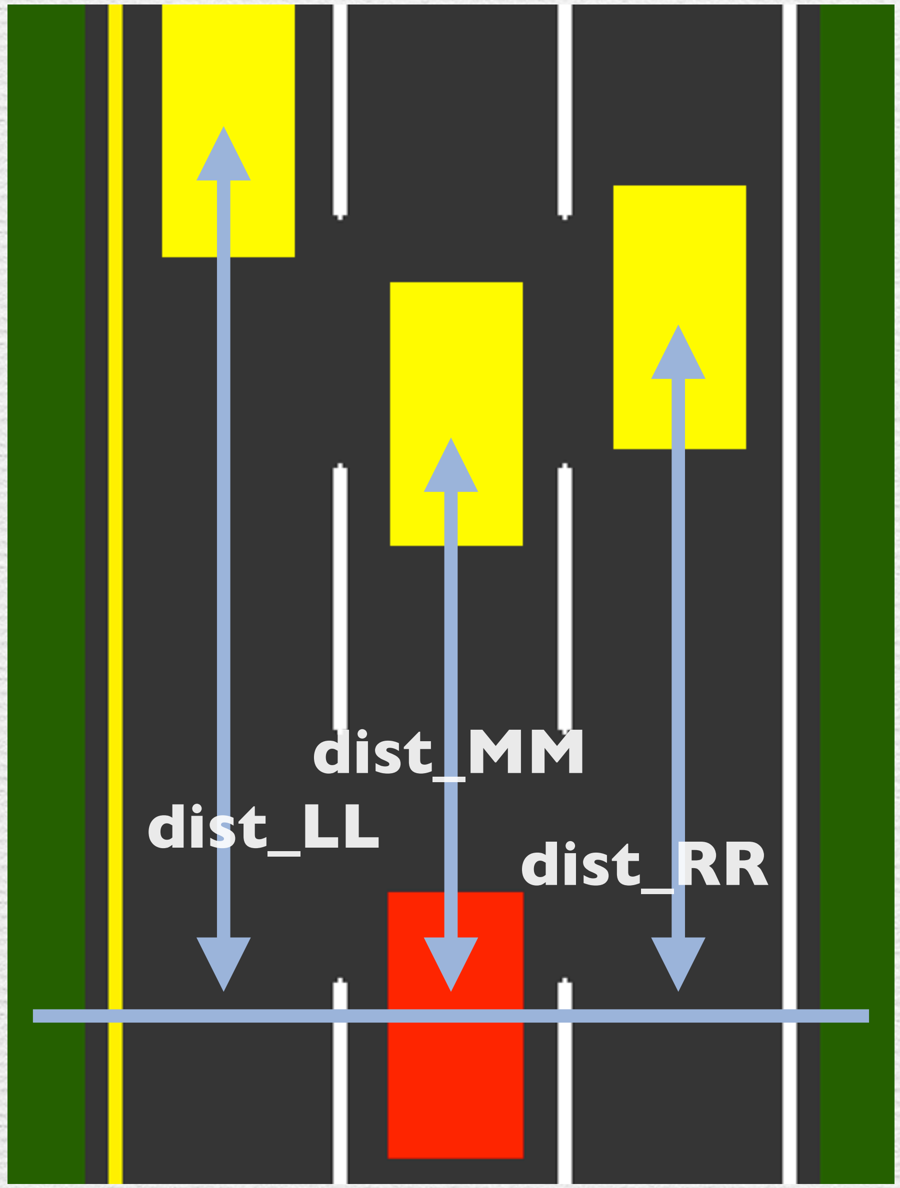


Chen, Chenyi, et al. "Deepdriving: Learning affordance for direct perception in autonomous driving." Proceedings of the IEEE International Conference on Computer Vision. 2015.

End-to-end (Intermediate Approach)

DeepDriving - 2015

Learn the traffic representation

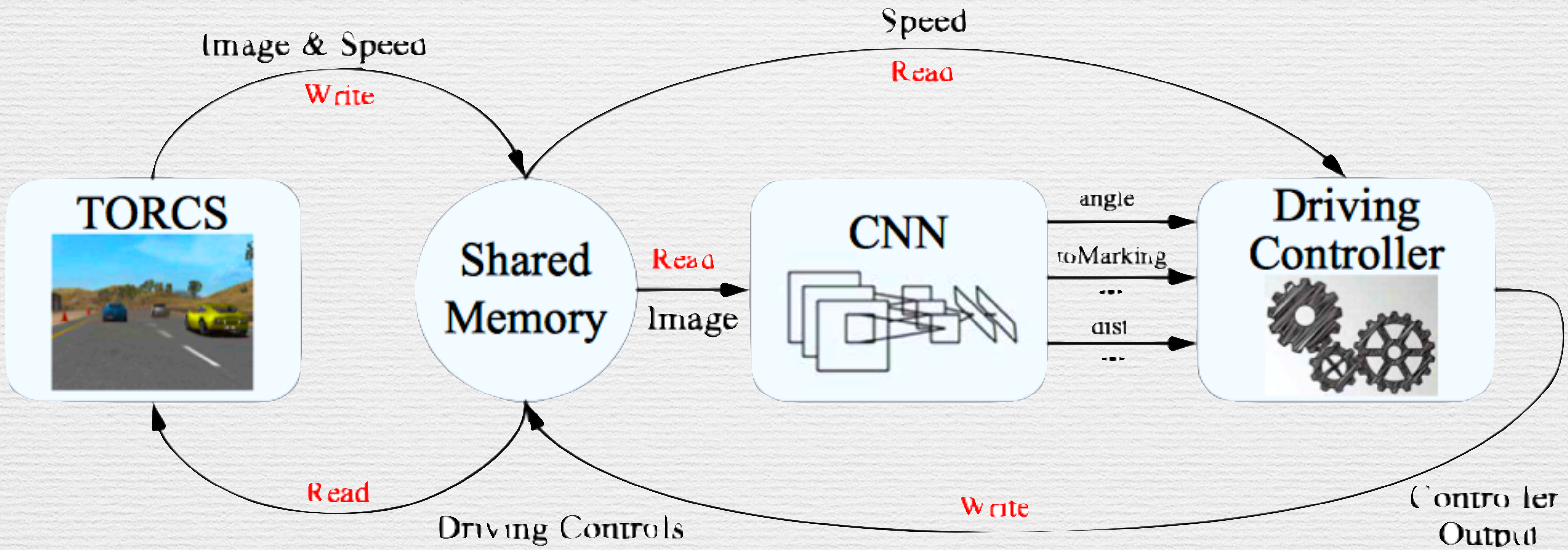


1) **angle**: angle between the car's heading and the tangent of the road "in lane system", when driving in the lane:
2) **toMarking LL**: distance to the left lane marking of the left lane
3) **toMarking ML**: distance to the left lane marking of the current lane
4) **toMarking MR**: distance to the right lane marking of the current lane
5) **toMarking RR**: distance to the right lane marking of the right lane
6) **dist LL**: distance to the preceding car in the left lane
7) …

Chen, Chenyi, et al. "Deepdriving: Learning affordance for direct perception in autonomous driving." Proceedings of the IEEE International Conference on Computer Vision. 2015.

End-to-end (Intermediate Approach)

DeepDriving - 2015



The ConvNet processes the TORCS image and estimates 13 indicators for driving. Based on the indicators and the current speed of the car, a controller computes the driving commands which will be sent back to TORCS to drive the host car in it.

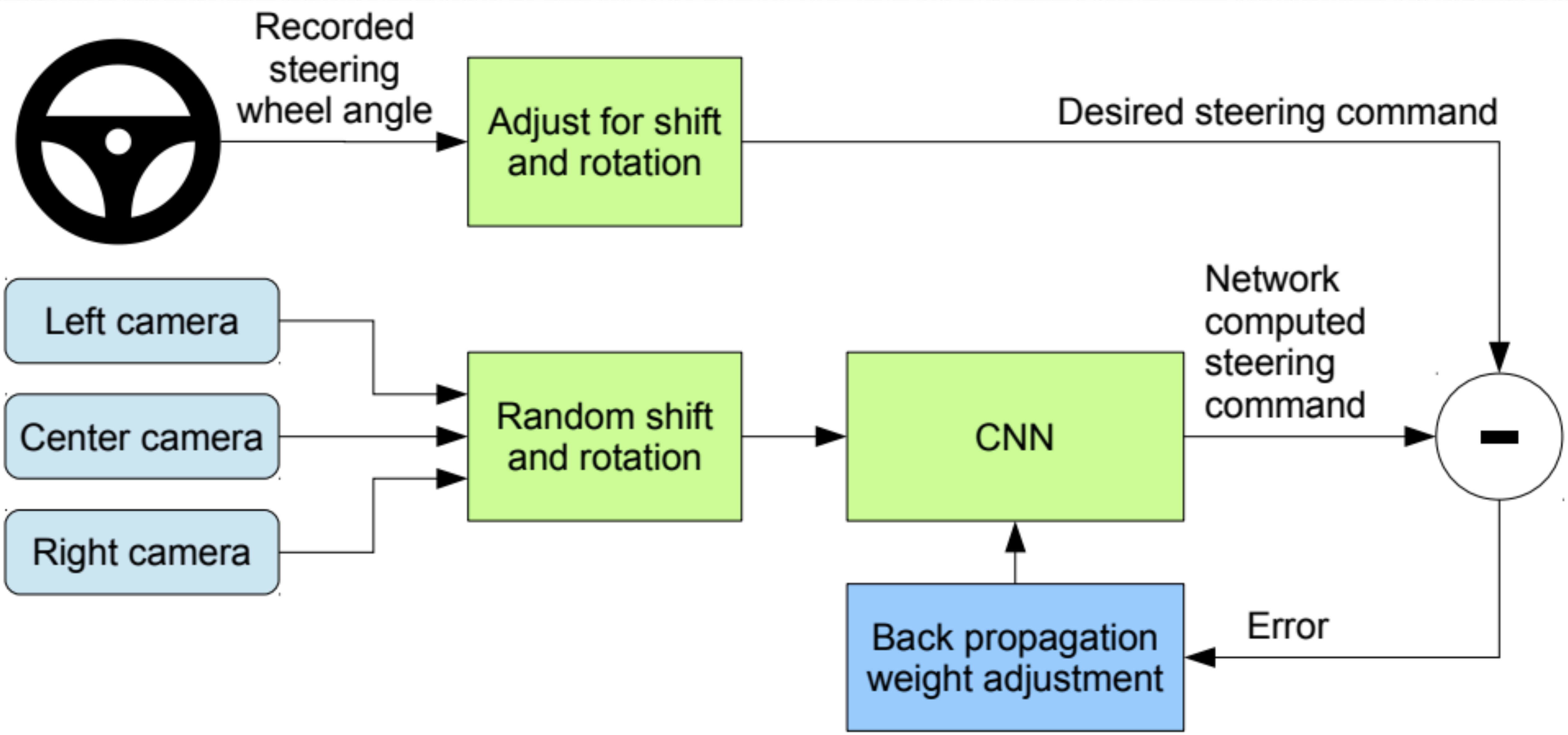
Chen, Chenyi, et al. "Deepdriving: Learning affordance for direct perception in autonomous driving." Proceedings of the IEEE International Conference on Computer Vision. 2015.

End-to-end (Intermediate Approach)

- Better interpretability
- Less human-design modules
- Can’t cover all the corner cases

End-to-end

Self-driving Car - 2016



仿真实验中，90% 的情况下 CNN 可以自动驾驶

路测表明，不同路况自动驾驶的概率为 98%

Bojarski, Mariusz, et al. "End to end learning for self-driving cars." arXiv preprint arXiv:1604.07316 (2016).

