Spring 2019

Mobile Robots | **Introduction and Lecture Overview**

Autonomous Mobile Robots

https://online.ethz.ch/courses/course-v1:ETH+AMRx_FS2019+2019_T1/about

Roland Siegwart, Margarita Chli**,** Nick Lawrance

Autonomous mobile robot | your teachers

Roland Siegwart, ETH Zurich

Margarita Chli, ETH Zurich

Nick Lawrance ETH Zurich

Video segments

Marco Hutter, ETH Zurich

Davide Scaramuzza, Univ. of Zürich

Paul Furgale, Facebook Oculus Zurich

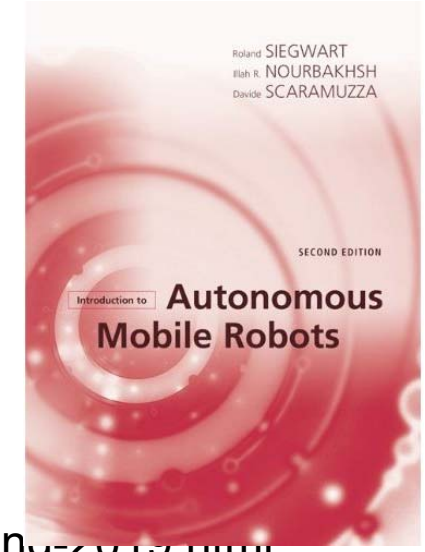
Martin Rufli, IBM Research

Autonomous mobile robot | about the course

https://online.ethz.ch/courses/course-v1:ETH+AMRx_FS2019+2019_T1/about

- Running as an ETH-internal MOOC (Massive Open Online Course)
  - Over 30 short video lectures that we call “segments”.
  - The “segments” are complemented with:
    - short questions for each segment to verify your understanding and progress
    - various exercises (problem sets)
    - videos showing the current state-of-the-art in the field
  - Please register
    https://online.ethz.ch/courses/course-v1:ETH+AMRx_FS2019+2019_T1/about
- Textbook
  „Introduction to Autonomous Mobile Robots“
  Roland Siegwart, Illah Nourbakhsh, Davide Scaramuzza, The MIT Press

On sale in LEE J206 for CHF 45



- Other materials
  - http://www.asl.ethz.ch/education/lectures/autonomous_mobile_robots/spring-2019.html

The Lecture

- We expect you to view and study the following elements beforehand:
  - **video segment**
  - **relevant AMR book chapters**
  - **problem sets and quizzes**
- Lecture on Tuesday 10:15 – 12:00 in NO C 60
  - We want your active participation!!
  - Video Segments will not be repeated
  - Focus on putting the learnt content into context
    - Questions from students (in forum until Friday before the related lecture)
    - go over difficult problems
    - go a bit more in detail where needed (e.g. proofs of theorems, etc.)
- Exercises on Tuesday 14:15 – 16:00 in CAB G 11 (around every second week)
  - Special exercises only supported for ETH students

Lecture Program

ETH Master Course
Autonomous Mobile Robots - 151-0854-00L

ETH zürich

Agenda Spring 2019
Lecture: *Weekly on Tuesday 10.15 - 12.00, NO C 60*
Exercises: *Approximately every second week, Tuesday 14.15 - 16.00, CAB G 11*
MOOC: https://online.ethz.ch/courses/course-v1:ETH+AMRx_FS2019+2019_T1/about

Responsable MOOC:
Margarita Grinvald <margarita.grinvald@mavt.ethz.ch>; Michel Breyer <michel.breyer@mavt.ethz.ch>

Week #	Date	Topic	Lecture segment names	Lecturer	Online release date and problem set	Number worked exercises	Problem set (yes/no)	Problem set due date
1.	19.02.2019	Introduction and Motivation	Introduction and Lecture Overview	Roland Siegwart	13.02.2019			
2.	26.02.2019	Locomotion Concepts	Introduction to Legged Robotics Basics of Rigid Body Kinematics Application of Rigid Body Kinematics (optional) *Worked Exercise 1 & 2 (optional)* Example of Wheeled, legged and Flying Robots (lecture)	Marco Hutter	20.02.2019	2	optional	02.03.2019
Ex1	26.02.2019	Introduction to V-Rep simulator		In Kyu Sa, Karen Bodie	20.02.2019			
3.	05.03.2019	Mobile Robots Kinematics	Introduction to Wheeled Locomotion Differential Kinematics Wheeled Kinematics *Worked Exercise*	Roland Siegwart	27.02.2019	1	yes	09.03.2019
4.	12.03.2019	Perception I (to 4.3)	Sensors IMU GPS Motion Capture systems Laser range finder *RGBD/time-of-flight/sonar*	Roland Siegwart	06.03.2019		no	
5.	19.03.2019	Perception II (to 4.4)	Camera Image Formation, Perspective Projection Introduction to Computer Vision Omnidirectional Projection, Camera Calibration, Unified Model Stereo Vision *Worked Example: Structure from Motion*	Margarita Chli	13.03.2019		yes	23.03.2019
Ex2	19.03.2019	Kinematics and Control of a differential drive vehicle		Anurag Vempati, Max Brunner	13.03.2019			
6.	26.03.2019	Perception III: Image Saliency (to 4.5)	Correlation and Convolution Edges and Points *Worked Example on Image Filtering*	Margarita Chli	20.03.2019	1	yes	30.03.2019
7.	02.04.2019	Perception IV: Place Recognition & Line Fitting (to 4.5)	Place Recognition The Error Propagation Law Line Extraction	Margarita Chli	27.03.2019		yes	06.04.2019
Ex3	02.04.2019	Line extraction		Hermann Blum, Lukas Bernreiter	27.03.2019			
Quiz 1		Quiz 1		Margarita Grinvald, Michel Breyer	02.04.2019			16.04.2019
8.	09.04.2019	Localization I (to 5.2)	Introduction to Map-Based Localization Refresher on Probability Theory	R. Siegwart	03.04.2019		yes	13.04.2019
9.	16.04.2019	Localization II	The Markov Approach The Kalman Filter Approach	R. Siegwart	10.04.2019		yes	20.04.2019
Ex4	16.04.2019	Line-based Extended Kalman Filter		Hermann Blum, Lukas Bernreiter	10.04.2019			
	23.04.2019	Week off - Easter Holiday						
10.	30.04.2019	SLAM I	The SLAM problem	M. Chli	24.04.2019		no	
11.	07.05.2019	SLAM II	Monocular SLAM and beyond *Worked Example on SLAM*	M. Chli	01.05.2019	1	yes	11.05.2019
Ex5	07.05.2019	EKF SLAM		Thomas Schneider, Florian Tschopp	01.05.2019			
12.	14.05.2019	Planning I (to 6.2)	Introduction Collision Avoidance Potential Field Methods *Worked Example on Harmonic Potential Fields*	Nick Lawrance	08.05.2019	1	yes	18.05.2019
13.	21.05.2019	Planning II (to 6.3)	Graph Construction Graph Search *Worked Example on A**	Nick Lawrance	15.05.2019	1	yes	25.05.2019
Ex6	21.05.2019	Dijkstra's algorithm and the dynamic window		Daniel Dugas, Rik Bähnemann	15.05.2019			
Quiz 2		Quiz 2		Margarita Grinvald, Michel Breyer	21.05.2019			04.06.2019
14.	28.05.2019	Summary	Summary	Roland Siegwart	22.05.2019		no	

