Autonomous and Mobile Robotics

Prof. Giuseppe Oriolo

Introduction:
Applications, Problems, Architectures

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Automatica e Gestionale Antonio Ruberti

Sapienza
Università di Roma

practical information

- course timetable 2023/24: 26 Sept-21 Dec 2023, Mon&Tue 10-12, Thu 9-11, room B2
- 6 ECTS credits, 60 hrs
- office hours: Thu 14:00-16:00 (by appointment only, room A211 or Zoom)
- e-mail oriolo@diag.uniroma1.it
- AMR website www.diag.uniroma1.it/~oriolo/amr/
- Google Group: AMR_GG

audience

- students of the Master in Artificial Intelligence and Robotics (MARR) and of the Master in Control Engineering (MCER)

teaching

- mixed style: blackboard + companion slides vs. slides

grading

- *Midterm Test (50%) + Final Project (50%) (for MT top grades)*
- midterm test (50%) + final test (50%) *(for those who pass MT)*
- conventional exam

theses

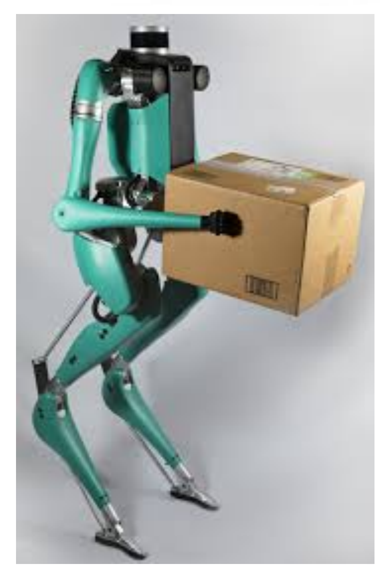
- Master Theses on the topics studied in this course are available at the DIAG Robotics Lab

course objective

- to master the basic planning and control methods for achieving mobility and autonomy in mobile robots
- …in principle, everything mobile!






outline of this lecture

- why mobile robots
- applications of mobile robots
- gallery
- the key problems of mobile robotics
- autonomy
- a basic underlying functionality: perception
- deliberative architecture
- other architectures

why mobile robots

- industrial fixed-base robots are fast and accurate in a limited, structured, known, static workspace

- to be useful in the outside world, robots must be able to move freely in large, unstructured, uncertain, dynamic environments

applications of mobile robots

structured environments
(service robots)

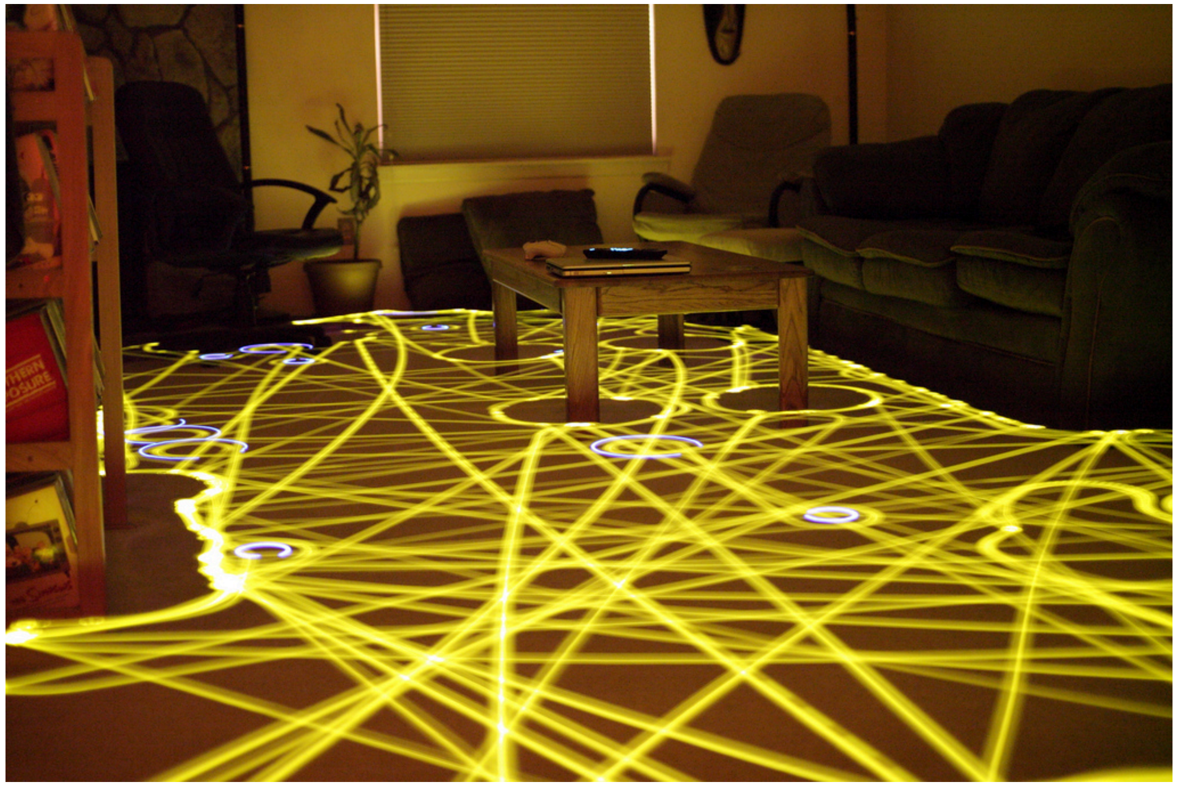
- transportation (industry, logistics)
- cleaning (homes, large buildings, cities)
- customer assistance (museums, shops)
- surveillance
- entertainment

unstructured environments
(field robots)

