Self-driving Vehicles, Can They Be Safe in Mixed Traffic?

Prof. Jonas Sjöberg,

Department of Electrical Engineering
Chalmers University of Technology
Göteborg, Sweden

CHALMERS

Acknowledge to contributing colleagues & present and former PhD students

Jonas Sjöberg

Professor

Paolo Falcone

Professor

Jonas Fredriksson

Professor

Nikolce Murgovski

Associate Professor

Robert Hult

PhD

Arian Ranjbar

PhD

Ivo Batkovic

PhD

John Dahl

PhD Student

Angelos Toytziaridis

PhD Student

Masoud Bahraini

PhD Student

Maliheh Sadeghi Kati

PhD

Johan Karsson

PhD Student

Ankit Gupta

PhD

Tommy Tram

PhD Student

Daniel Åsljung

PhD Student

See webpages for publications by us.
Some illustrations taken from the web, acknowledged

CHALMERS

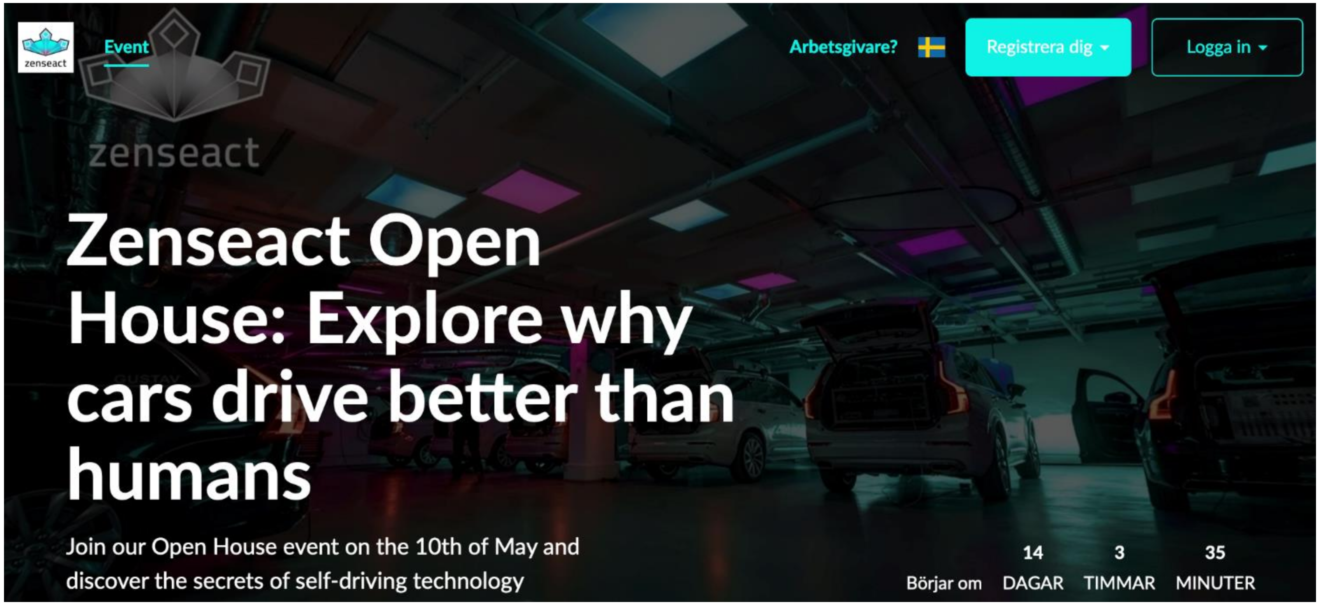
Göteborg / Gothenburg

CHALMERS
UNIVERSITY OF TECHNOLOGY

- Chalmers university
- Volvo Trucks
- Volvo Cars
- AutoLiv
- Zenseact (Zenuity)
- Veoneer
- + more supliers

Research in cooperation with, mainly, the local automotive industry eco-system

Is the problem solved? You are welcome to join this Open House event



Human decisions requires slow speed

Outline of the talk and for algorithms for self-driving vehicles

- One vehicle: Traffic situation is known – just calculate the optimal trajectory.
- If several autonomous vehicles are involved – communicate and solve as above.
- Traffic situation change, “surprises” due to other road users’ decisions: repeat optimization frequently, MPC.
- Possible surprises known, described them with probabilities and include in the optimization.
- So far, decision problem described as based on traffic situation. This means no interaction. More realistic: Other road users react on your decision. This is feedback with delay – dangerous.