End-to-end

Conditional Imitation Learning - 2017

The vehicle was given the command
“turn right at the next intersection”

Codevilla, Felipe, et al. "End-to-end driving via conditional imitation learning." arXiv preprint arXiv:1710.02410 (2017).

Dataset

Real data

- Udacity
- Oxford
- Comma.ai
- **Berkeley**
- **Baidu Apollo**

Simulation data

- OpenAI
- Universal
- DeepMind
- TORCS
- Virtual KITTI

Berkeley Data Drive

30 fps
720 p

Over 400 hours of HD video sequences across many different times in the day, weather conditions, and driving scenarios. Our video sequences also include GPS locations, IMU data, and timestamps.

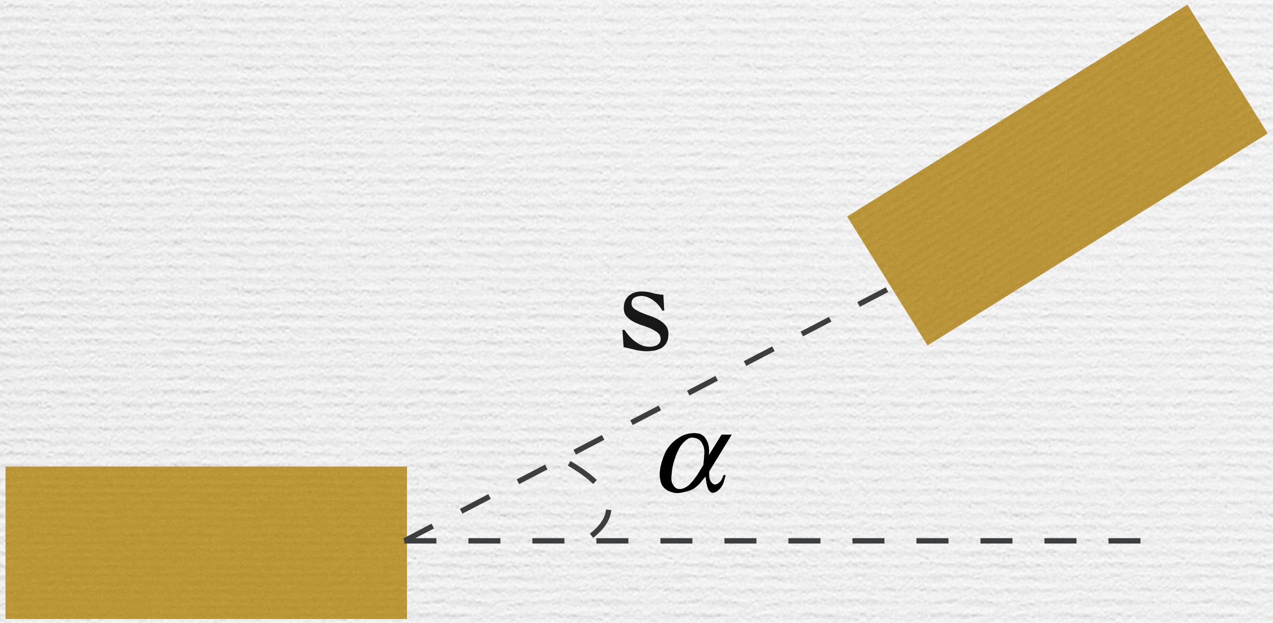
How to apply these dataset to a real driving task?

Imitation Learning - Behavior Cloning

(state_0, action_0, state_1, action_1, …, state_n)

state: images from 3 camera
action: steering angle

Self-driving Formulation - Egomotion Prediction



$$F(s,a): S \times A \to \mathbb{R}$$

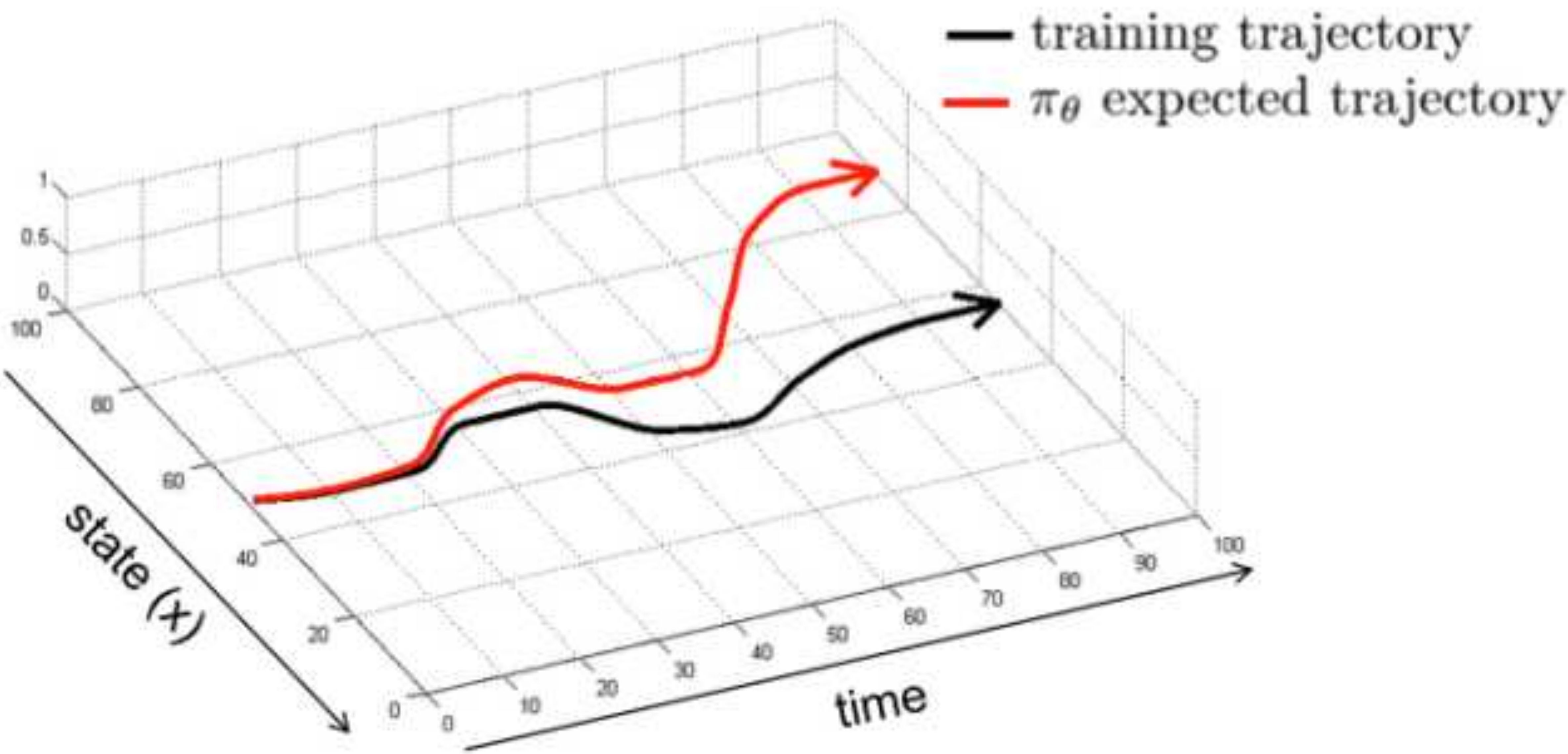
Not be affected by vehicle parameters

- State s:
  - visual information
  - vehicle dynamic state estimation
- Action a:
  - discrete: GO, STOP, LEFT, RIGHT
  - continuous: turning angle and acceleration next 0.1s
  - 6 DOF motions

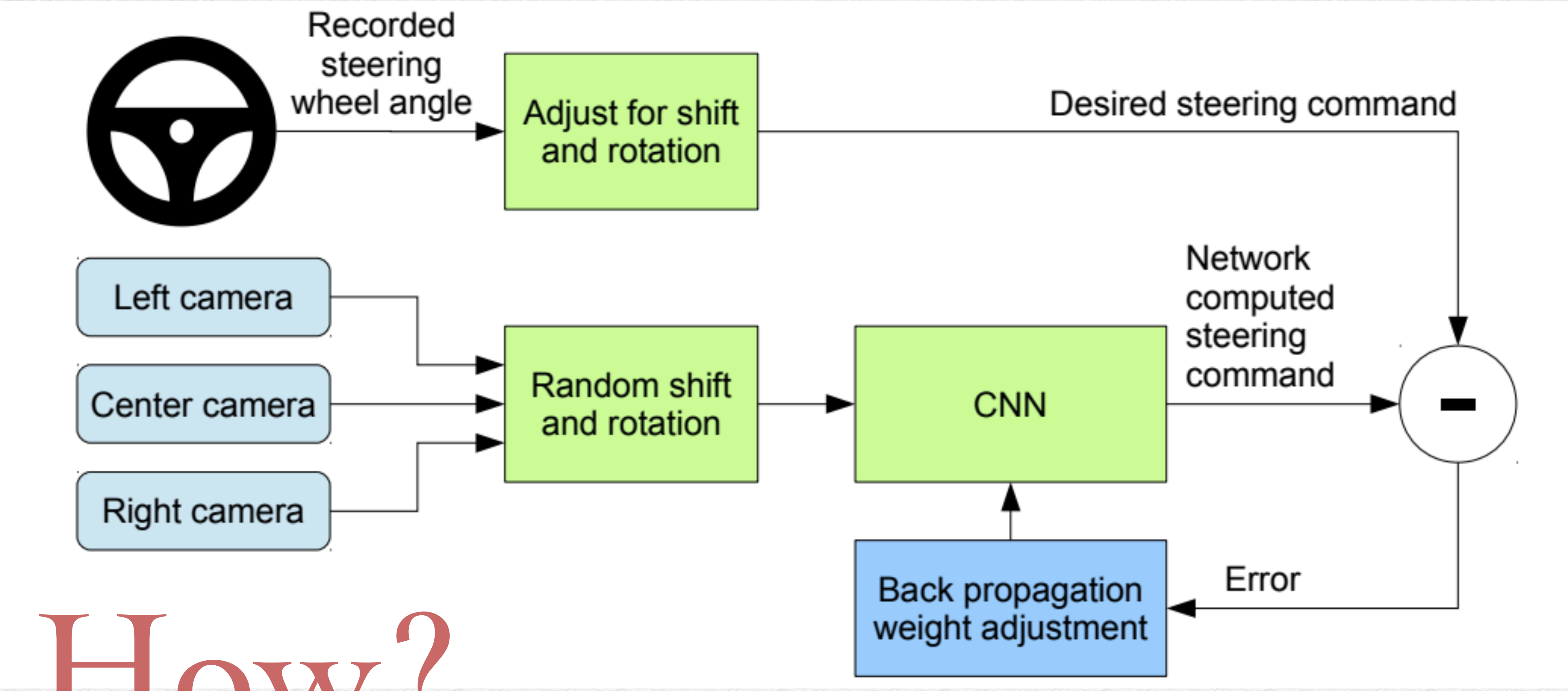
Problem: Compounding errors

$$E[errors] \leq \varepsilon(T + (T-1) + (T-2) + \ldots + 1) \propto \varepsilon T^2$$

Distribution mismatch



Self-driving Car - 2016



How?