- exploration (sea, space)
- monitoring (sea, forests)
- rescue
- demining
- agriculture
- construction
- transportation
- military :-(

gallery

on wheels/1



Roomba by iRobot
(cleaning)

gallery

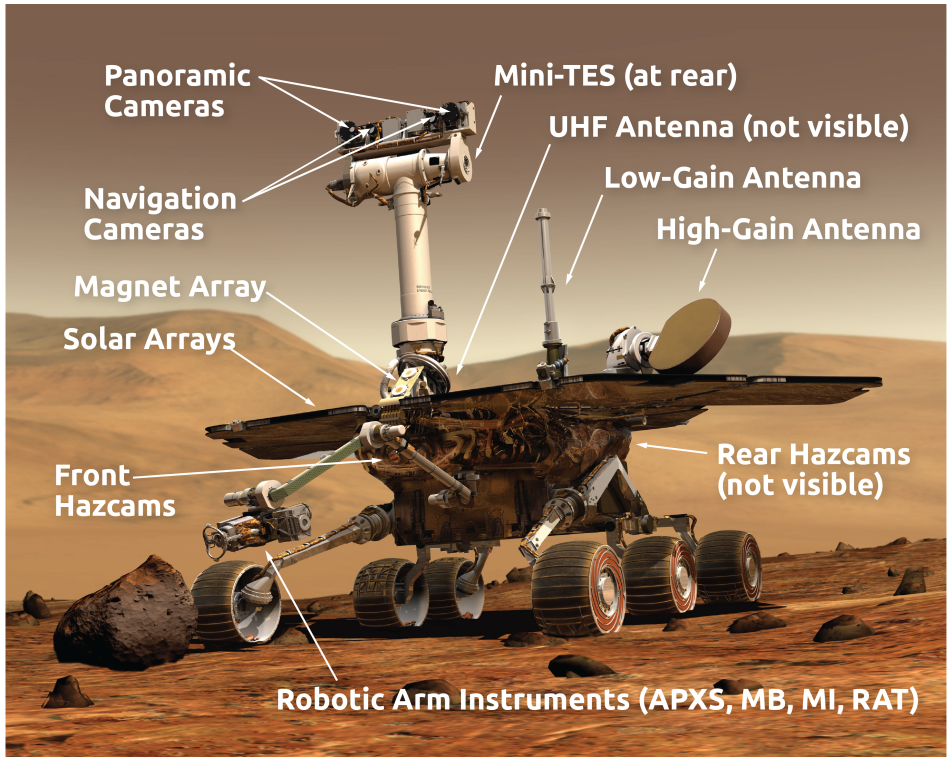
on wheels/2

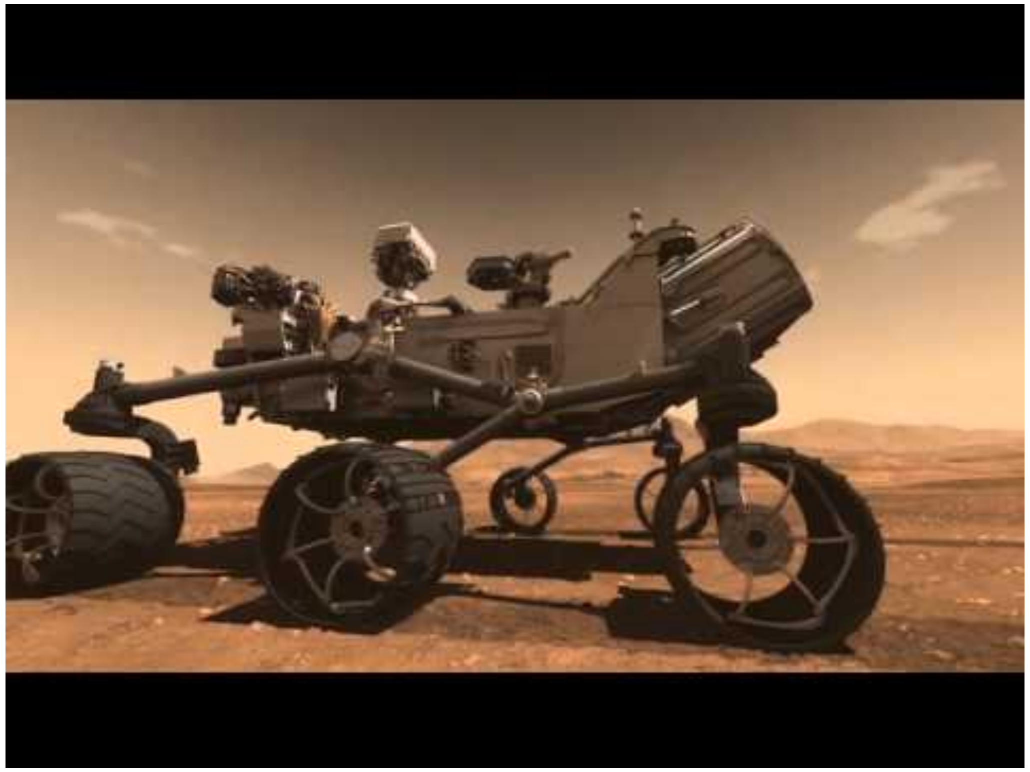
Swisslog SpeciMinder
(healthcare)

