



POLITECNICO
MILANO 1863

Autonomous Racing Cars: will a robot driver ever beat a human?

May 18th 2022 - Udine



2022
ZERO PROTOTYPES
SUMMIT



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move.deib.polimi.it





1		Massachusetts Institute of Technolog... Cambridge, United States	11		EPFL Lausanne, Switzerland	=21		Institut Polytechnique de Paris Palaiseau Cedex, France
2		University of Cambridge Cambridge, United Kingdom	12		Harvard University Cambridge, United States	=21		The University of Manchester Manchester, United Kingdom
3		University of Oxford Oxford, United Kingdom	13		Politecnico di Milano Milan, Italy	23		The University of New South Wales... Sydney, Australia
4		Nanyang Technological University, ... Singapore, Singapore	14		Tsinghua University Beijing, China (Mainland)	24		The Hong Kong University of Science... Hong Kong SAR, Hong Kong SAR
5		Stanford University Stanford, United States	15		California Institute of Technology... Pasadena, United States	25		University of California, Los Angeles... Los Angeles, United States
6		ETH Zurich - Swiss Federal Institute of... Zürich, Switzerland	16		Georgia Institute of Technology Atlanta, United States	=26		University of Texas at Austin Austin, United States
7		National University of Singapore (NUS) Singapore, Singapore	17		The University of Tokyo Tokyo, Japan	=26		Universit Paris-Saclay Gif-sur-Yvette, France
8		Imperial College London London, United Kingdom	18		Carnegie Mellon University Pittsburgh, United States	=28		KTH Royal Institute of Technology Stockholm, Sweden
9		University of California, Berkeley (UCB) Berkeley, United States	19		Technical University of Munich Munich, Germany	=28		Tokyo Institute of Technology (Tokyo... Tokyo, Japan
10		Delft University of Technology Delft, Netherlands	20		KAIST - Korea Advanced Institute of... Daejeon, South Korea	30		The University of Melbourne Parkville, Australia

<https://www.topuniversities.com/university-rankings/university-subject-rankings/2022/engineering-technology>

MOVE: Faculty (6) + PhD students (30+) + MsC students (70+)



Large research group fully focused on Systems&Control in vehicles (20 years of experience)



Prof. Sergio M. Savaresi

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Artificial Intelligence (A.I.) in motorsport



“Mega-trends” in personal mobility



Big & heavy



Small & light



Fossil-fuel



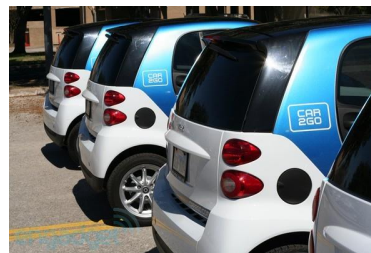
Electric (Battery/H2)



Personal



Shared/Service



Human-driven



Autonomous



Mega-trends “self-reinforcement” towards electrification

Size-reduction



Electrification (with Battery or H2)



Service-ization of the mobility (sharing)



Automation of the driver

Autonomous car will catalyze all the other trends («big-bang»)

The autonomous car: the «ultimate challenge» in «robotization» of a human task

Arc de triomphe roundabout, Paris



Tesla boss Elon Musk admits autonomous tech is “a hard problem” and the “difficulty is obvious”

NEW MODELS

After a number of deaths in the US linked to Tesla owners placing too much faith in autonomous driving systems – and amid ongoing investigations by road safety regulators there – Elon Musk says mastering the tech is more difficult than he expected.

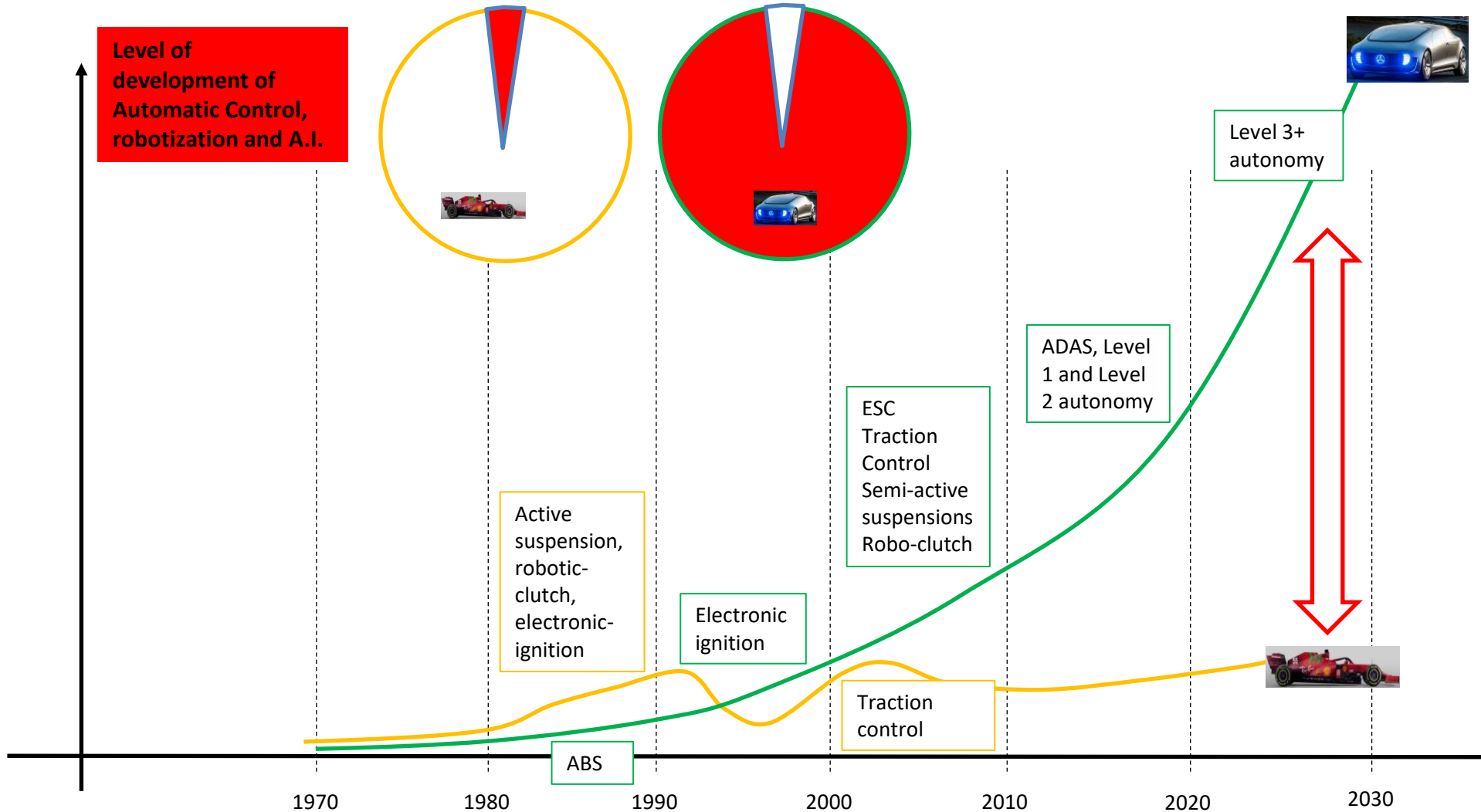
Autonomous car challenge: the most important technology trend

- complete **revolution of the mobility model**
- Major **changes in automotive industry** (tier «0.5», digital players,..)



