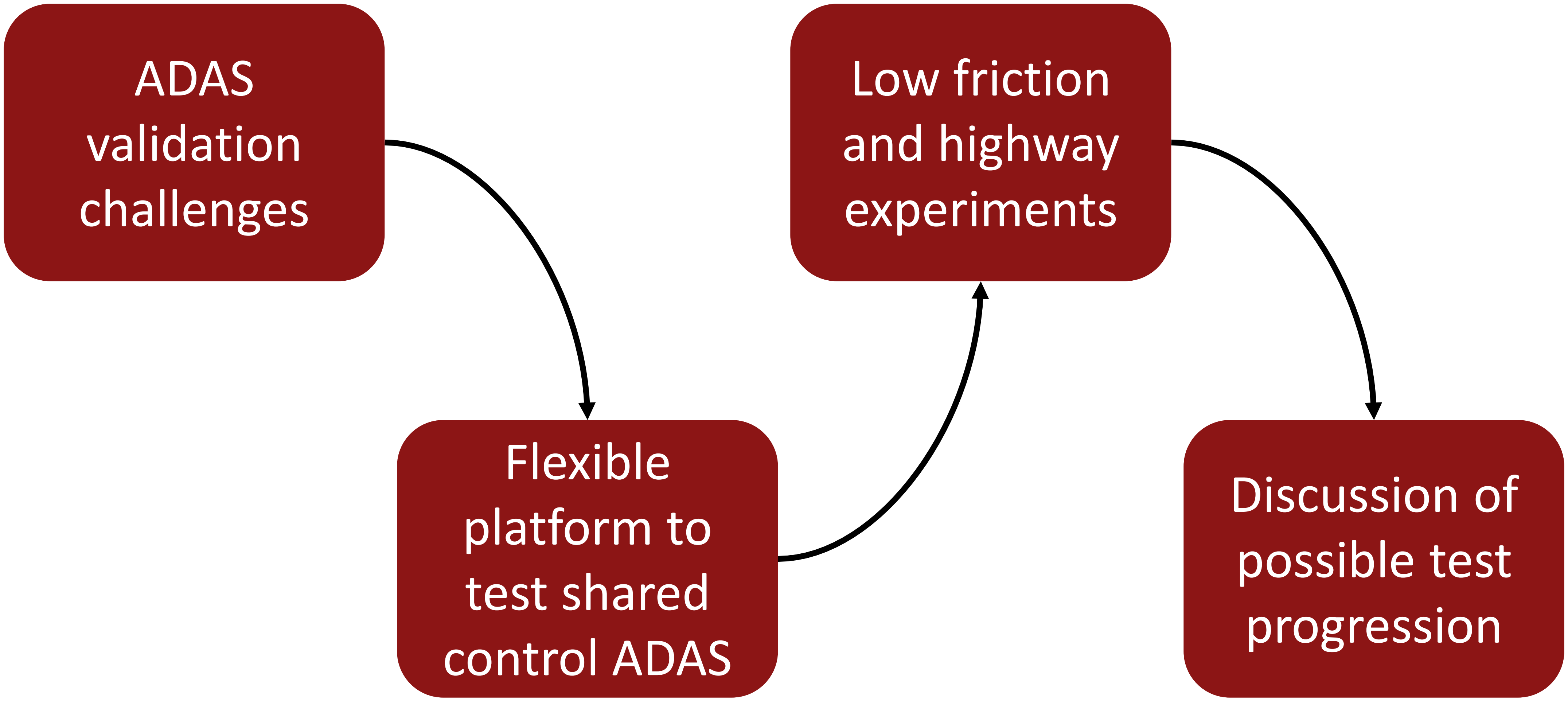
Combining Virtual Reality and Steer-by-Wire Systems to Validate Driver Assistance Concepts

Elliot Weiss, John Talbot, and J. Christian Gerdes
Department of Mechanical Engineering, Stanford University
{elliotdw, john.talbot, gerdes}@stanford.edu

5th Workshop on Ensuring and Validating Safety for Automated Vehicles (EVSAV)
5 June 2022

Outline


ADAS validation challenges
Flexible platform to test shared control ADAS
Low friction and highway experiments
Discussion of possible test progression

Established Driver Assistance System Testing

- Several production assistance systems on the road today

Automatic Emergency Braking

ectronic Stability Control

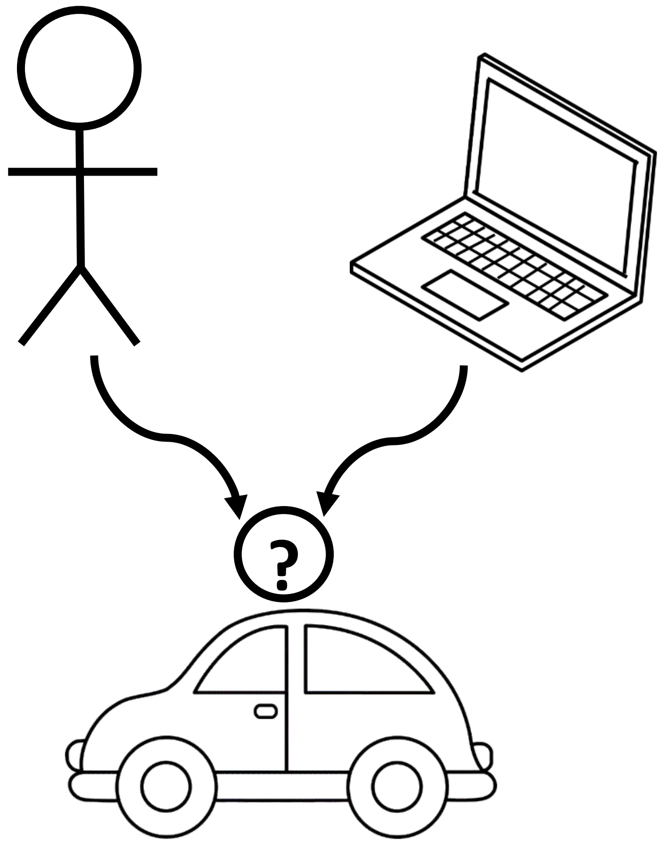
- In many well defined tests, driver input is effectively automated
  - AEB: vehicle maintains constant speed and lane position, no braking from driver [1] or automated braking profile [2]
  - ESC: specified sine steer [3]