Objectives

- Shorter travel time
- Energy efficiency

- Higher throughput
- Less infrastructure

- Verified safety

Outline of the talk and for algorithms for self-driving vehicles

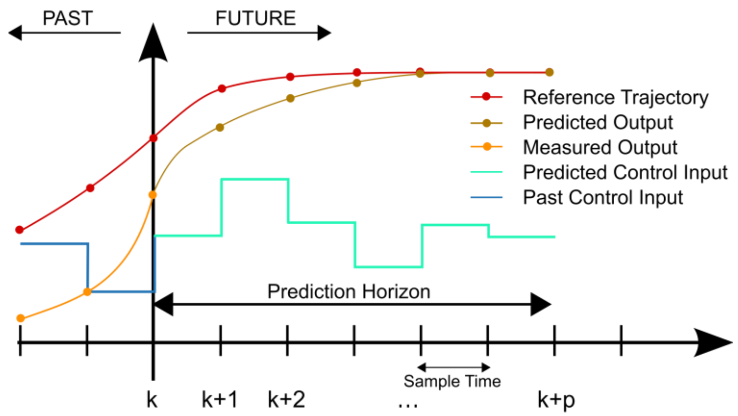
- One vehicle: Traffic situation is known – just calculate the optimal trajectory.
- If several autonomous vehicles are involved – communicate and solve as above.
- Traffic situation change, “surprises” due to other road users’ decisions: repeat optimization frequently, MPC.
- Possible surprises known, described them with probabilities and include in the optimization.
- So far, decision problem described as based on traffic situation. This means no interaction. More realistic: Other road users react on your decision. This is feedback with delay – dangerous.

Formulate decision: steering and velocity as an optimization problem

$$\max_{Vehicle\ commands} Vehicle\ Performance$$

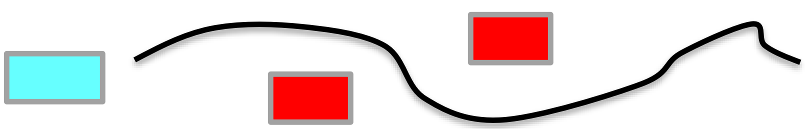
Subject to

Vehicle dynamics
Control authority
Performance requirements
Collision avoidance

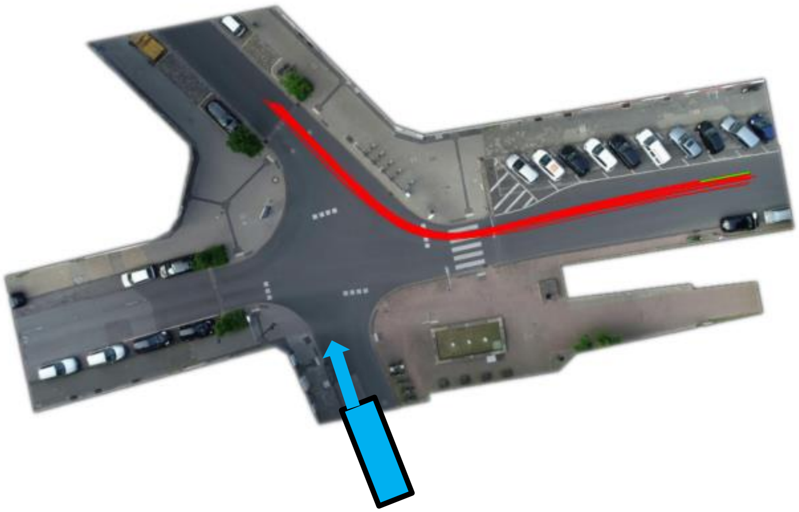


Challenges:

- Knowledge of traffic situation now and future
- Real-time solving the optimization



Predicting other vehicles, human driven or self-driving



Three approaches:

1. Vehicle model, s(t), v(t), a(t), steering
2. Based on logged data
3. Or combination of both

- Green vehicle can be predicted using the logged data.
- Easy to predict, as long as no surprise decision taken.