gallery

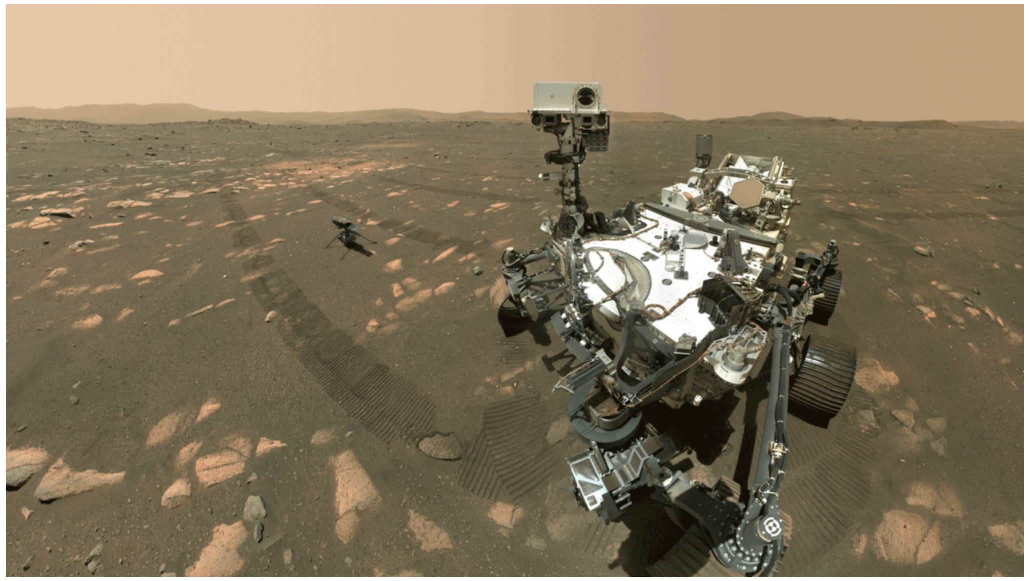
on wheels/3

https://mars.nasa.gov/mer/





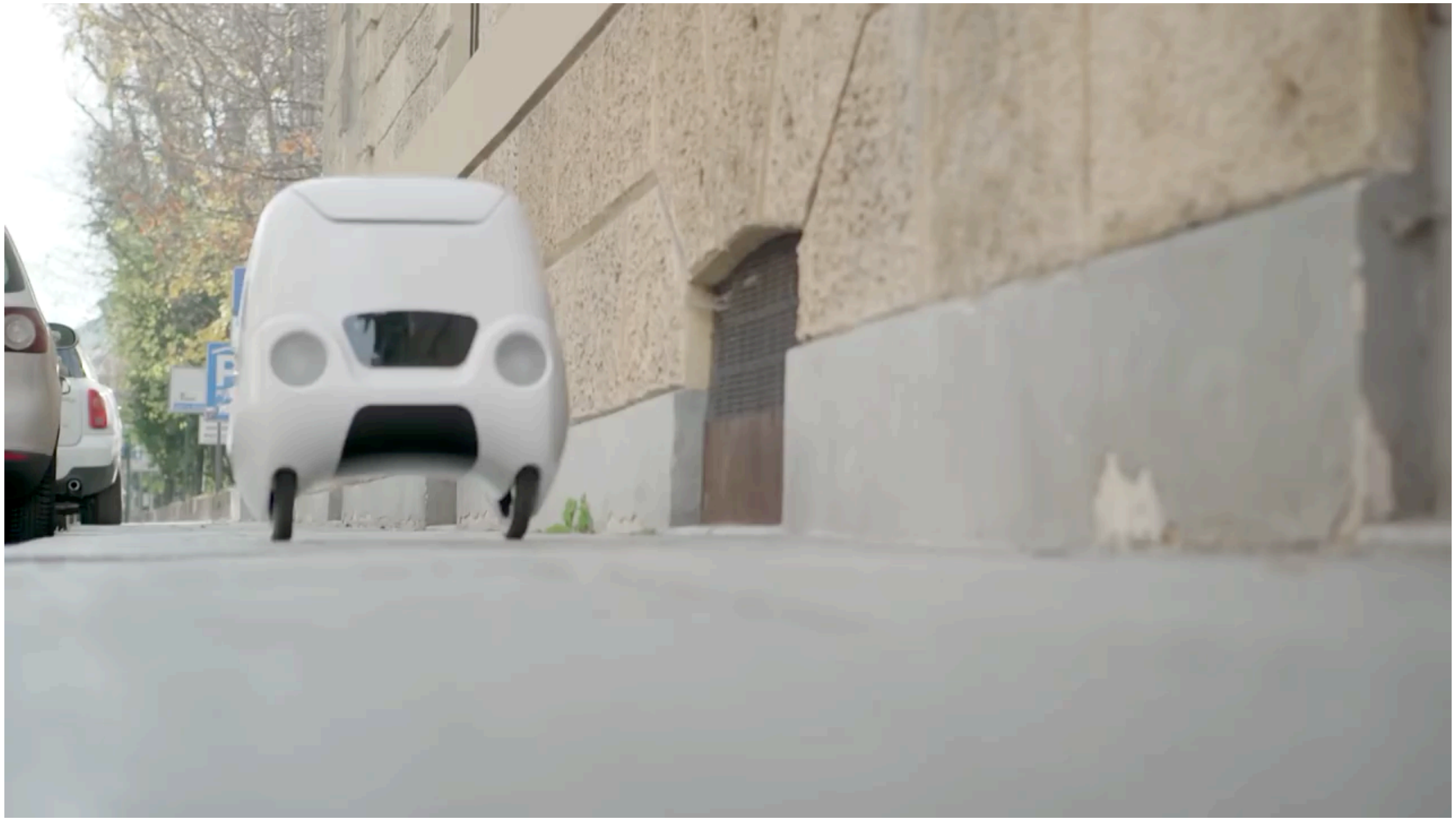
Spirit+Opportunity, Curiosity, Perseverance+Ingenuity by NASA (planetary exploration)



gallery

on wheels/4

https://yapemobility.it



Yape by e-Novia
(urban transportation)

gallery

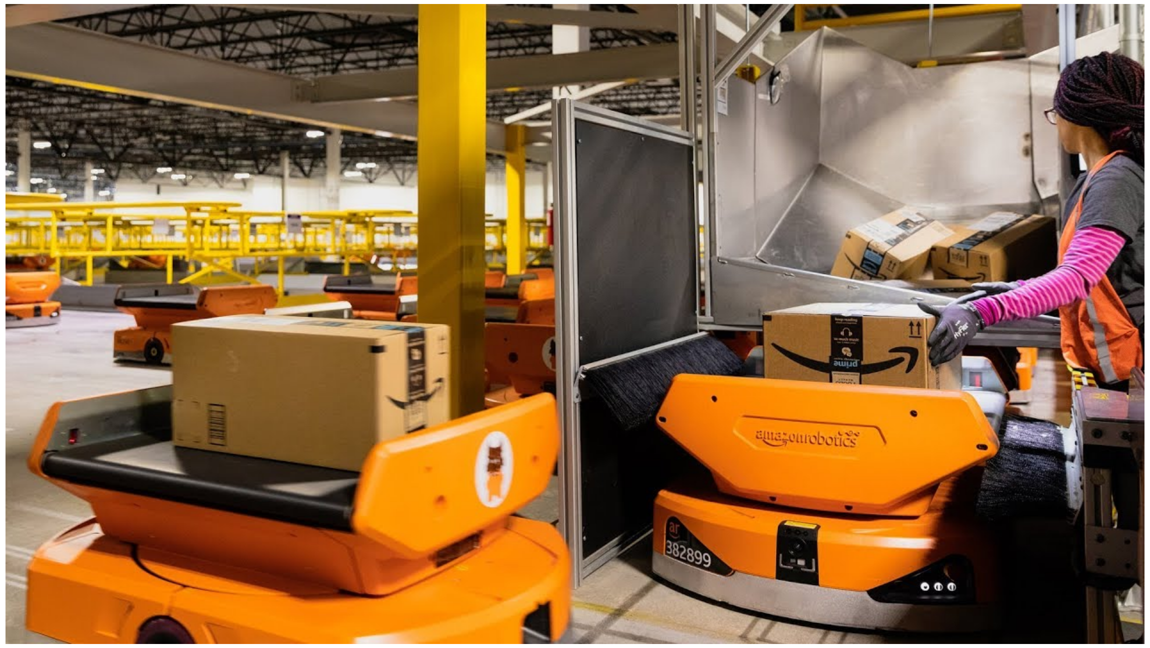
on wheels/5

https://mygita.com

Gita by Piaggio
(urban transportation)