Emerging Shared Control ADAS

- Many emerging ADAS share control with driver
  - Guaranteed safe sets:

    Arwashan *et al.* – ADAS that smoothly blends steering with driver to stay within safe set [4]
  - Receding horizon controller:

    Schwarting *et al.* – nonlinear MPC for coupled control [5]
- Key idea: driver remains in the loop throughout operation



Shared Control Validation Challenges

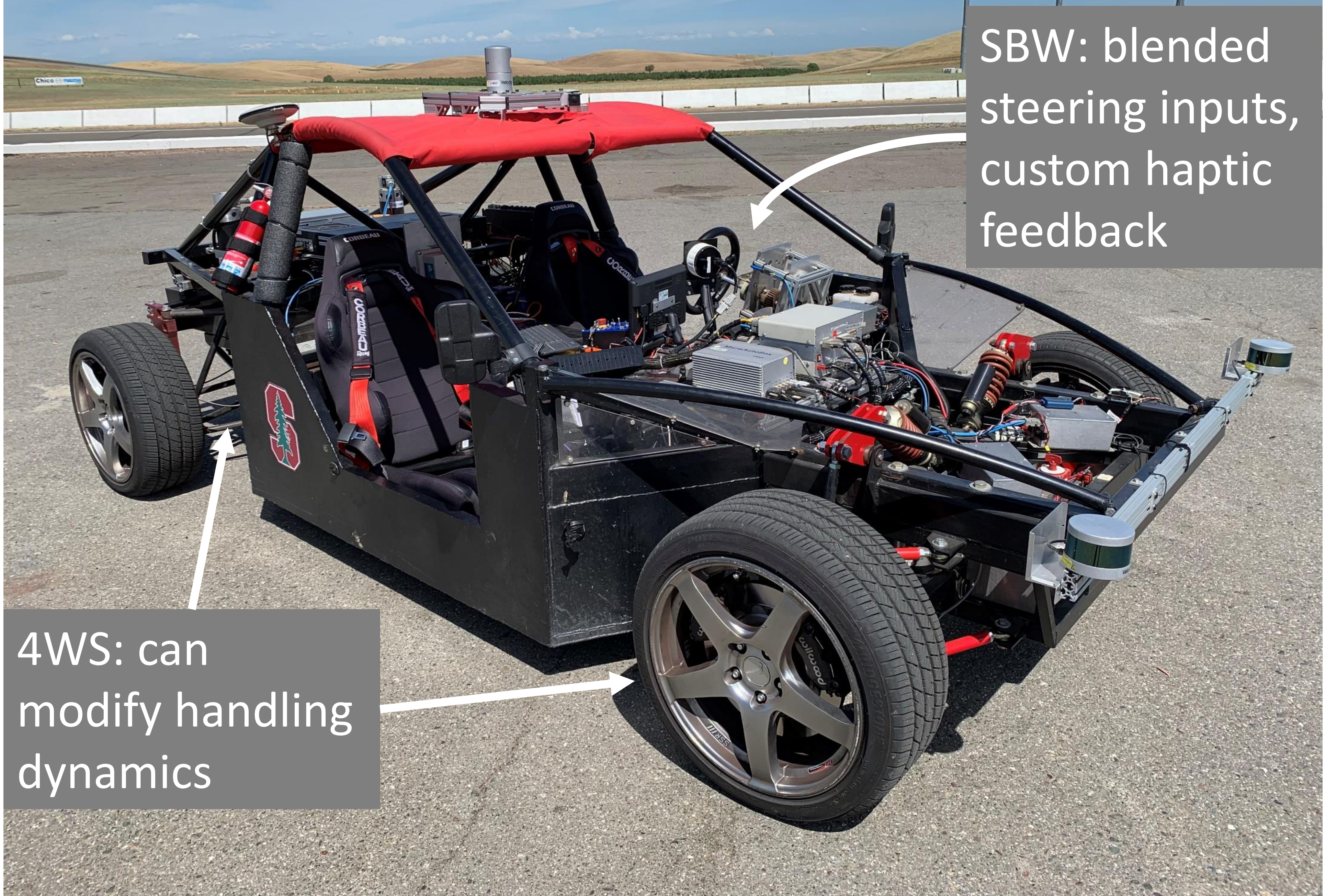
1. Drivers rely on sensory feedback for vehicle control
2. ADAS should be validated across wide variety of test conditions on real vehicle
3. Track testing is expensive and limited
4. Experiments with other road users can be dangerous

Question: how can we accomplish high test coverage for shared control ADAS despite these challenges?

Promising Solution: Human&Vehicle-in-the-Loop

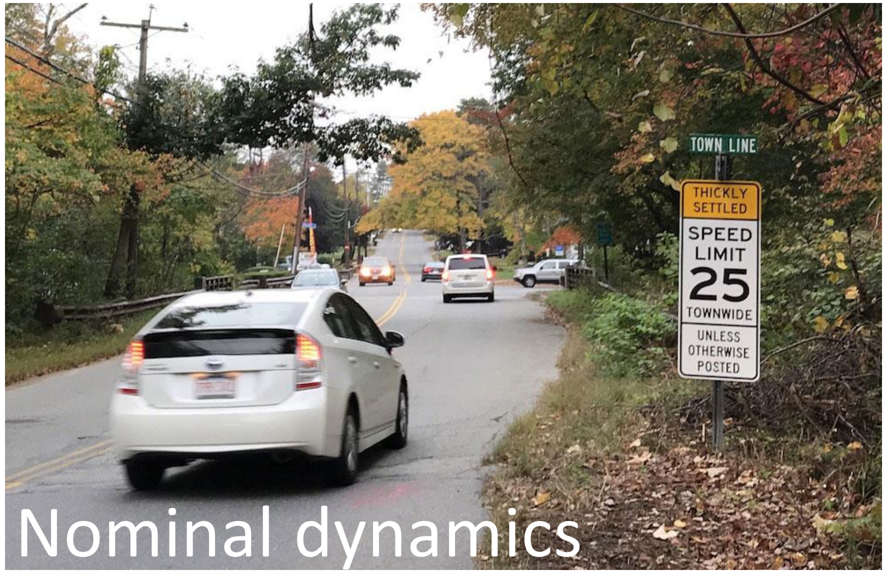
- Idea: place driver in real vehicle with virtual graphics
- First Hu&ViL platform developed and validated by Bock *et al.* in 2007 for ADAS testing [6]
- Park *et al.* present recent VR-based ViL platform, using it to test AEB and lane-keeping assist systems [7]
- Hu&ViL platforms so far limited by dynamics of production test vehicles