Data from: J. Bock, R. Krajewski, T. Moers, S. Runde, L. Vater, and L. Eckstein, "The ind dataset: A drone dataset of naturalistic road user trajectories at german intersections," in 2020 IEEE Intell. Vehicles Symp. (IV).

Outline of the talk and for algorithms for self-driving vehicles

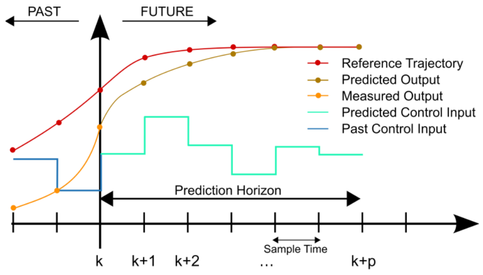
- One vehicle: Traffic situation is known – just calculate the optimal trajectory.
- Traffic situation change, “surprises” due to other road users’ decisions: repeat optimization frequently, MPC.
- If several autonomous vehicles are involved – communicate and solve as above.
- Possible surprises known, described them with probabilities and include in the optimization.
- So far, decision problem described as based on traffic situation. This means no interaction. More realistic: Other road users react on your decision. This is feedback with delay – dangerous.

Several collaborative self-driving vehicles

$$\max_{Time\ slots, Vehicle\ commands} \sum_{i=1}^{number\ of\ vehicles} Performance\ Vehicle\ \#i$$