gallery

on wheels/6

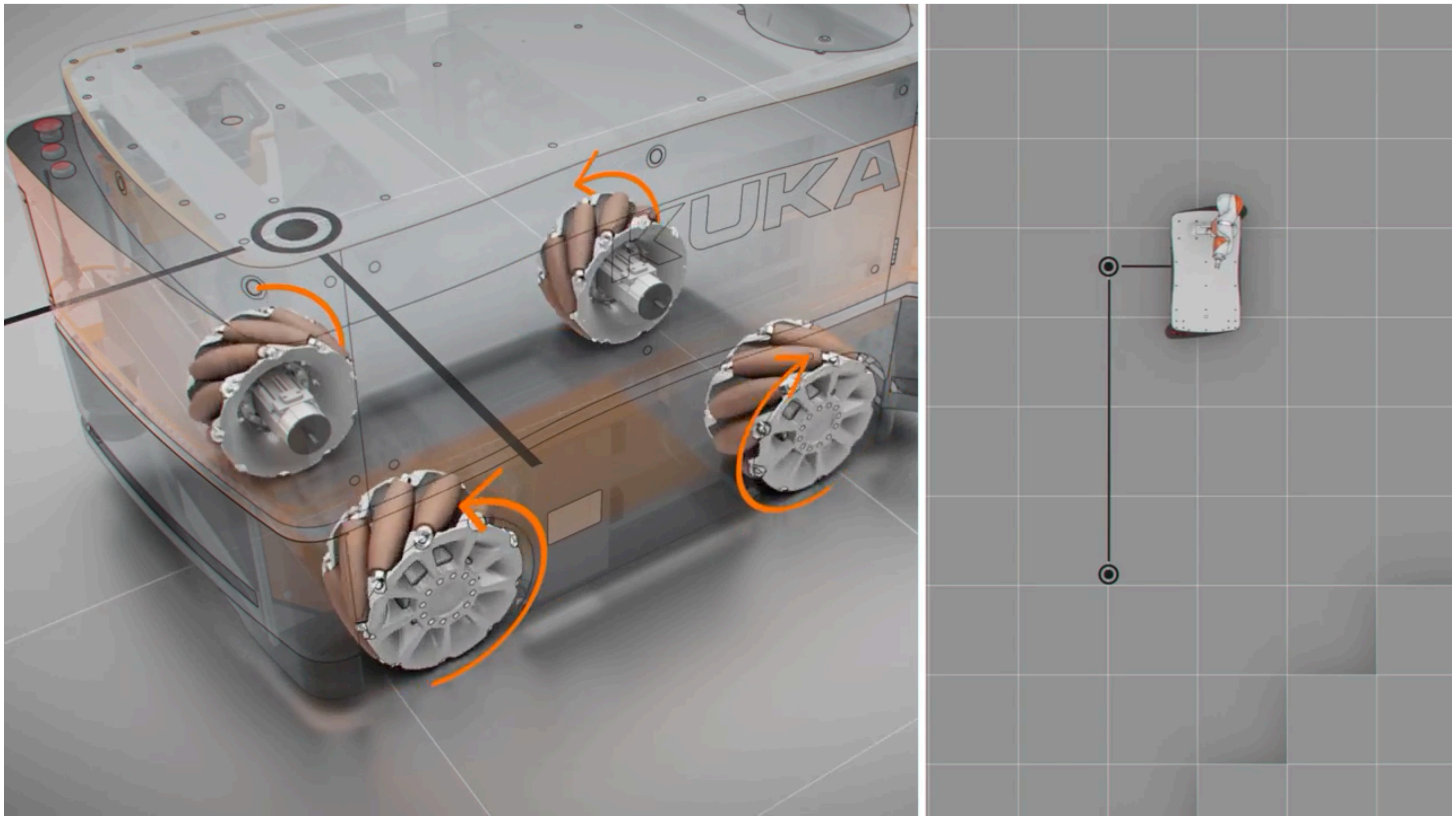


Amazon Robotics
ex-KIVA
(internal logistics)