Exam

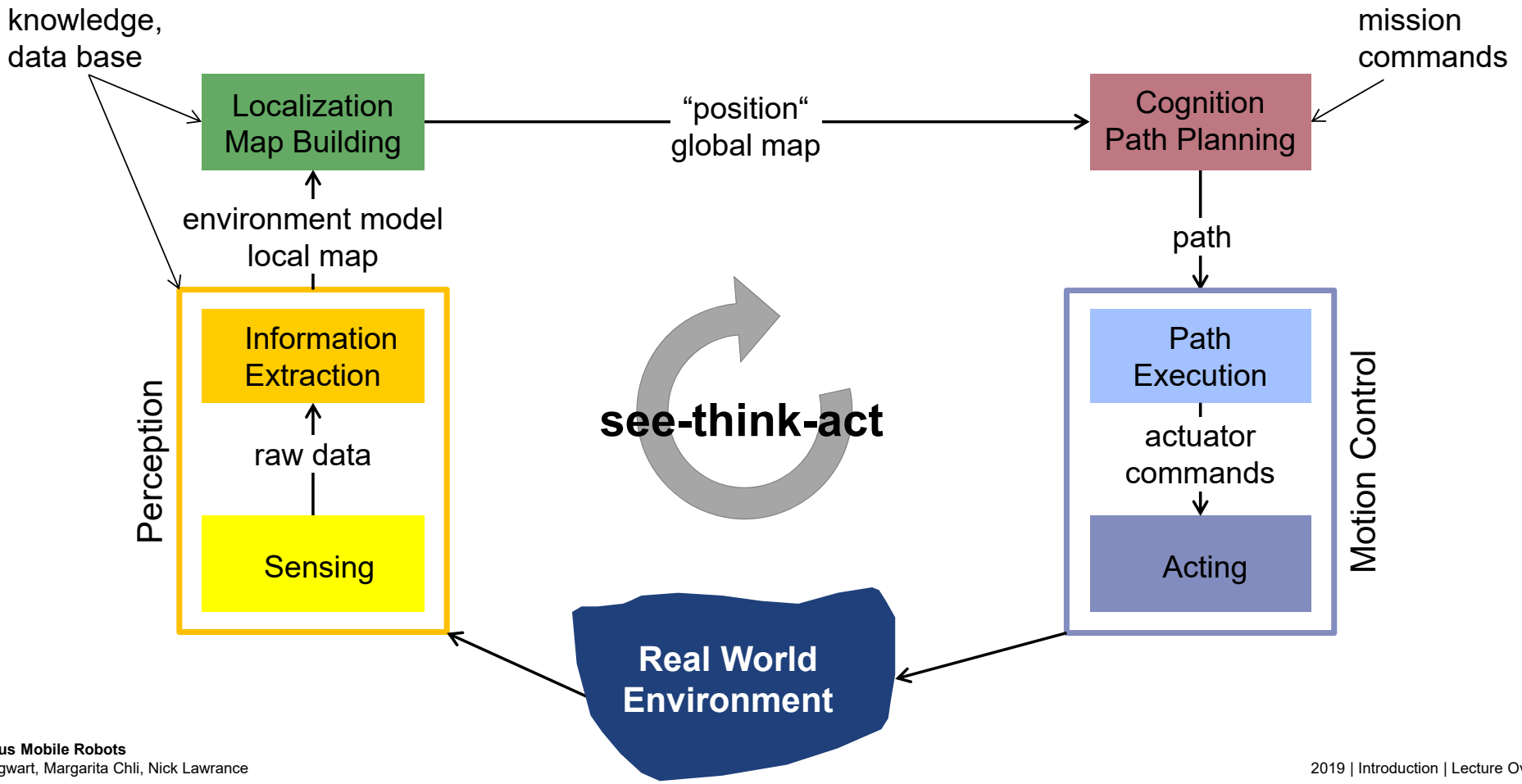
- Type
  - Written session examination
- Language of examination
  - English
- Course attendance confirmation required
  - No
- Repetition
  - The performance assessment is only offered in the session after the course unit. Repetition only possible after re-enrolling.
- Mode of examination
  - Multiple Choice and comprehension questions
  - Calculations, similar to exercises, but simpler and solvable without computer
- Written aids
  - 4 A4-pages personal summary

Autonomous mobile robot | the key questions

- The three key questions in Mobile Robotics
  - Where am I ?
  - Where am I going ?
  - How do I get there ?

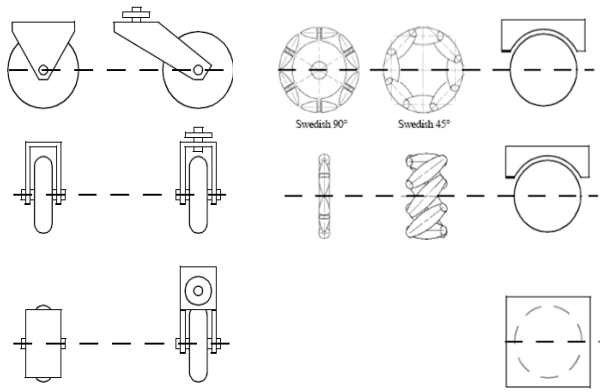
- To answer these questions the robot has to
  - have a model of the environment (given or autonomously built)
  - perceive and analyze the environment
  - find its position/situation within the environment
  - plan and execute the movement

Autonomous mobile robot | the see-think-act cycle



Motion Control | kinematics and motion control

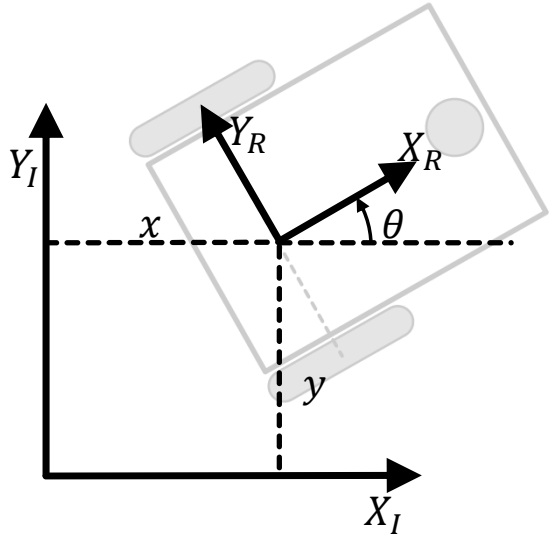
- Wheel types and its constraints
  - Rolling constraint
  - no-sliding constraint (lateral)



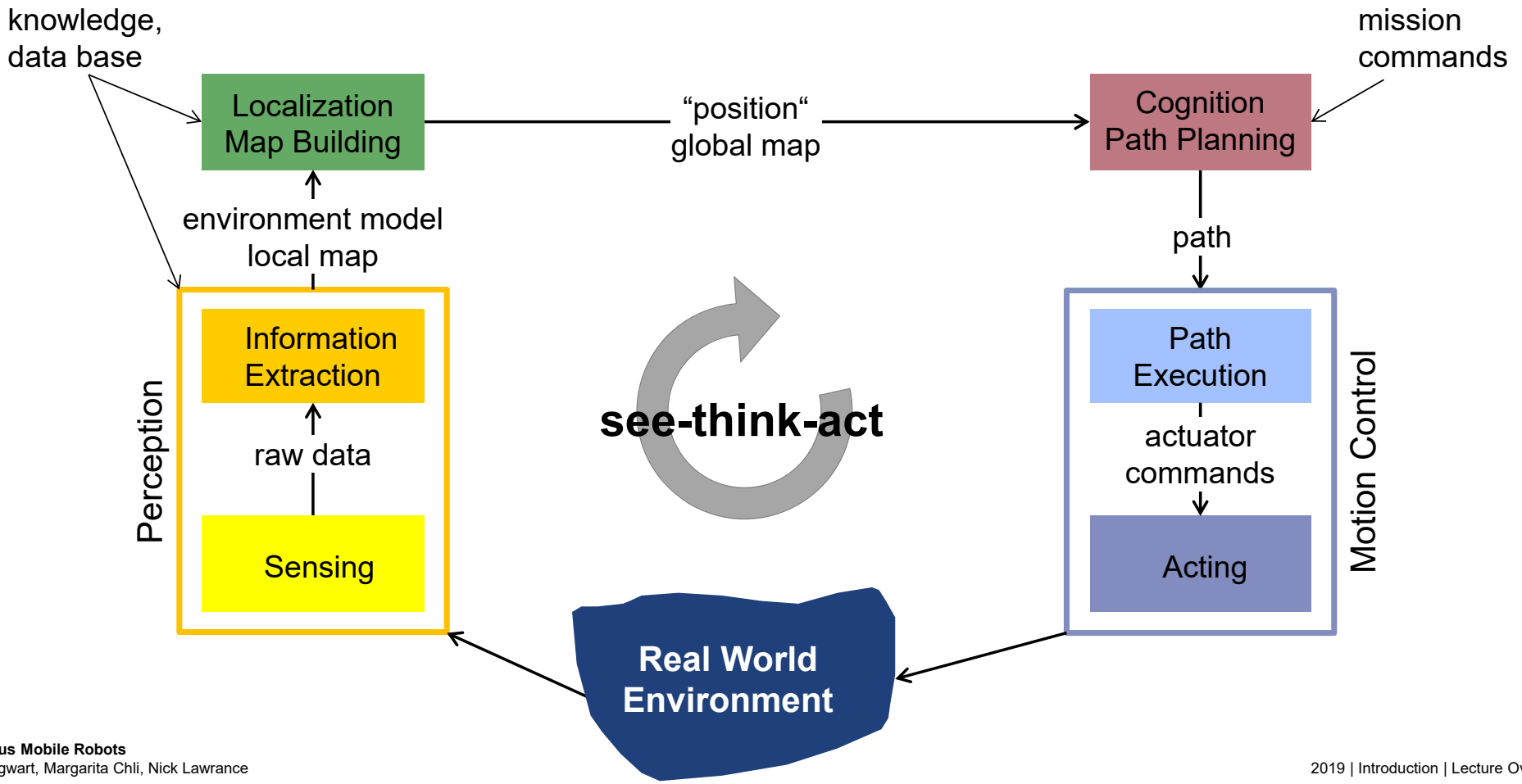
- Motion control

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = f(\dot{\varphi}_1 \cdots \dot{\varphi}_n, \theta, geometry)$$

$$\begin{bmatrix} \dot{\varphi}_1 \\ \vdots \\ \dot{\varphi}_n \end{bmatrix} = f(\dot{x}, \dot{y}, \dot{\theta}) \quad ?$$