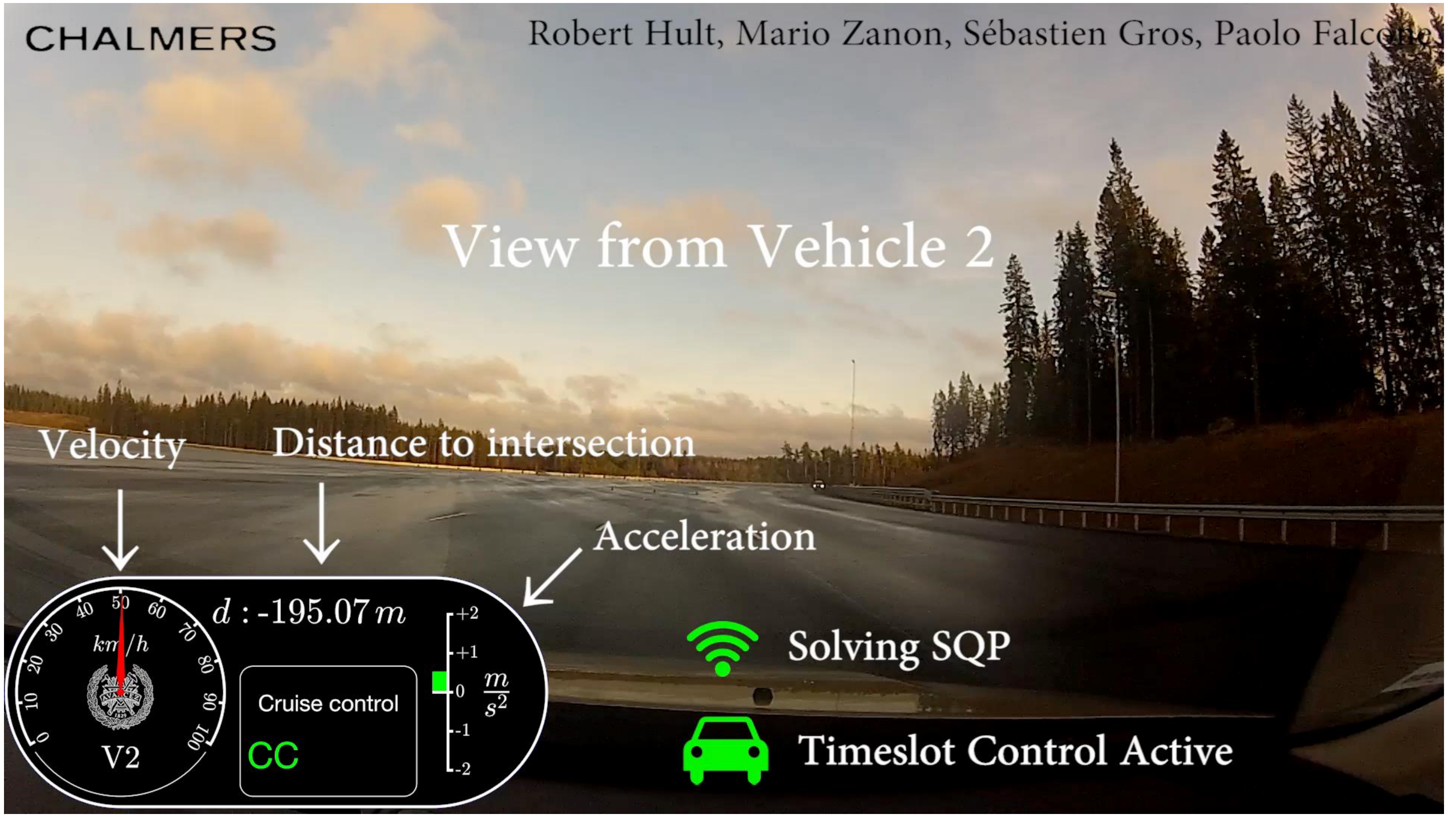
Subject to

Vehicle dynamics
Network delays and information losses
Control authority
Performance requirements
Collision avoidance



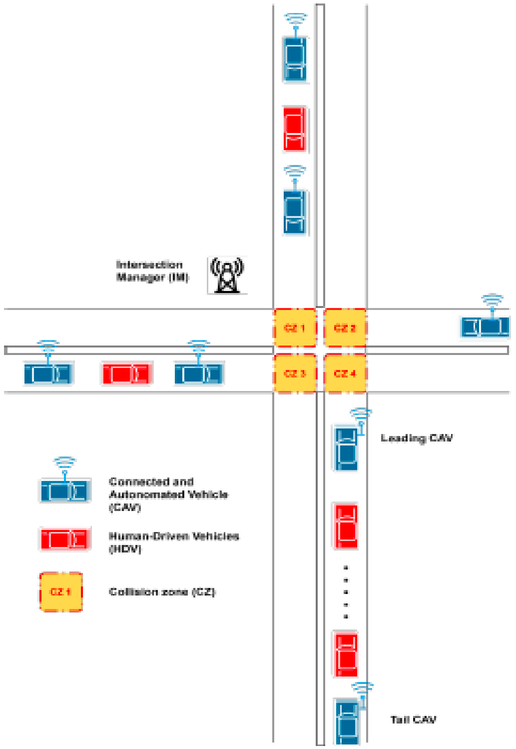
- The optimization problem becomes more complex
- Solution dependent of reliable communication

Experiments with Wifi (802.11p)



Mixed traffic – reduce uncertainty of human driven vehicles by placing them in platoons whith coolaborative autnomous vehicles

In this way, the platoons can be scheduled in a similar way as if their were individual cooperative autonomous vehciles



Muhammad Faris, Paolo Falcone, Jonas Sjöberg, ”*Optimization-based Coordination of Mixed-Traffic at Unsignalized Intersections Based on Platooning Strategy*”, accepted in 33rd IEEE Intelligent Vehicles Symposium (IV), 2022.