gallery

on wheels/7

https://www.kuka.com

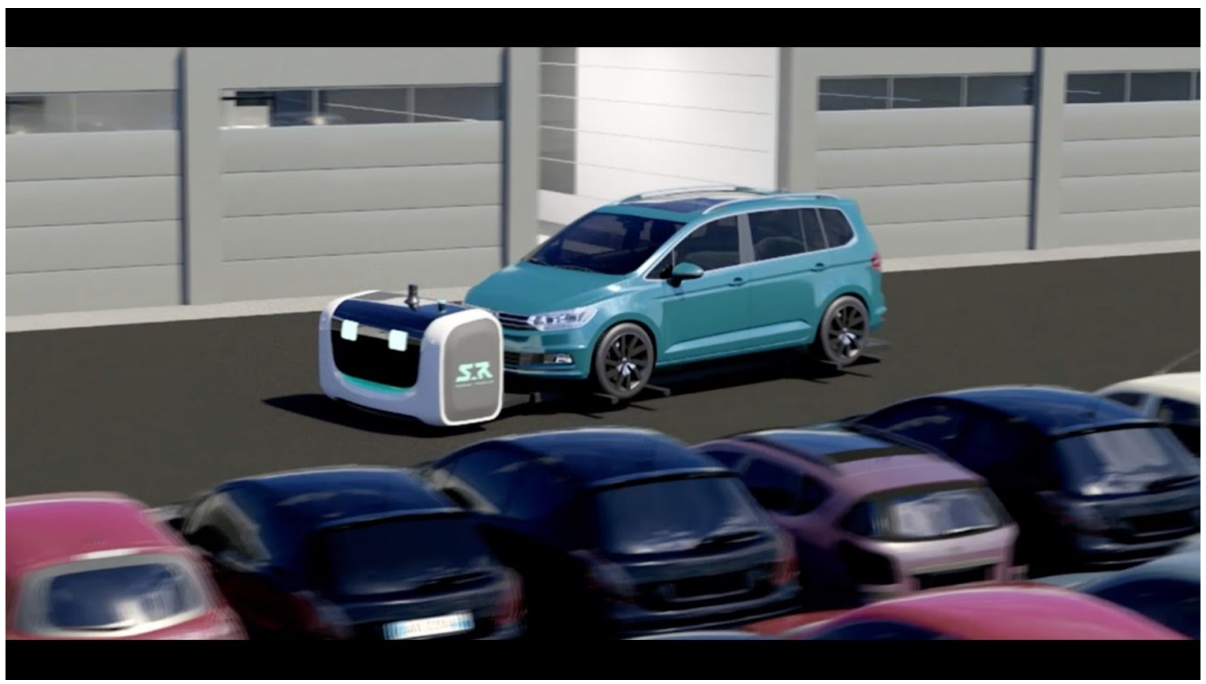


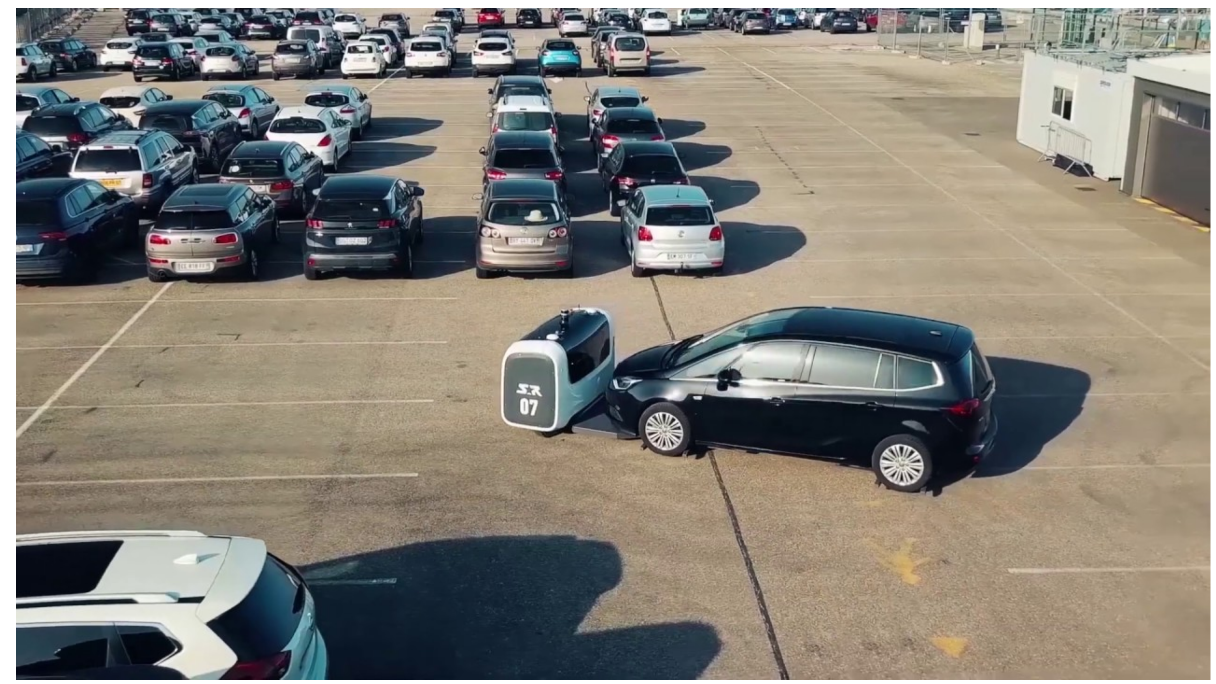
omniMove by KUKA
(internal logistics)

gallery

on wheels/8

https://stanley-robotics.com

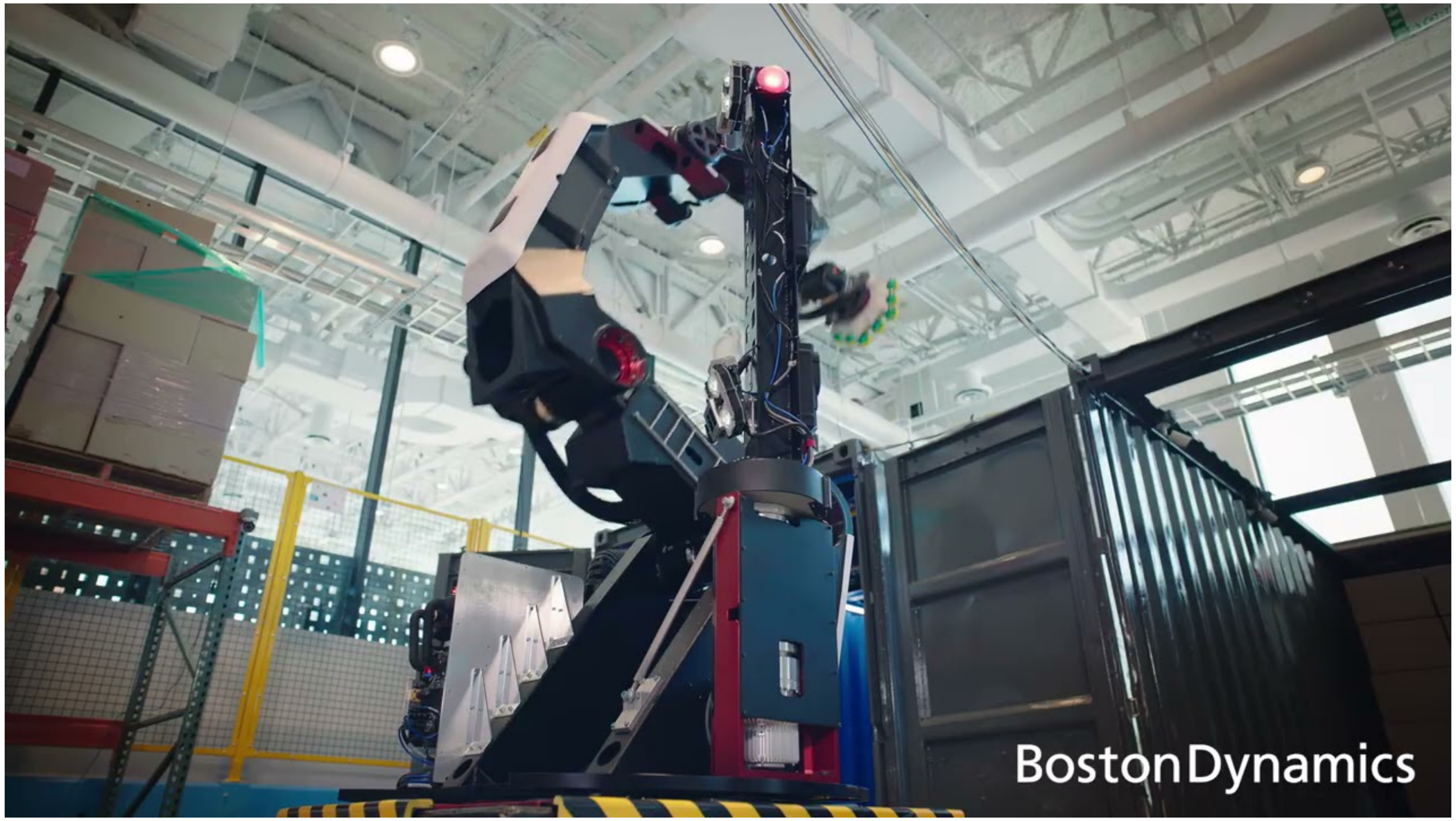




Stan by Stanley Robotics
(automated parking)

gallery

on wheels/9



Stretch by Boston Dynamics
(internal logistics)

