TSFS12: Autonomous Vehicles – planning, control, and learning systems

Lecture 1: Erik Frisk <erik.frisk@liu.se>

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Course personnel

Lecturers

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Outline – todays lecture

- Course description, outline
- Rest of this lecture — video
  - Introduce autonomous systems and autonomous vehicles
  - Autonomous systems, a broader context
  - Enabling technologies
  - Autonomous vehicles
- Next lecture we'll start with methods— first topic is discrete planning methods for motion planning

Course organization

Course

- Give basic understanding of models, methods, and software libraries to work with autonomous vehicles
  - Focus on planning and control functions ~ a bit down in the software architecture stack, not the highest level functions
  - Implementation important as a means to understand methods
- Autonomous systems and vehicles is too large a topic to cover in a 6 credit course
  - Decision making
  - Perception
  - Planning and control [focus]
  - Sensors
  - Societal, ethical, and legal aspects
  - …

Course

- Course is cross-disciplinary in nature; and we have participants from a wide range of educational background.
  - 7 different engineering programs (Y/D/U/IT/M/I/ED)
  - Exchange students from Chile, Germany, Spain, France, Mexico, Taiwan
  - There are background material that is new to some but not all;
  - You will have to read up. You will be expected to explore new areas
- It is a rather new course, third edition; still growing and developing. We've made several improvements for this year.
- We encourage continuous feedback and comments (although we might not always agree with you); we want to know if something is not working

Course literature

- Course literature will consist of
  - Scientific papers/articles
  - Chapters from books
  - Lecture notes
  - Links to resources on-line
- This is a developing topic with intensive research and the literature will reflect that. This also means no single course book.
- Download links to material will be available, possibly via LiU library login
- Breadth vs depth:
  You will be expected to read advanced texts where you might not be able to understand everything. But don't worry, keep at it, and continue reading.

Examination

- No standard written exam.
- To pass with grade 3 you need:
  - Accepted solutions for 5 hand-in assignments.
    Done in groups of 2.
  - Participate in a mini-project. These are done in groups of 4-5.
- To pass with grade 4 or 5; all requirements for grade 3 *and*
  - Extra tasks for hand-ins (2 and 3 passed for grade 4 and 5 respectively)
- Hand-in assignments, basic exercises, done in groups of 2.
- Extra tasks for higher grade are done individually;
  handed in no-later than the end of the year.

Main examination: Hand-ins

- 5 Hand ins
    1. Discrete Planning in a Structured Road Network
    2. Planning for Vehicles with Differential Motion Constraints
    3. Vehicle motion control
    4. Collaborative control
    5. Learning for autonomous vehicles
- Hand-ins are the main examination; they will take time and you are advised to keep in pace.
    - HI 2 and 3 are the most time-consuming hand-ins, while 1, 4, and 5 require slightly less work.
- Matlab or Python, up to you (not a programming course, you will need some skill)
- Groups of 2; with single person groups there will be more reports to grade than our resources allow so find a partner (we can be of assistance in pairing groups)

Main examination: Hand-ins

- Examination
  - It is allowed to discuss the exercises on a **general** level with other course participants.
  - Code sharing outside groups is not allowed
  - Both students in the group should be fully involved in performing all exercises
- Hand-ins are reported either orally or through a short report.
- **Runnable** code should *always* be submitted via Lisam. Code that does not run is not accepted or evaluated.
- **Deadline for uploading code for hand-ins are Mondays @ 12:00 each week.**
- Possible to ask questions during the exercise sessions when hand-ins are introduced.
- Please do not distribute or make your solutions publicly available, e.g., via a public GitHub repository.

Course material – Lisam, git, and web

- Lisam page will be used for messages and handing in your solutions. There is a course WWW-page, static and not used during the course.
- All material will be distributed via course git-repository https://gitlab.liu.se/vehsys/tsfs12
  - Lecture notes
  - Links to reading material
  - Hand-in assignments
  - Updated continuously during the course
- You don't have to know a lot (but do learn) http://git-scm.com/
  - `% git clone https://gitlab.liu.se/vehsys/tsfs12`
  - `% git pull # when getting new files`

Lecture plan

Week	No	Lecture title
35	1	Introduction
	2	Discrete motion planning
36	3	Modeling of ground vehicles
	4	Planning with differential constraints
	5	Optimization for motion planning
37	6	Control of autonomous vehicles I
	7	Model Predictive Control for Autonomous Vehicles
38	8	Control of autonomous vehicles II
	9	Collaborative control
39	10	Learning for autonomous vehicles I
40	11	Learning for autonomous vehicles II and guest lecture

Schedule overview

	Monday	Tuesday	Wednesday	Thursday	Friday
35		Lecture 1	Lecture 2	Hand-in 1 Computer intro	
36		Lecture 3	Lecture 4	Hand-in 2 TA hand-in 1	Lecture 5 Extra TA session
37	Deadline Hand in 1	Lecture 6	Lecture 7	Hand in 3 TA hand-in 2	Extra TA session
38	Deadline Hand in 2	Lecture 8	Lecture 9	Hand in 4 TA hand-in 3	Extra TA session
39	Deadline Hand in 3	Mini-project, start	Lecture 10	Hand in 5 TA hand-in 4	Extra TA session
40	Deadline Hand in 4			Lecture 11	Extra TA session
41	Deadline Hand in 5		Resource		
42				Project seminars	

Mini-projects – a few alternatives

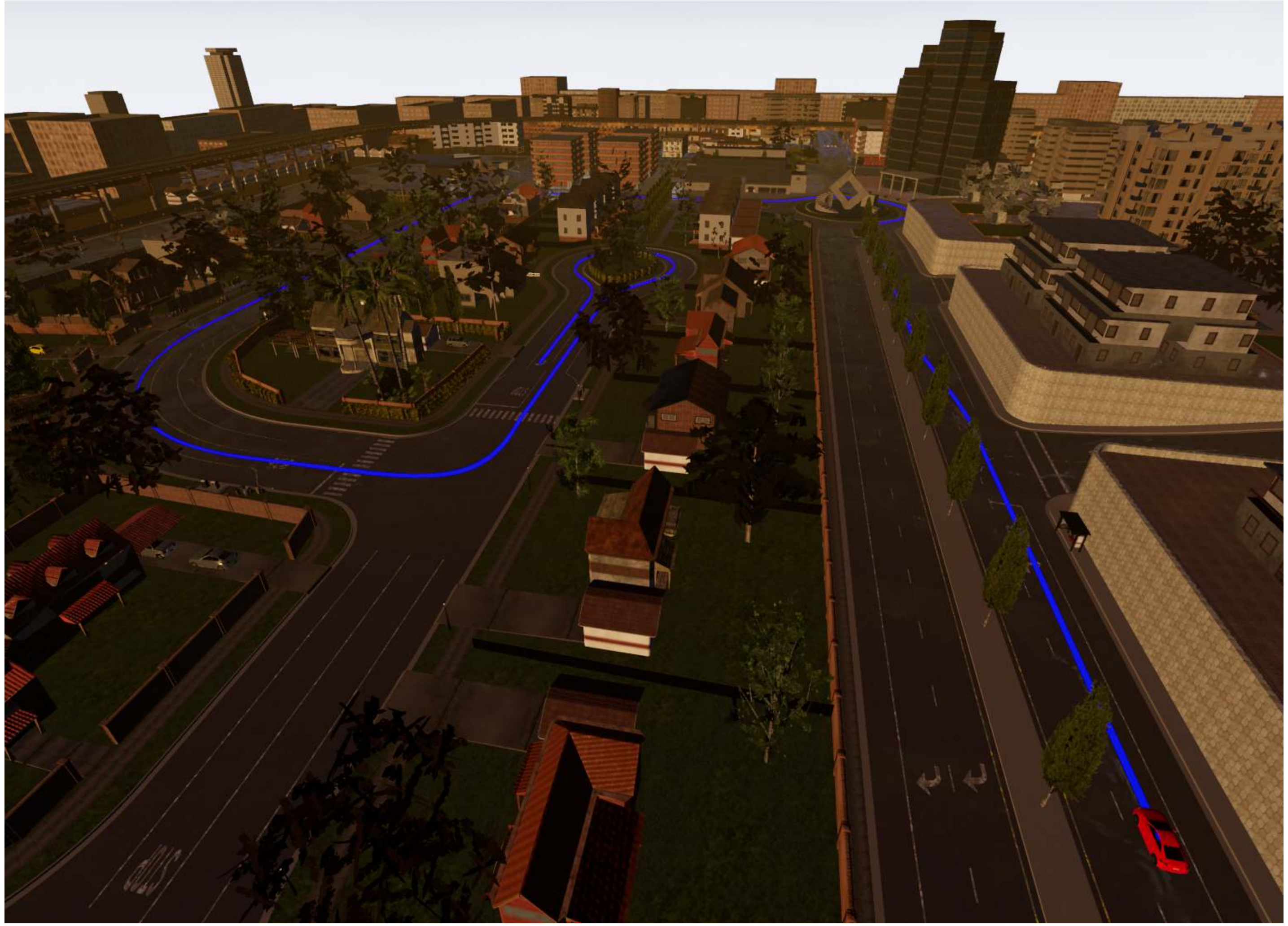
- Idea is to make an implementation on a real platform or a relevant simulation environment to get initial practical experience
- Your own interests form the project — large freedom to explore topic of choice
- Some emphasis on *mini*, free to explore your own interests
- Group size 4-5
- Examined with an oral presentation + submission of slides and video
- Hardware alternative 1: CrazyFlie — small quad-copters
    - Radio-based positioning system
    - Visionen, camera based positioning system
    - HTC Vive based positioning
- Hardware alternative 2: Remote controlled car(s) with extra equipment
    - Python/C++
    - Robot Operating System (ROS)

Simulation and Theoretical mini-projects

- There are plenty of opportunities to further investigate algorithms from the course, or expand to more research oriented tasks; with the aid of an advisor
- Large possibility to shape your own project depending on your interests; Planning, Control, Machine Learning, Reinforcement learning, …
- We will provide a catalog of candidate projects
    - Advanced motion planning techniques
    - MPC or reinforcement learning for roundabout driving, which is best?
    - Trajectory prediction of surrounding vehicles based on recorded traffic data
    - Planning for buses and large vehicles; control the swept area
    - Autonomous formula student inspired project
    - …

Carla – a simulator for autonomous vehicles

- Open-source simulator for autonomous driving research (www.carla.org)
- Based on the Unreal Gaming Engine
- Python and C++ API
- Can install at home (Linux/Windows)
- Requires decent GPU-card (room Asgård Nvidia RTX-2060, Olympen, Nvidia GTX-1080)
- Not photo-realistic, but nice looking




New map Town 06 (Caladan):
Urban town inspired by “Michigan left” situations.