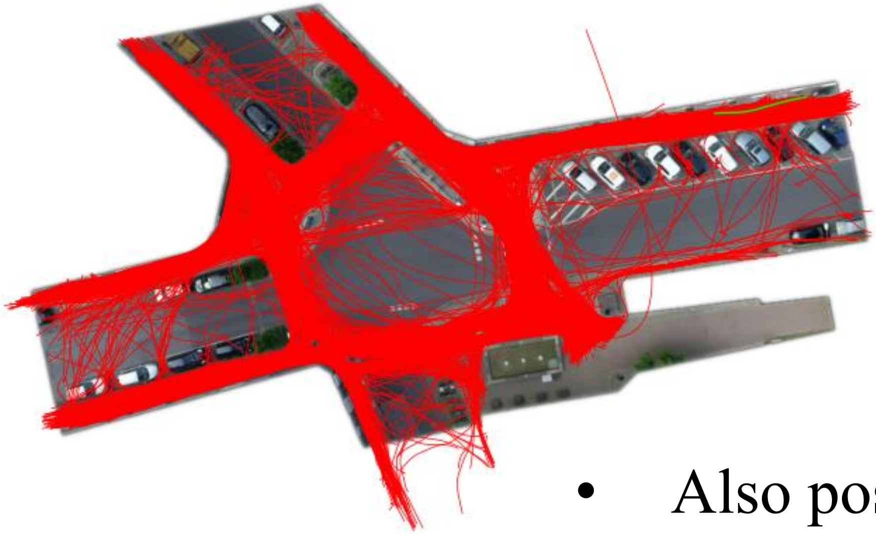
Experiments with 5G PoC at AstaZero

The use of the communication system is part of the optimization problem.

Pedestrians are hard to predict

- The road seems clear – cross the road
- One vehicle arrives and stops
- Second vehicle….
- … and now they change their mind and turn around and go back.

Pedestrian prediction based on data



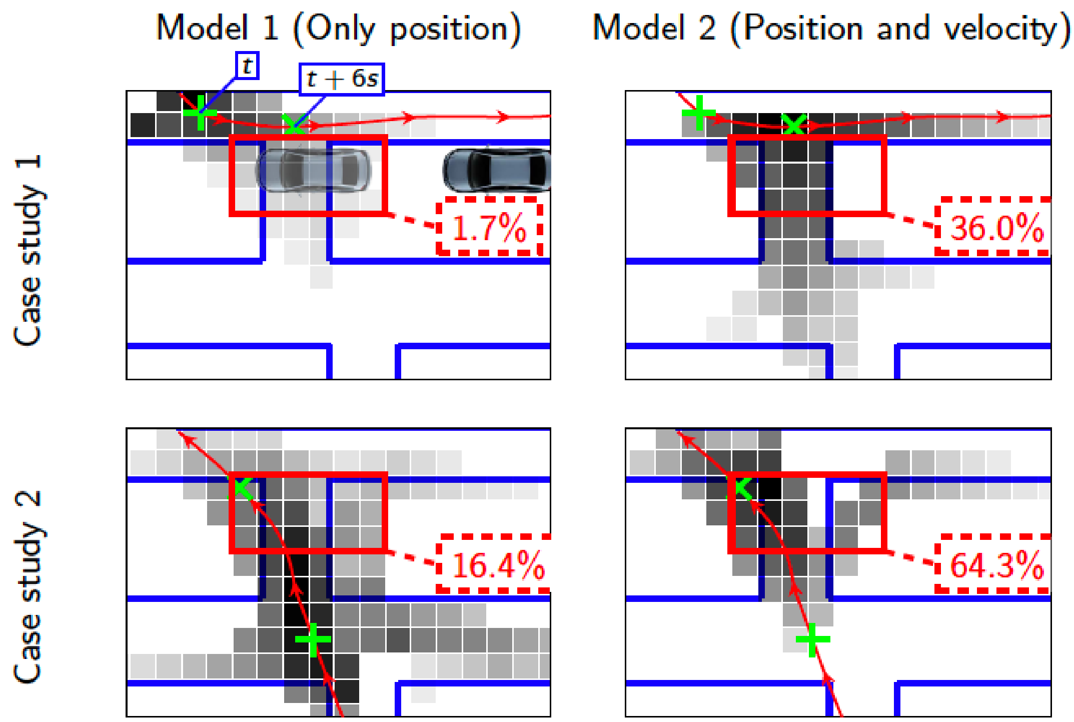
- Also possible, stochastic model
- Rational pedestrian has a goal
- Pedestrain follow Newton's laws…
- But not the traffic laws!

Data from: J. Bock, R. Krajewski, T. Moers, S. Runde, L. Vater, and L. Eckstein, "The ind dataset: A drone dataset of naturalistic road user trajectories at german intersections," in 2020 IEEE Intell. Vehicles Symp. (IV).