X1: Four-Wheel SBW Vehicle



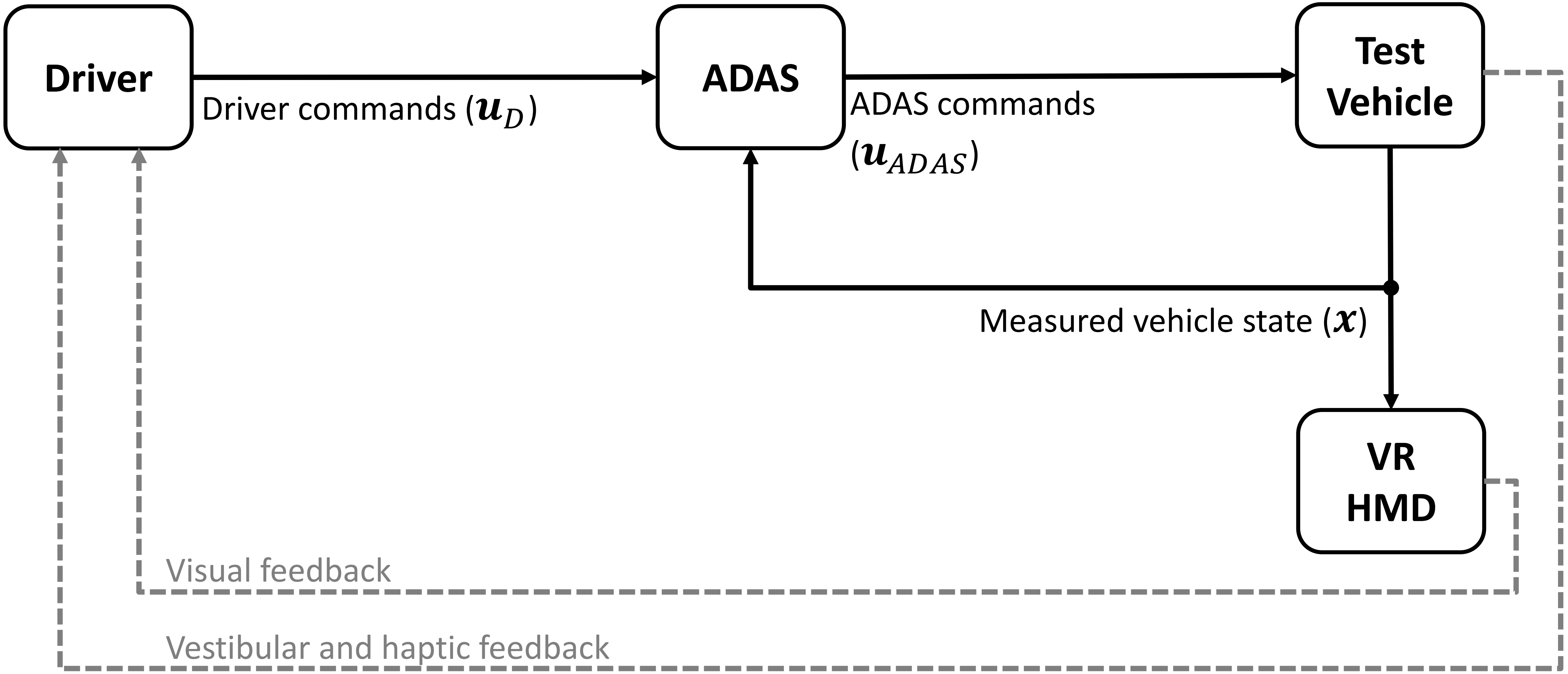
Hu&ViL Platform on X1

Many Platform Configurations Possible



Stanford University

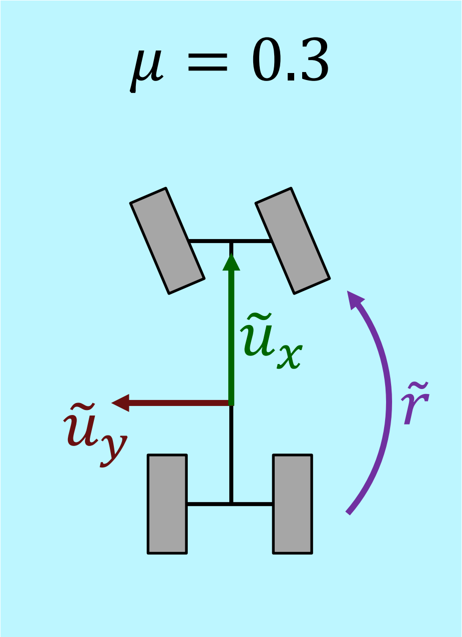
Nominal Dynamics Configuration



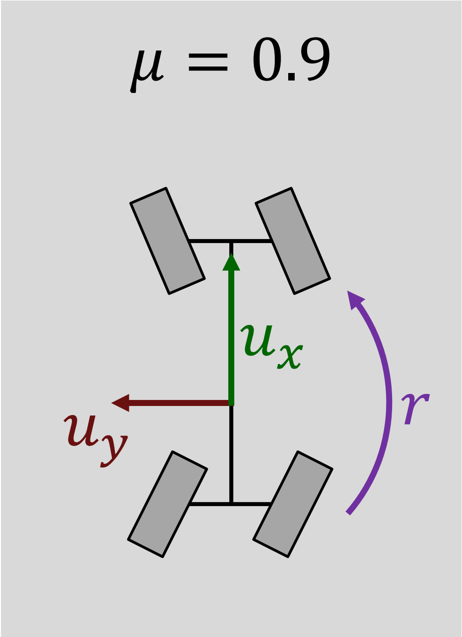
Low Friction Emulation

- Test vehicle drives as if on snowy/icy surface [8]
- Track low friction velocity states with 4WS