TSFS12 - 2019

SAMPLE PROJECTS

Corona

- Directives may change, but as of now we are in distance mode
- Many lectures will be pre-recorded, some might be given live
  - Links on course-git
  - Recorded in segments
  - Videos from last year will be available — lectures will be updated
- Hand-ins
  - Python/Matlab-based, no need for specialized hardware
  - We will arrange questioning sessions over Zoom
- Final mini-projects
  - Depends a little on development of the pandemic; we will adapt
  - Will be possible to do a simulation based project

Changes from course last year

- No major changes, course went according to plan last time
- Due to Corona, the course will be given in a similar way as last year
- Of course, there is always room for improvement
  - Slightly revised lecture series;
  - All hand-ins revised and improved
  - Fifth hand-in; Learning for autonomous vehicles
    - Major updates with extended reinforcement learning tasks
- Lecture videos from last year will be available
  - Could be revised; slides will be updated.
  - Could be complemented with live lectures, depends on the extent of revisions

Autonomous systems – a broader context

Excerpt from WASP video:
https://youtu.be/cEbdTTNaHBI

The Knut and Alice Wallenberg Foundation

Autonomy research @ LiU

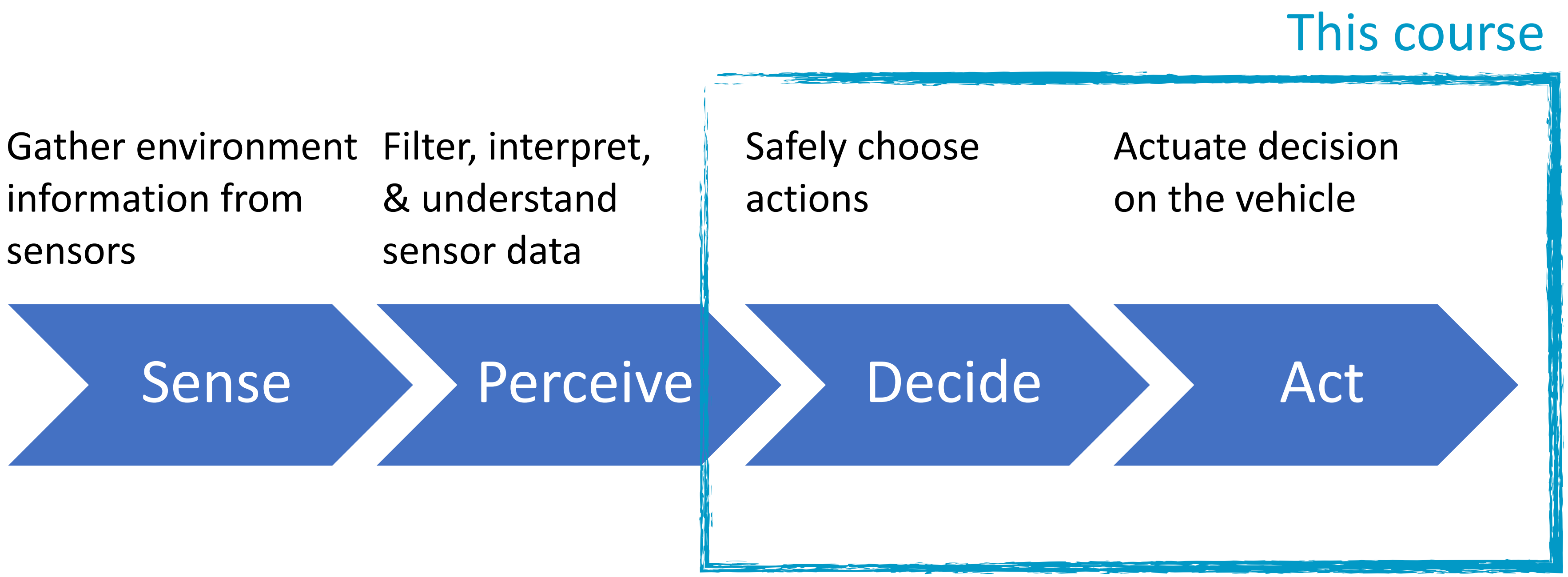
- Media and Information Technology [ITN]
- Computer Vision Laboratory [ISY]
- Sensor fusion and automatic control [ISY]
- Vehicular Systems [ISY]
- Statistics and Machine Learning [IDA]
- Real-Time Systems [IDA]
- AI and Integrated Systems [IDA]

What is an autonomous system?

An autonomous system is a cyber-physical system that is situated in some environment, and that is capable of acting independently and exhibiting control over its internal state in this environment in order to meet its delegated objectives.

Definition from F. Heintz, PhD course in autonomous systems

Autonomous vehicles



Military: OODA-loop (Observe - Orient - Decide - Act)

- Here focus on planning and control of vehicles
- Broad rather than deep course; integration of methods is a main objective

Why autonomy? Depends on who you ask

- In general, reduce cognitive load for decision makers
  - Let short-time decisions be taken autonomously and leave strategic decisions, on a long time-scale, to human operators (if any)
- Driverless cars
  - safety, increased traffic flow, mobility-as-a-service, improved city environment due to less traffic jams, new services …
- Transport
  - a complete change in business model
  - vehicles are part of a logistic chain
- Work sites
  - Reduce cognitive load on operators; shift from short-term decision making to long-term planning

Example work site

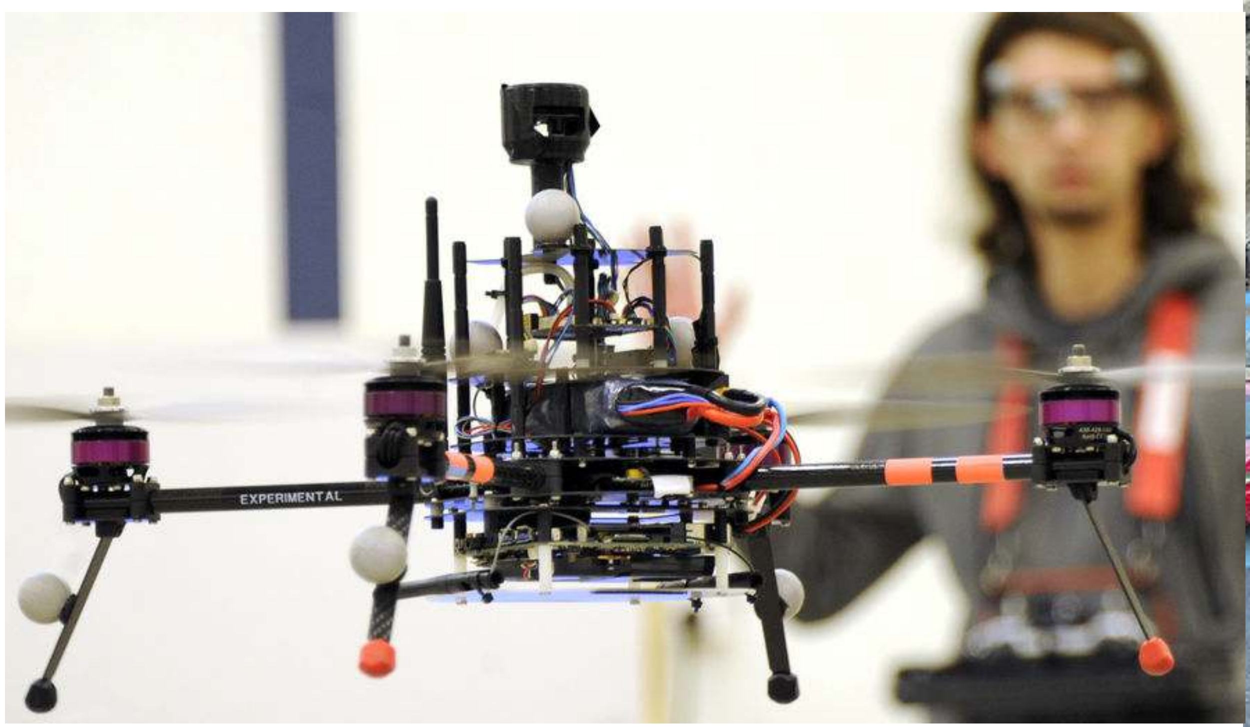
Example from Volvo Construction Equipment — Electric Site project