仿真实验中，90% 的情况下 CNN 可以自动驾驶

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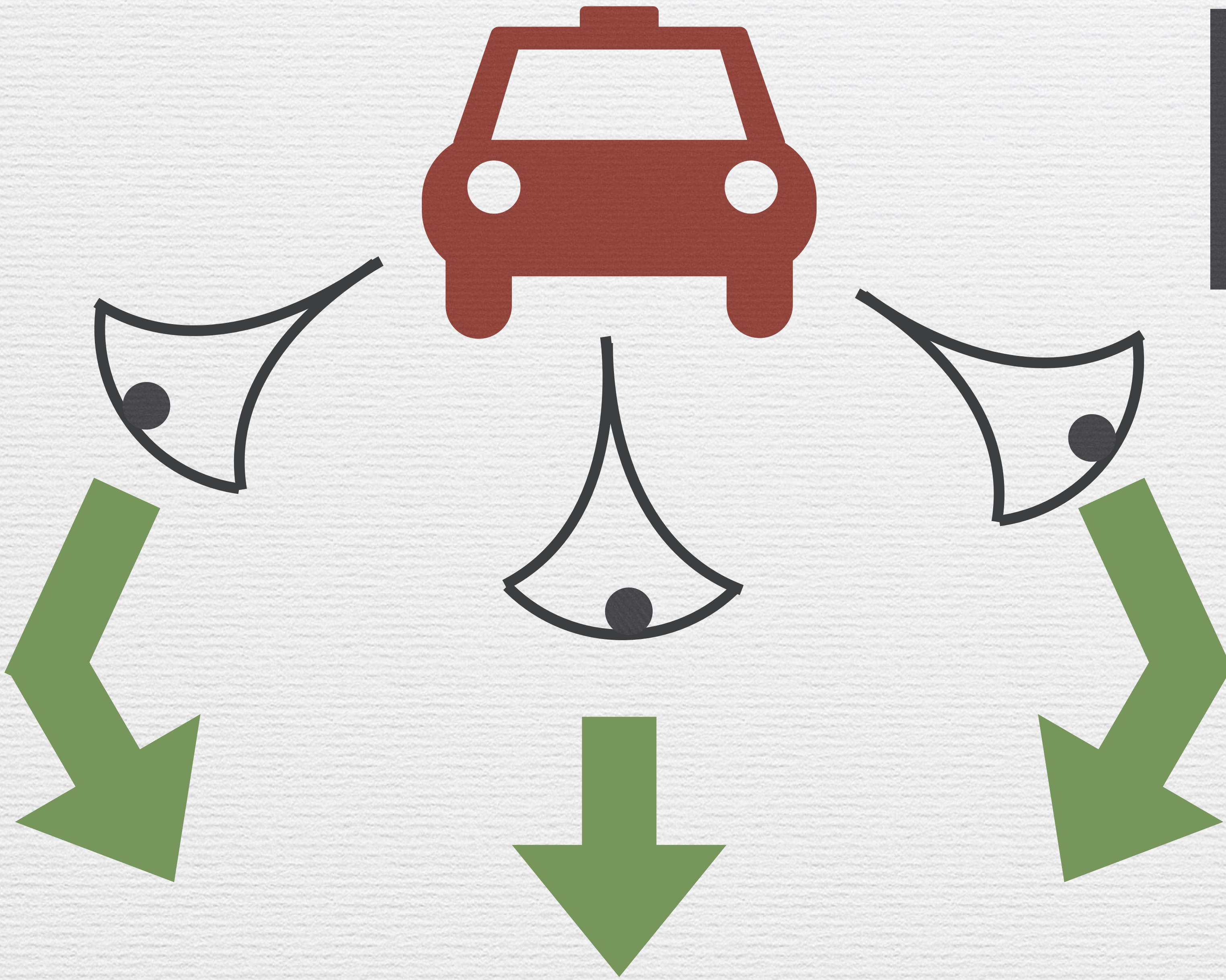
Bojarski, Mariusz, et al. "End to end learning for self-driving cars." arXiv preprint arXiv:1604.07316 (2016).

Self-driving Car - 2016



左右摄像头可以令无人车从部分糟糕的状态中恢复

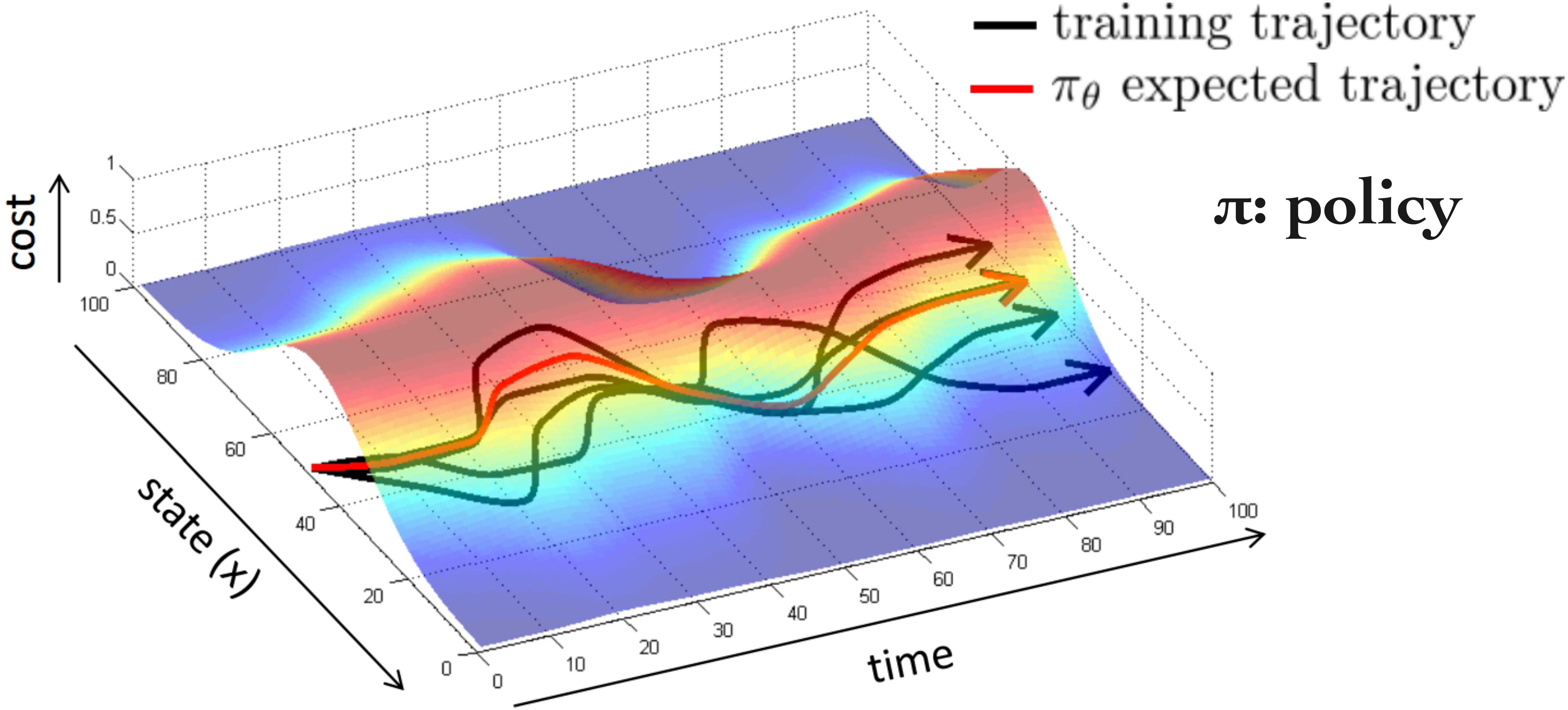
self-stability

Recover from bad case.

Bojarski, Mariusz, et al. "End to end learning for self-driving cars." arXiv preprint arXiv:1604.07316 (2016).