Outline of the talk and for algorithms for self-driving vehicles

- One vehicle: Traffic situation is known – just calculate the optimal trajectory.
- Traffic situation change, "surprises" due to other road users' decisions: repeat optimization frequently, MPC.
- If several autonomous vehicles are involved – communicate and solve as above.
- Possible surprises known, described them with probabilities and include in the optimization.
- So far, decision problem described as based on traffic situation. This means no interaction. More realistic: Other road users react on your decision. This is feedback with delay – dangerous.

Experimental results



A. Toytziaridis, P. Falcone and J. Sjöberg, "A Data-driven Markovian Framework for Multi-agent Pedestrian Collision Risk Prediction,"
B. 2019 IEEE Intelligent Transportation Systems Conference (ITSC), 2019, pp. 777-782, doi: 10.1109/ITSC.2019.8917142.

Automated Driving in Complex Environments

Ivo Batkovic[1,2], Mario Zanon[2], Mohammad Ali[1], and Paolo Falcone[2]

[1] Zenuity AB

[2] Chalmers University of Technology

CHALMERS ZENUITY WASP WALLENBERG AUTONOMOUS SYSTEMS AND SOFTWARE PROGRAM

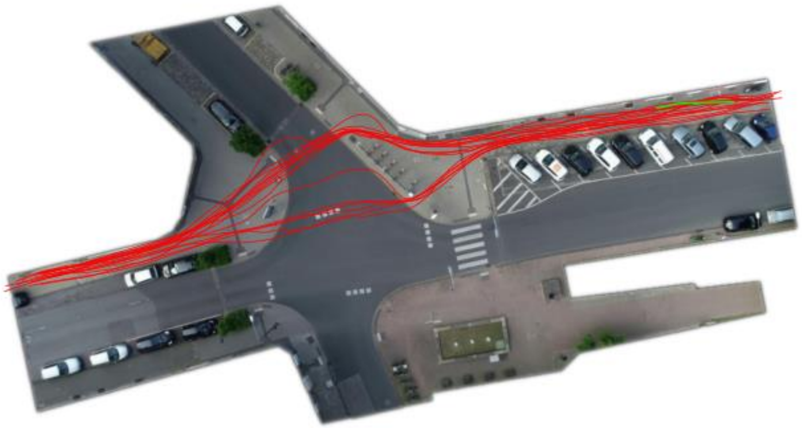
zenseact

I. Batkovic, M. Zanon, M. Ali and P. Falcone, "Real-Time Constrained Trajectory

II. Planning and Vehicle Control for Proactive Autonomous Driving With Road Users,"

III. 2019 18th European Control Conference (ECC), 2019, pp. 256-262, doi: 10.23919/ECC.2019.8796099.

Time dependent pedestrain pattern



Morning

Lunch

Evening

- Pedestrian movement change over the day.
- Autonomous vehicle recives statistics while approaching the crossing and can optimize its decision taking with respect to that.

Collective Decision Making using Attractive and Repulsive Forces in Markovian Opinion Dynamics, Carl-Johan Heiker, Paolo Falcone, Pre-print

,

Some insights

- Predicting pedestrians decision making can never reach 100%.

- A safe algo l so that emergency stops are possible.
- Hence, sp f pedestrian are present.
- Good stoc ls can however lower the risk of (unpleasant) emergency braking. And in that way permitting a higher speed than without the models.

Pedestrian prediction with low uncertainty

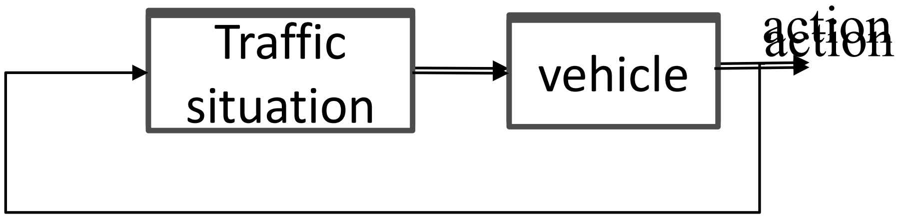
- Solutions like this are necessary to allow speed and safety.
- Pedestrains must be keept away!
- It is similar, with human driven vehicles if safety is prioritiesed.