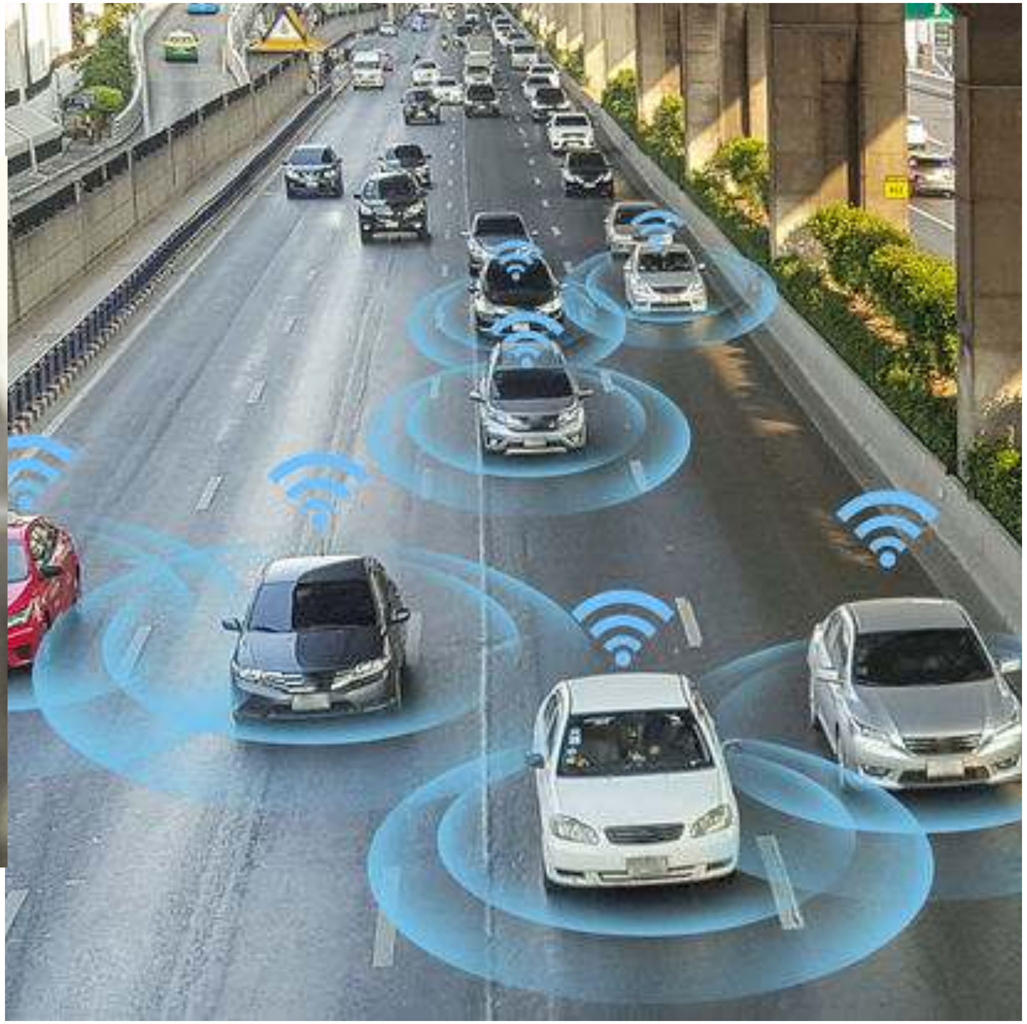
Excerpt from Volvo video:
https://youtu.be/m4wLPfOz-c4

Why autonomy? Depends on who you ask

- Autonomous aviation
  - Search and rescue
  - Precision agriculture
  - Distributed healthcare
  - Package delivery
- Marine and Shipping
  - Manage fleets of ships and complete logistic chains, remote supervision
  - Personnel cost and increase cargo capacity
  - Rescue operations

Autonomous vehicles





Autonomous vehicles

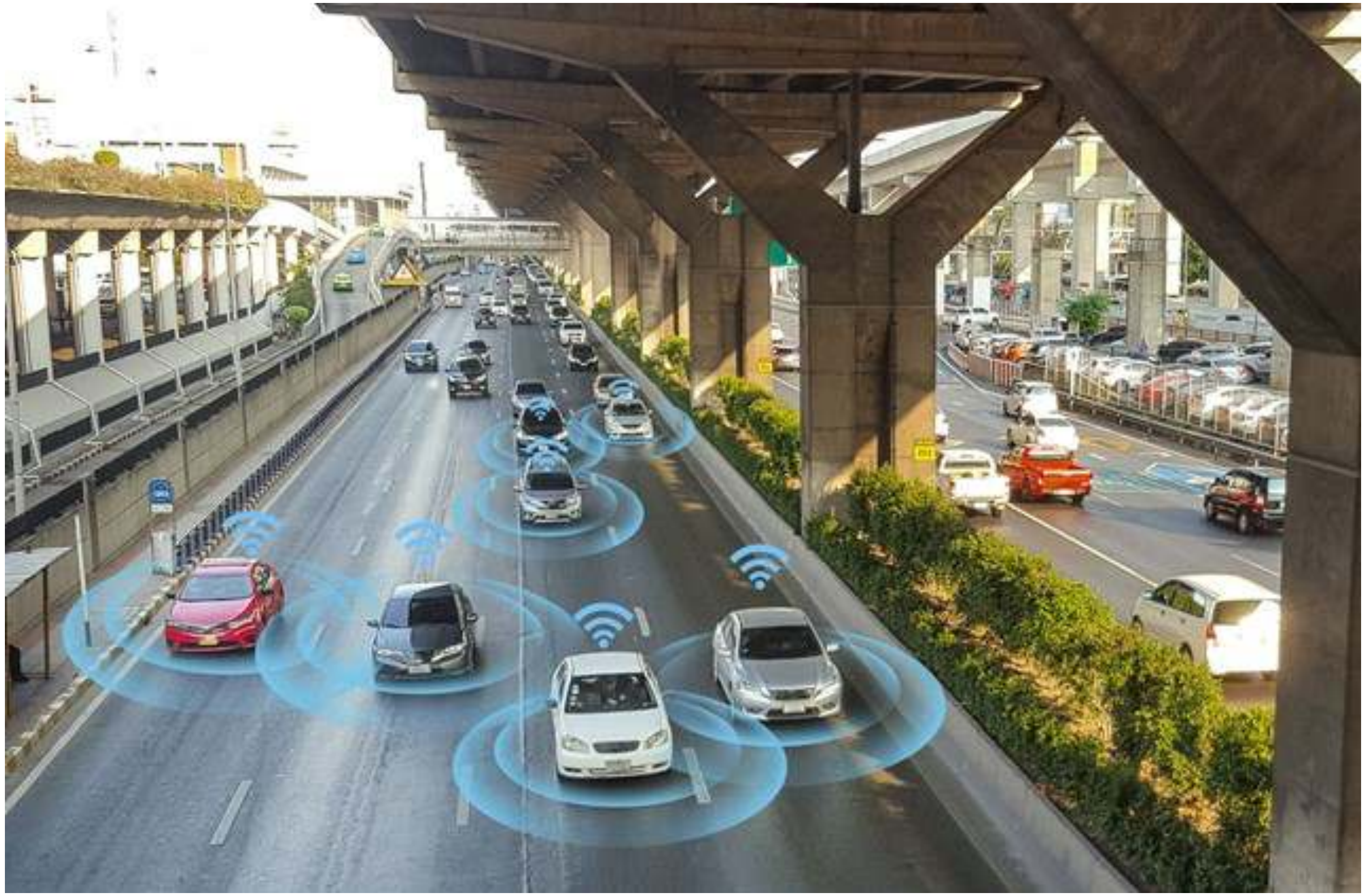
Autonomous vehicles

Autonomous vehicles

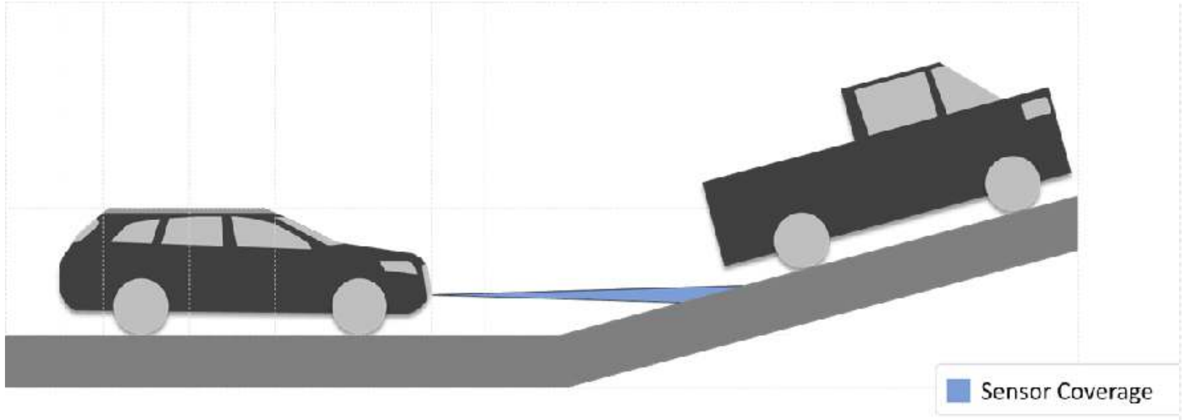
- Reading material: A. Pernestål et al. "*Effects of driverless vehicles-Comparing simulations to get a broader picture*" European Journal of Transport & Infrastructure Research 19.1 (2019).

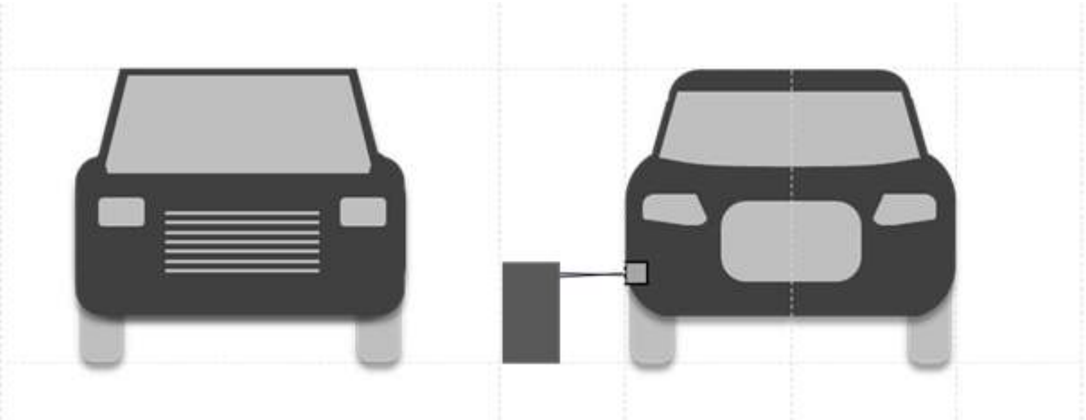
Sensors and communication – discover environment