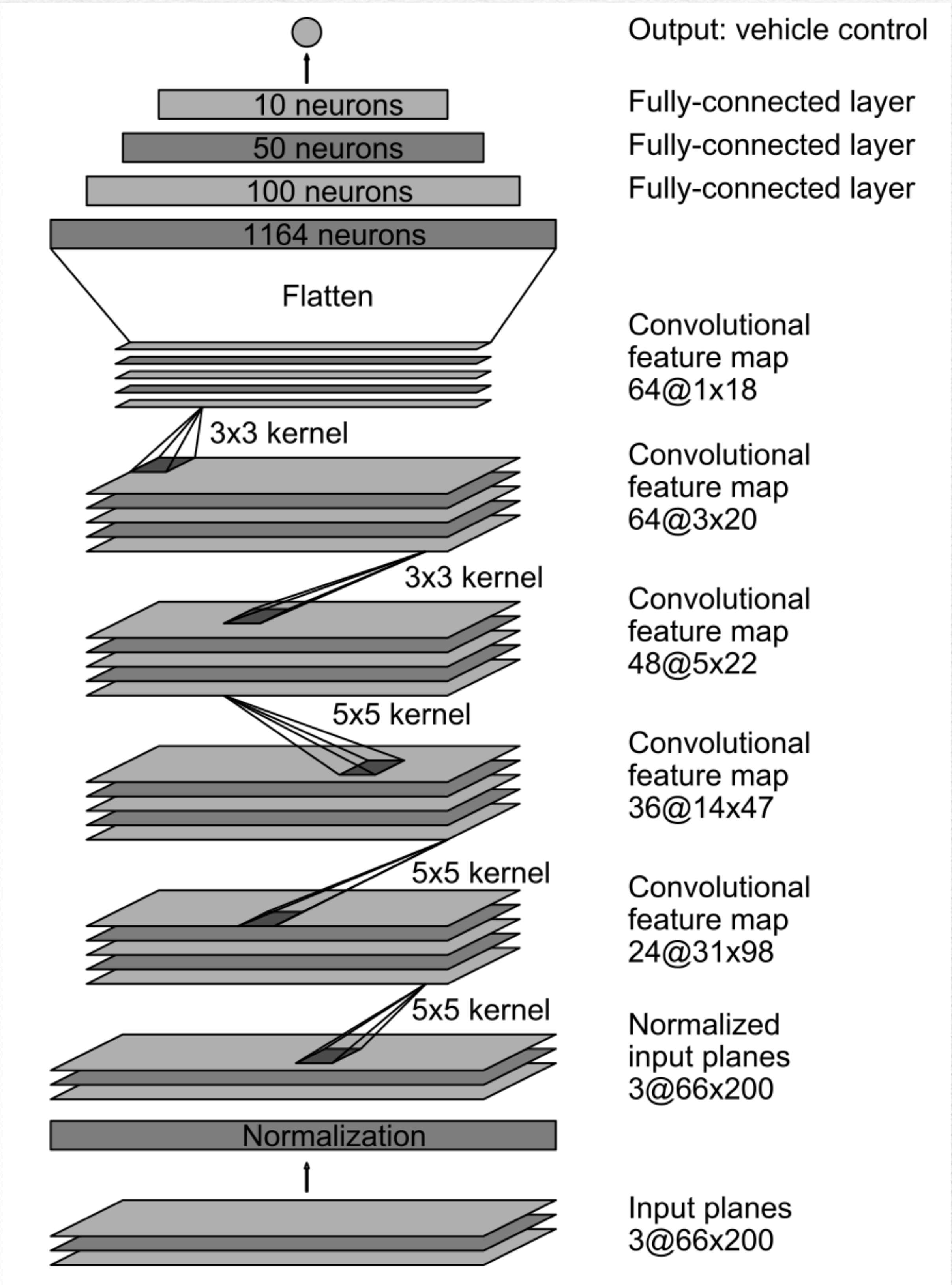
The better way…

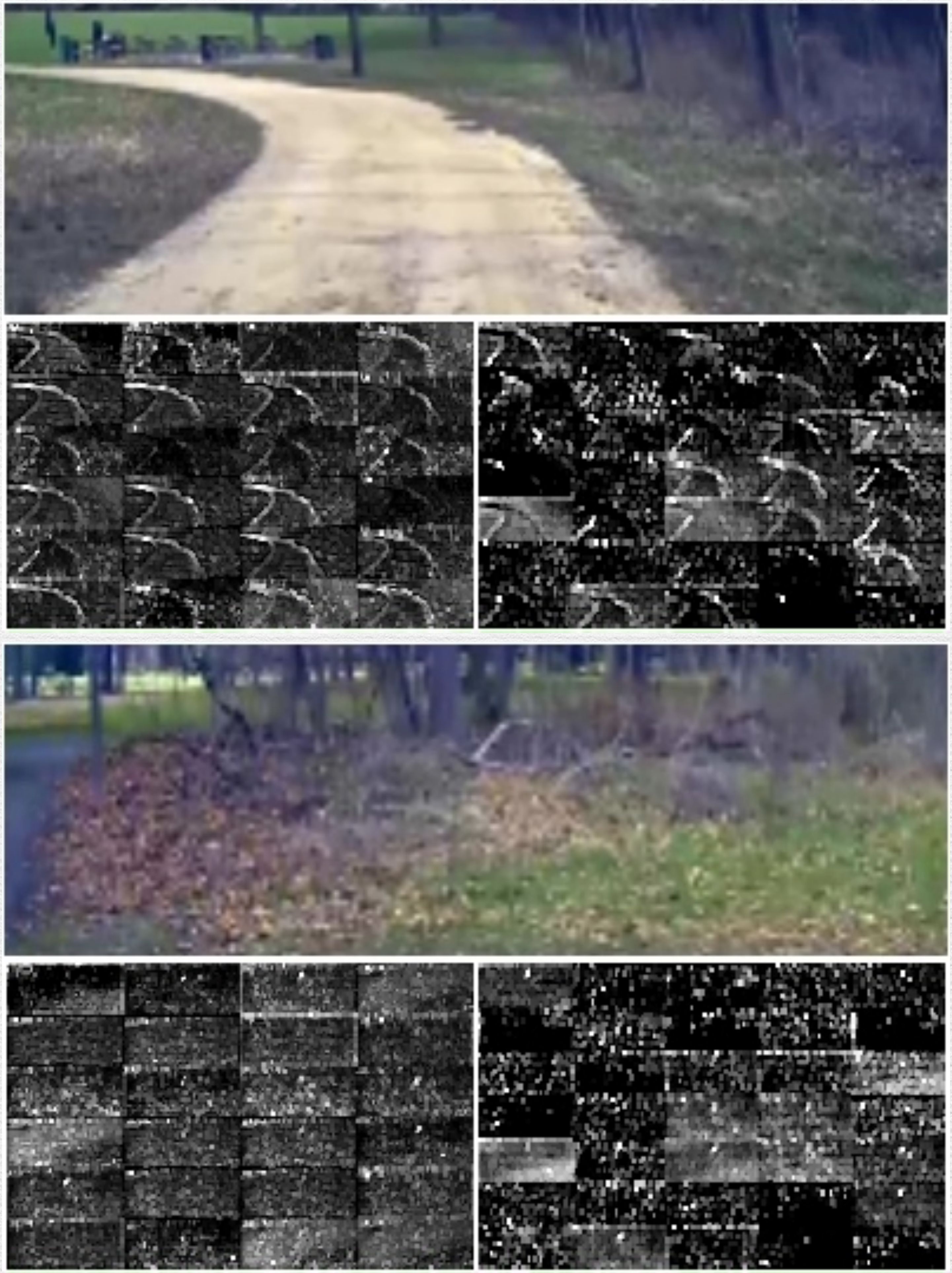
make $P_{data}(O_t) = P_\pi(O_t)$



π: policy

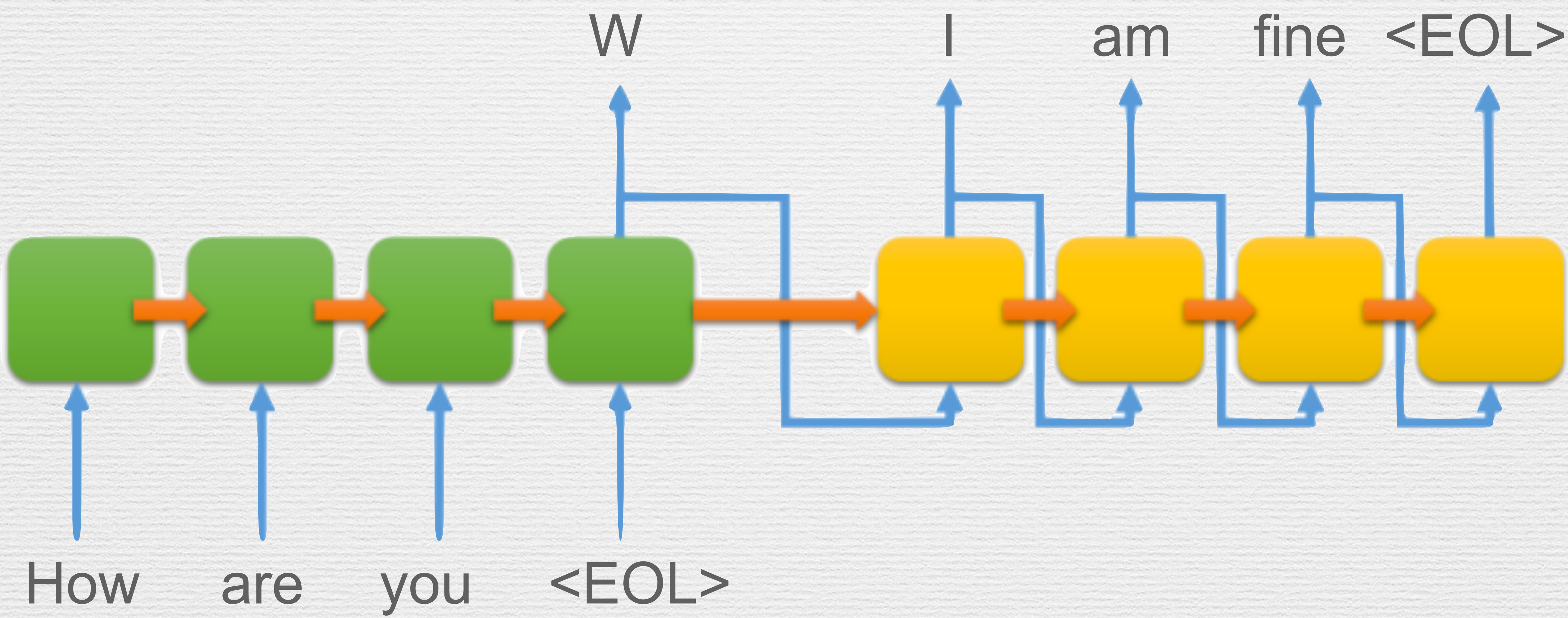
Experiments





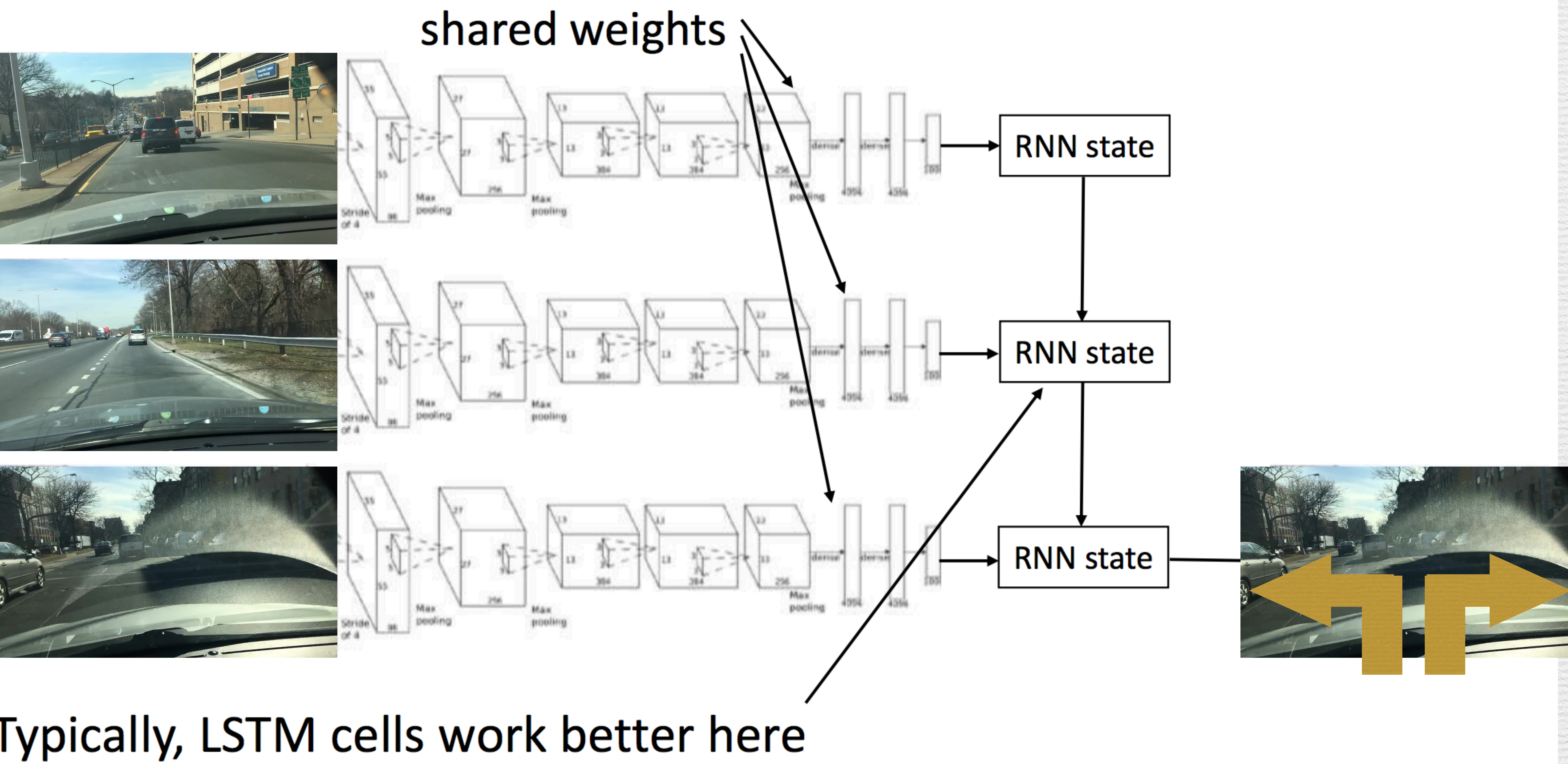
Bojarski, Mariusz, et al. "End to end learning for self-driving cars." arXiv preprint arXiv:1604.07316 (2016).