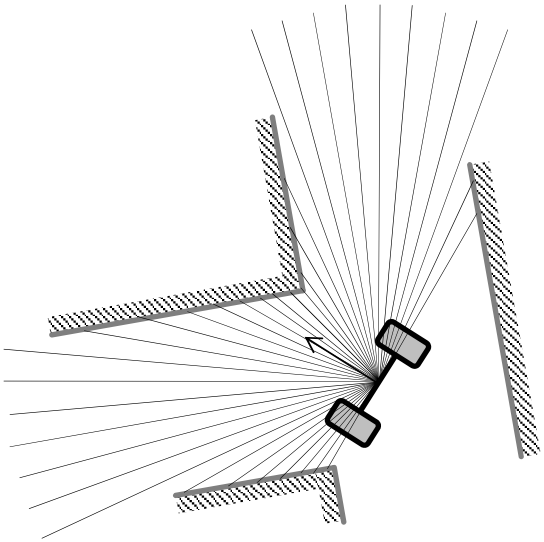


Autonomous mobile robot | the see-think-act cycle

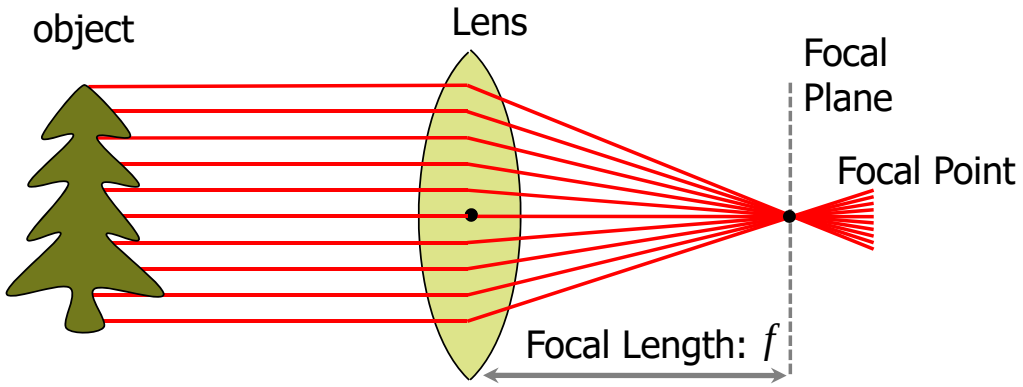


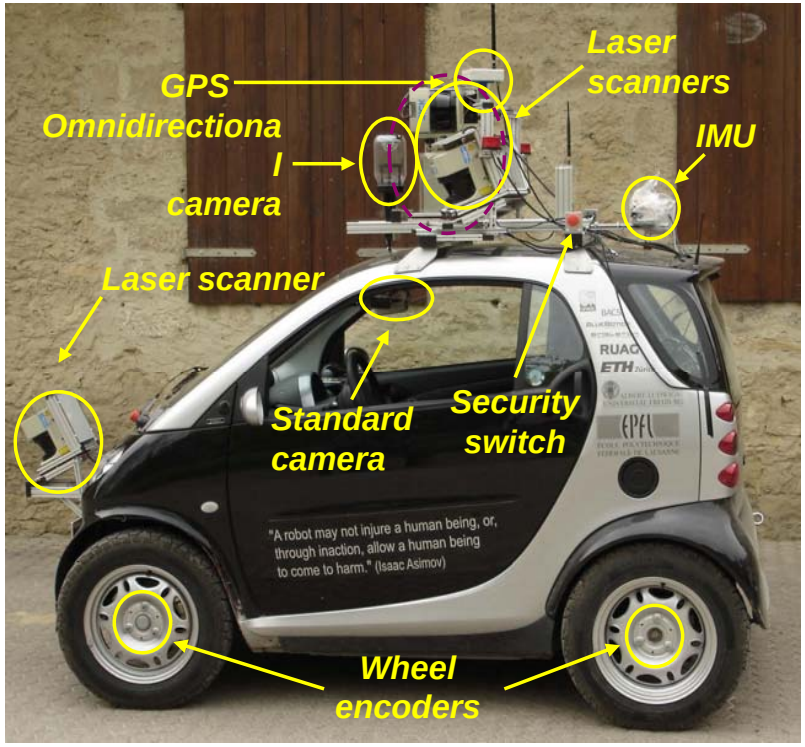
Perception | sensing

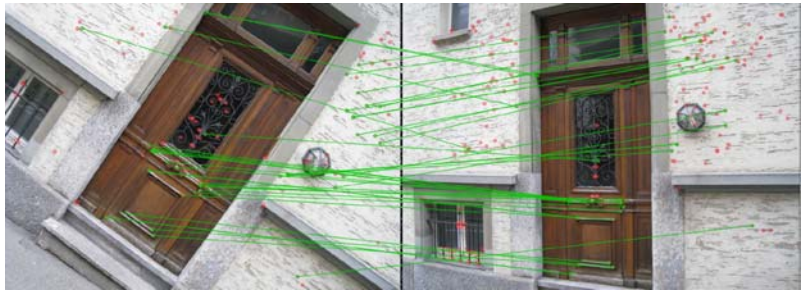
- Laser scanner
  - time of flight



- Camera

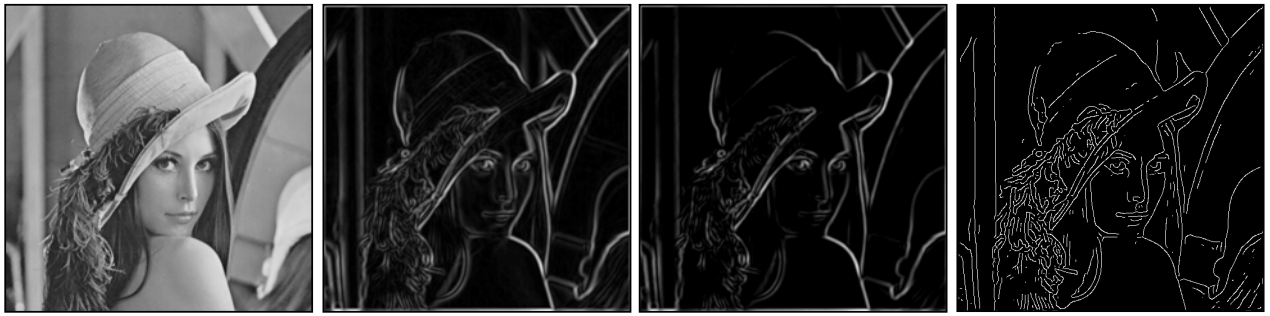






https://www.youtube.com/watch?v=yvgPrZNp4So

Perception | information extraction



- Filtering / Edge Detection

- Keypoint Features
  - features that are reasonably invariant to rotation, scaling, viewpoint, illumination
  - FAST, SURF, SIFT, BRISK, …

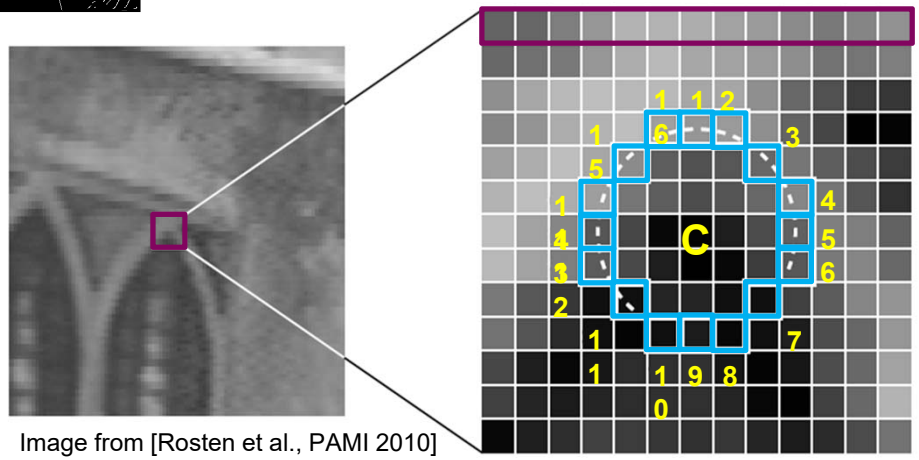


Image from [Rosten et al., PAMI 2010]

- Keypoint matching
  - BRISK example

Virtual and Augmented Reality (VR / AR) on your Smartphone

RosieReality

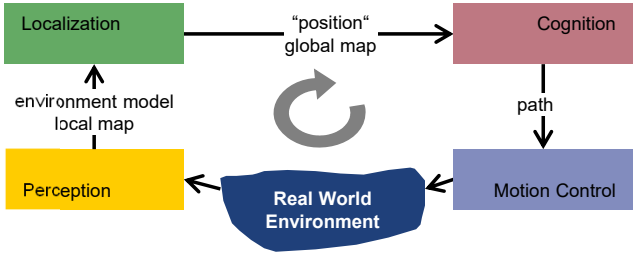
Spinoff ETH zürich

Collaborative Visual-Inertial Navigation | *teach and repeat*

Google Project Tango

https://www.youtube.com/watch?v=pDIQXsOrgI4

From Perception to Understanding



Fusing & Compressing Information

Places / Situations
A specific room, a meeting situation, …

Servicing / Reasoning

- Functional / Contextual Relationships of Objects
  - imposed
  - learned
  - spatial / temporal/semantic