**A technology still to be largely developed
(10+years to reach Level 5)**

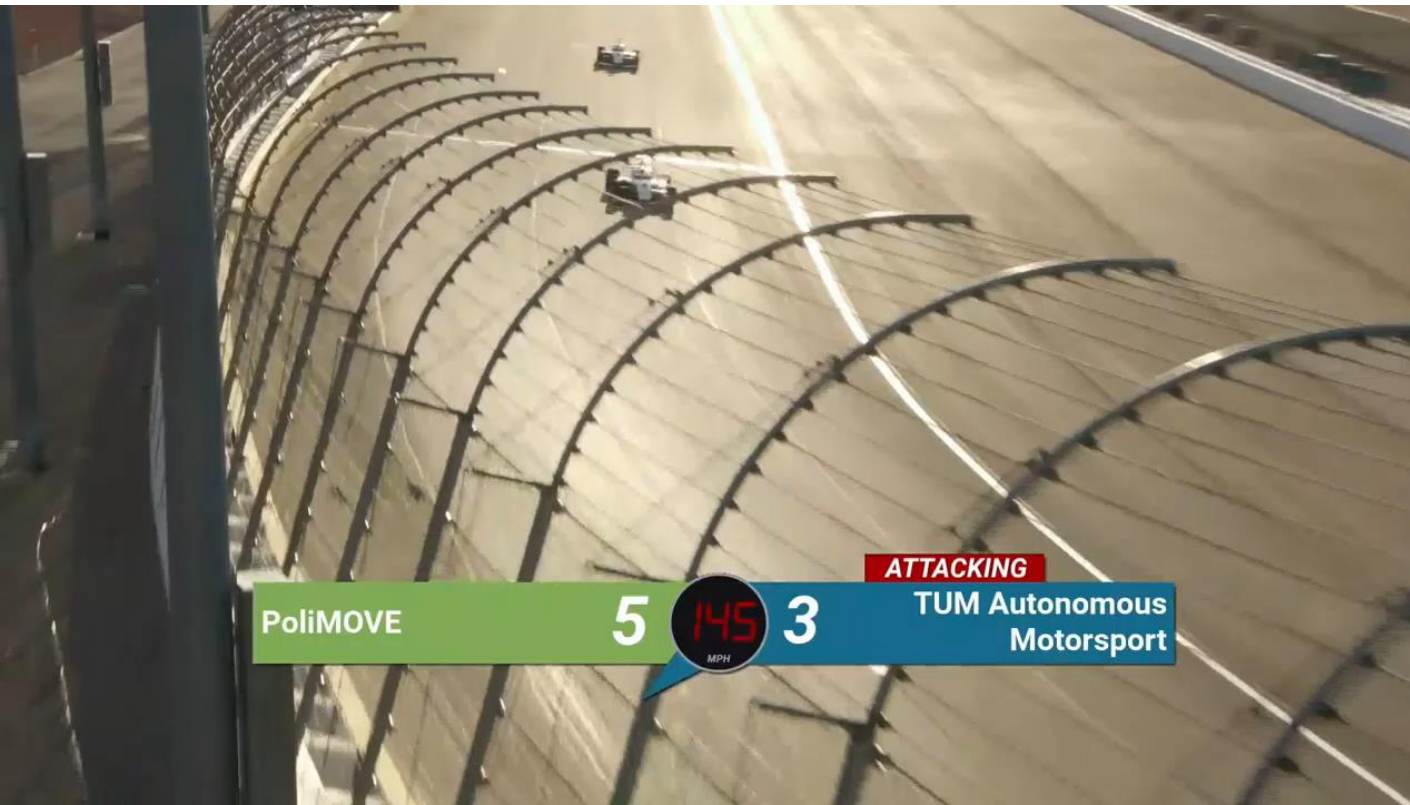
Artificial Intelligence in motorsport: the Automatic Control gap



Automatic control & A.I. are clearly the next big leap in automotive

The gap with motorsport cars is growing and becoming constantly more significant

Autonomous Challenge @ CES (Las Vegas) 1/7/22: the birth of Autonomous racing



Winning team:
Polimove,
Politecnico di
Milano

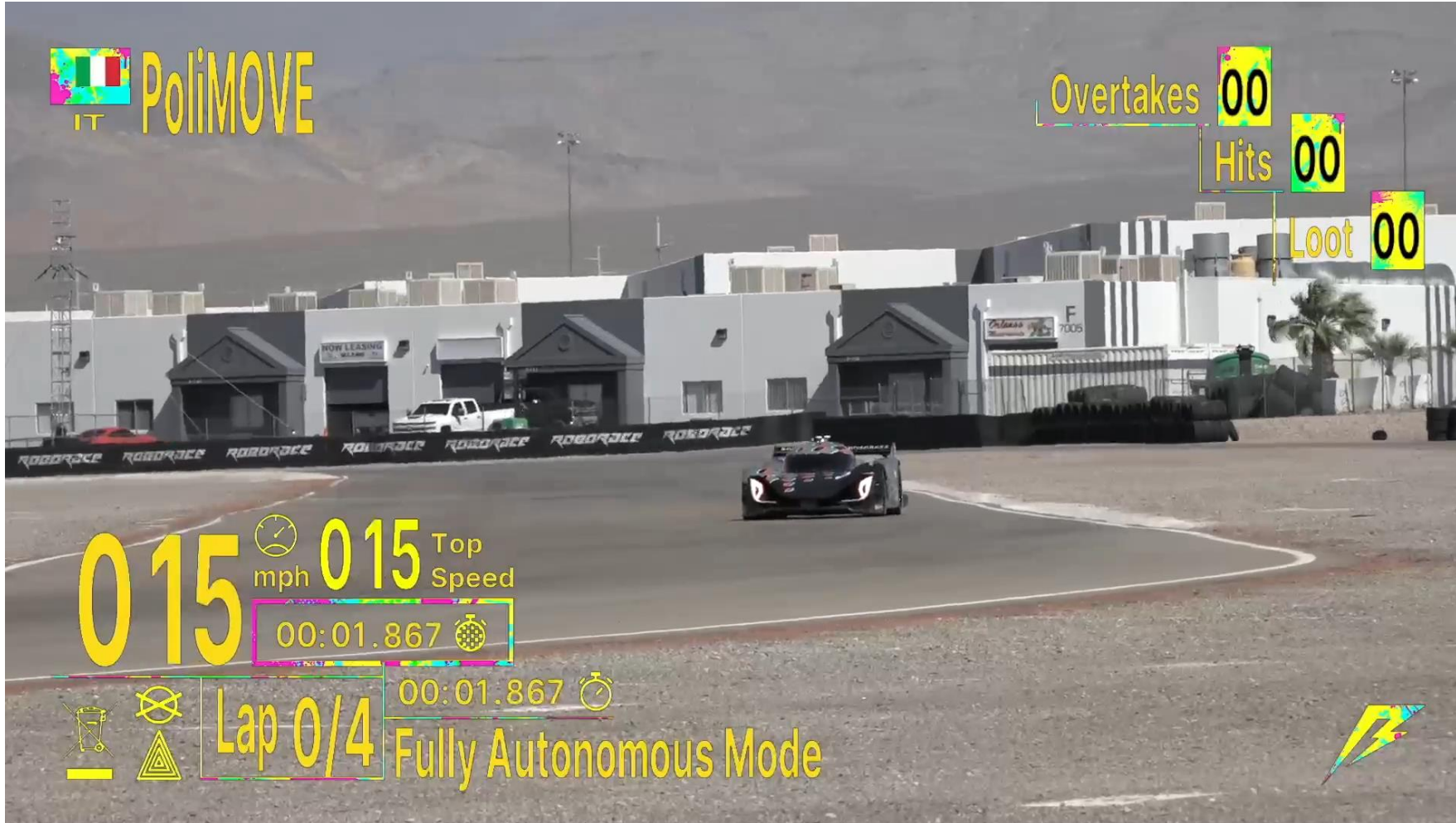


First ever competition:

- **fully autonomous**
- **multi-agent** (head-to-head)
- **high-speed (up to 280kmh)**

Half of all CES® 2022 Media Coverage mentioned IAC in the headline or opening summary

2021-2022: the birth of Autonomous Racing (Roborace, “test” seasons alpha and beta)



Introduction of a **mix of real car and metaverse cars/obstacles**



Possible interactions: autonomous motorsport future formats

Car Driver



Human



A.I.(autonomous)



Real car (on-track)



Simulated Car

CAR

Car 1

×

×

Car 2

×

×

Car 1

×

×

Car 2

×

×

Car 1

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Car 2

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Car 1

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Car 2

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Car 1

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×

Car 2

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Car 1

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Car 2

×

×



Classic Motorsport



Classic Gaming



«Sim-Race» of A.I. Drivers (first step of Indy Autonomous Challenge)



Indy Autonomous Challenge



Human vs. A.I. but 1 real car and 1 Holo-car on track



Human vs A.I. on real cars
(ultimate goal, higher complexity)



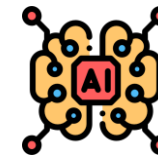
AR-Helmet: an enabling technology for Hybrid-racing



REMARK: Motorsport driver is the only top athlete where human and A.I. can compete in the same event



Little to no chance for Human vs A.I. competition (at least for the next 20-30 years)



Concrete chance for Human and A.I. to be mixed in the same competition



Remark | Kasparov vs DeepBlue – a similar story?

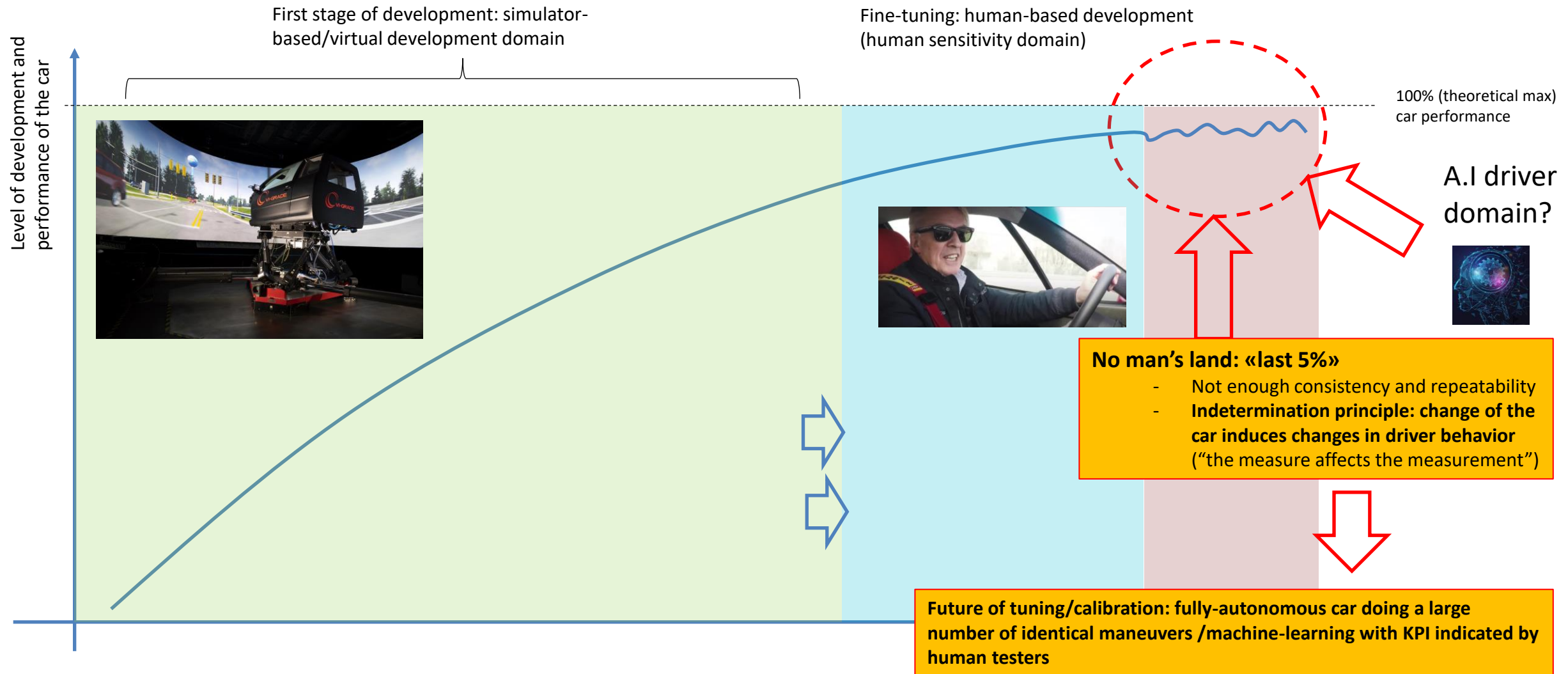


Chess is a matter of (large) finite number of future actions
At some point (computational power, memory) **a computer can easily win against a human**

Race-driving is a **completely different level of complexity - real «A.I.» is needed**

- Expected comparable performance: **2030?**
- Expected A.I. consistently better than a human: **2050-2060?**
- Expected A.I. consistently better than a A.I.-assisted human (augmented human): **2100? (or...never?)**

Remark: High-perf car development



Autonomous motorsport: the dawn of a new era?



- Motorsport will quickly follow the “autonomous car trend”



- Most likely long-term direction: human vs. A.I.