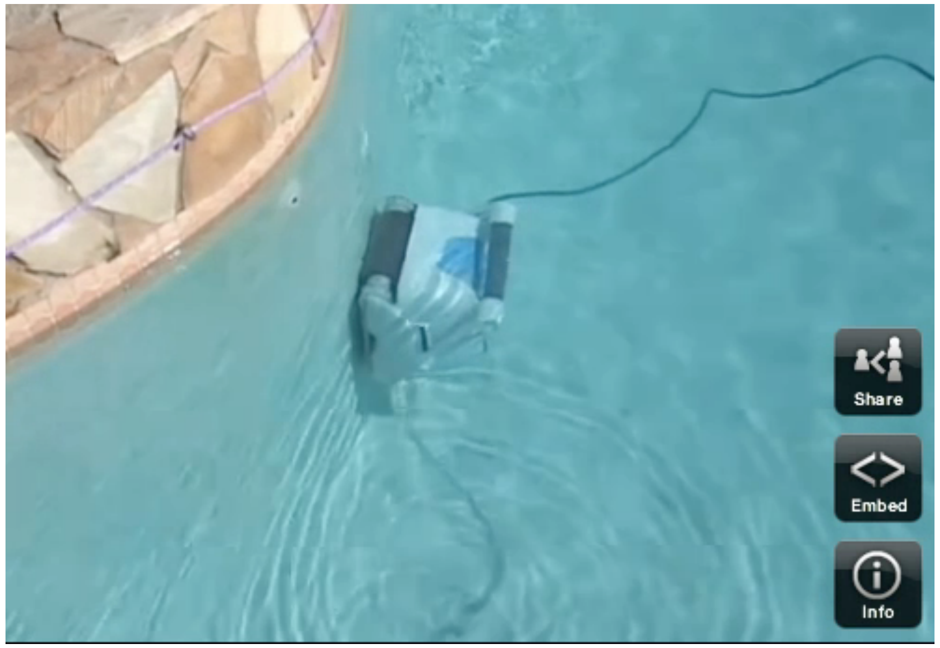
gallery

on wheels (& legs)/10

Handle by Boston Dynamics
(internal logistics)

gallery

on tracks



Verro by iRobot
(pool cleaning)

MAXXII by Robodyne
(all-terrain navigation)

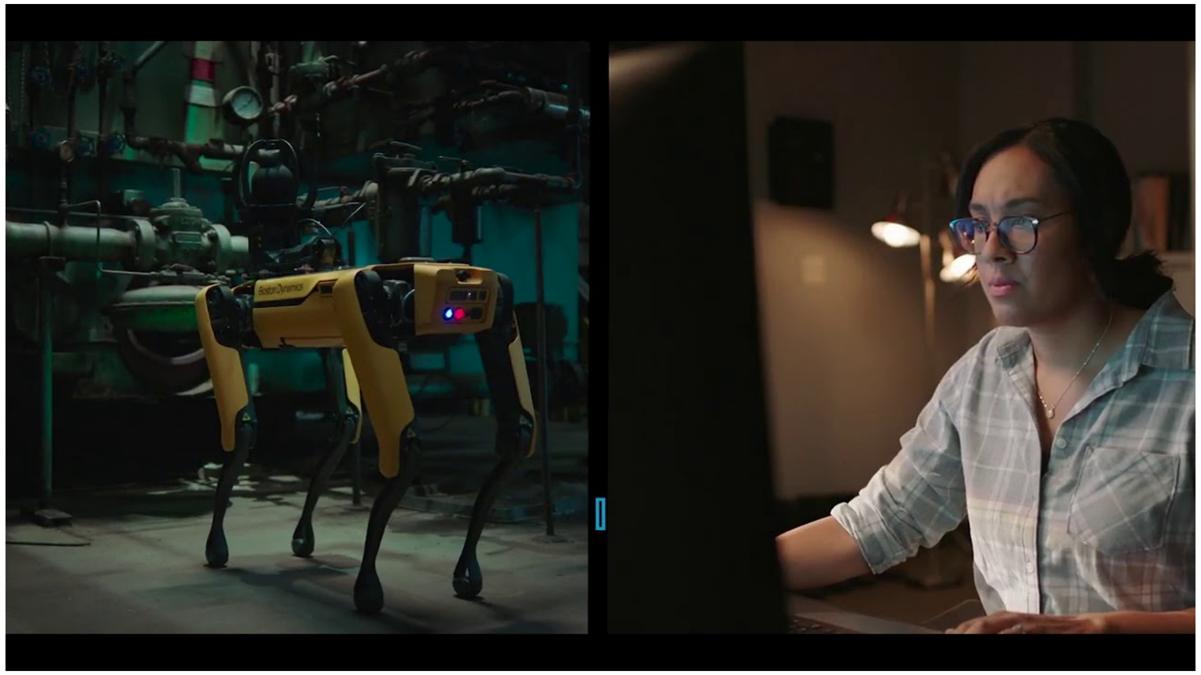
gallery

on legs/1

BigDog and LS3
by Boston Dynamics
(military transportation)

gallery

on legs/2



Spot by Boston Dynamics
(remote monitoring
and intervention)

gallery

on legs/3

Cheetah
by MIT
(research)

ANYmal
by ANYbotics
(inspection)