Objects
Doors, Humans, Coke bottle, car , …

Interaction

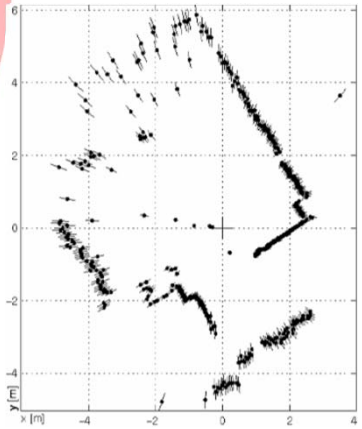
- Models / Semantics
  - imposed
  - learned

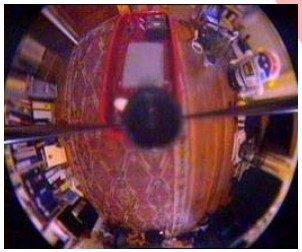
Features
Lines, Contours, Colors, Phonemes, …

Navigation

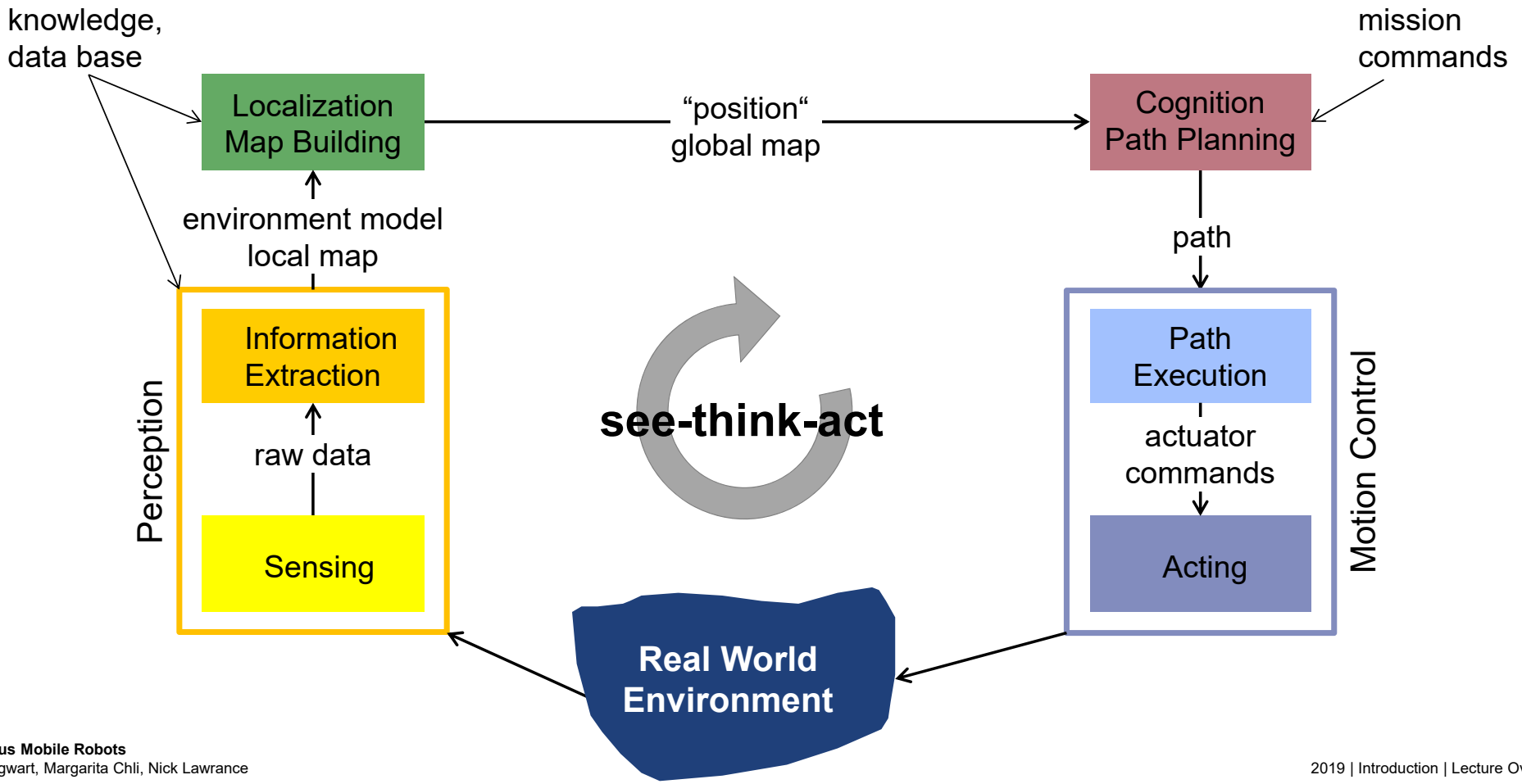
- Models
  - imposed
  - learned

Raw Data
Vision, Laser, Sound, Smell, …



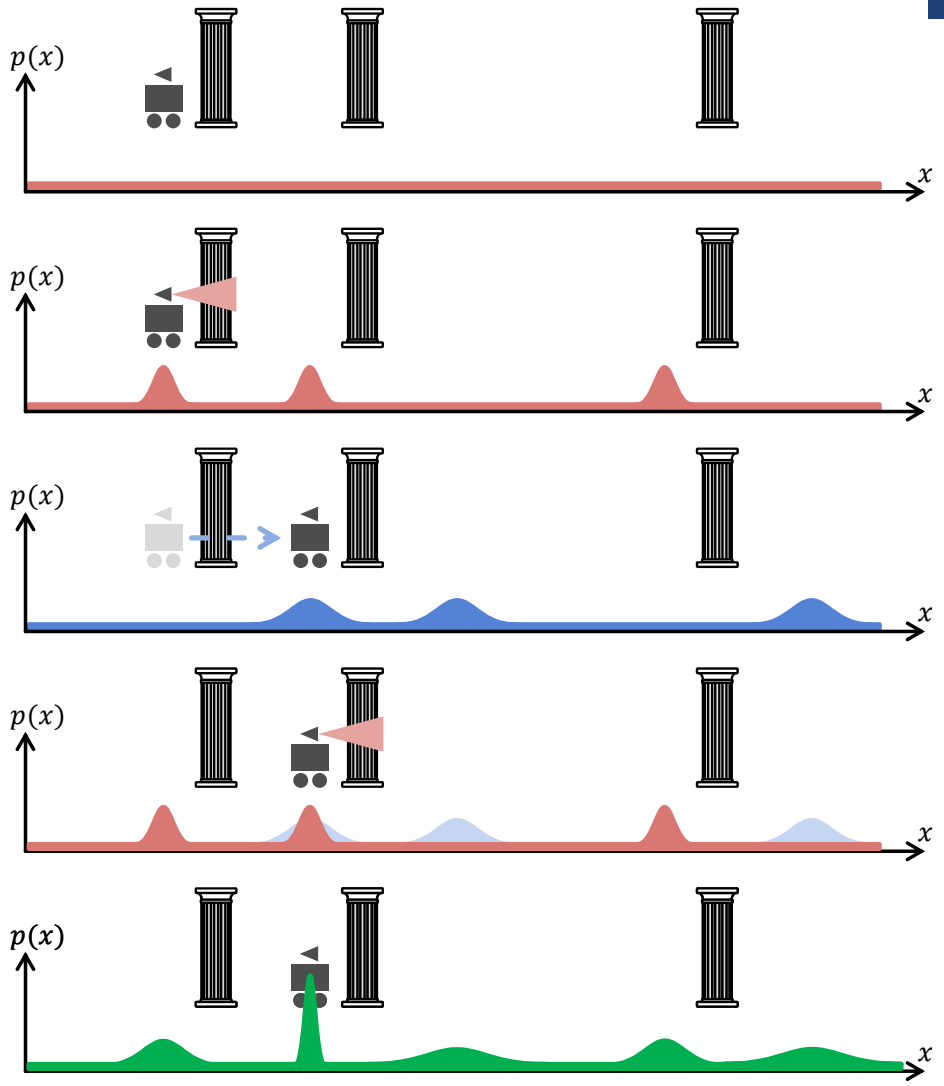


Autonomous mobile robot | the see-think-act cycle

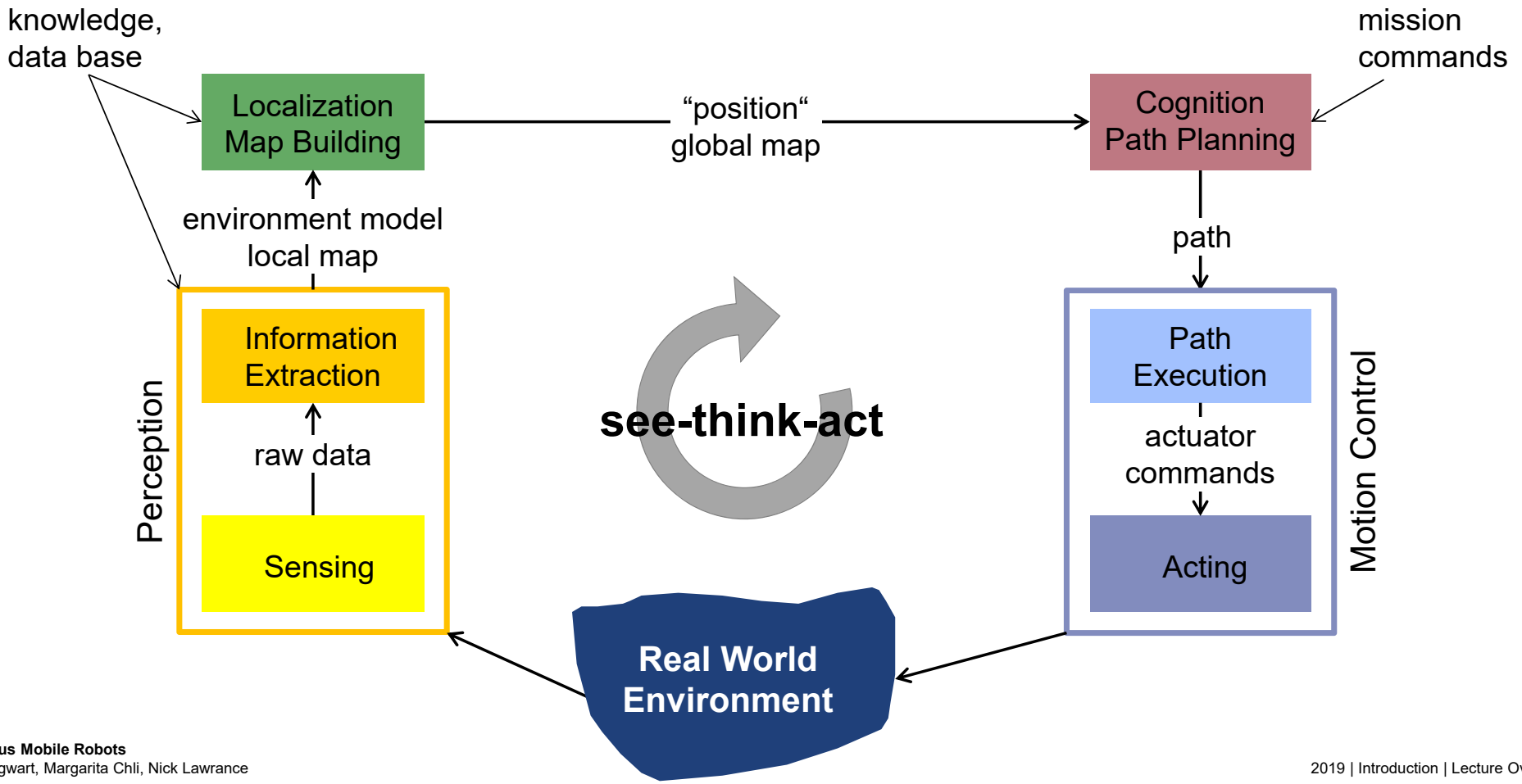


Localization | where am I?

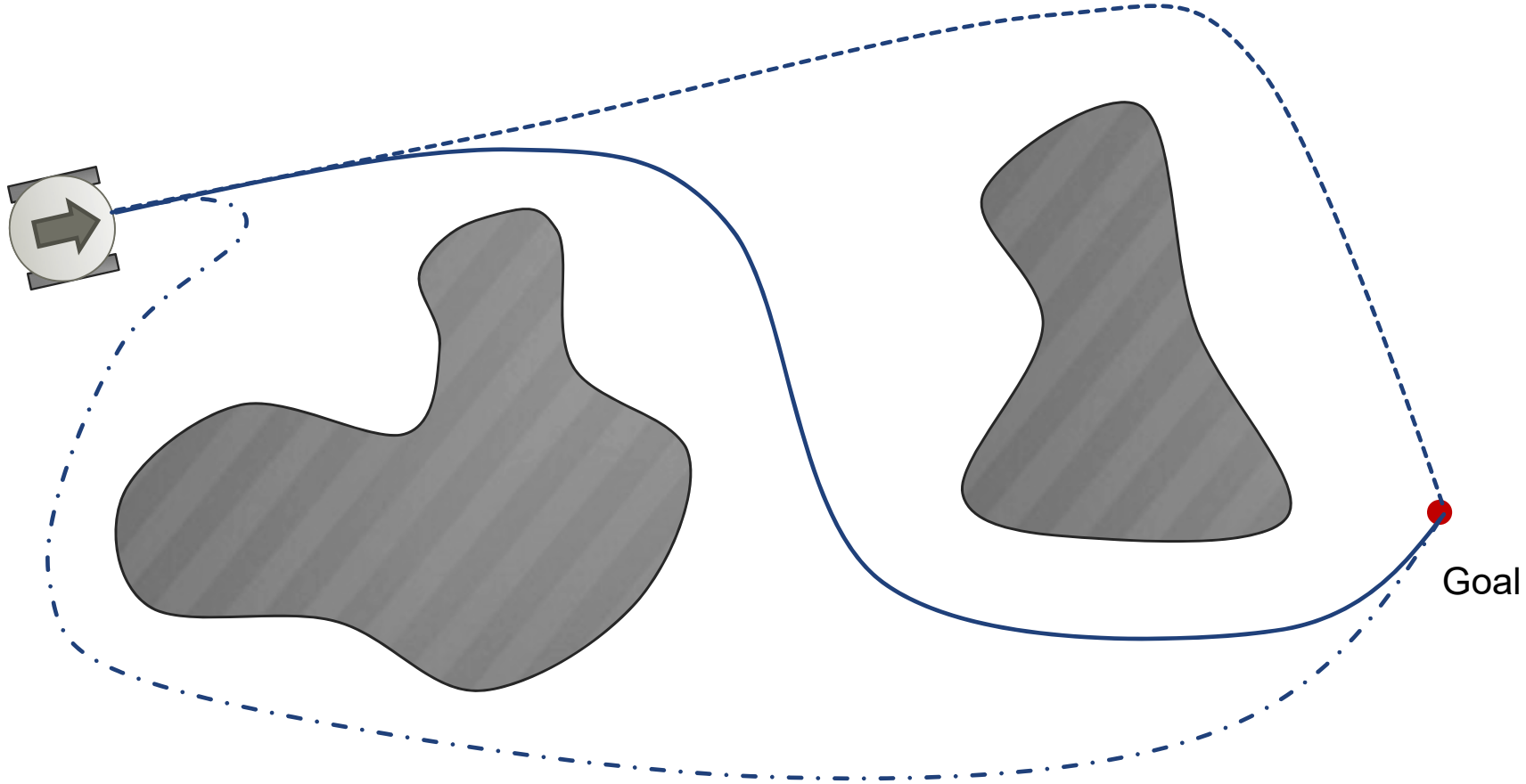