- Hybridization of real cars with metaverse

The AS.CAR.I project (AutonomouS CAR Intelligence)



Registered trademark



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AS.CAR.I. for motorsport



AS.CAR.I project: long-term “dream”



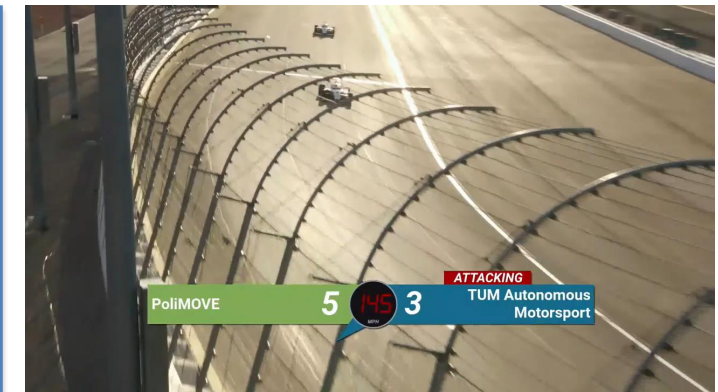
Develop a top-driver
competing in (?) 2030
top-class hybrid **Human**
vs. A.I. championships



AS.CAR.I project: Achievements @ Indy Autonomous Challenge 2021. Always the fastest; almost almost a triple win



October 23rd 2021, IMS; **3rd place** (for a technical glitch not due to PoliMOVE algorithm) in the final run
Winner of the top speed competition (157Mph)



January 7th, 2022 (CES, Las Vegas).
Winner of the first ever competition:

- **fully autonomous**
- **multi-agent** (head-to-head)
- **high-speed (up to 280kmh)**

Fastest lap (32.5s)

Top-speed (173mph)

AS.CAR.I project [DS]: (Indy Autonomous Challenge) world record- (27/4/2022)

Space Florida launch&landing facility, at NASA Kennedy Space Center in Cape Canaveral, FL



New world record holder for a fully-autonomous car: **309.3kph=192.2mph** (two-ways average, average over 1Km); 310.4kph=192.8mph (two-ways average, average over 100m); 311.9kph=193.8mph (top speed). The previous record was held by Roborace since 2019 (282,4kph=175,5mph, two-ways average, average over 100m).

AS.CAR.I project: 2022 plan (Indy Autonomous Challenge)

2022: «mastering the ovals»

November 2022: race #1 at Texas Motor Speedway



Car: Dallara AV-22
(upgrade of AV-21)

January 2023: race#2 at Las Vegas Motor Speedway (within CES)



AS.CAR.I project: 2023 plan (Indy Autonomous Challenge)

2023: «moving to road-course circuits»

September 2023: race #1 at a **road-course** track (Austin or Laguna Seca)

December 2023: race #2 at Yas Marina (Abu Dhabi, UAE), near F1 GP

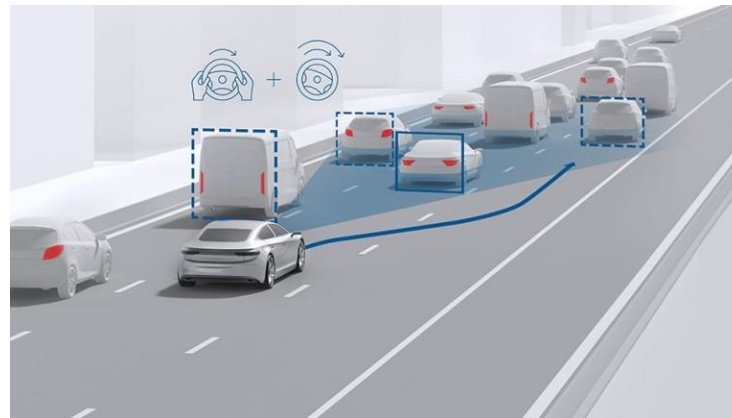
January 2024: race#3 at Las Vegas Motor Speedway road-course track (within CES)



Car: Dallara AV-23
(upgrade of AV-22)



AS.CAR.I. for production cars



Product #1: driver assistant on-track (ACTIVE)



«**Virtual-fence**» mode :car is driven by human driver and A.I. drivers takes control in case of driver **errors**



Traditional
«internal»
electronic
assistants

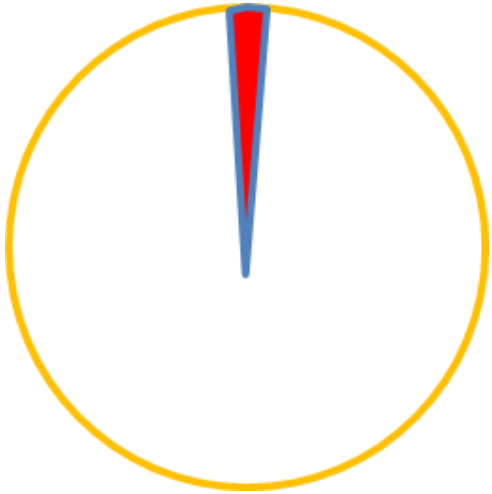
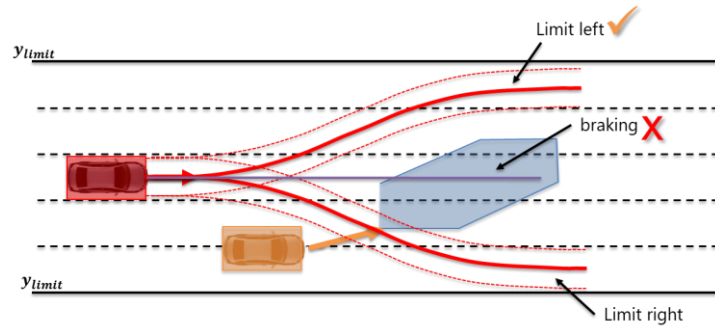
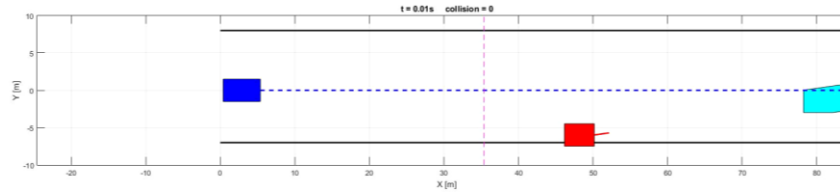


Track-assistant
("angel"): **predict errors
and is ready to protect,
but without
interference**

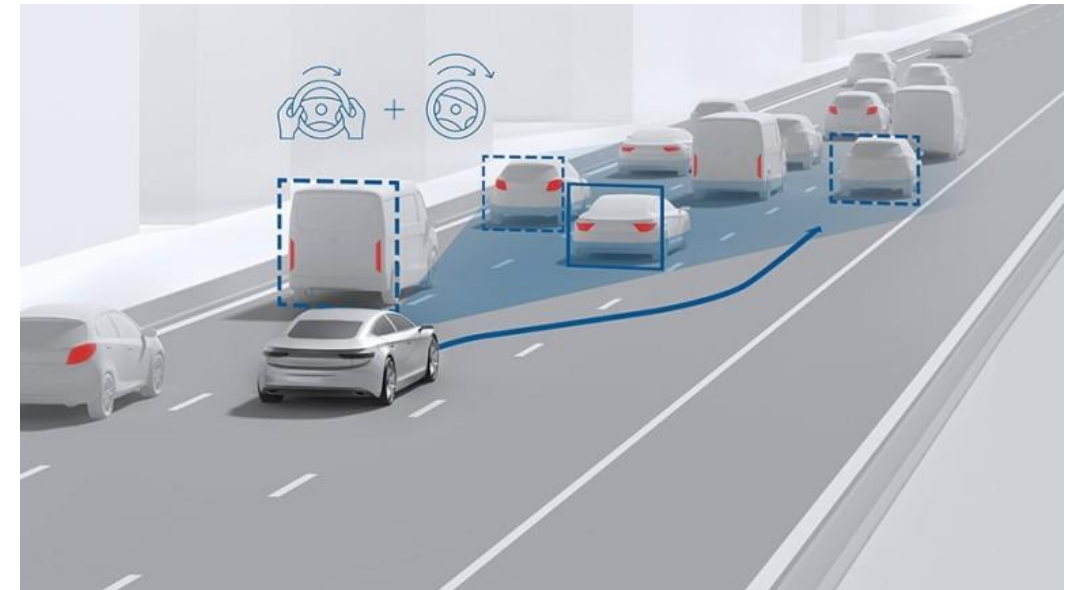
Product #2: emergency module for L3/L4/L5 autonomous cars