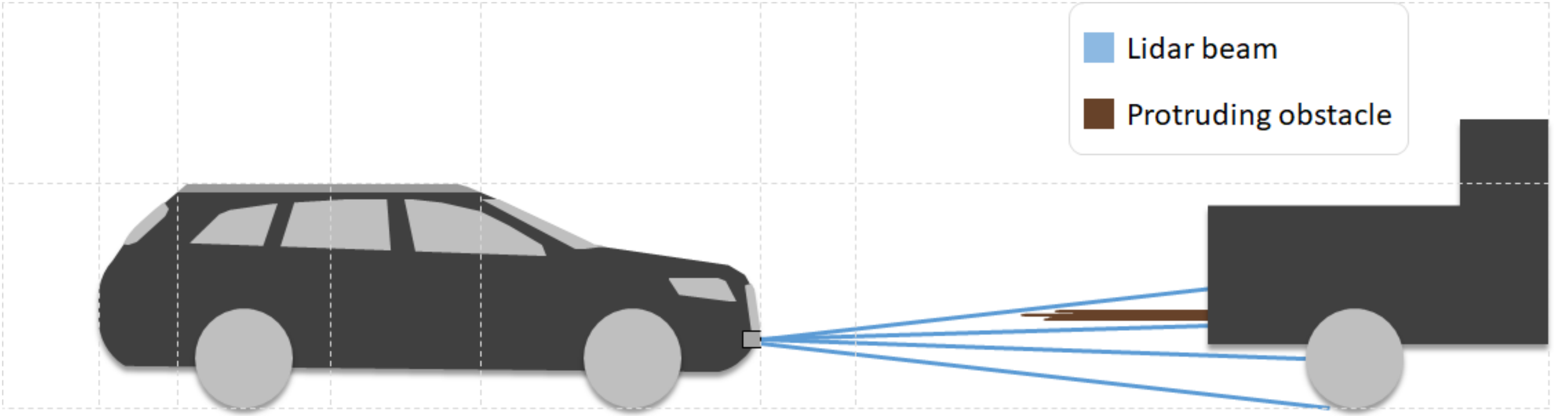
- Cameras
  - Multiple, stereo, infrared, …
  - passive
- Radar
- Lidar
- Ultrasound
- Microphones
- …
- Outside the scope of this course, but essential

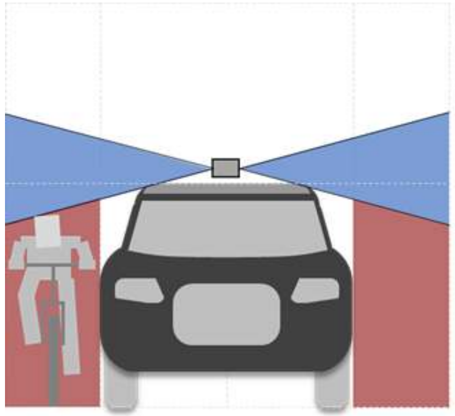


Sensor placement and selection

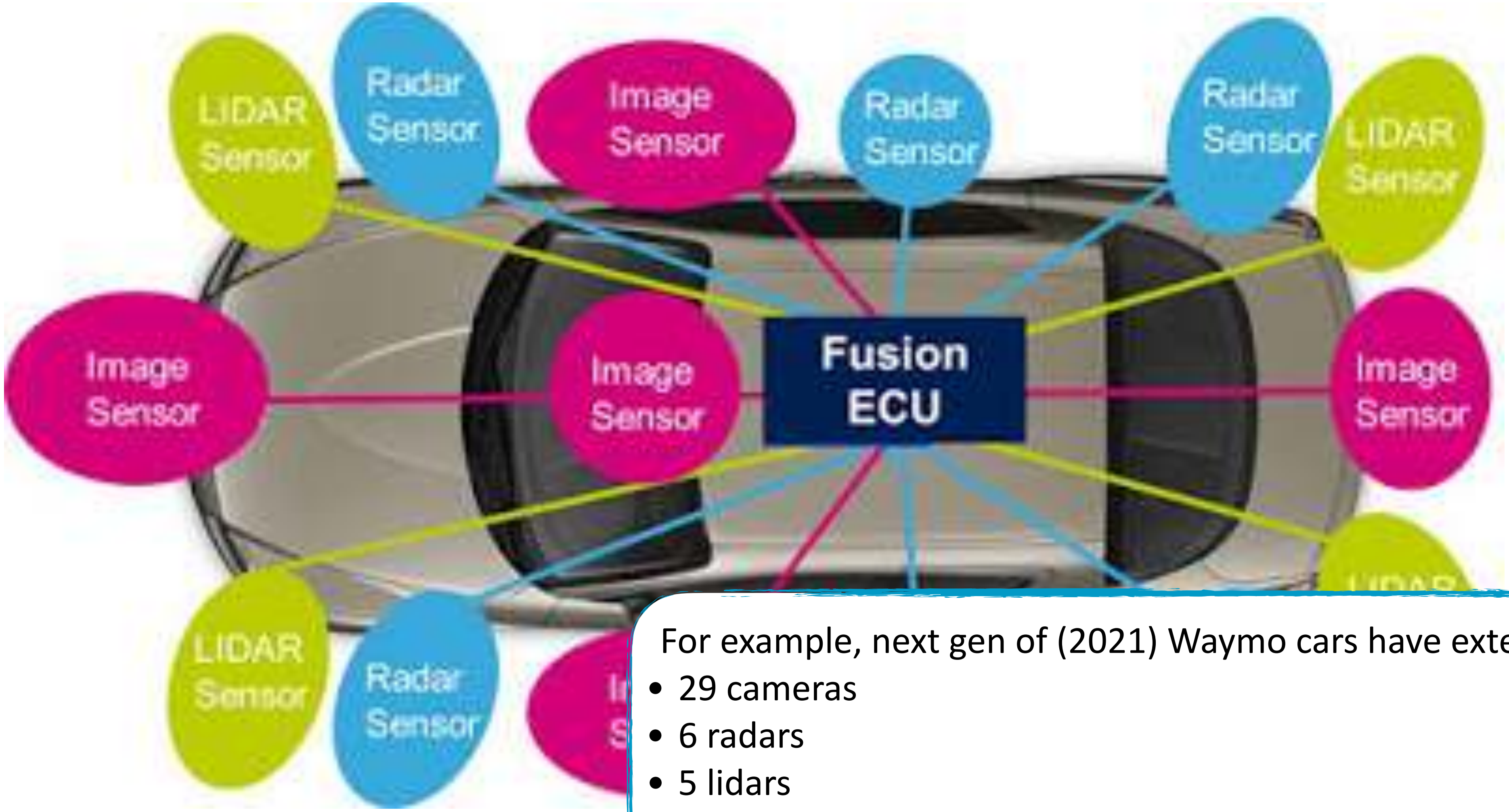








Sensors



For example, next gen of (2021) Waymo cars have extensive sensing:

- 29 cameras
- 6 radars
- 5 lidars

Src: Interview with Waymo CTO (https://youtu.be/P6prRXkI5HM)

Challenges

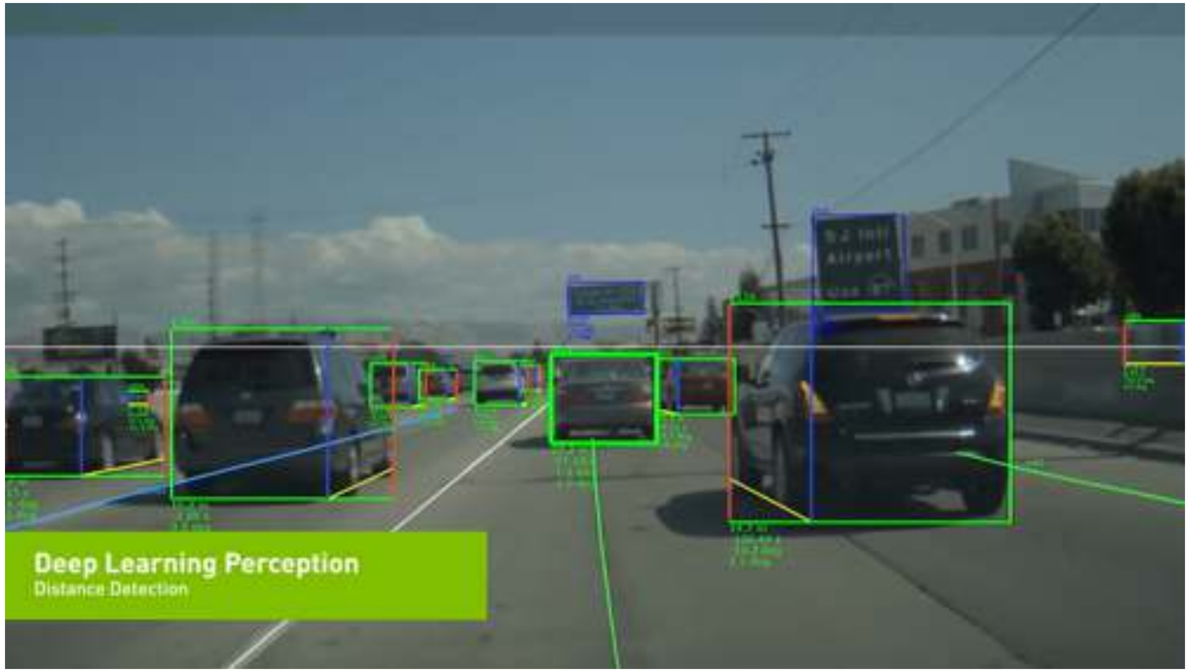
- Cyber security
  - How to ensure automated vehicles are not tampered or influenced from unauthorized agents
- Safety — how, where, and when can we reach human performance or better
- Cost - extra sensors and equipment are expensive (*right now*) (estimates of $100, 000/level 4 vehicle has been mentioned, but will likely decrease significantly with time)
- Robustness — the systems should not only work on summer roads in California, or on a clear summer sky with no wind, with no unexpected events happening.
- Functional safety — how to ensure, and *prove* safety of operation (like aerospace has done for a long time)