- SEE: The robot queries its sensors → finds itself next to a pillar
- ACT: Robot moves one meter forward
  - motion estimated by wheel encoders
  - accumulation of uncertainty
- SEE: The robot queries its sensors again → finds itself next to a pillar
- Belief update (information fusion)



Autonomous mobile robot | the see-think-act cycle

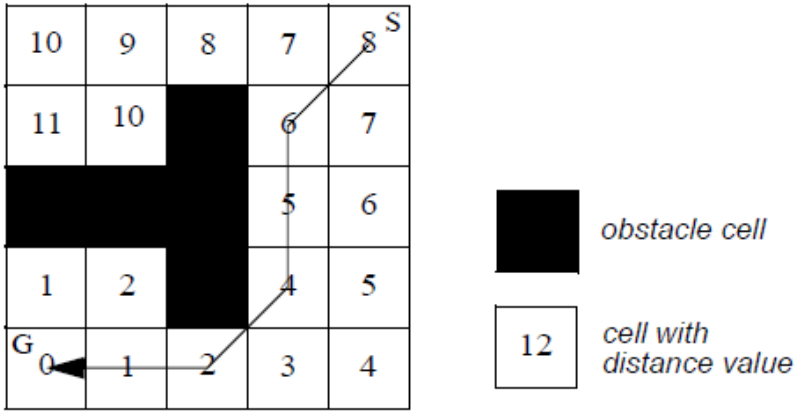


Cognition | Where am I going ? How do I get there ?

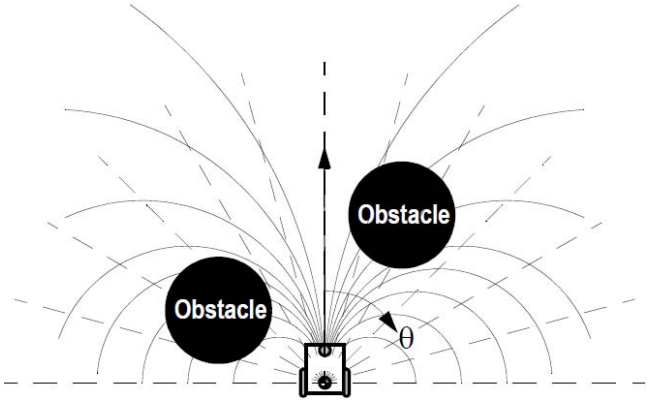


Cognition | Where am I going ? How do I get there ?