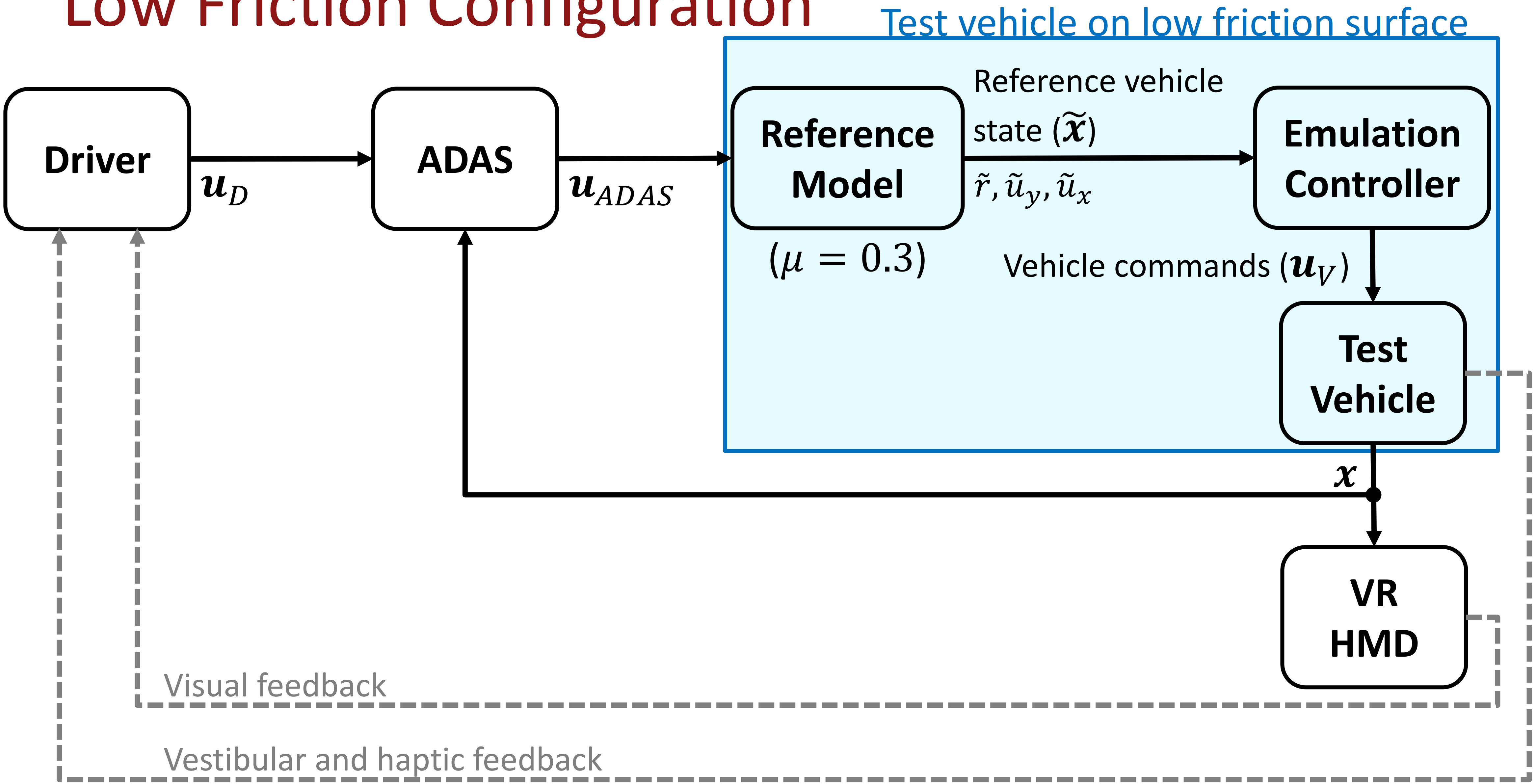
Reference model



Test vehicle



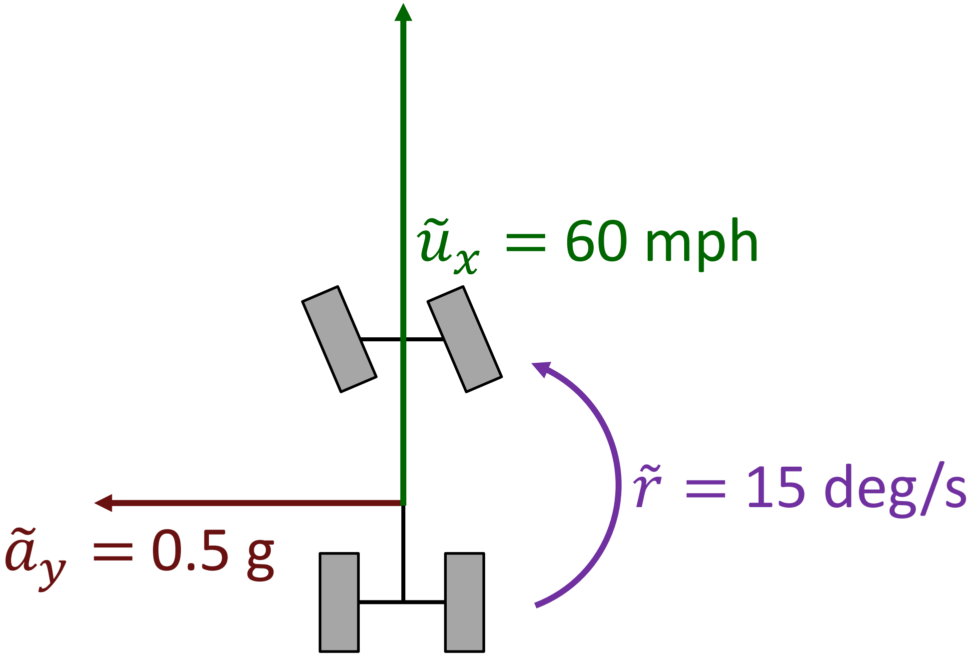
Low Friction Configuration



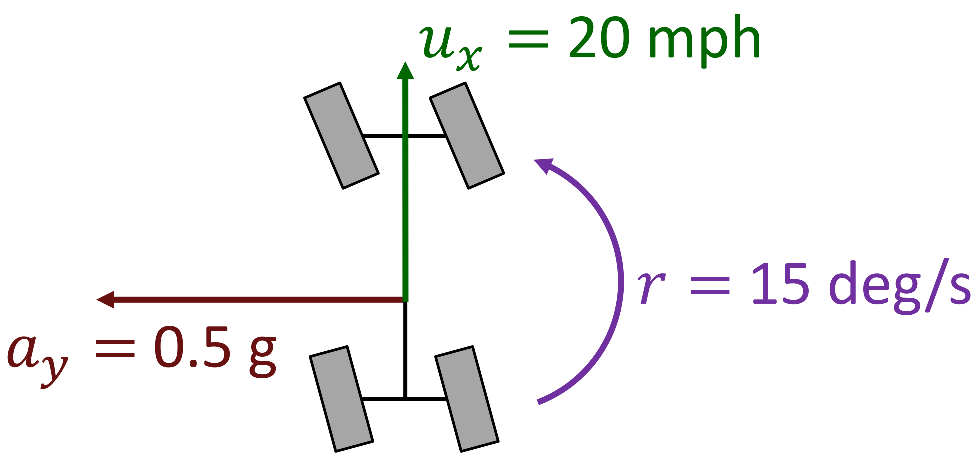
High Speed Emulation

- Scale speed of test vehicle by constant $f > 1$ in virtual world [9]
- Track reference lateral acceleration and yaw rate on vehicle