“Edge case” (highway scenario): emergency module in

- High-speed
- Low-friction
- High car density
- Sudden/unexpected obstacle

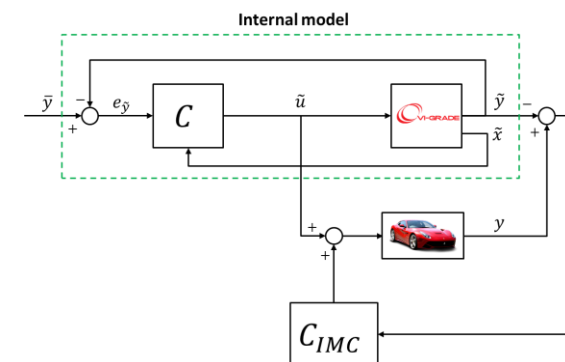
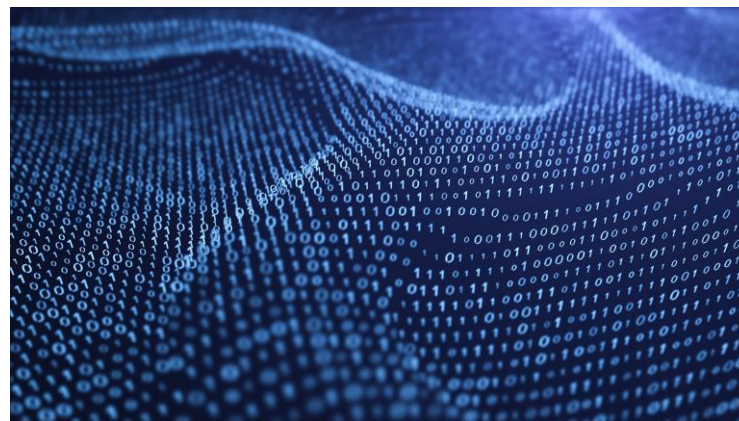
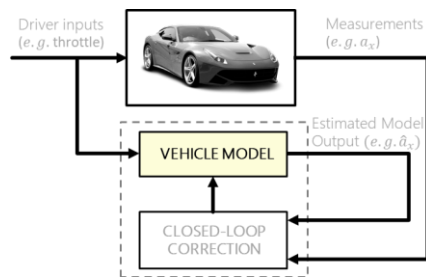


- Small but high-value safety-module
- Still largely unexplored
- Direct take-away from on-track and motorsport experience/knowhow



New “revolutionary” methodology for state estimation and control:

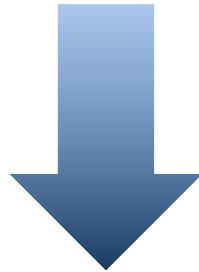
the “SIMulator-in-the-LOOP” (SIL or “SIMLOOP”)



Vehicle simulators – future perspectives

Present

Development/prototyping
stage only



Future

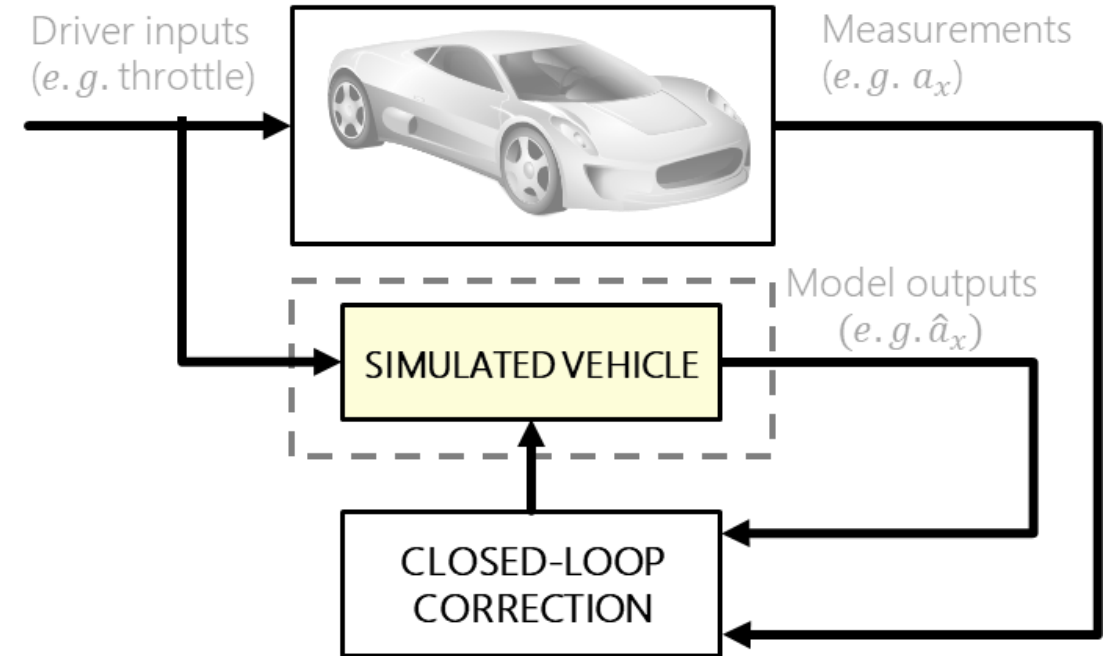
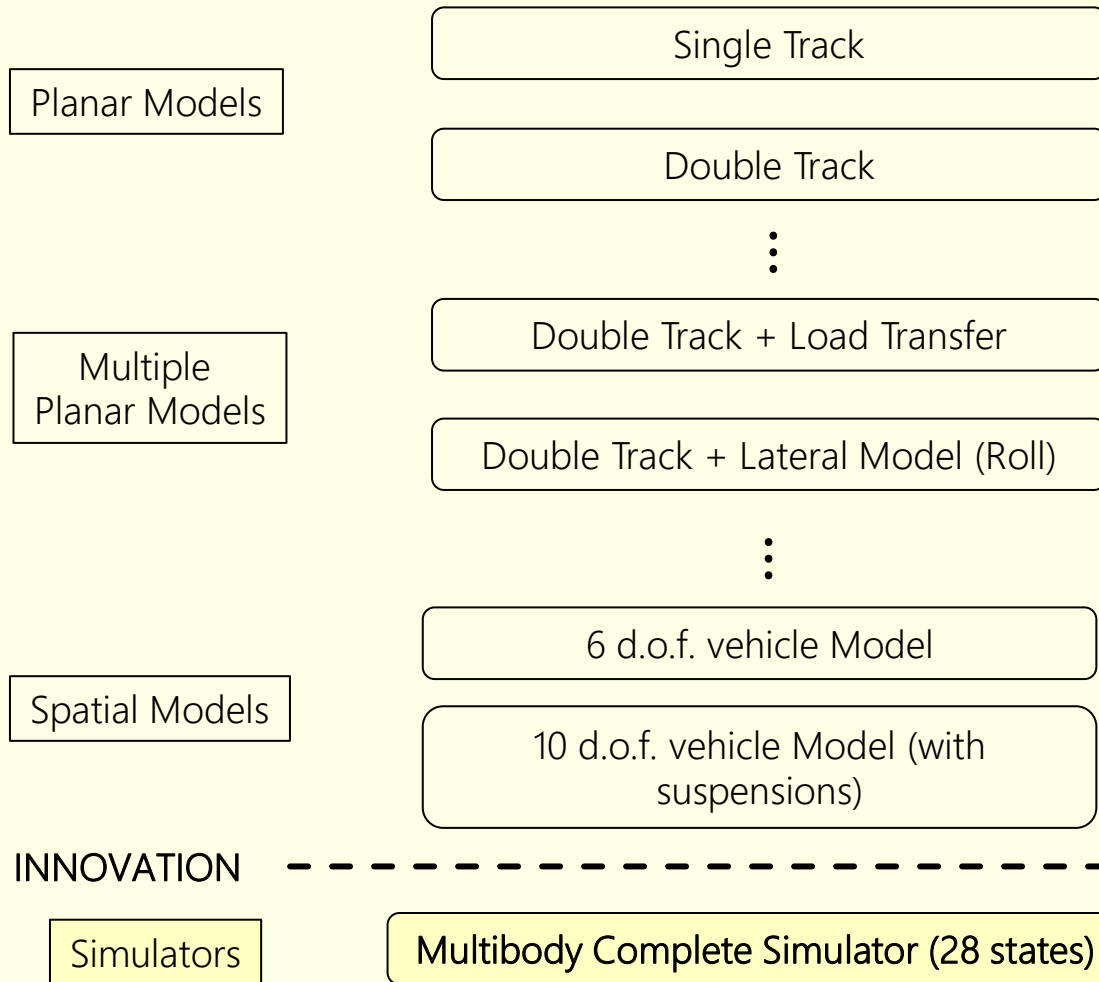
Can we use them on-
board at real-time?