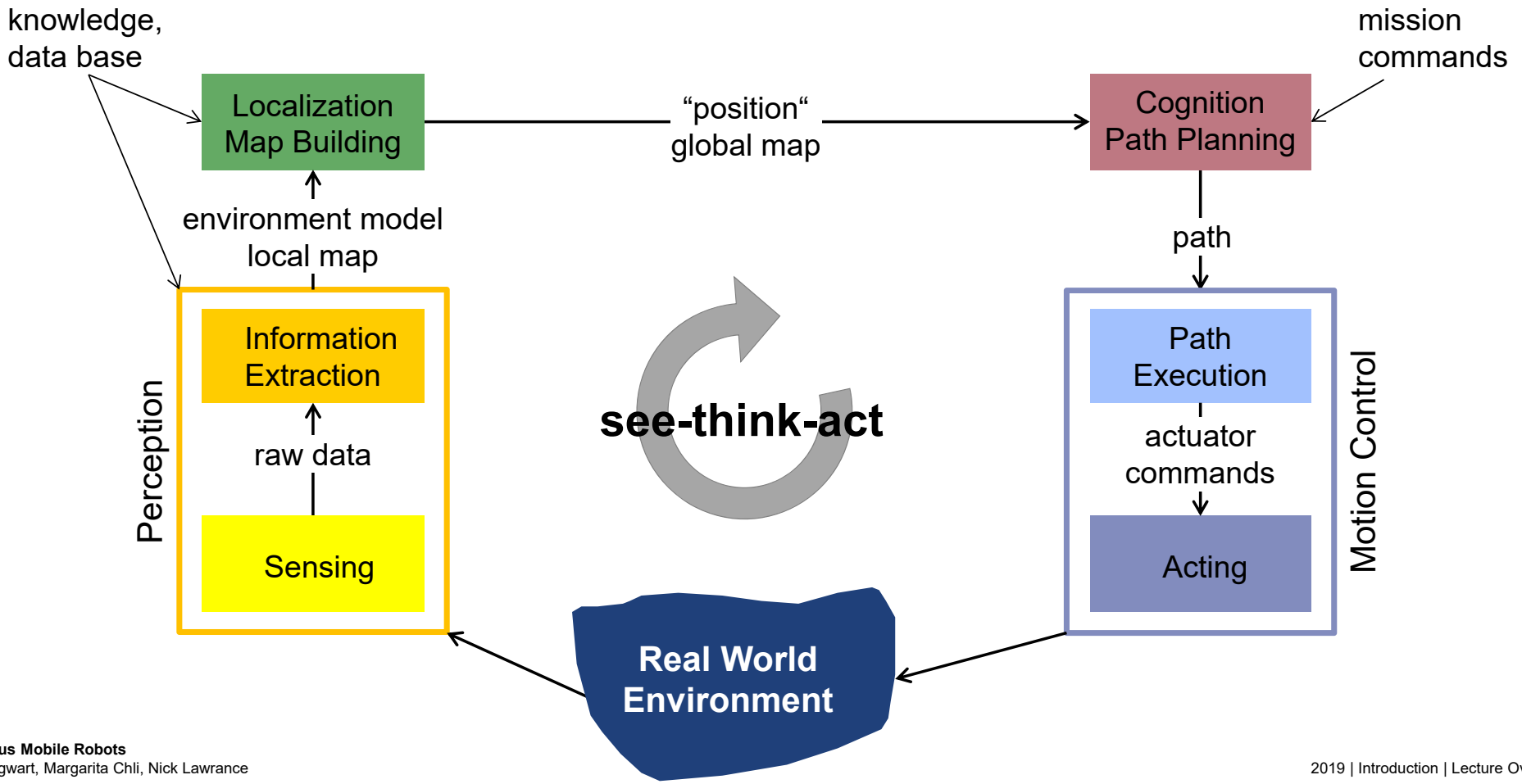
- Global path planning
  - Graph search



- Local path planning
  - Local collision avoidance

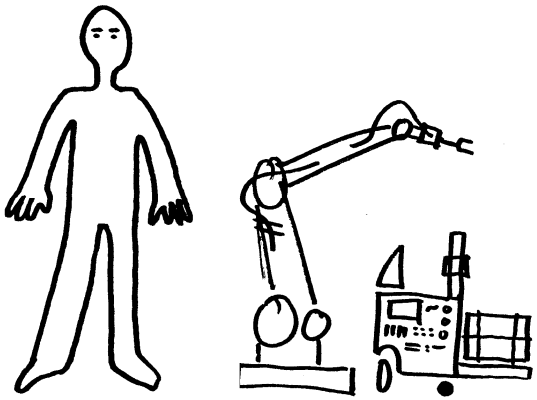


Autonomous mobile robot | the see-think-act cycle

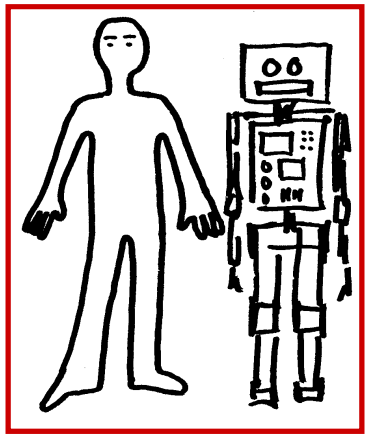


Next generation of Robots

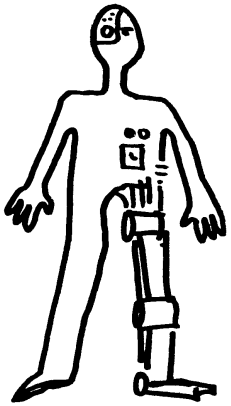
| mobile, smart, connected, adaptive and closer to humans



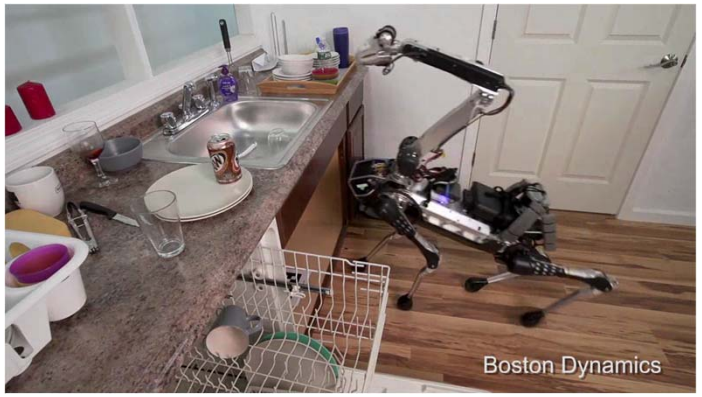
Industrial Robots



Service Robots



Cyborgs



Robotics | challenges and technology drivers

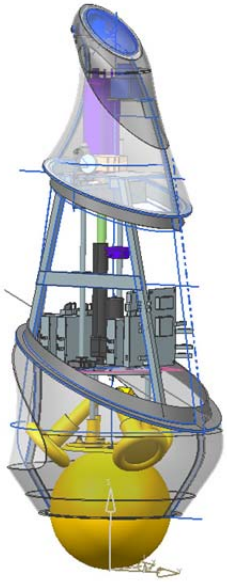
- The challenges
  - ***Seeing***, ***feeling*** and ***understanding*** the world
  - Dealing with ***uncertain*** and ***partially available*** information
  - ***Act*** appropriately onto the environment

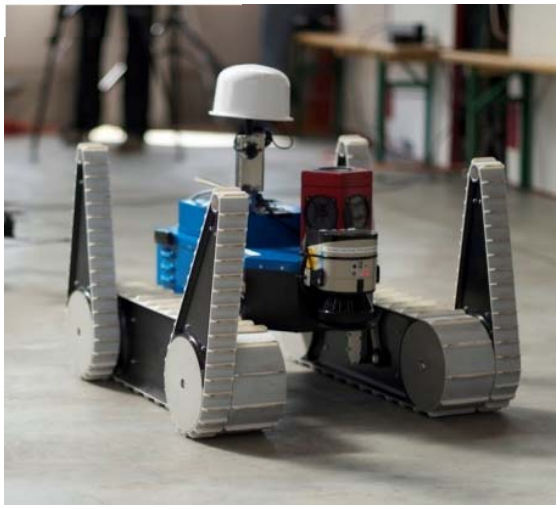
Willow Garage

- Technology drivers
  | *technology evolutions enable robotics revolutions*
  - Laser time-of-flight sensors
  - Cameras and IMUs combined with required calculation power
  - Torque controlled motors, “soft” actuation
  - New materials