Outline of the talk and for algorithms for self-driving vehicles

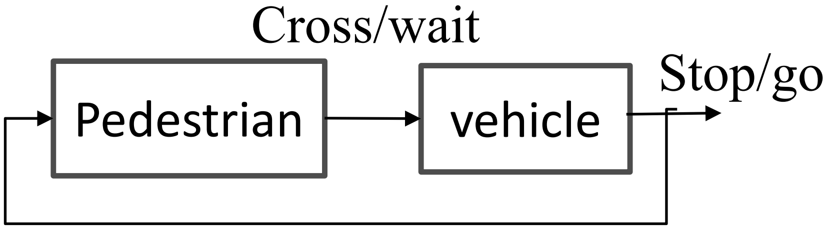
- One vehicle: Traffic situation is known – just calculate the optimal trajectory.
- Traffic situation change, "surprises" due to other road users' decisions: repeat optimization frequently, MPC.
- If several autonomous vehicles are involved – communicate and solve as above.
- Possible surprises known, described them with probabilities and include in the optimization.
- So far, decision problem described as based on traffic situation. This means no interaction. More realistic: Other road users react on your decision. This is feedback with delay – dangerous.

Interaction at zebra-crossong

- So far, decision taking depending on the traffic situation
- Interaction, ie two controllers in the loop

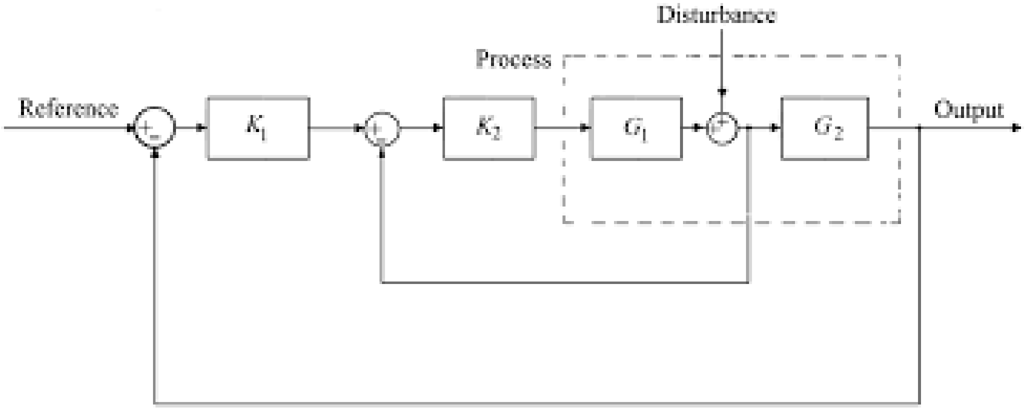


- This is, in general, not good, especially not with a human 1 second delay
- Possible oscillation between two possibilities