Simulator-in-the-
Loop Estimation

Simulator-in-the-
Loop Control

Simulator-in-the-Loop Estimator

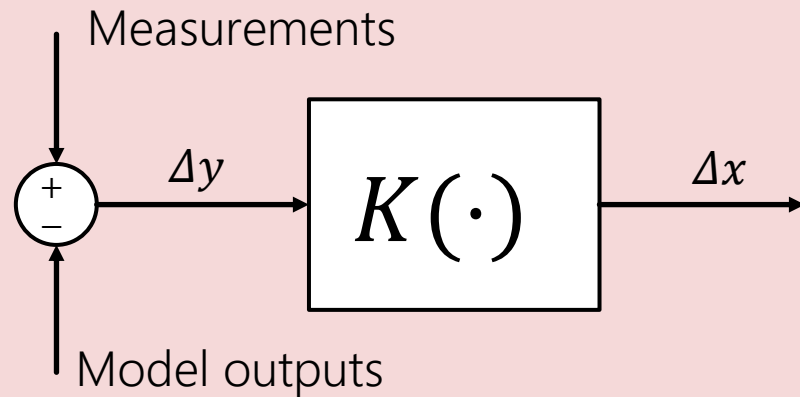
Sequence of employable models with increasing complexity:



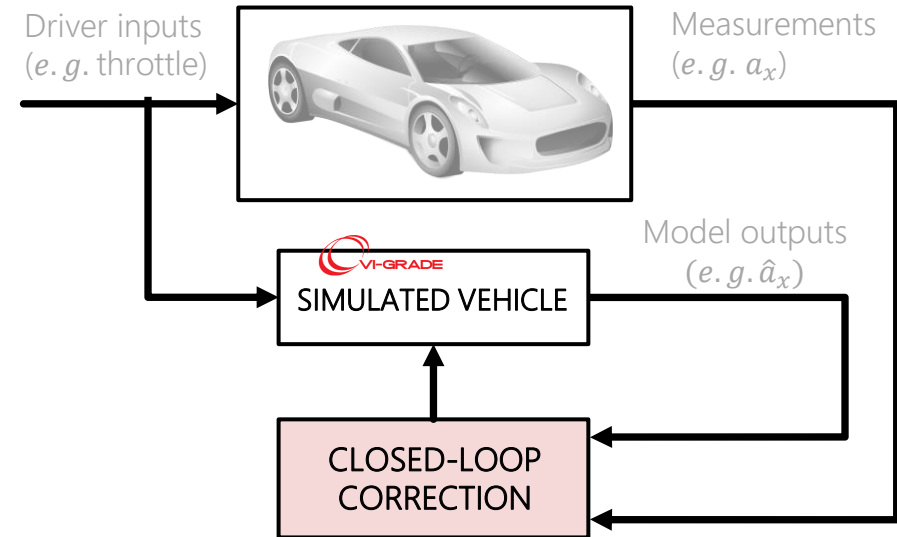
One fits all – a single model for all variables.

Simulator-in-the-Loop Estimator

Requires a simulator able to stop and refresh (correct) the state vector at every sampling time



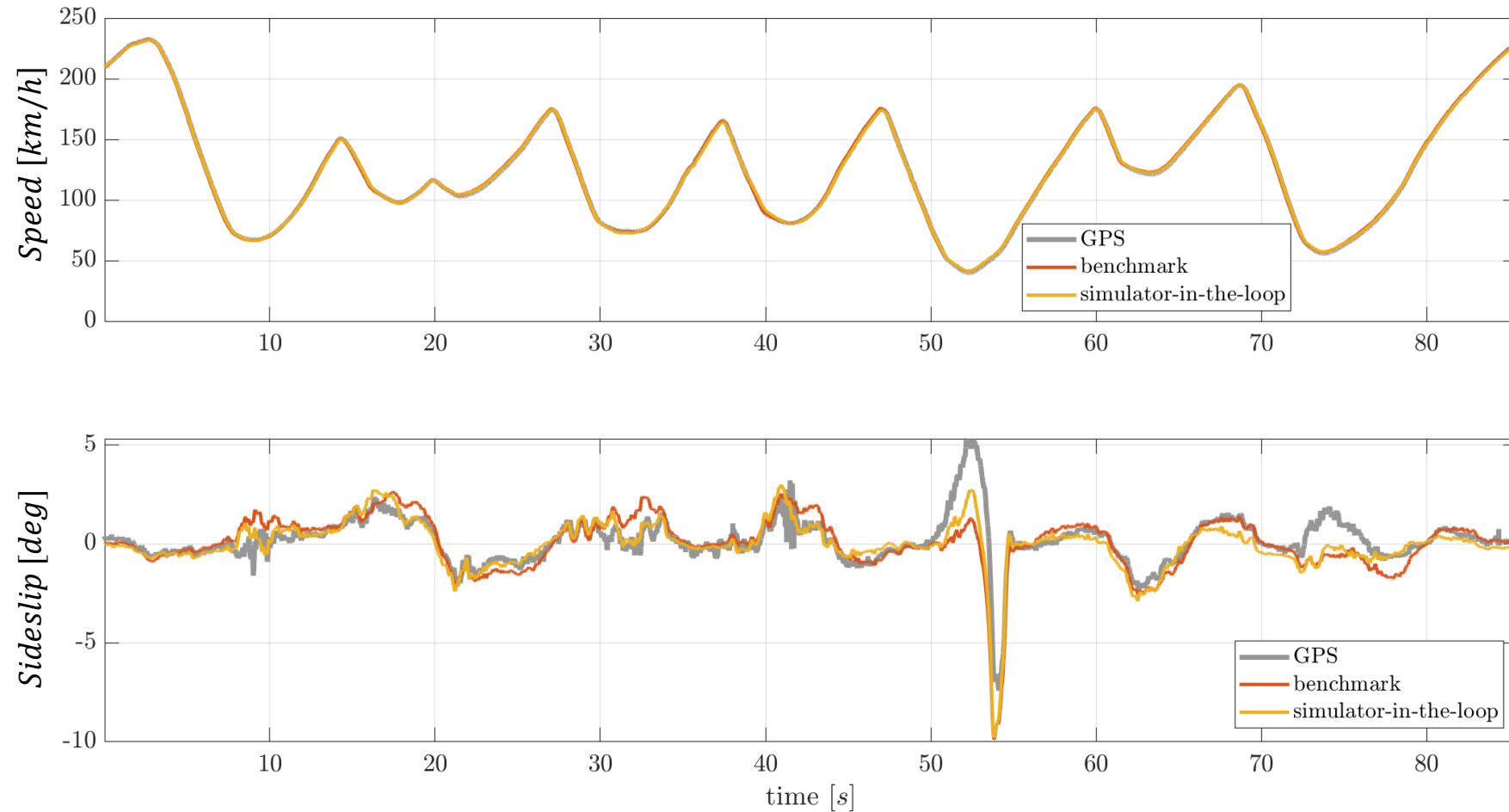
Machine learning approaches are used to optimize correction gains