Autonomous Mobile Robots | Some recent examples

Examples – not part of MOOC Video Segment



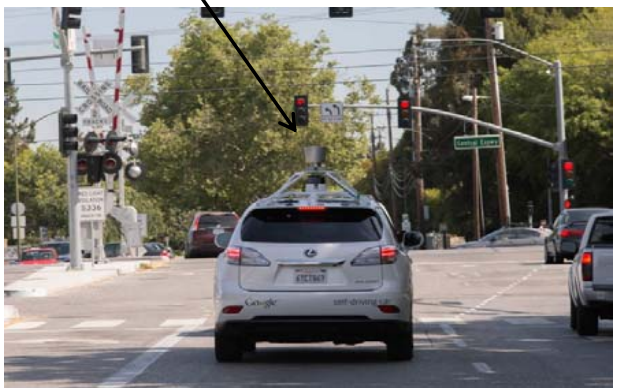


Autonomous mobile robot | we invite you to join the course

https://www.youtube.com/watch?time_continue=4&v=M4CQ7VW7iZ0

Today | 3D laser sensors

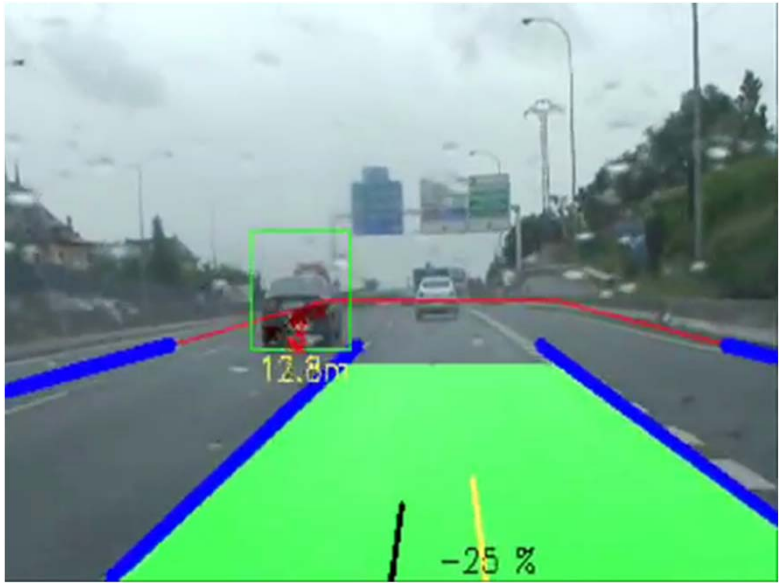
Expensive, complex and cumbersome



- Google Self-Driving Car Project (status summer 2015)
  - > 20 vehicles in use
  - > 2,7 mio km, 1.5 mio km in autonomous mode
  - > 11 accidents
    - No people insured
    - Non of them caused by car control algorithm

https://www.youtube.com/watch?v=eJCR2TaeSFc

Today | cameras (lane tracking, …)

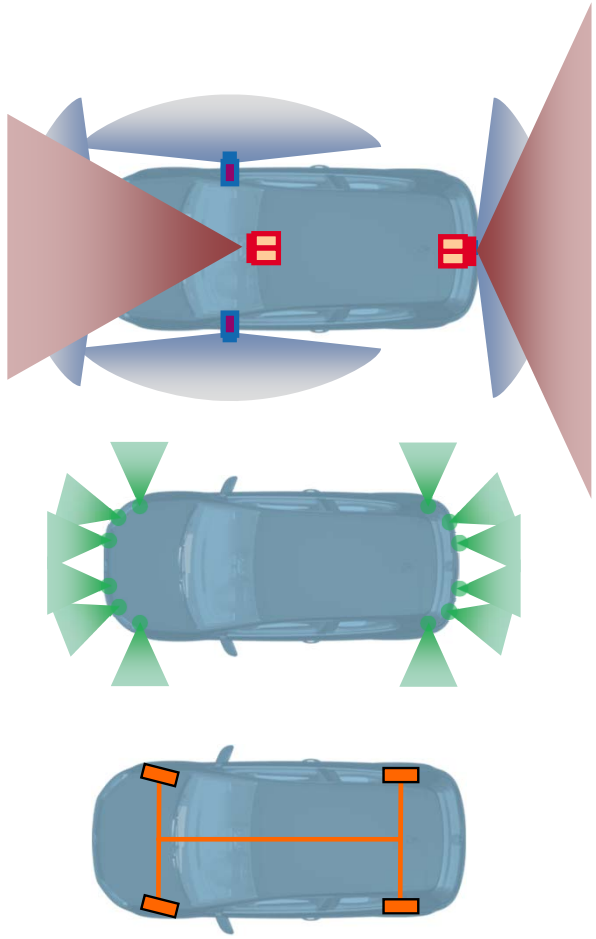


https://www.youtube.com/watch?v=JmxDIuCIIcg

https://www.youtube.com/watch?v=aGW4nRzx8Iw

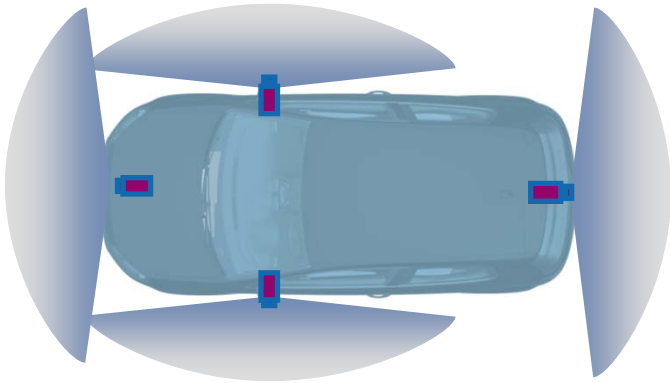
- Detection and tracking of
  - Lanes
  - Street signs
  - Other cars
  -

V-Charge | Automonous driving using close-to-market sensors



ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich
UNIVERSITY OF OXFORD
Technische Universität Braunschweig
VOLKSWAGEN AKTIENGESELLSCHAFT
UNIVERSITÀ DEGLI STUDI DI PARMA
BOSCH

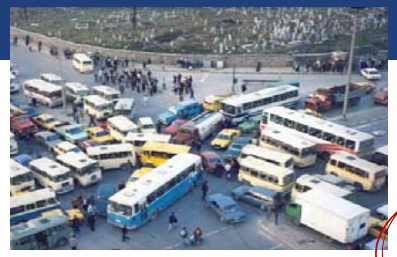
V-Charge | Autonomous driving using close-to-market sensors



Typical Situation

V-Charge Review 2 | **Driving Demo**

Autonomous Cars | roadmap



Fully autonomous Car
(you can sleep)

Autonomous car freeway

Interaction / negotiation between traffic participants

increasing complexity /understanding

learning and adaptation

Autonomous car urban

Driving Speed

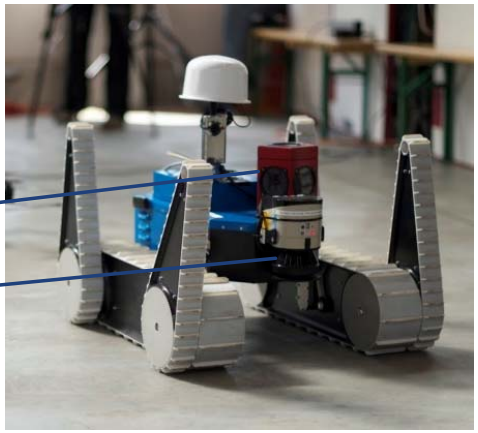
Complexity of Environment → Perception and Interaction

V-Charge | the ultimate vision

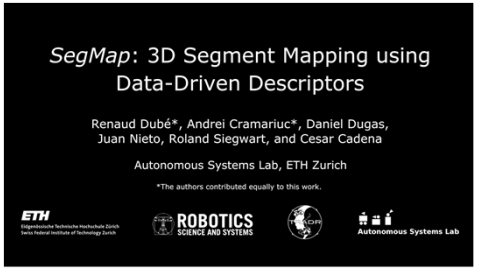
- Mixed-traffic scenarios

NIFTi / TRADR – Urban Search and Rescuing

- Project goals
  - Robotic help for Urban Search and Rescue
  - UGV and UAV combined for scene exploration
  - Yearly evaluation of system by firemen



- Environment modeling
  - Online 3D mapping from laser sensor
  - Based on enhanced ICP released open-source
  - Topological segmentation for human-robot interaction