Autonomous vehicles - enabling technologies

Some enabling technologies

- From the start, it became important to know where you are in the world
  ➠ Localization and mapping
- Then it became important to know more about surroundings
  ➠ Perception
  - Computer Vision
  - Sensor development, Lidar technology, …
- A current hot topic is how to model and *predict* behavior of the environment
- AI and Machine learning
- Distributed control, communication, and cloud computing

AI and machine learning



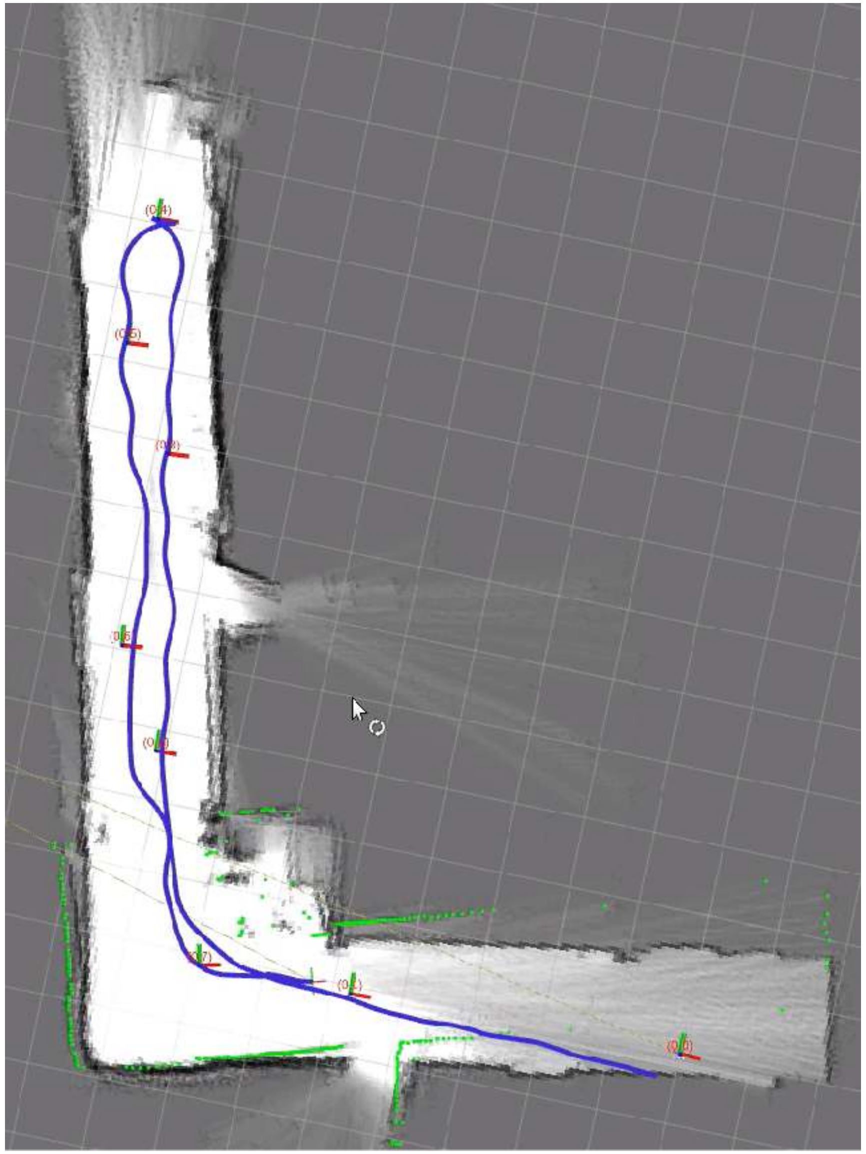
- Current systems are hand-crafted and are heavily based on advanced sensor techniques
- Learning systems have the potential to make high-level autonomy an everyday reality — but we're not there yet
- Probable components where deep-learning systems will be core
  - computer vision and perception modules
  - (model-based) reinforcement learning for decision making
- ML will most likely be an important part of the solution (but most likely not *the only* solution)

Localization - a fundamental requirement for autonomy

- You need to know your position in the environment
  - GNSS systems — GPS (~ meter), DGPS (~ centimeter)
  - GPS not useful indoors, depend on other sensors
  - Cellular network contains localization information, even more with 5G
- Inertial navigation systems — drift
- Availability of maps depends on application
  - Road network, probably available
  - The insides of a burning building; probably not
- SLAM - Simultaneous Localization And Mapping
  - Simultaneously estimate your position and create a map of the environment

SLAM fundamentals

- Basic idea:
  - Vehicle moves around in an unknown environment m
  - Control the vehicle using steer commands U. Assume you have an uncertain model on how the vehicle moves.
  - Obtain measurements Z from the environment. Assume that the environment doesn't change and associate measurements to *landmarks*, i.e., points of interest (door, wall, …)
  - Fuse the information to obtain estimate of vehicle position x
- Example measurements: Lidar, IMU, Cameras, WiFi network, cellular network



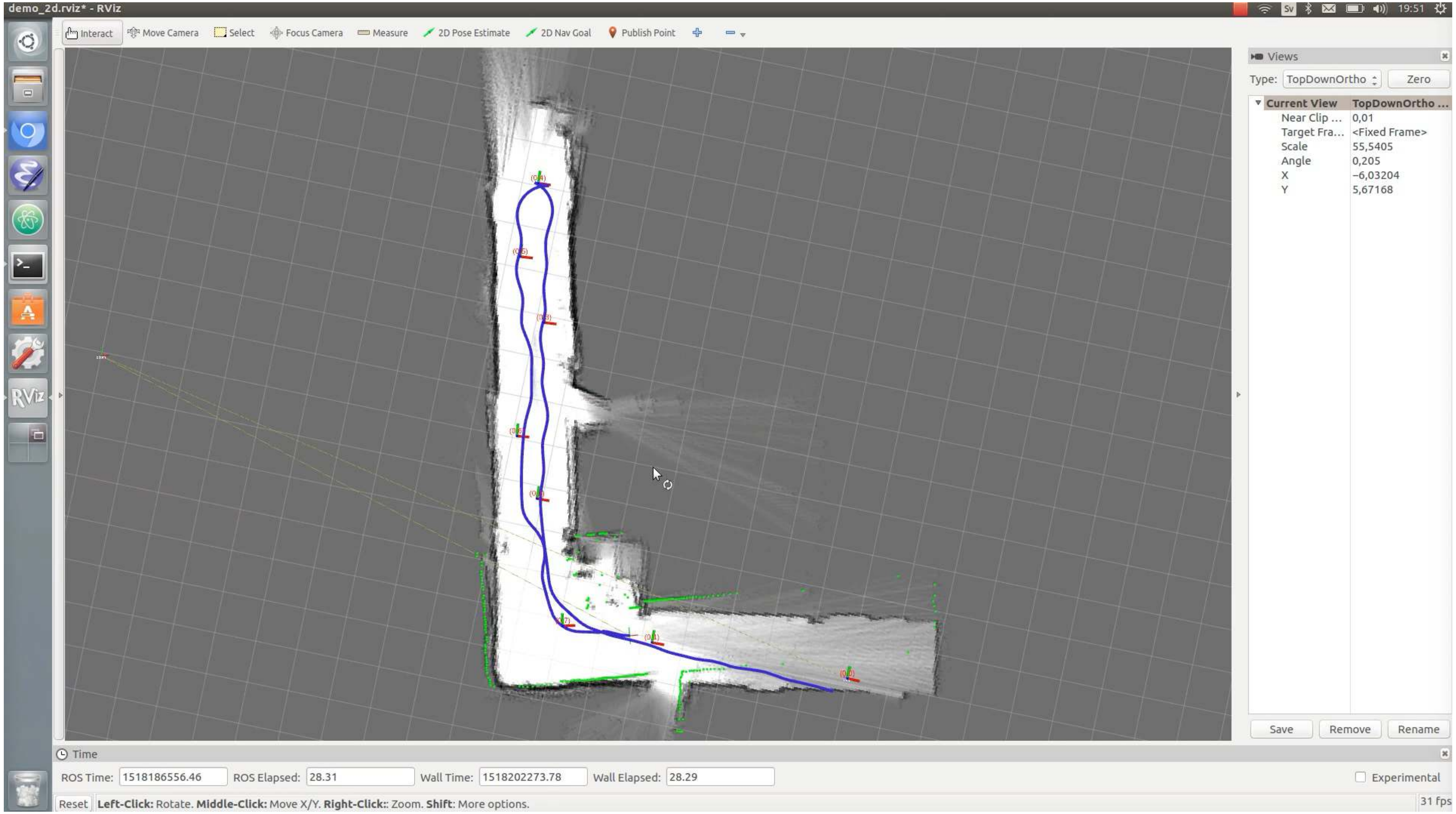
Slam fundamentals

- Often formulated in probabilistic setting

$$p(x, m \mid Z, U)$$

- Varying degree of difficulty
    - Static or dynamic environment
    - Landmarks with id or automatic data association
- Reading material: Topic for a full course; not covered here. An introduction to the topic, is Chapter 46.1 in Robotics handbook. Link on git-page
- Active area of research, if you are interested I recommend the course TSRT14 – "*Sensor Fusion*" given here at ISY@LiU

Googles Cartographer algorithm (Lidar + Odometry)