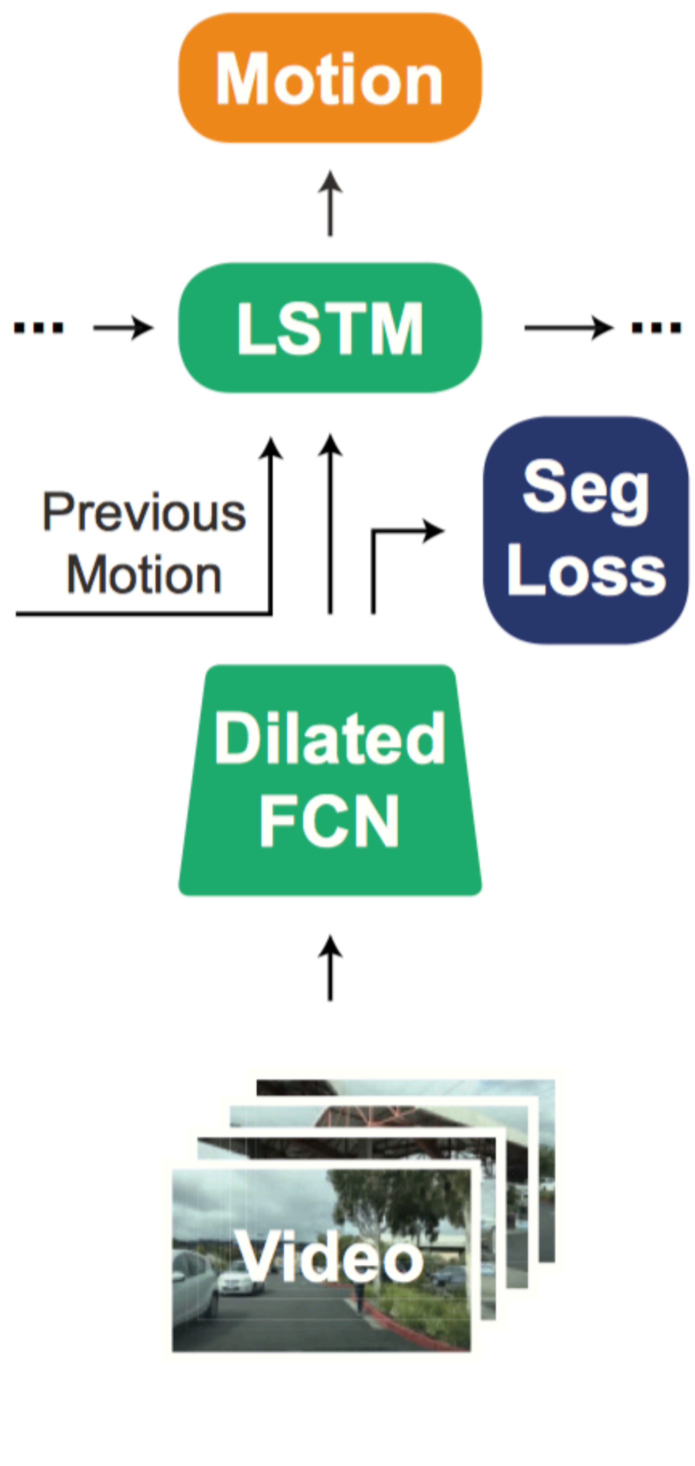
How to model historical information



Seq2Seq Model (RNN)

RNN based architecture





(a) FCN-LSTM

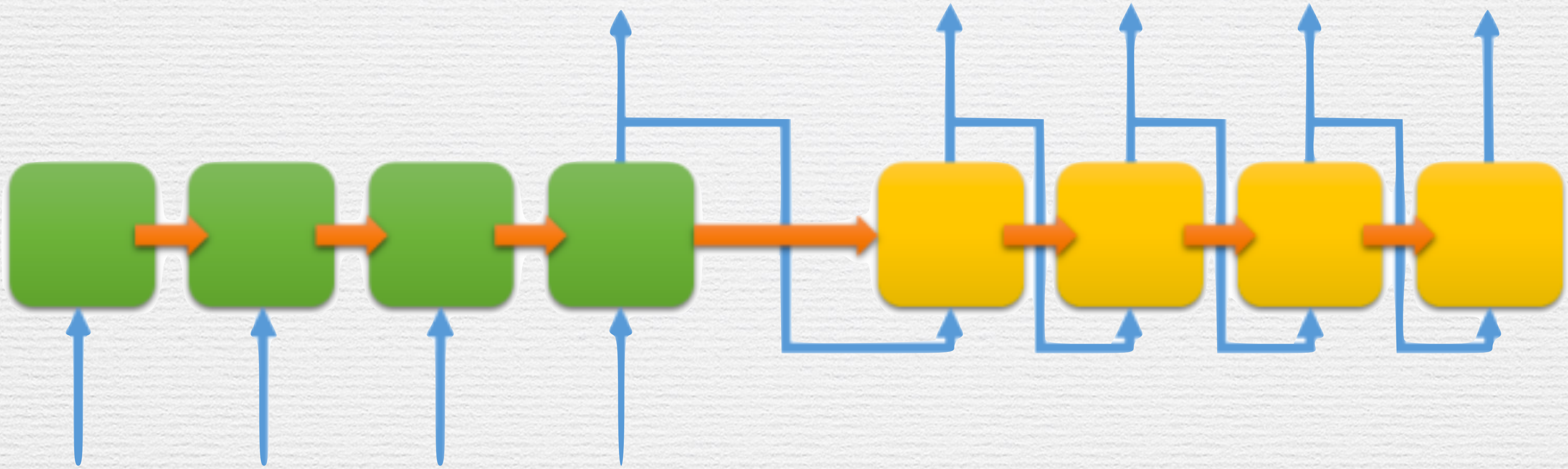
Xu, Huazhe, et al. "End-to-end learning of driving models from large-scale video datasets." arXiv preprint arXiv:1612.01079(2016).

Discrete Action Driving Model

Xu, Huazhe, et al. "End-to-end learning of driving models from large-scale video datasets." arXiv preprint arXiv: 1612.01079(2016).

Continuous Action Driving Model

Xu, Huazhe, et al. "End-to-end learning of driving models from large-scale video datasets." arXiv preprint arXiv: 1612.01079(2016).

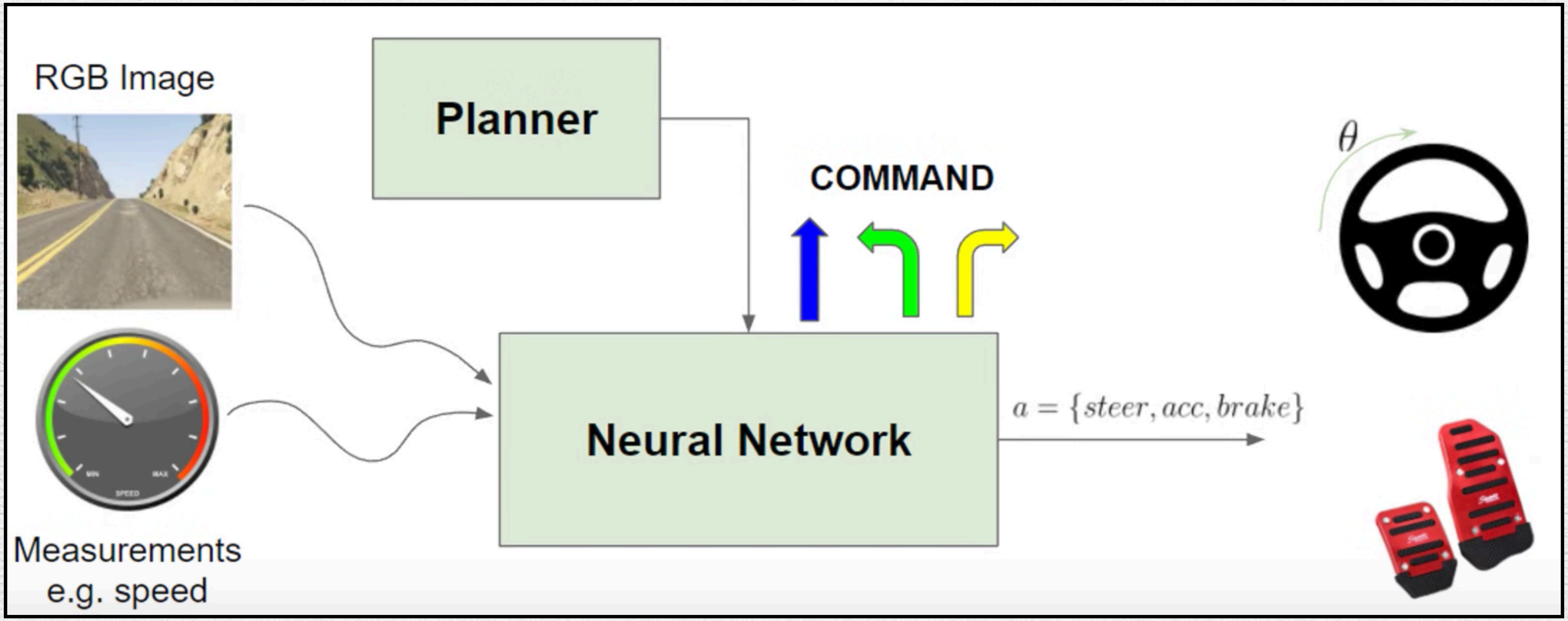


Advanced ideas：

- Attention mechanism
- 横纵向关联关系
- time-series
- …

Conditional Imitation Learning - 2017

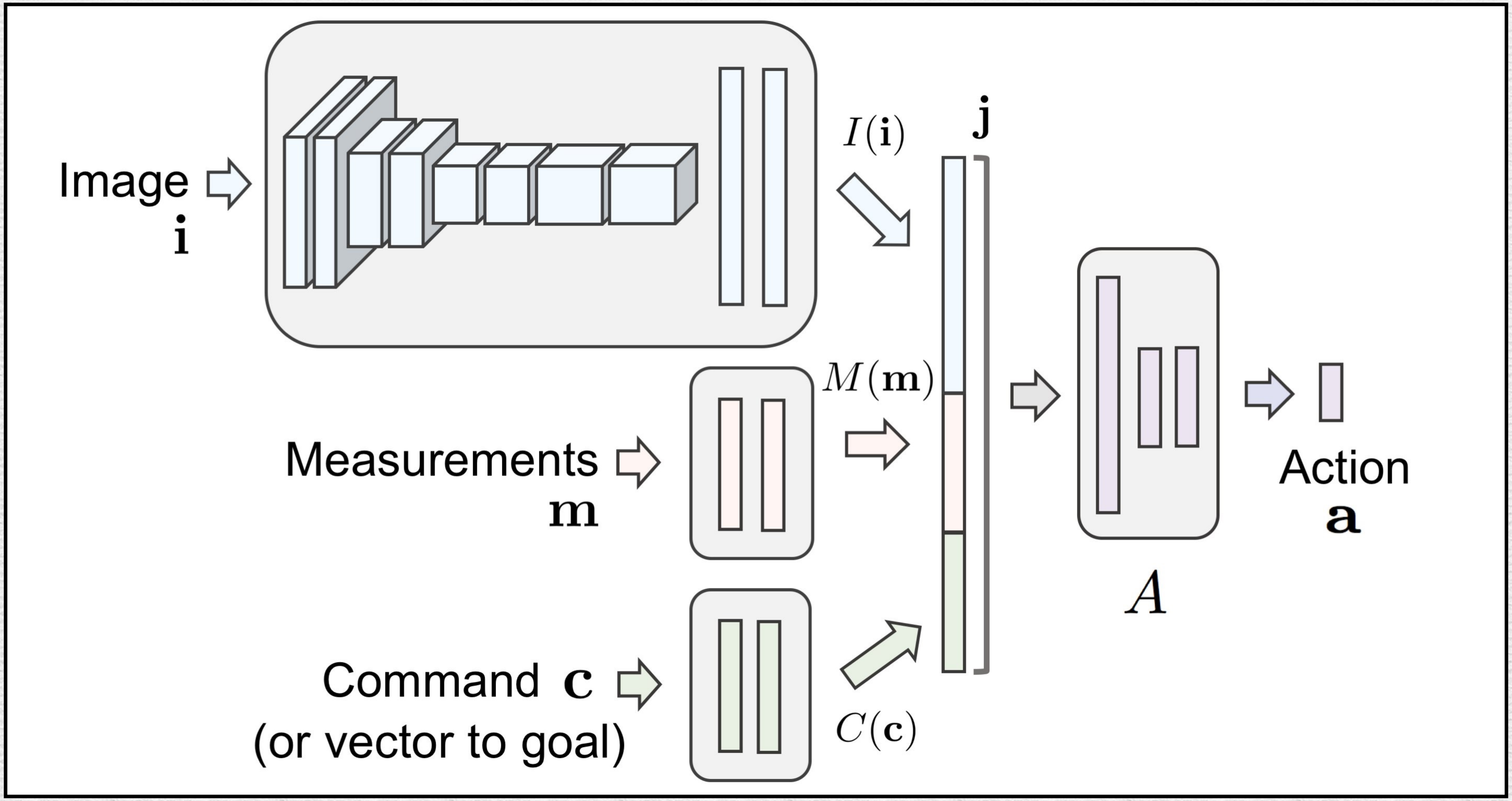
High-level overview



Codevilla, Felipe, et al. "End-to-end driving via conditional imitation learning." arXiv preprint arXiv:1710.02410 (2017).