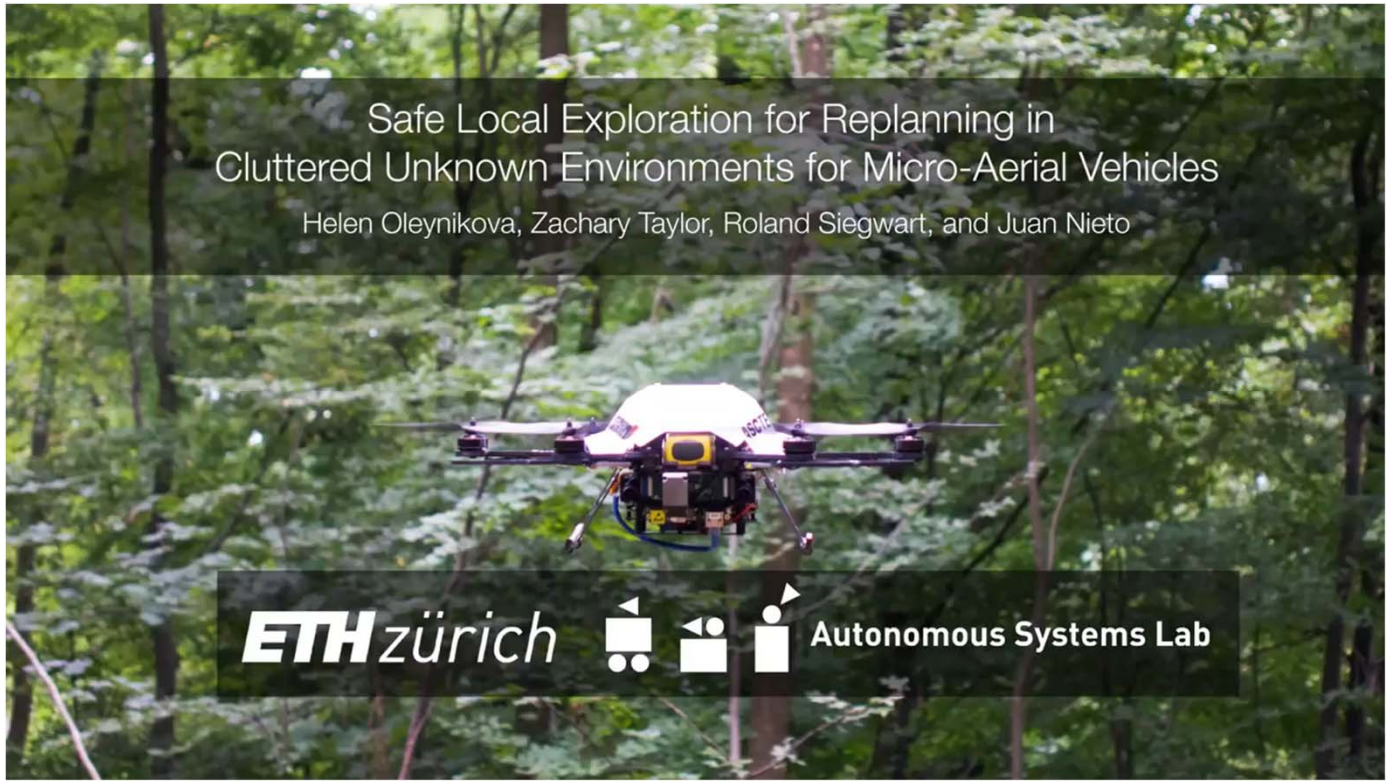
https://www.youtube.com/watch?v=CMk4w4eRobg

Vision only UAV navigation

www.sfly.ethz.ch/

- Swarm of small helicopters
  - Vision only navigation (one camera, GPS denied)
  - Fully autonomous with on-board computing
  - Feature based visual SLAM

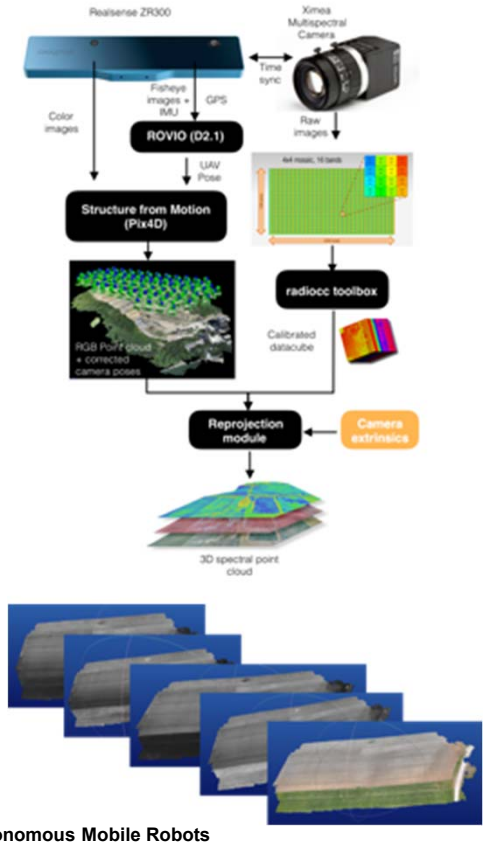
Navigation & Planning in Cluttered Environments



https://www.youtube.com/watch?v=rAJwD2kr7c0

Flourish – Aerial Data Collection and Analysis, and Automated Ground Intervention for Precision Farming

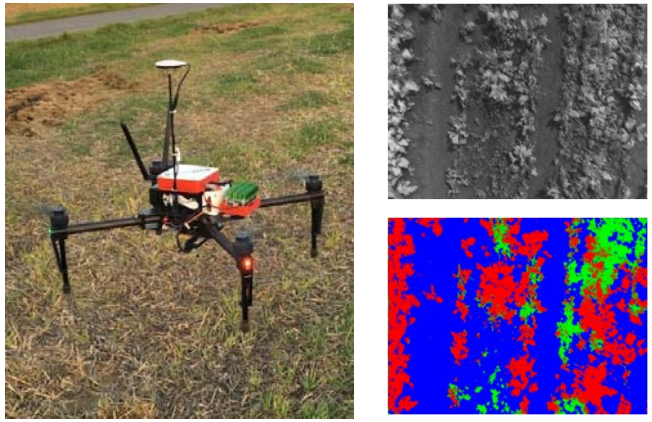
Spatio-Temporal Spectral Environment Modeling



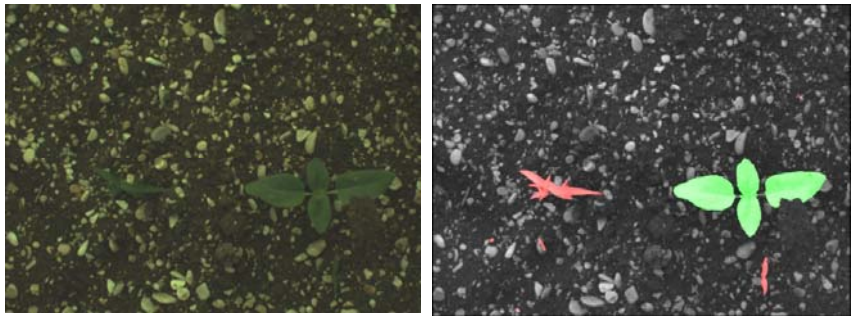
https://youtu.be/5f1EtfW76Qc

Autonomous UAV landing

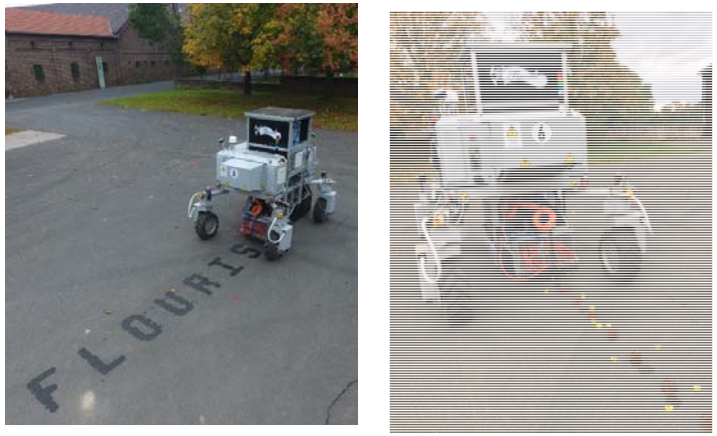
UAV onboard weed detection



Weed classification on UGV (Sunflower ~95% acc.)



Automated spraying and stamping



Collaborative Visual-Inertial Navigation

in collaboration with

RSL Robotic Systems Lab

Prof. Marco Hutter

https://www.youtube.com/watch?v=9PprNdIKRaw

Beyond Mobility | PR2 robot from Willow Garage

Fold towels https://www.youtube.com/watch?v=gy5g33S0Gzo

Courtesy of Willow Garage

Clean-up

ETH Zurich | a melting pot for **robotics, systems and control**

Artificial Intelligence

Joachim Buhmann
Machine Learning Lab

Andreas Krause
Learning and Adaptive Systems

Otmar Hilliges
Advanced Interactive Technologies Lab

Autonomous Robots

Roland Siegwart
Autonomous Systems Lab

Margarita Chli
Vision for Robotics Lab

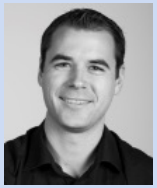
Marc Pollefeys
Computer Vision and Geometry Lab

Computer Vision

Luc van Gool
Computer Vision Laboratory

Stelian Coros
Computational Robotics Lab

Marco Hutter
Robotic Systems Lab



Raffaello D'Andrea
Dynamic Systems and Control

Medical /Biomedical Robotics

Roger Gassert
Rehabilitation Engineering Lab

Simone Schürle
Responsive Biomedical Systems Lab

Walter Karlen
Mobile Health Systems Lab

Brad Nelson
Multi-Scale Robotics Lab

Robert Riener
Sensor Motor Systems Lab

Emilio Frazzoli
Information and Decision Systems

Maryam Kamgarpour
Automatic Control Lab

Melanie Zeilinger
Intelligent Control Systems

Automation and Control

Roy Smith
Automatic Control Lab

Florian Dörfler
Automatic Control Lab

John Lygeros
Automatic Control Lab

Autonomous Mobile Robots
Roland Siegwart, Margarita Chli, Nick Lawrance

Switzerland | a melting pot for robotics technology