gallery

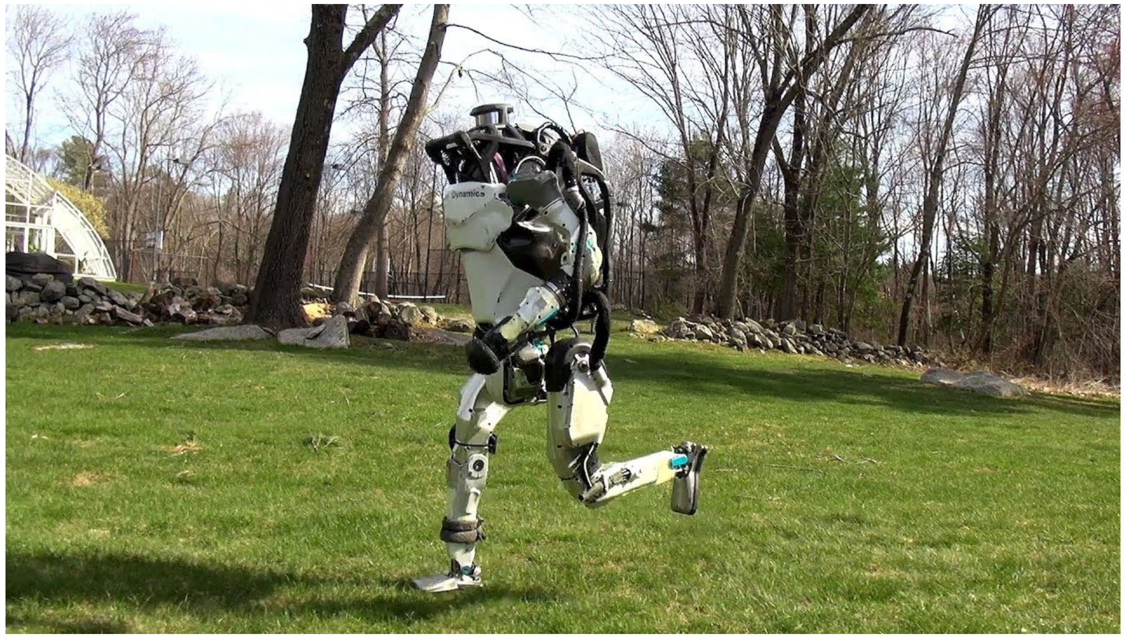
on legs/4

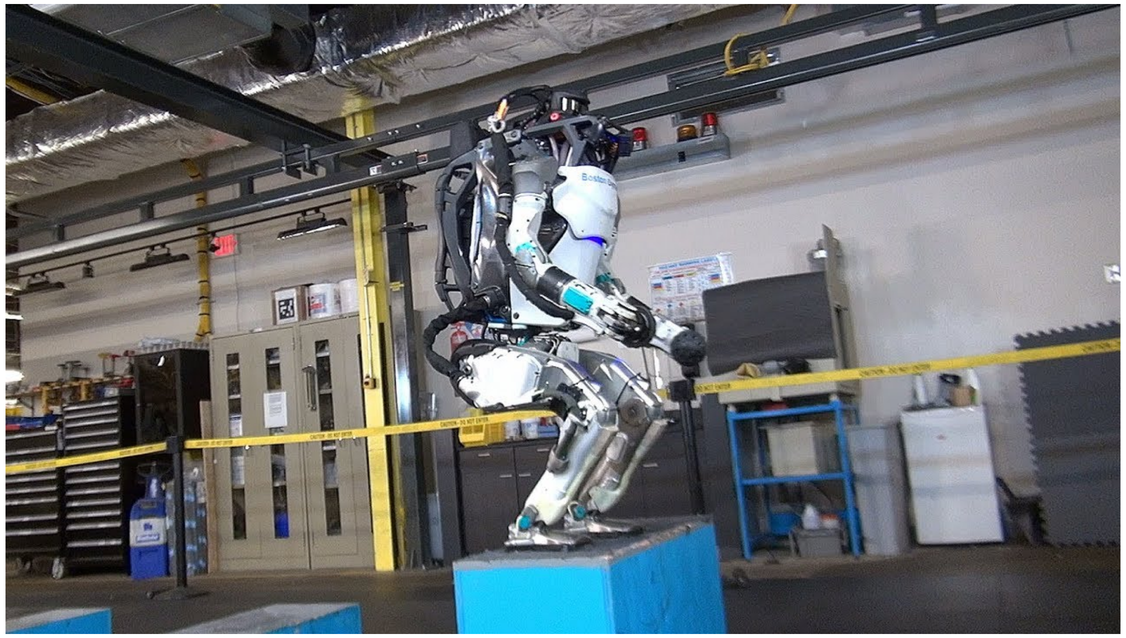
ASIMO by Honda
(research)