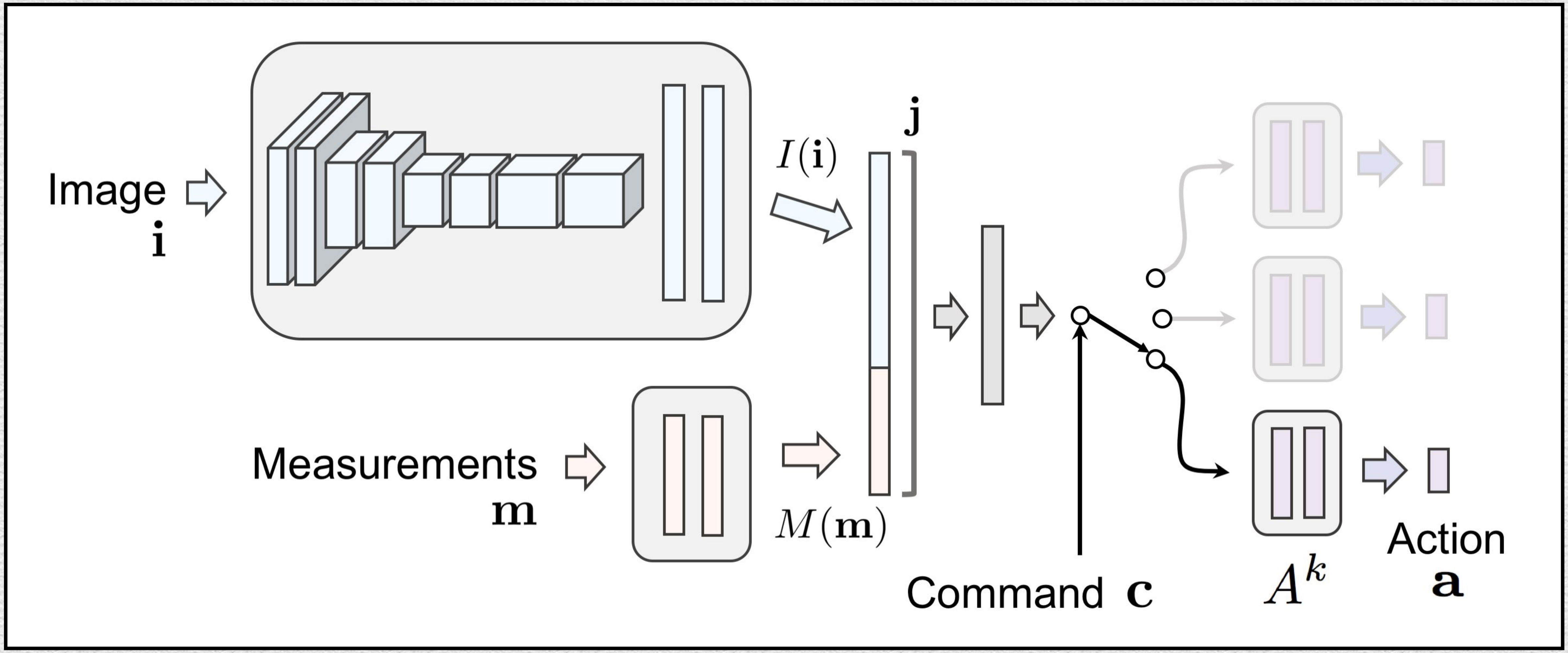
Conditional Imitation Learning - 2017

Network architecture I: command input

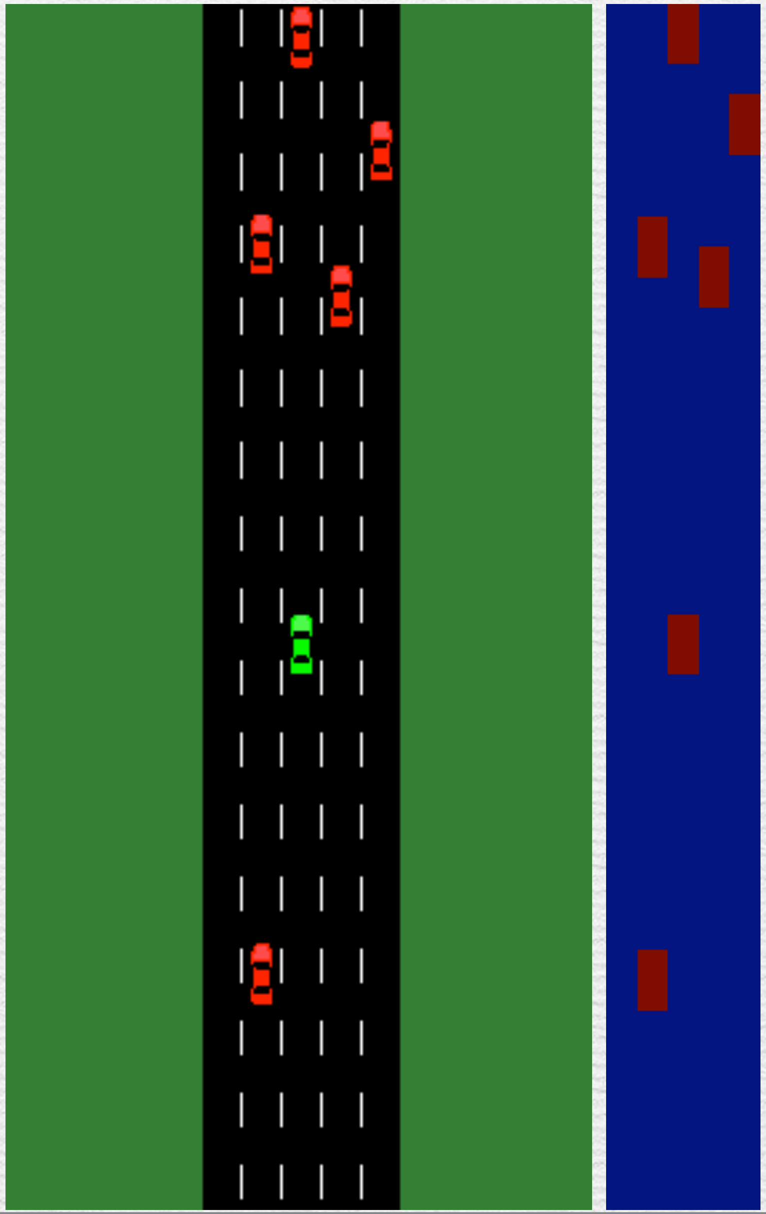


Conditional Imitation Learning - 2017

Network architecture II: branched

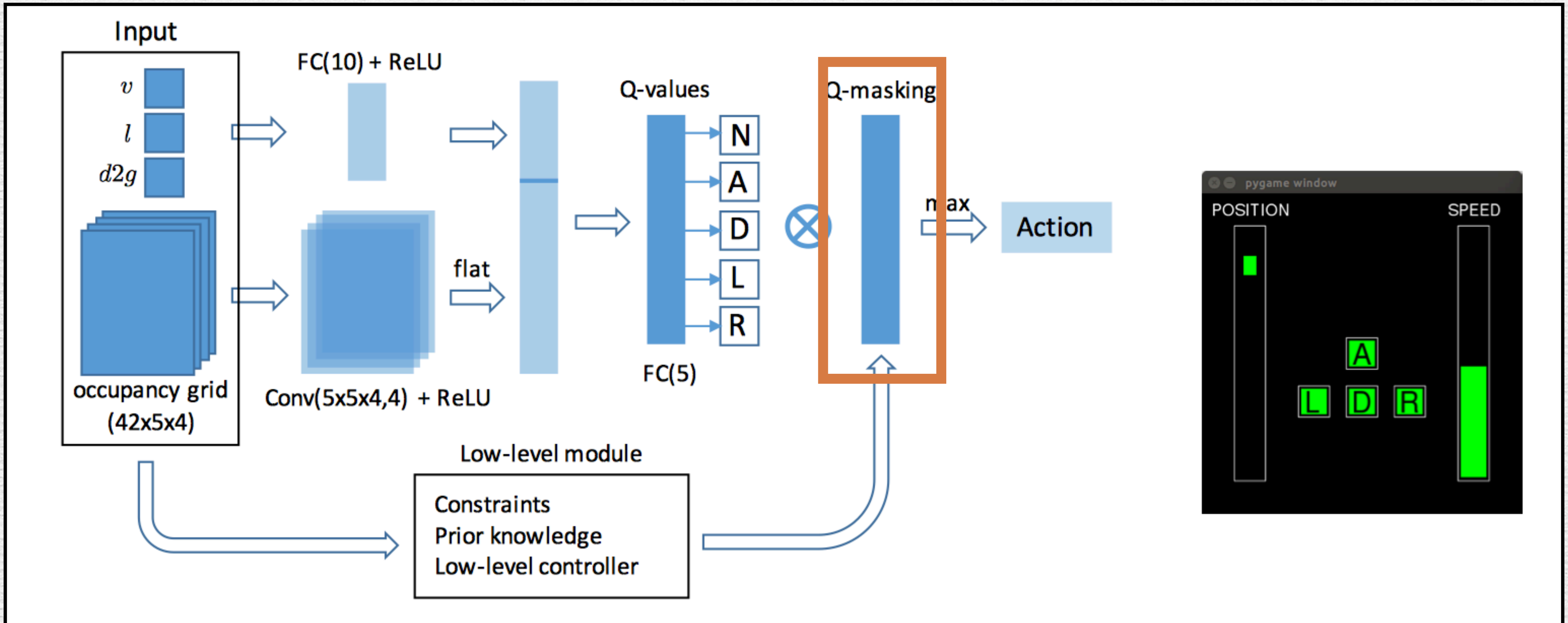


Lane Changing with Reinforcement Learning - 2017



Mukadam, Mustafa, et al.
"Tactical Decision Making for Lane Changing with Deep Reinforcement Learning." (2017).