Case study – comparison with industry grade estimators

Longitudinal speed and sideslip estimation

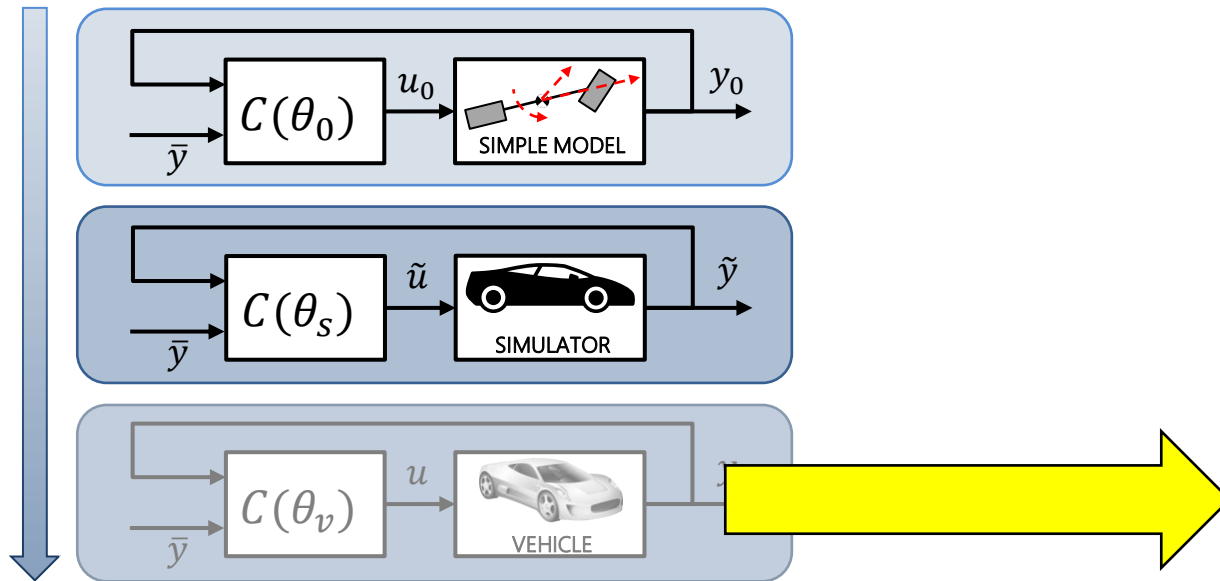
Variable	Error	
	SIL	Bench.
Speed $\left[\frac{km}{h}\right]$	0.83	1.10
Sideslip $[deg]$	0.74	0.92



Simulator-in-the-loop-Control – shifting the paradigm

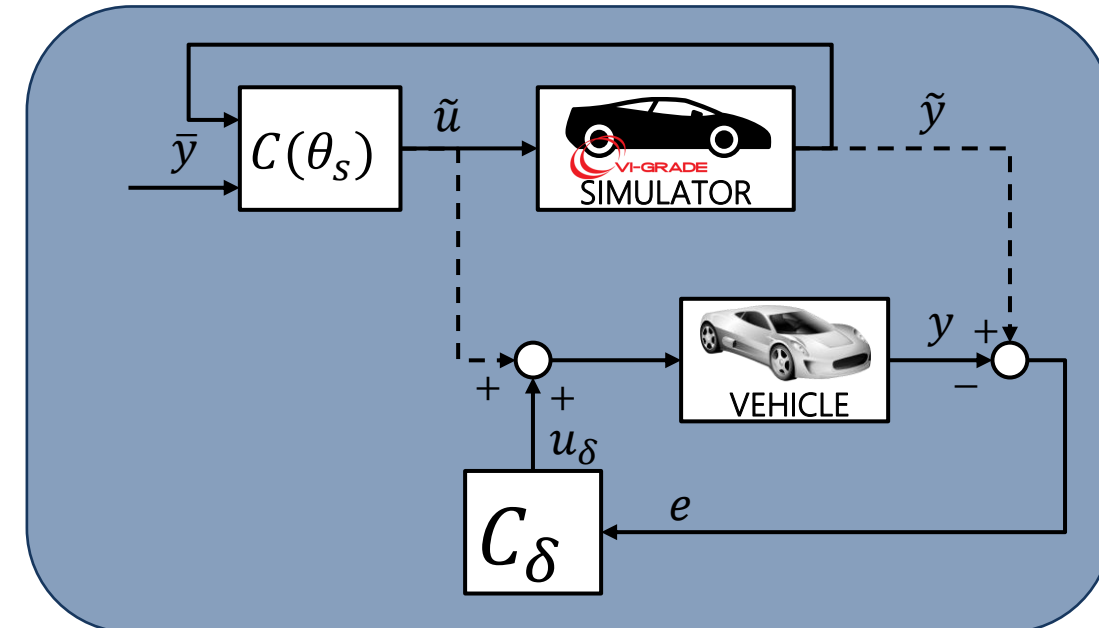
Traditional framework

- Control calibration goes through many steps;
- Many experiments to achieve end-of-line tuning;