Vision based systems

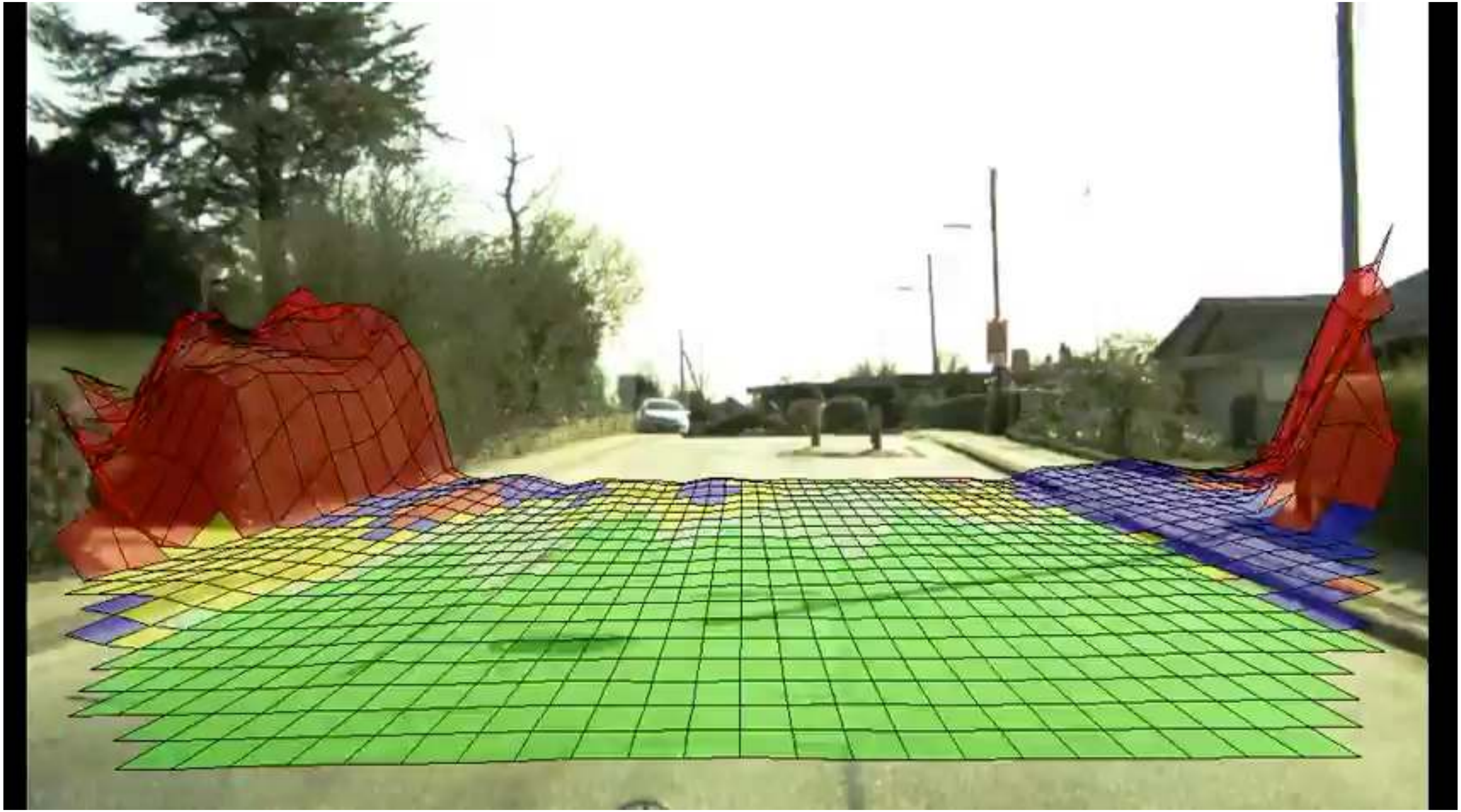
- Maps are good; but need detailed information about environment that is not included in maps,
  - Detection of other vehicles, pedestrians, cyclists,
  - Road boundaries, road condition, rain, …
  - Traffic lights, signs, …
  - Detection of free space
  - Detection of people in a search and rescue mission
- Vision systems and cameras are cost-effective compared to, e.g., Lidar systems
  - Some thinks Lidars isn’t necessary or even desirable, others consider they essential

Vision based systems

- Machine learning methods have enhanced the field tremendously during the last years, but still a long way to go
  - Robustness
  - Reduce need for labeled data
  - Verification of function based on ML models
- Big area for autonomous vehicles that is not covered in this course: recommend courses from computer vision laboratory:

  TSBB17 - Visual Object Recognition and Detection

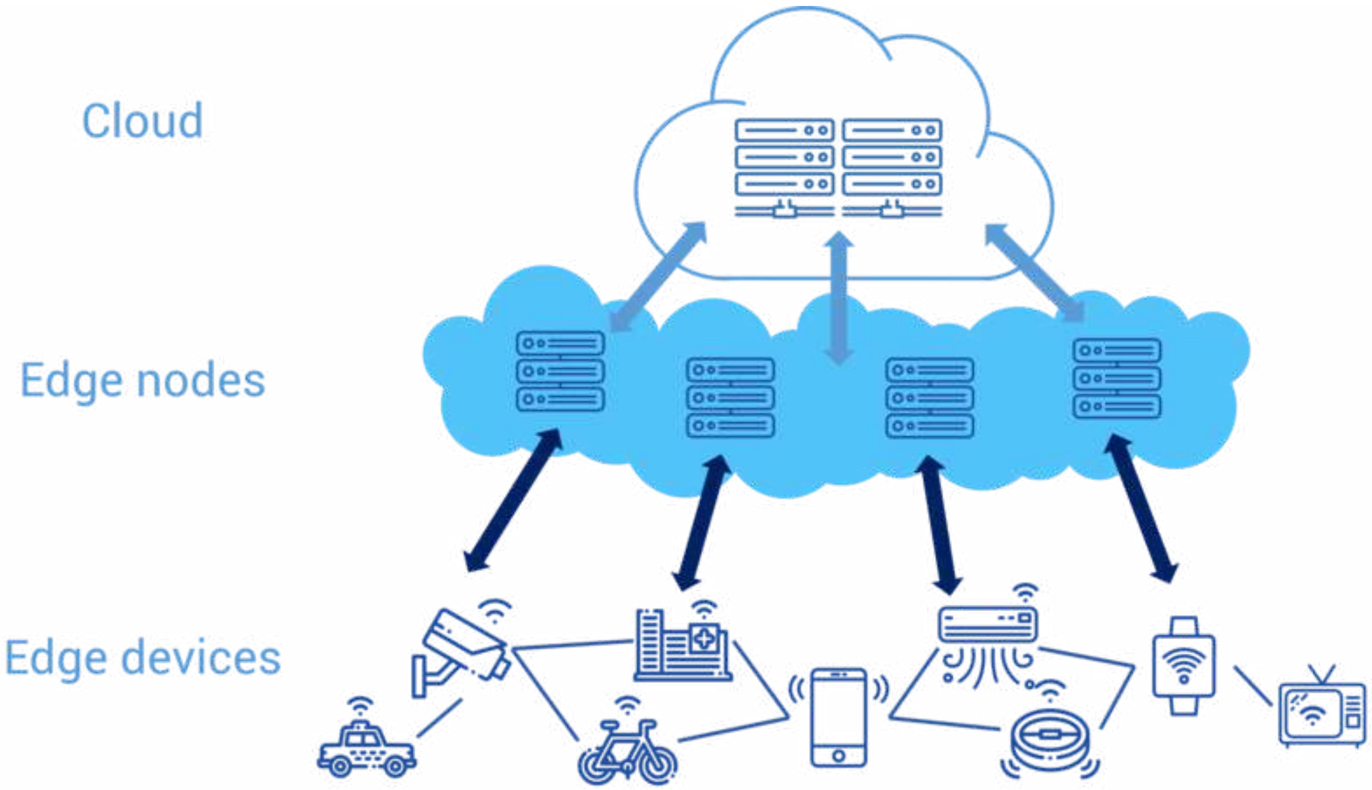
Conditions matter – sun and clean roads, snow, rain, …



Excerpt from Veoneer video: https://youtu.be/d6d38b-G2NI

Distributed control, cloud computing, and communication

- Distributed computations — possibly important to handle the large amounts of computations needed to realize an autonomous system
- Low-latency communication over cellular network — 5G Distributed control
- Cloud and edge computing
- Cybersecurity



Autonomous vehicles

Autonomous flight

- Autonomous flight is, in many aspects, easier than autonomous driving
  - Air-space is free-space
  - No (almost) other vehicles
- Autopilot has been around for a long time, the first cross-atlantic automated flight already in 1947
- Control more complex
- Drones; extremely agile and there is extensive knowledge how to control them
- Therefore, in this lecture I will spend a little more time on ground vehicles

Robot-Piloted Plane Makes Safe Crossing of Atlantic

No Hand on Controls From Newfoundland to Oxfordshire—Take-Off, Flight and Landing Are Fully Automatic

By ANTHONY LEVIERO

Special to THE NEW YORK TIMES.

WASHINGTON, Sept. 22 — A Douglas C-54 Skymaster with a mechanical brain landed without human aid near London today after a robot directed hop from Newfoundland.

The revolutionary flight across the Atlantic, effected by the push of the button, was hailed by Air Force leaders as a feat with vast new possibilities for war and peace.

The robot Skymaster, only one of its kind in the world, lifted itself off the field at Stephenville, Newfoundland, at 5 P. M. Eastern standard time, yesterday. This morning, 10 hours and 15 minutes later, the Skymaster eased itself onto the field at Brise Norton, forty miles west of London. The ship had flown 2,400 miles.

Fourteen crew men and observers were aboard the unique plane, but not once was it necessary for any of them to take a control or to intervene in any way with the mechanically prescribed course.

Delicate instruments, which did not falter, guided the ship. Air Force spokesmen said. Two ships somewhere in the Atlantic furnished bearings to the Skymaster's brain. She had 3,700 gallons of fuel aboard.

Great Britain several weeks ago had asked as a favor that the Air Force send the Skymaster there to make demonstration flights for Royal Air Force technicians. Thereupon, according to an official announcement, the Air Force decided to make the transatlantic flight itself without human control, if possible.

The plane was rolled out at Stephenville. The pilot, Col. James M. Gillespie of Wilmington, Ohio, chief of the All-Weather Flying Division, and the other passengers climbed aboard. The Skymaster was pointed to its distant goal. Its brain was adjusted for the task. On the field someone pushed a button.

The plane taxied down the field at maximum power, became airborne, and at 800 feet the brain

Continued on Page 2, Column 3

Fig. 2 *New York Times*, Sept. 23, 1947.