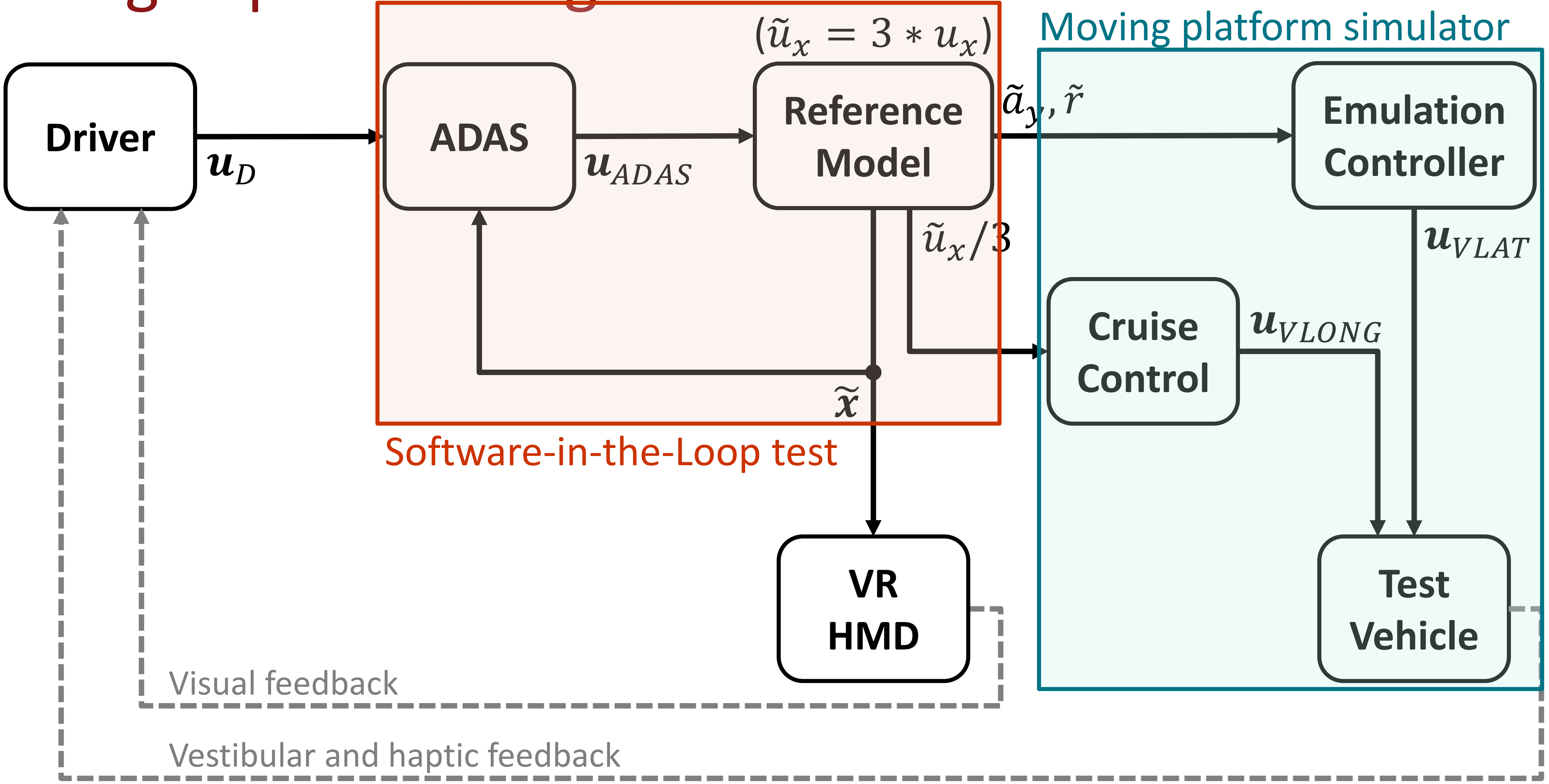
Reference model



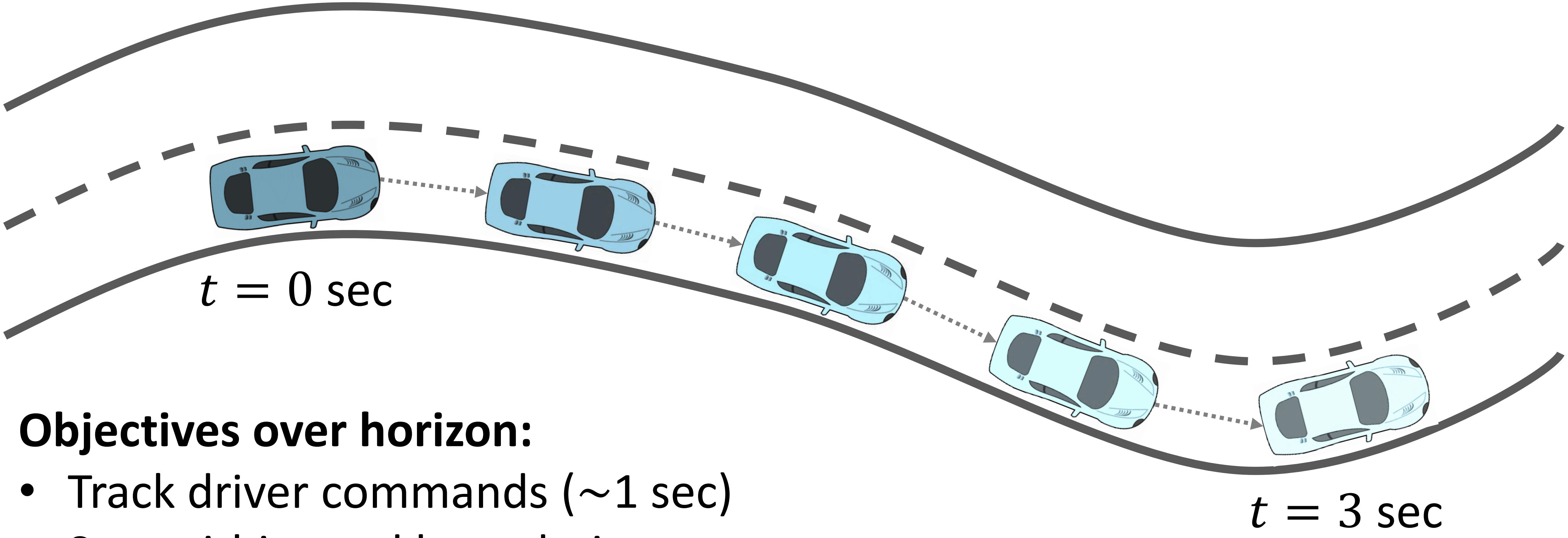
Test vehicle



High Speed Configuration



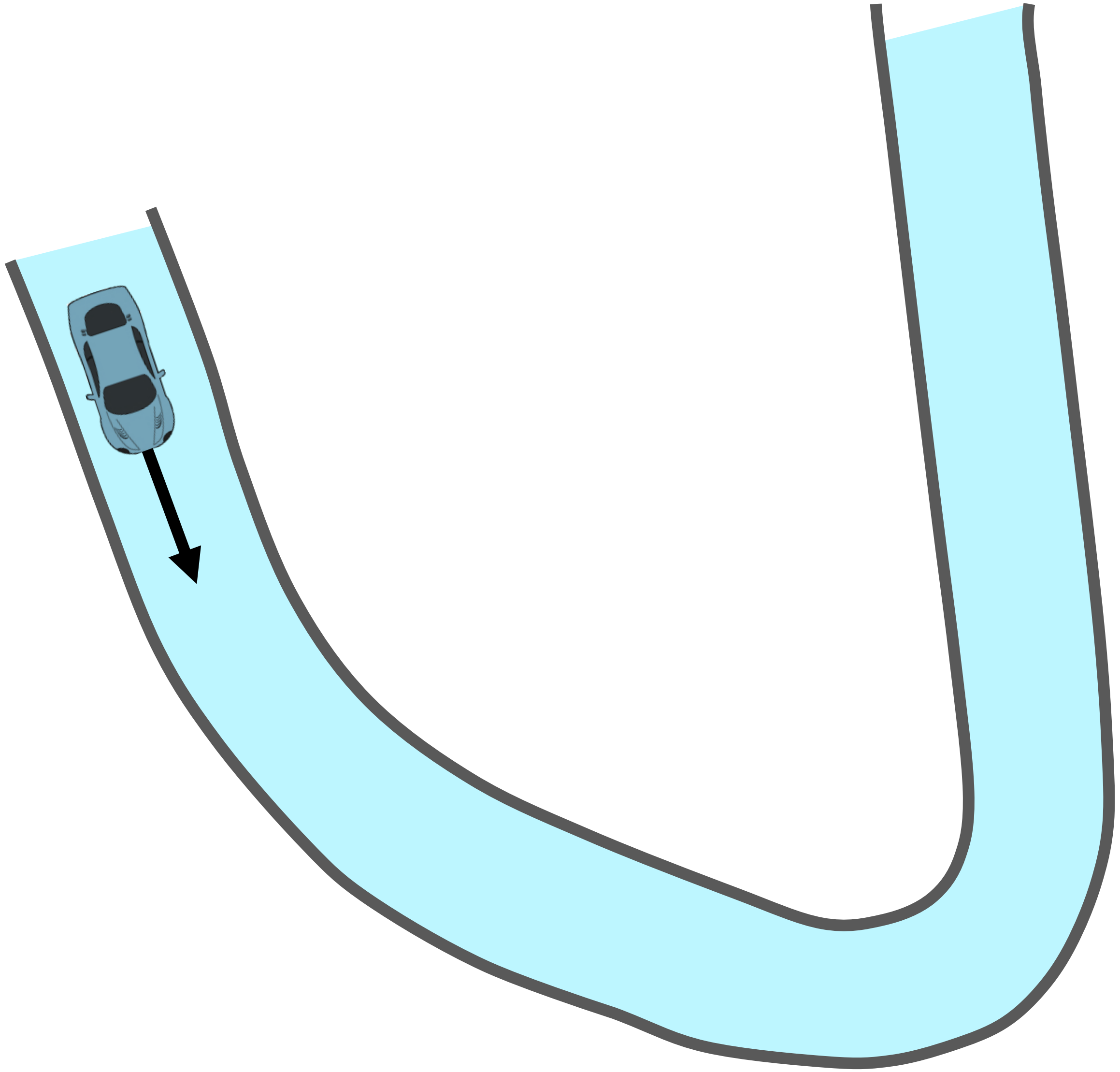
Our ADAS: Receding Horizon Shared Control



Objectives over horizon:

- Track driver commands (~1 sec)
- Stay within road boundaries
- Avoid other vehicles
- Respect coupled lateral + longitudinal dynamics