Framework

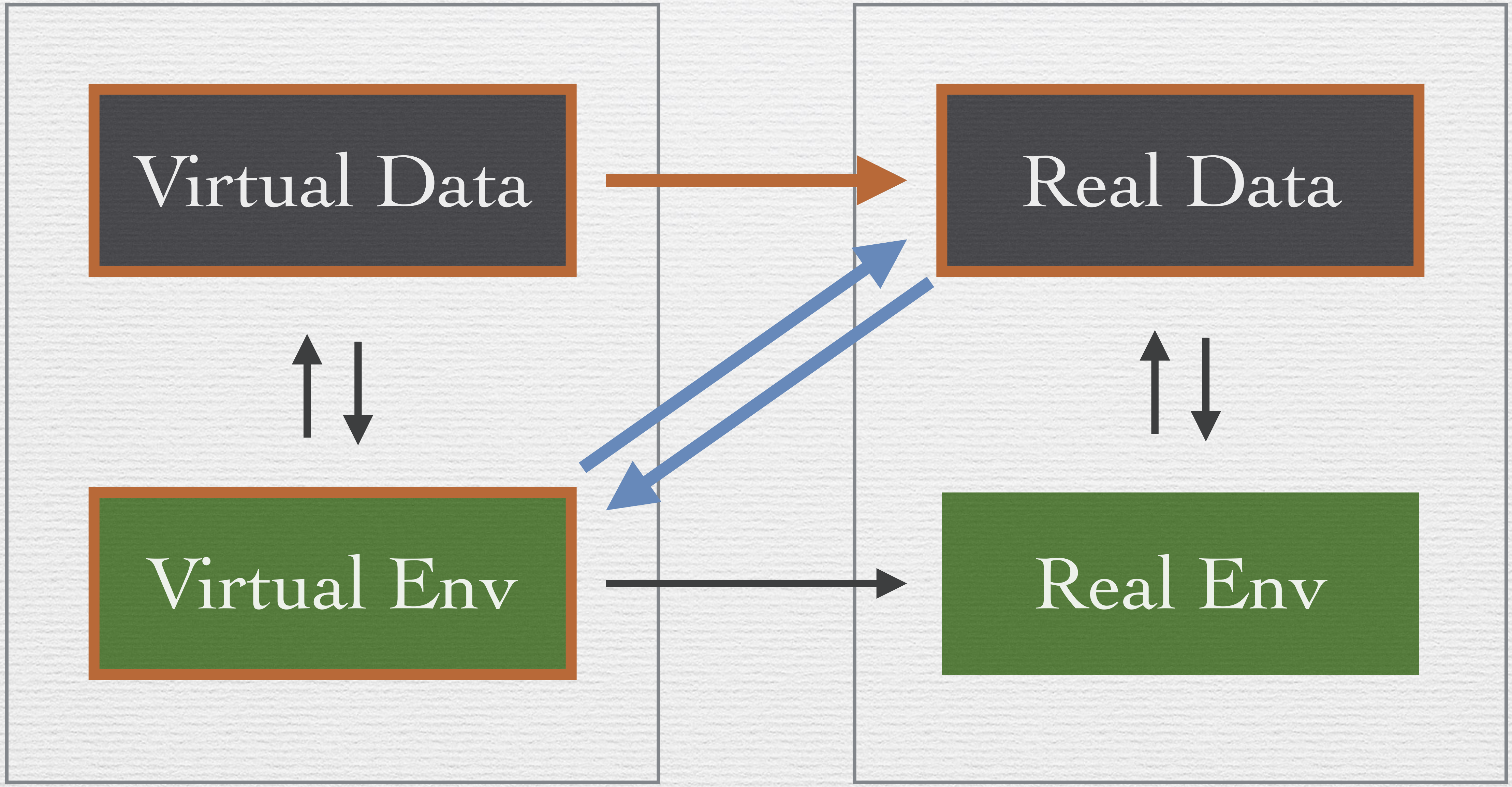


(a)

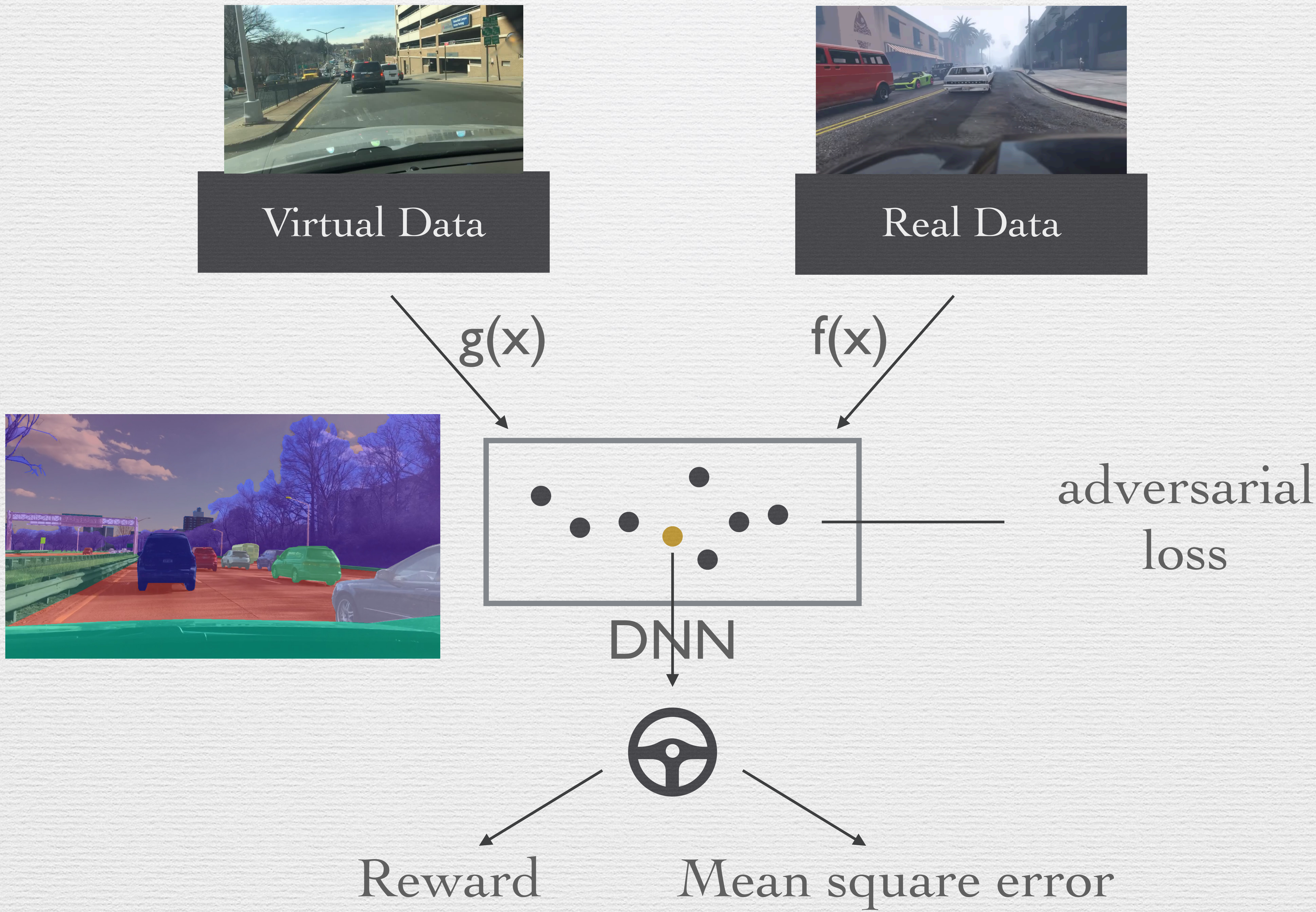
(b)

Our work

Task Doing: From Real to Virtual and From Virtual to Real

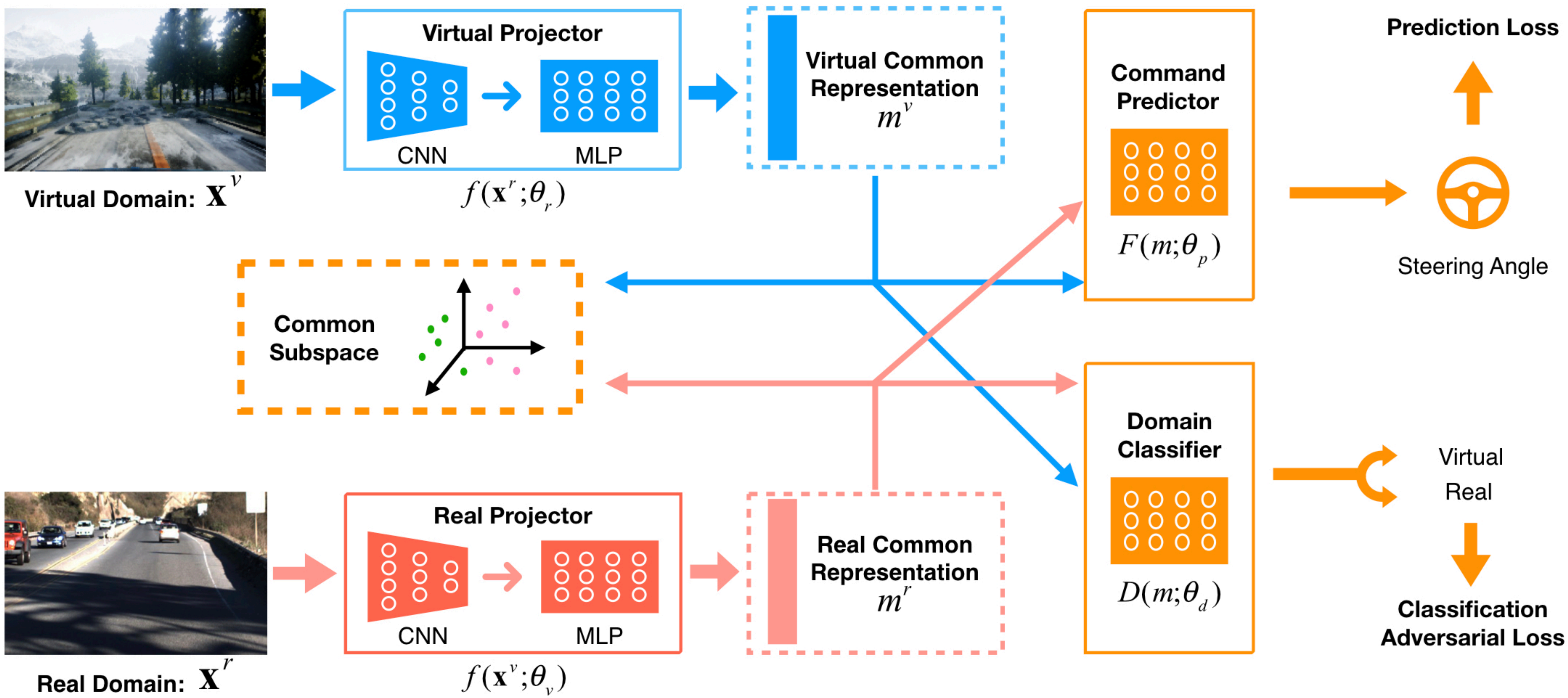


Deep Reinforcement Learning
Generative Adversarial Network



Virtual Data
Real Data
g(x)
f(x)
adversarial
loss
DNN
Reward
Mean square error

Adversarial End-to-end Self-driving on Both of Virtual and Real Worlds

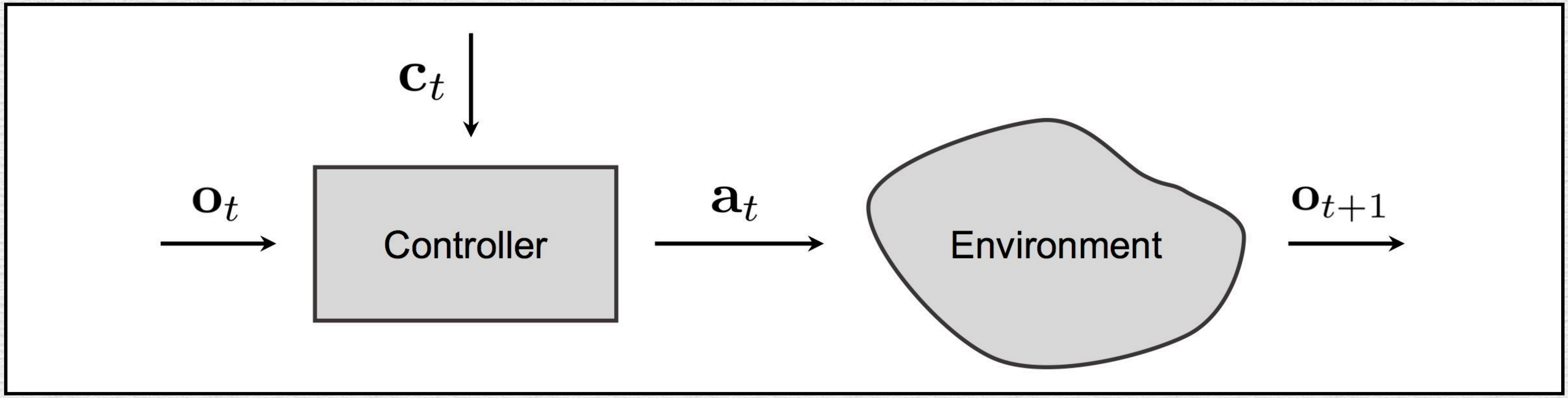


Experiments

Dataset	Model	MAE
Udacity [24]	PilotNet [1]	4.81
	DU-Drive [26]	4.52
	PilotNet-ADAED-UC	4.13
	PilotNet-ADAED-UA	**3.88**
	PilotNet-ADAED-w/oAL-UA	4.27
	PilotNet-JT-UA	13.19
AirSim [16]	PilotNet [1]	1.89
	PilotNet-ADAED-UA	**1.87**
	PilotNet-ADAED-w/oAL-UA	1.92
	PilotNet-JT-UA	8.65
CARLA [5]	PilotNet [1]	5.09
	PilotNet-ADAED-UC	**5.32**
	PilotNet-ADAED-w/oAL-UC	5.38
	PilotNet-JT-UC	15.22

Table 2. Comparison of the steering angle prediction performance in terms of mean absolute error (MAE).