McRuer, Duane, and Dunstan Graham. "*Eighty years of flight control-Triumphs and pitfalls of the systems approach*." Journal of Guidance and Control 4.4 (1981): 353-362.

Where are we now?

- I've borrowed to this introduction from a plenary talk from the June 2020 IFAC World Congress (IFAC - International Federation of Automatic Control)
- "*Reflections on the Learning-to-Control Renaissance*" — highly recommended lecture by Benjamin Recht - UC Berkley
- Well spent 45 minutes

https://youtu.be/IEZFwh8sw8s

Where are we now?

Boston Dynamics

ETH Zürich

Waymo, Tesla, …

Why is this so difficult in practice?

- Uncertainty, robustness, humans, …
- Worlds like Go, chess follow simple rules (although succeeding in these games is certainly not simple …).
  - Closed-world assumption holds true.
- CWA not true for real driving/flying environments; Anything can happen
- Modeling the real world is difficult; significant model errors inevitable
- How do you ensure safety? Humans are fragile and unpredictable.

A main challenge

Introduce robustness, safety, and resilience in autonomous systems

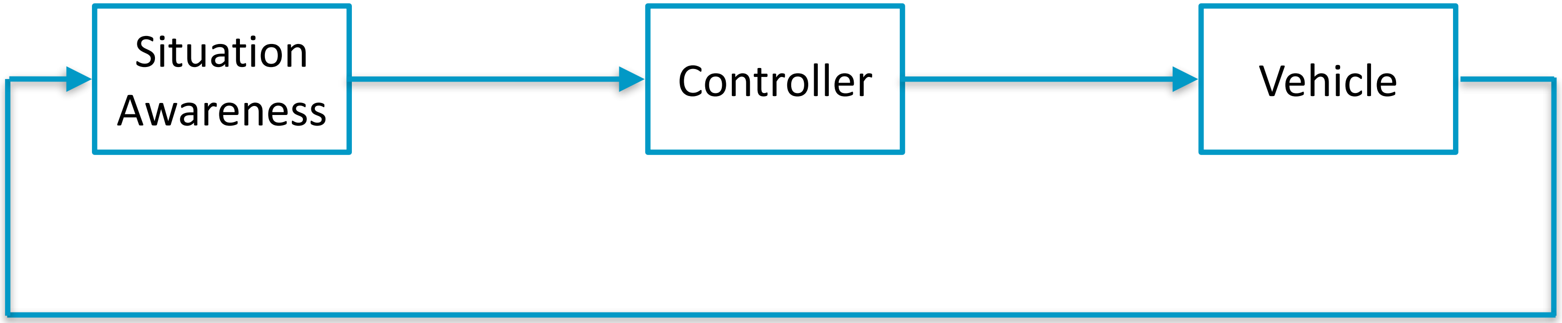
Excerpt from Tesla video:
https://youtu.be/tlThdr3O5Qo

The case for autonomy, some arguments

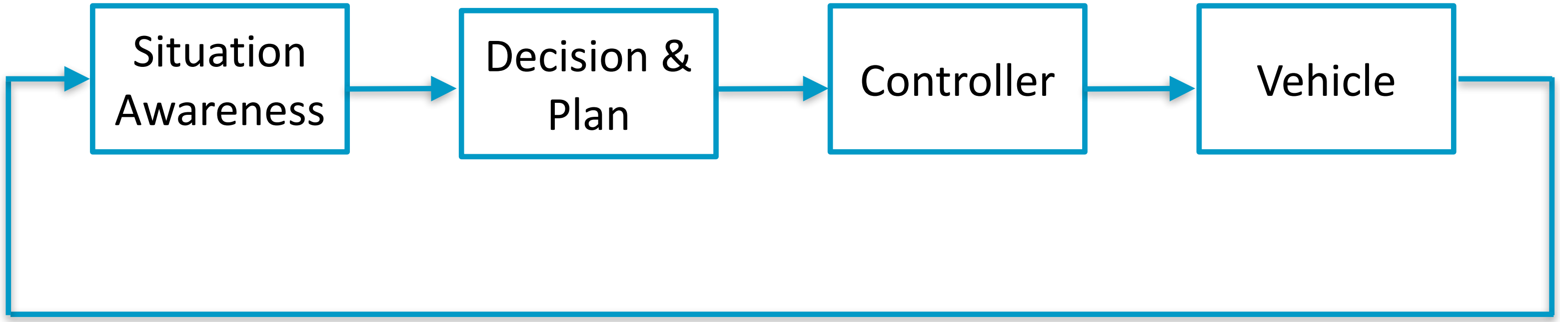
- Passenger cars
  - Safety
  - Increased traffic density
  - New services
- Something not as visible; but with strong commercial potential and a lower hanging fruit than automated taxis in Manhattan
  - Work sites
    - Automated wheel loaders
    - Automated mining vehicles
  - Transportation
    - Dedicated lanes
    - Limited scenarios compared to general driving

Reactive vs deliberate architectures

Reactive



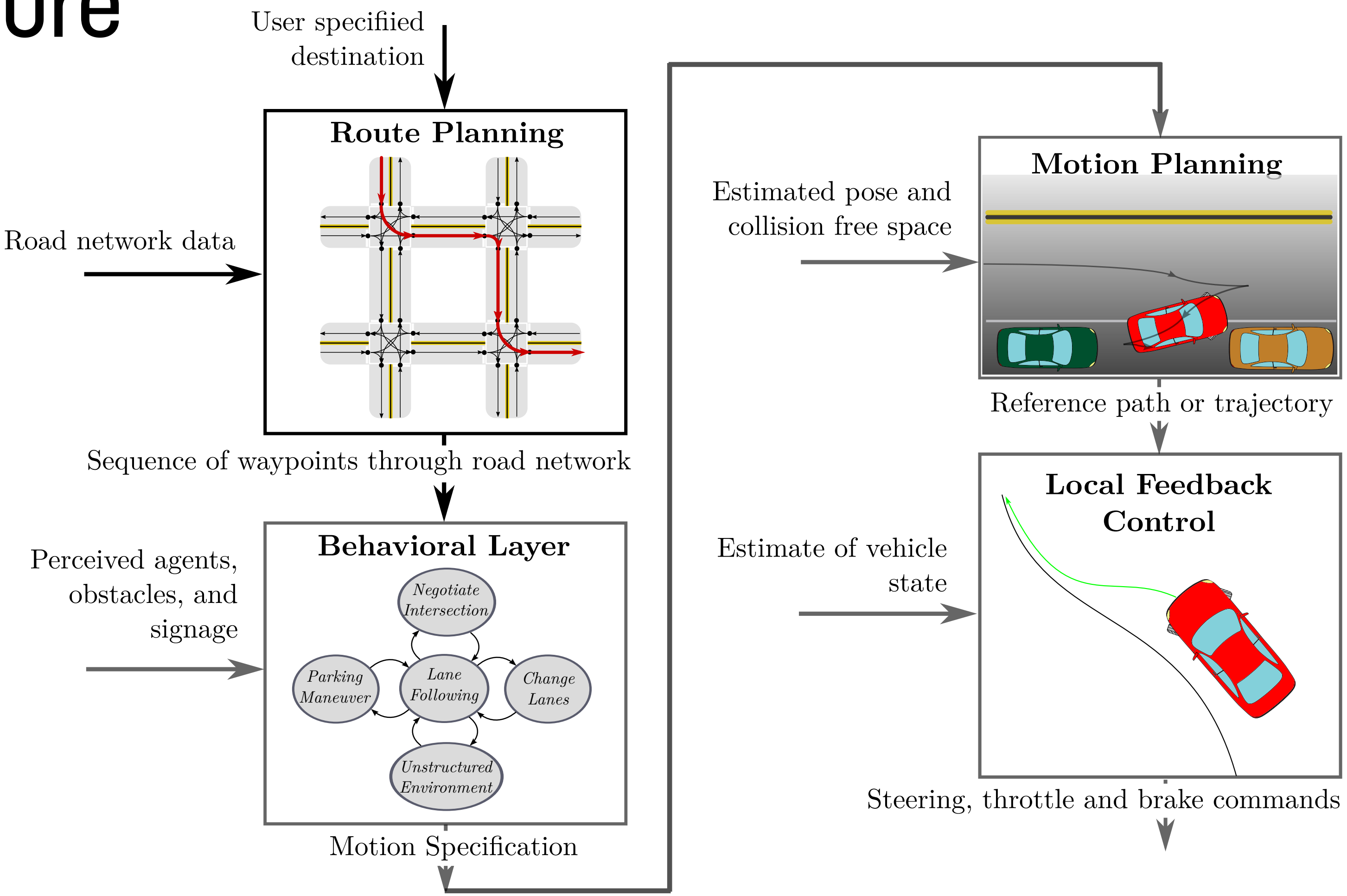
Deliberate



Control architecture

Perception
- Cameras
- Lidars
- Radars
- ...

Geographical Information Systems and Road Data



Control architecture from Paden et al., IEEE Trans. Intell. Vehicles, 1:1, 2016.

What about human drivers?

- There is a lot of research on human driver behavior
- Good to be aware when designing autonomous agents
- Not necessarily imitate

From: Michon, John A., 1985.