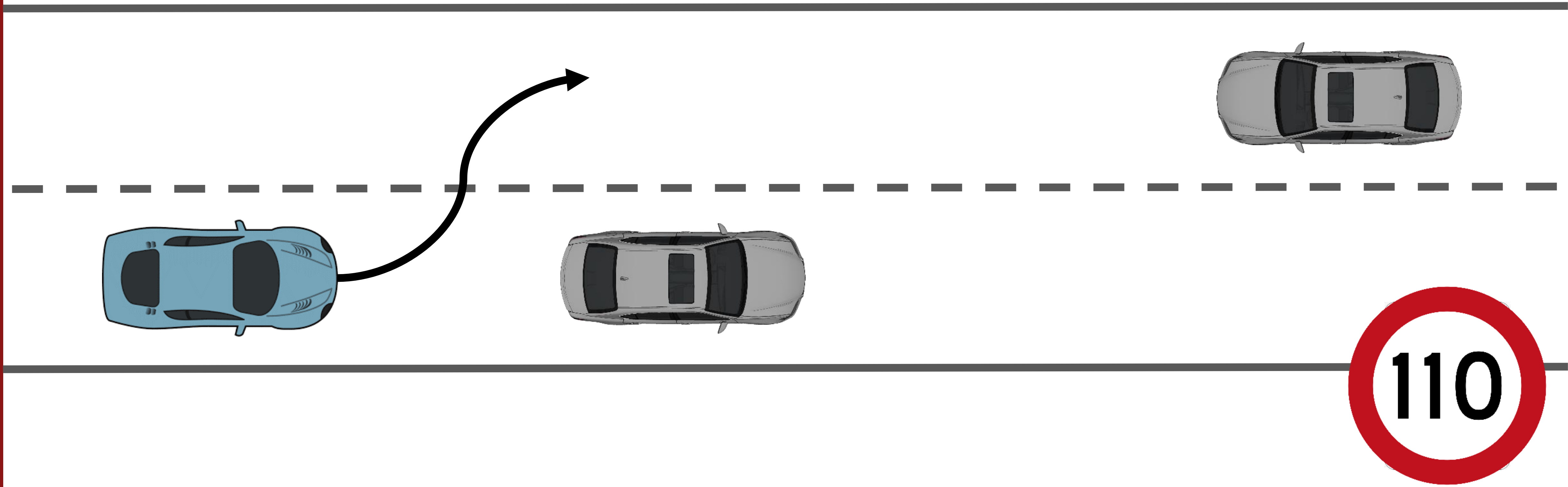
Experiment 1: Cornering on Snow



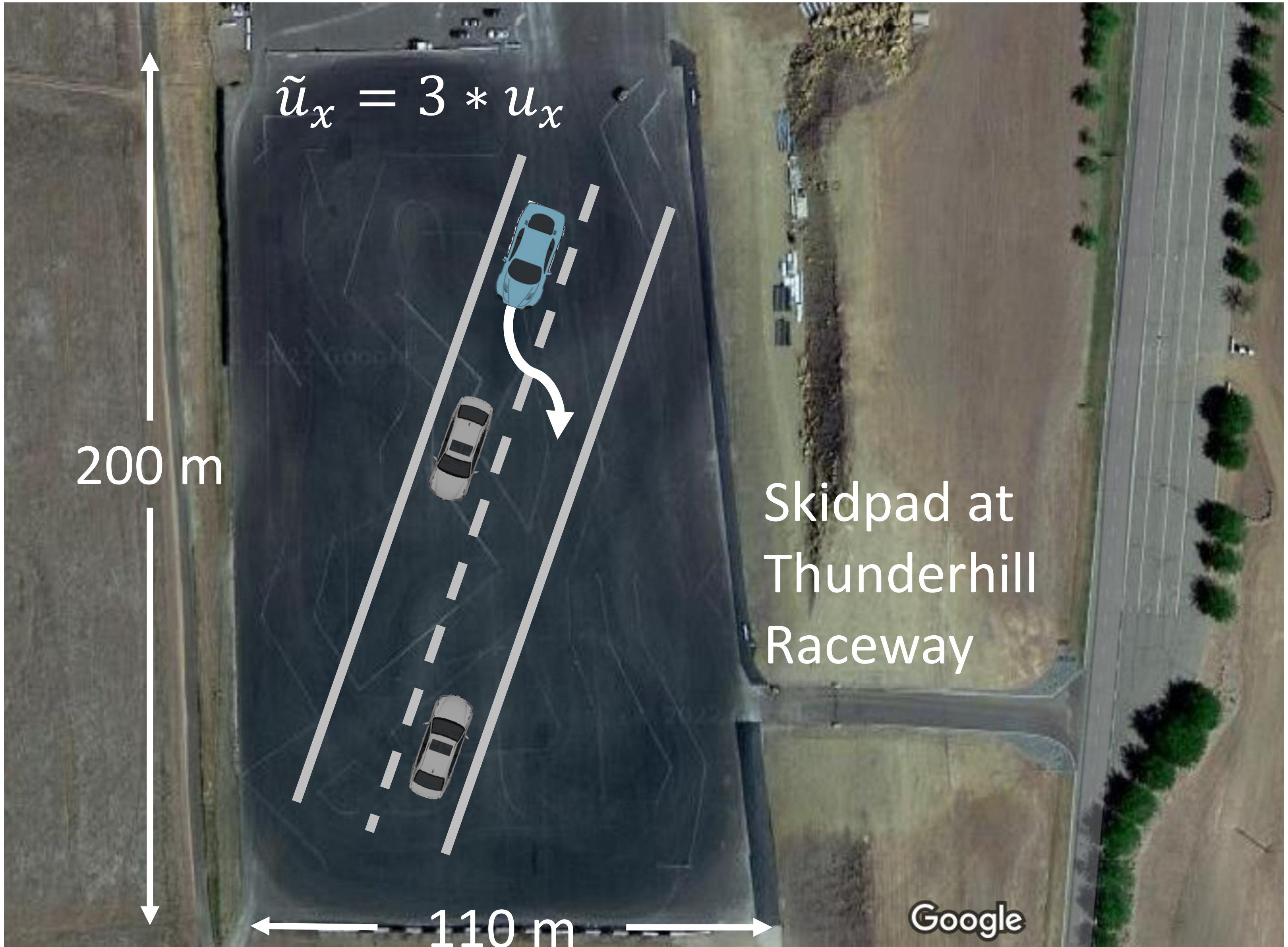
Experiment 1: Cornering on Snow

Cornering on Snow: Video

Experiment 2: Highway Overtaking



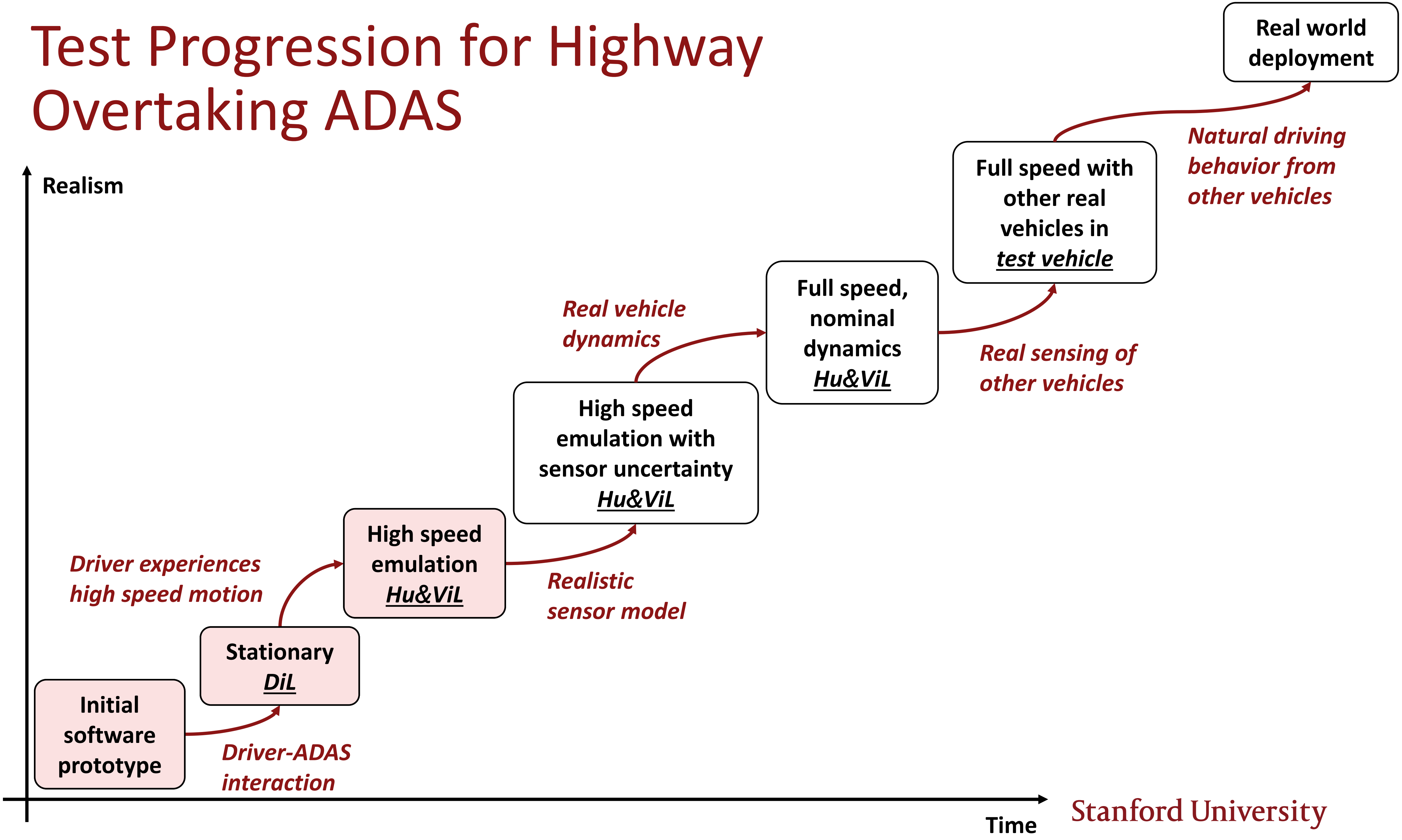
Experiment 2: Highway Overtaking



Highway Overtaking: Video

How might we test and validate a novel ADAS for overtaking on the highway?

Test Progression for Highway Overtaking ADAS



Takeaways

- Validating shared control ADAS technology requires a few key elements:
  - Driver experiences accurate feedback
  - ADAS interacts with real vehicle
  - Possibility of interactions with other road users
- Virtual reality on steer-by-wire test vehicle provides wide coverage of test cases
- Open questions: when have we reached sufficient validity on a given platform? how do we validate both system performance and human interaction?

References

[1] Autonomous Emergency Braking Test Protocol (Version I), *Insurance Institute for Highway Safety*, October 2013.

[2] Test Protocol – AEB Systems, *European New Car Assessment Programme*, March 2017.

[3] Standard No. 126; Electronic stability control systems for light vehicles, *Federal Motor Vehicle Safety Standards*, January 2012.