Task TODO: Conditional Imitation Learning for Real Cars



Furthermore…

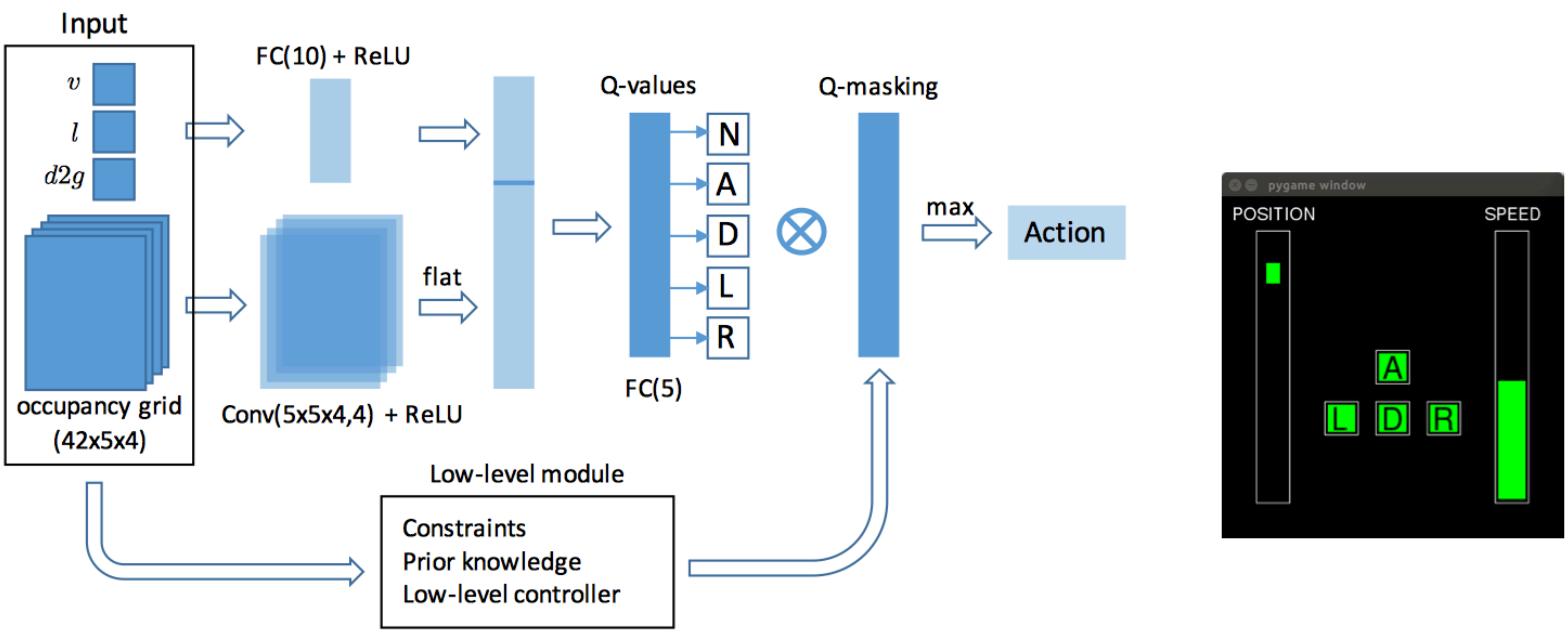
Use **reinforcement learning** for high-level control
conditional **imitation learning** for low-level control

VIDEO

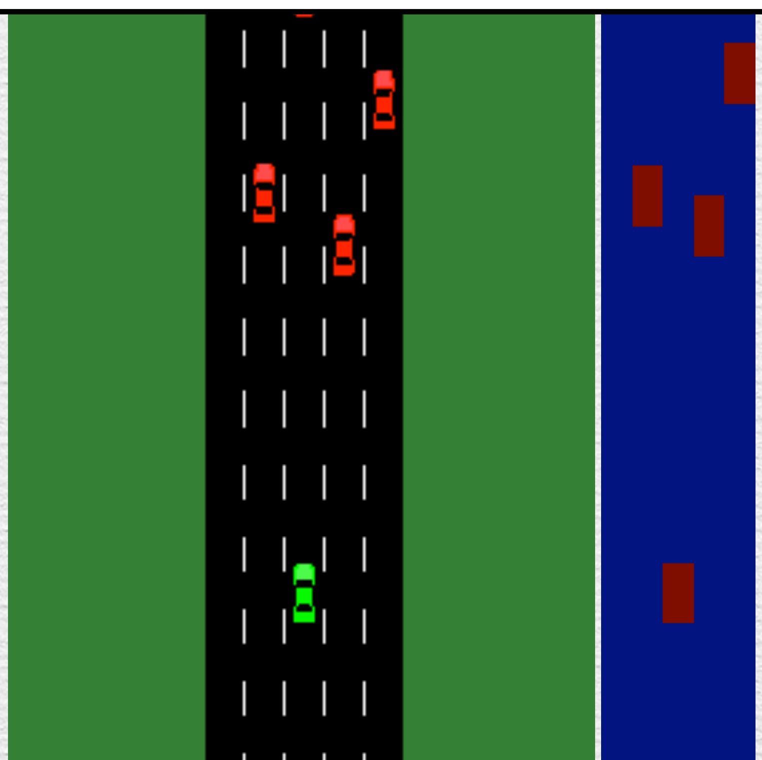
End-to-end Driving via Conditional Imitation Learning

Felipe Codevilla, Matthias Mueller, Alexey Dosovitskiy, Antonio Lopez, Vladlen Koltun

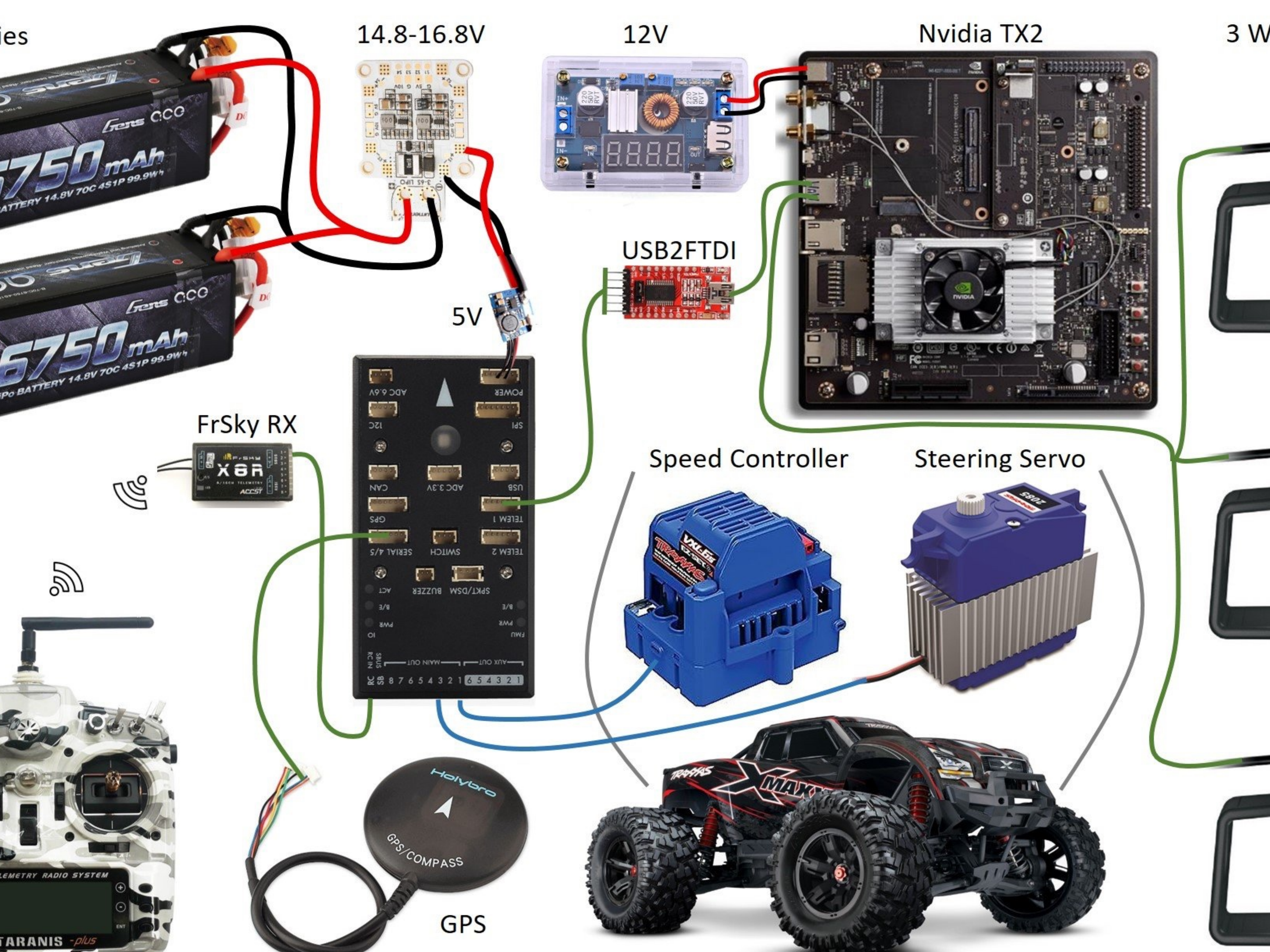
Submitted to ICRA 2018


Input
v
l
$d2g$
occupancy grid
(42x5x4)
FC(10) + ReLU
Conv(5x5x4,4) + ReLU
flat
Q-values
N
A
D
L
R
FC(5)
Q-masking
max
Action
Low-level module
Constraints
Prior knowledge
Low-level controller
pygame window
POSITION
SPEED
A
L
D
R

(a) (b)



Goal: give a GPS coordinate, then get there


ies
14.8-16.8V
12V
Nvidia TX2
3 W
USB2FTDI
5V
FrSky RX
Speed Controller
Steering Servo
GPS
6750 mAh
BATTERY 14.8V 70C 4S1P 99.9Wh
POWER
ADC 6.6V
I2C
SPI
CAN
ADC 3.3V
USB
GPS
TELEM 1
SERIAL 4/5
SWITCH
TELEM 2
BUZZER
SPKT/DSM
MAIN OUT
AUX OUT
GPS/COMPASS
Holybro
TARANIS

Thanks.