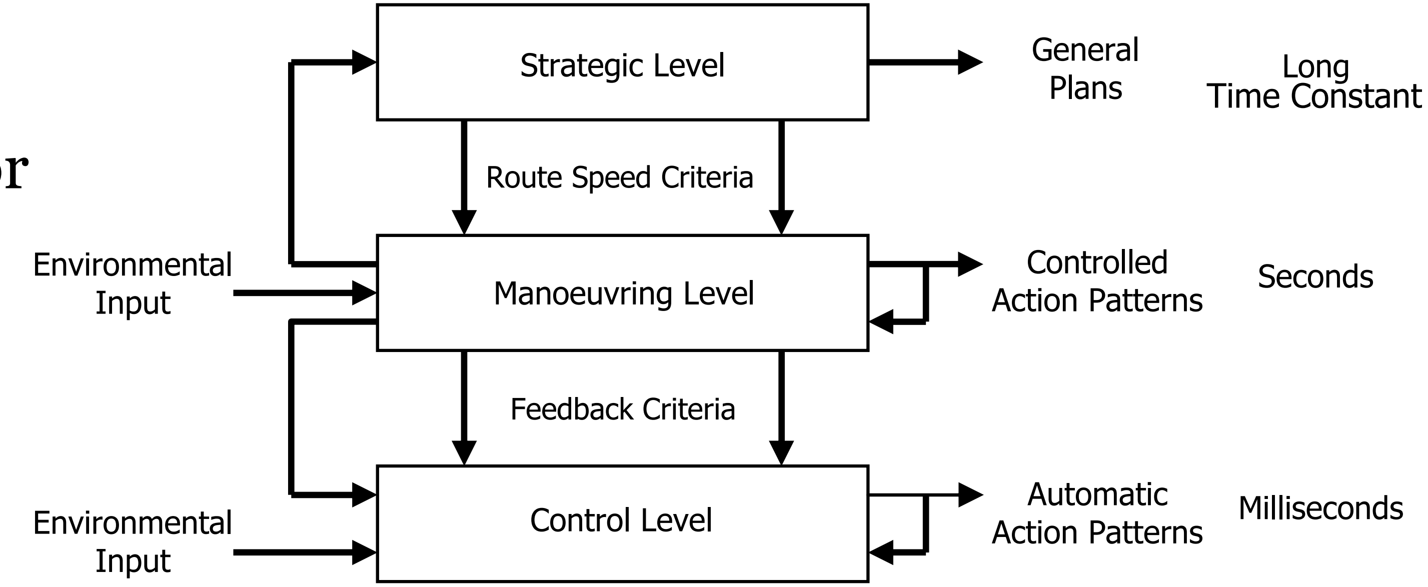


Figure 2 The hierarchical structure of the road user task. Performance is structured at three levels that are comparatively loosely coupled. Internal and external outputs are indicated (after Janssen, 1979).

- Reading material: Michon, John A. "*A critical view of driver behavior models: what do we know, what should we do*?." Human behavior and traffic safety. Springer, Boston, MA, 1985. 485-524. Link on git.

Levels of autonomy – (SAE J3016 standard)

SAE level	Name	Narrative definition	Execution of steering and acceleration/ deceleration	*Monitoring* of driving environment	Fallback performance of *dynamic driving task*	System capability *(driving modes)*
***Human driver* monitors the driving environment**						
0	**No automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	**Conditional automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task,* even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

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(Figure above from WASP Foresight 2018 - www.wasp-sweden.org)
SAE J3016. Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. Tech. rep., SAE International, 2016 (link on course git repository).

Where are we today?

- Hard to tell; many major car manufacturers have significant investments in the area and also non-automotive actors like Google/Waymo, Apple, Uber, Nvidia, …
- Several level 2 functions in production:
Tesla Autopilot, Volvo Pilot Assist, Mercedes-Benz Drive Pilot, Cadillac Super Cruise, …
- As an outsider, hard to know what is market positioning, PR, and what are solid products in the pipeline
    - Some manufacturers claim level 3 and even level 4 autonomy in products. A debate for another arena…
    - In this course, focus on fundamental methods
- Reading material: ”*National Highway and Traffic Safety Administration ODI on Tesla*” and some critique (opinion piece written by automotive industry analyst). Links on git-page.

Some main challenges for increased automation

- Safety — how to make this technology safe, and gain general trust
  - Recommended reading: U.S. Dept. of Transportation analysis of level 2 system (link on git)
- Cost — autonomy is expensive
- Level 3 — mixed responsibility is tricky

SAE level	Name	Narrative definition	Execution of steering and acceleration/ deceleration	*Monitoring* of driving environment	Fallback performance of *dynamic driving task*	System capability *(driving modes)*
3	**Conditional automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes

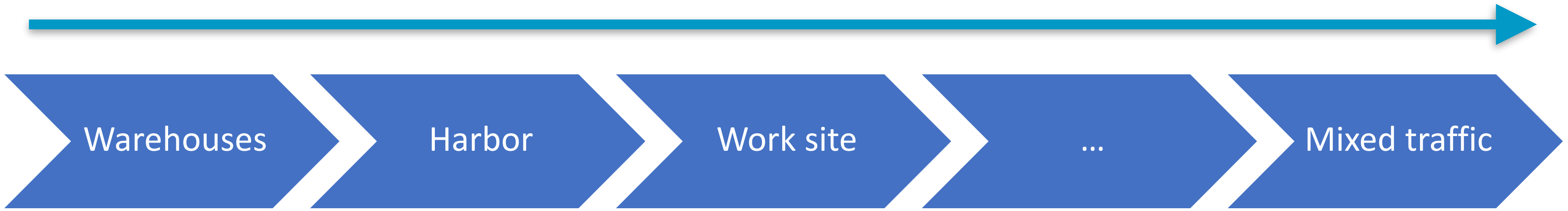
- Robust and reliable autonomous decision making

Some main challenges for increased automation

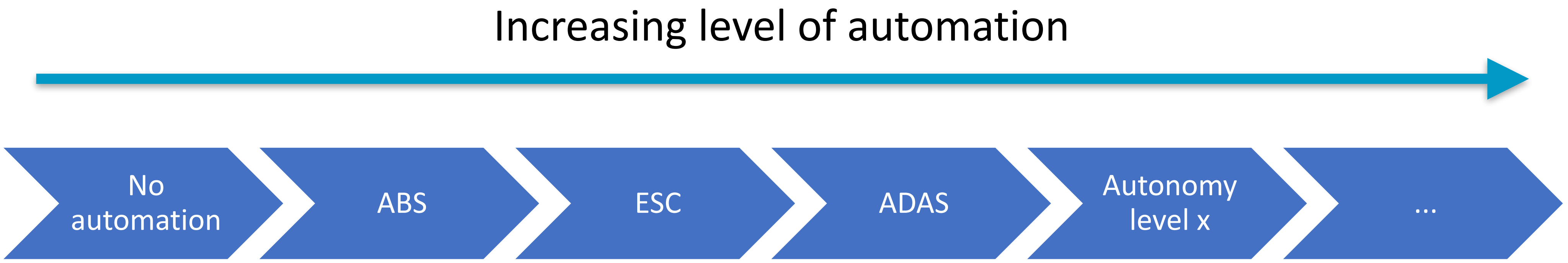
- Situation awareness is hard
  - robust and reliable vision and perception systems is an area of intensive development and research
  - Sensor reliability and cost
  - V2x - communication
    - Vehicle-to-vehicle
    - Vehicle-to-infrastructure
- Human in-the-loop
  - With human responsibility (level < 4), how ensure this? Many HMI-issues (see also discussion on this in NHTSA document)
  - Mixed initiative - a sliding scale of autonomy that may change during operation

Some main challenges for increased automation

- Verification and certification of machine-learning models
- Power consumption - those GPU cards and sensors do require significant power ~ say corresponding to an AC climate system (1.5 kW)
  - 2% fuel economy on a personal car
  - electric range will be significantly influenced
- Gradual scenario complexity



Autonomous cars - a gradual introduction

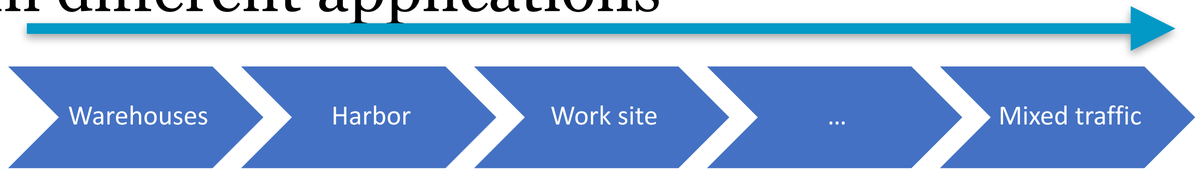


- ABS - Anti-lock Braking System,
- ESC - Electric Stability Control (sometimes referred to as ESP)
- ADAS - Advanced Driver Assistance Systems
  - Lane keeping
  - ACC - Adaptive Cruise Control
  - ….

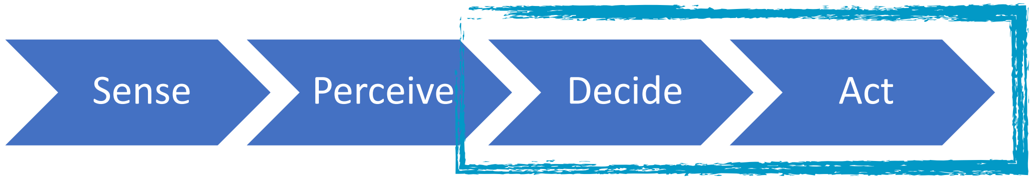
Summary

Summary of this lecture and what's next

- Autonomous systems — there is a larger context
  - Passenger cars, Transportation, Work sites, Aviation, Marine, …
  - Possibly large impact on business models and society
- Sliding scale of automation, with human-in-the-loop and HMI; gradual introduction of autonomy and in different applications



- This course; focus on planning and control of vehicles



- Perception, localization, computer vision, sensor fusion, communication, target tracking, …

Reading instructions

- “*Introduction to SLAM”*. Part E Chapter 46.1 in Siciliano, B., and Oussama K., eds. “Springer handbook of robotics”.
- "*National Highway and Traffic Safety Administration ODI on Tesla*”. Interesting text but there are parts that have met critique, see, e.g., NHTSA's Flawed Autopilot Safety Study Unmasked (opinion piece written by automotive industry analyst).
- Interesting discussion on “*The Artificial Intelligence podcast*” with Sertac Karaman (also author of material for lecture 4) on autonomous driving and flying.
- "*A critical view of driver behavior models: what do we know, what should we do?*" Michon, John A. Human behavior and traffic safety. Springer, Boston, MA, 1985. 485-524.
- "*Effects of driverless vehicles-Comparing simulations to get a broader picture*" A. Pernestål et al. European Journal of Transport & Infrastructure Research 19.1 (2019).

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