[4] M. Arwashan, T. Ge, Z. Liu, and N. Ozay, "Driving with guardian: Blending user inputs with safety ensuring barriers," in *2020 IEEE Conference on Control Technology and Applications (CCTA).* IEEE, 2020, pp. 326–333.

[5] W. Schwarting, J. Alonso-Mora, L. Pauli, S. Karaman, and D. Rus, "Parallel autonomy in automated vehicles: Safe motion generation with minimal intervention," in *2017 IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, 2017, pp. 1928–1935.

References

[6] T. Bock, M. Maurer, and G. Farber, "Validation of the vehicle in the loop (vil); a milestone for the simulation of driver assistance systems," in *2007 IEEE Intelligent vehicles symposium*. IEEE, 2007, pp. 612–617.

[7] C. Park, S. Chung, and H. Lee, "Vehicle-in-the-loop in global coordinates for advanced driver assistance system," *Applied Sciences*, vol. 10, no. 8, 2020.

[8] H. E. Russell and J. C. Gerdes, "Design of variable vehicle handling characteristics using four-wheel steer-by-wire," *IEEE Transactions on Control Systems Technology*, vol. 24, no. 5, pp. 1529–1540, 2015.

[9] E. Weiss and J. C. Gerdes, "High speed emulation in a vehicle-in-the-loop driving simulator," *IEEE Transactions on Intelligent Vehicles*, 2022, early access.