Simulator in the Loop framework

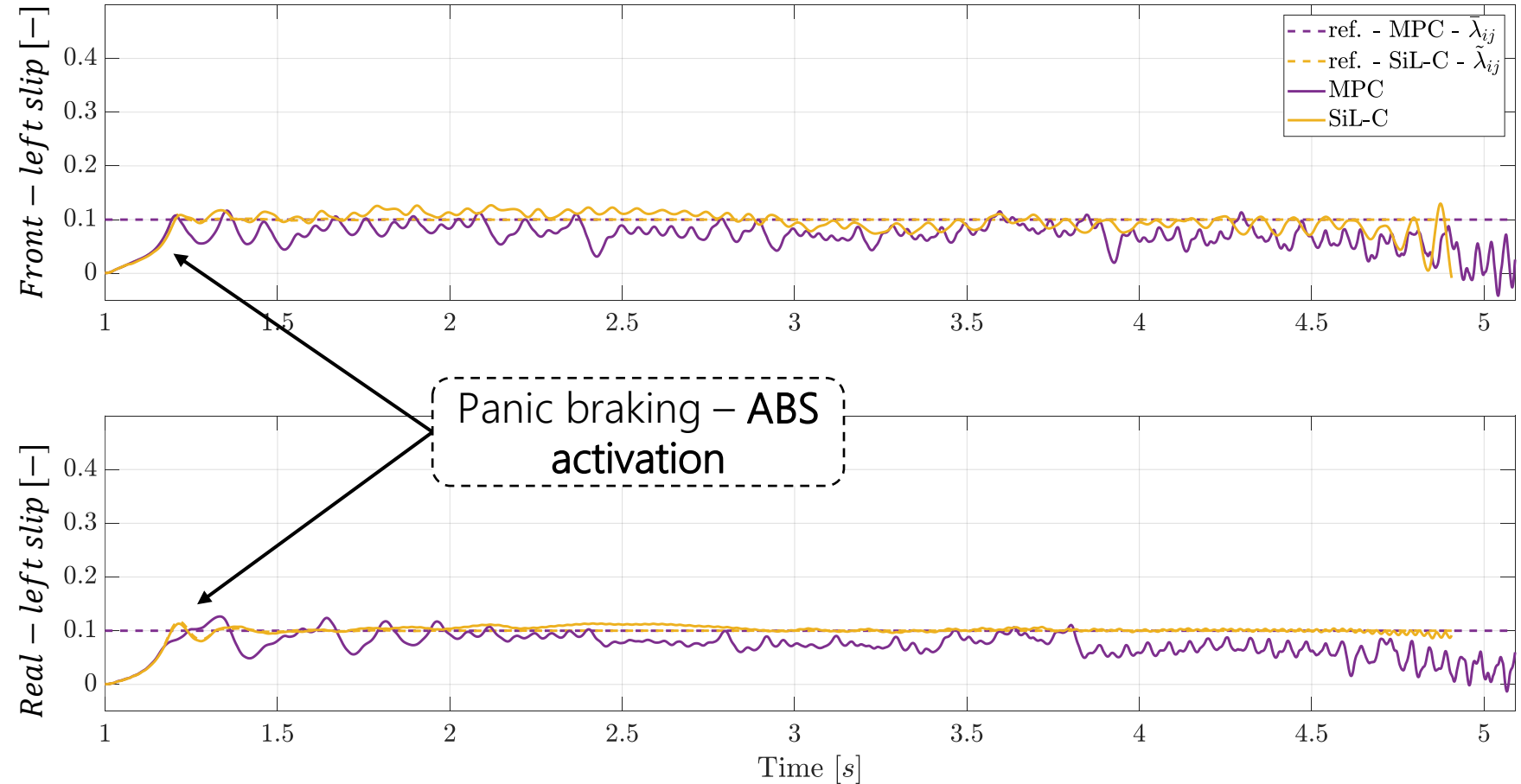
- Simulator directly used on-board to control the vehicle;
- Control tuned on the simulator – a small compensation is then added (Internal Model Control framework)



Case study – Active braking control

Wheel slip tracking - comparison with state-of-the-art Model Predictive Controller

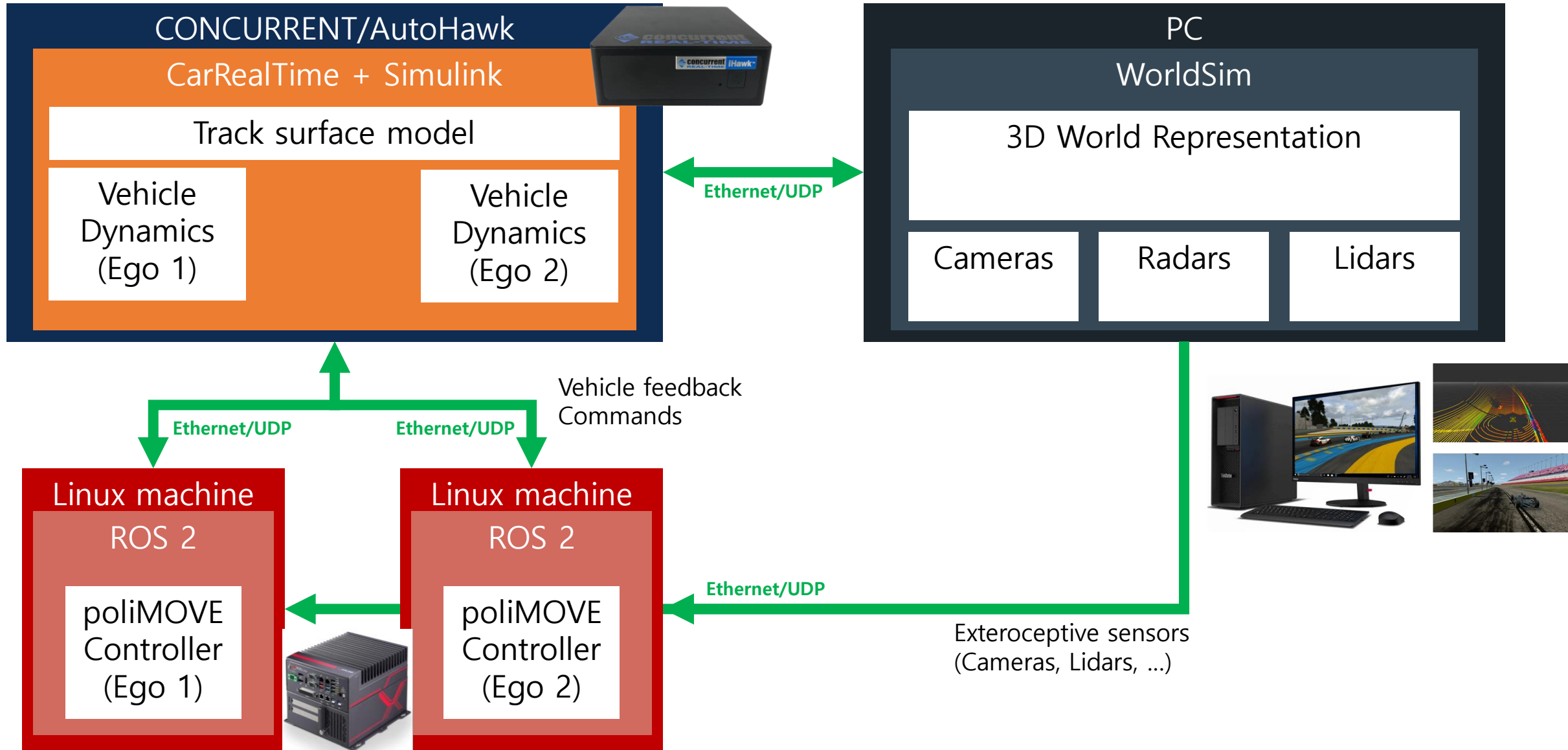
	Tracking error [%]
SIL	1.13
MPC	2.84
	+151%



Simulator-in-the-Loop paradigm: Indy Autonomous Challenge application (work in progress)



Simulation suite (work in progress)



Thanks for your attention!



Las Vegas Motor Speedway – first simulation results
(Carrealtime + Worldsim)