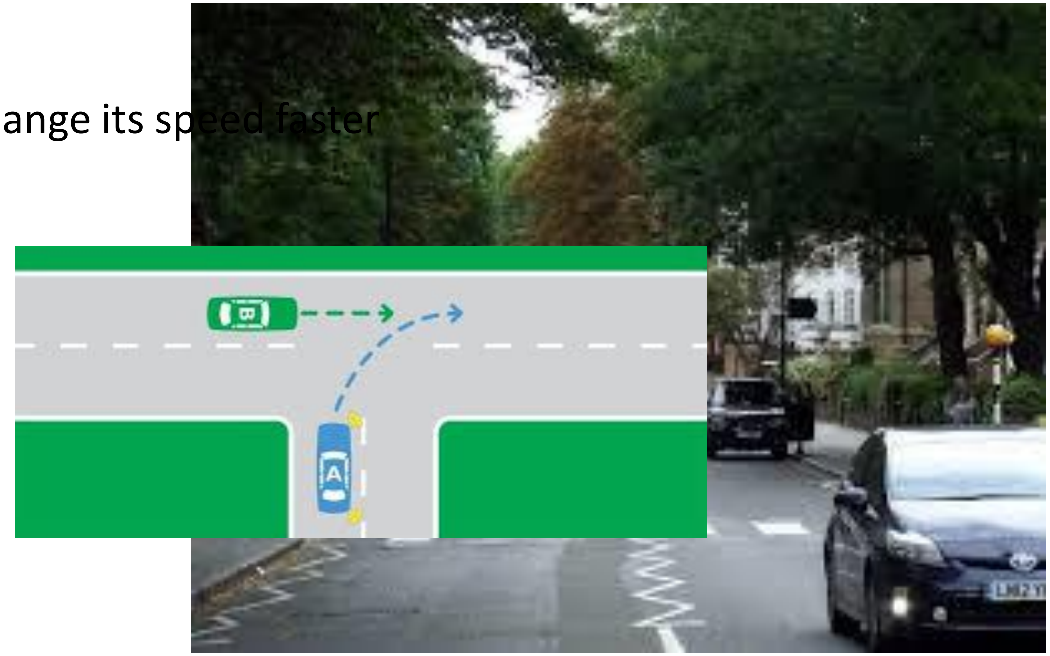
Two decision makers: Cascade control

- If inner loop is much faster than outer loop stability is easy to analys.
- In traffic this means that the one making fast adaptions, should adapt to the slow one.



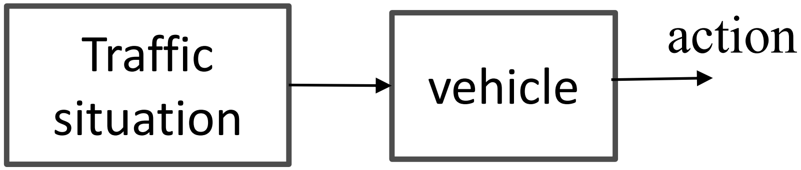
Who makes the fast decision?

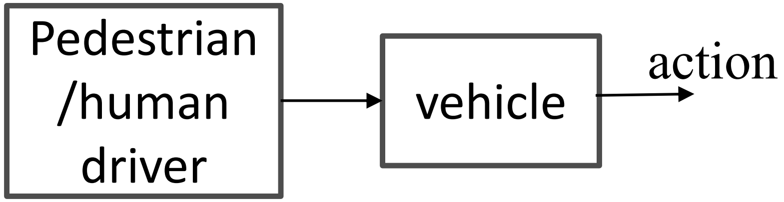
- This depends on the traffic sitation
- A fast vehicle is approach the pedestrain crossing
    - Pedestrian is faster and ”should” adapt to the vehcile. If not, the vehcile must reduce speed to become a fast decision maker
- A T-crossing
    - Slower vehicle can change its speed faster



Reflections

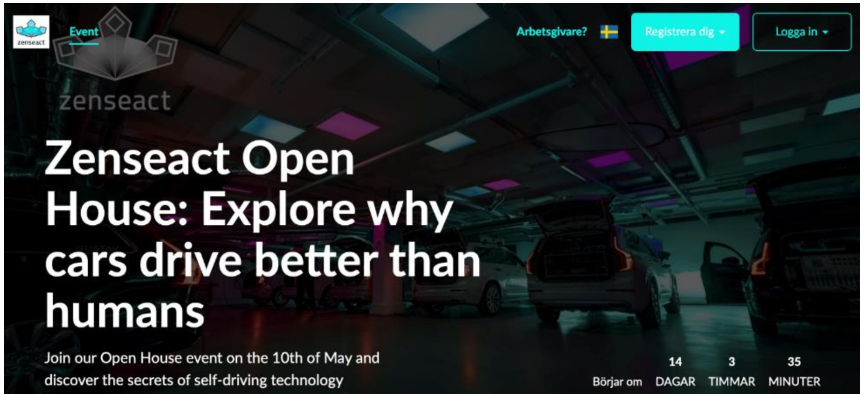
- This makes sense
- but means
- and we don’t want the pedestrian to be in command.
- Just “Safe mixed traffic” is not the traffic system we want. Something must be changed.





- Maybe automatic penalty or fee for rule breaking.
- Rewards for “well-behaving” road users. Necessary also between autonomous vehicles for smooth traffic

Is the problem solved?



- Not in mixed traffic if we want speed and 100% safety
- Separation is one possible solution