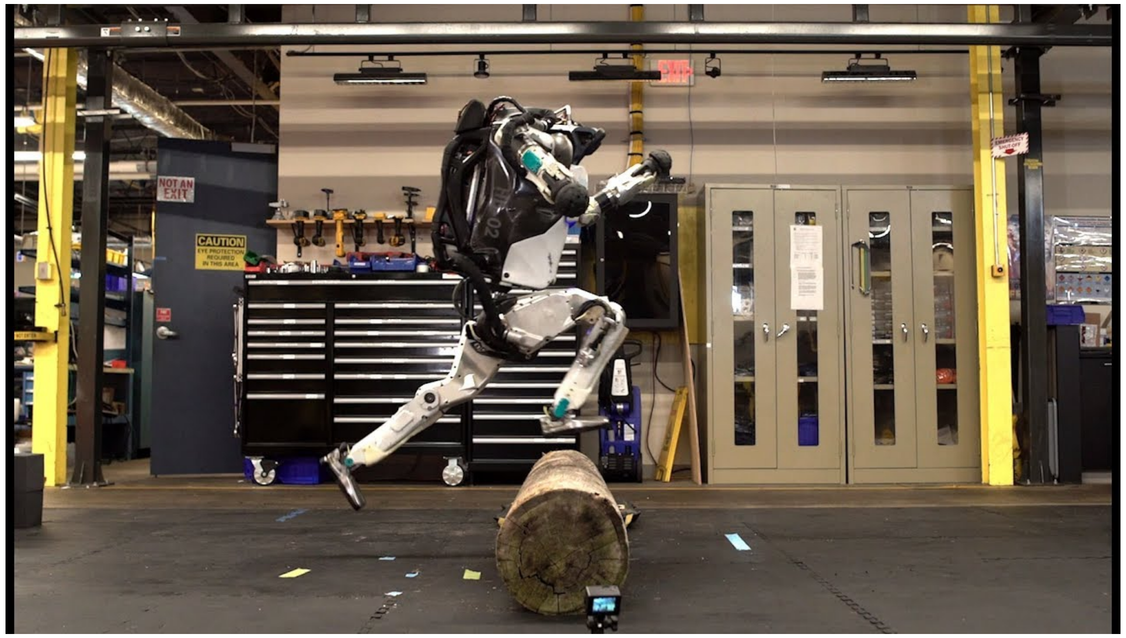
gallery

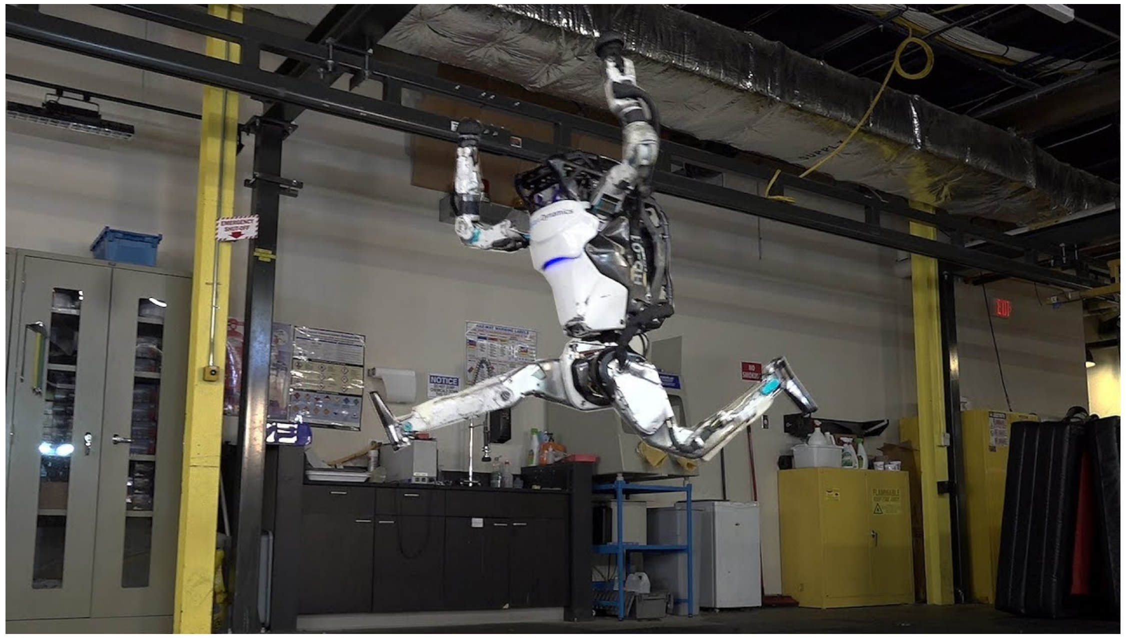
on legs/5

ATLAS by Boston Dynamics (research)









gallery

flying

Skydio 2 by Skydio
(aerial cinematography)

Amazon Prime Air
(delivery)

gallery

underwater

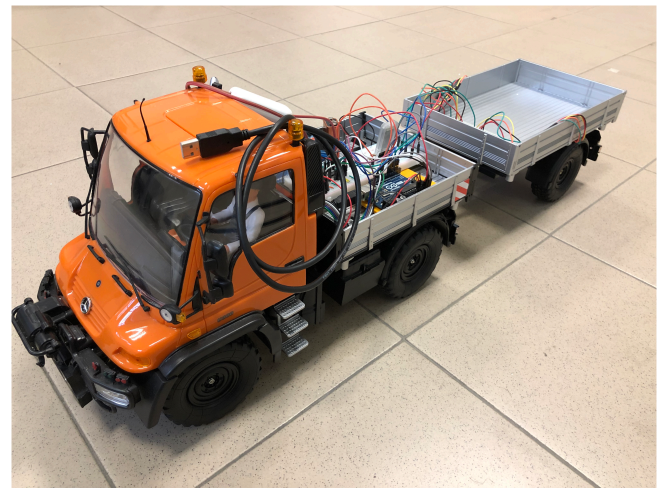
Seagoo ROV
(inspection)

Aquanaut by
Houston Mechatronics
(underwater operation)

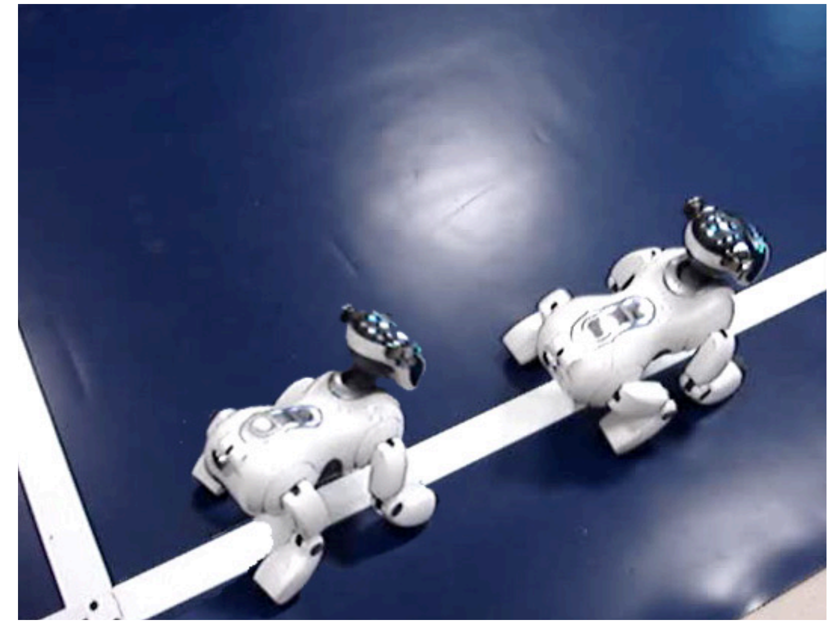
gallery

at DIAG Robotics Lab

Kheperas

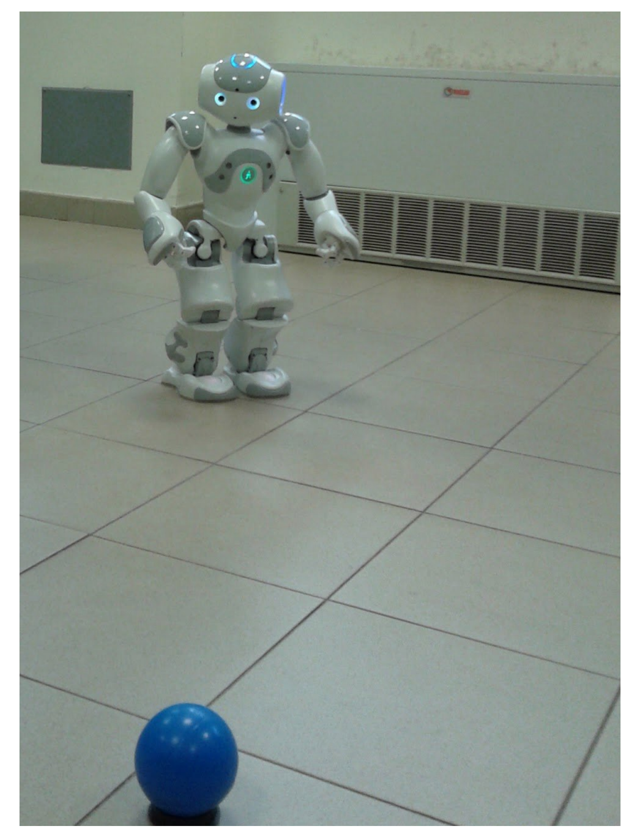


tractor-trailer prototype



AIBOs

NAOs



MagellanPro

Hummingbird, Pelican

gallery

at DIAG Robotics Lab

TIAGo

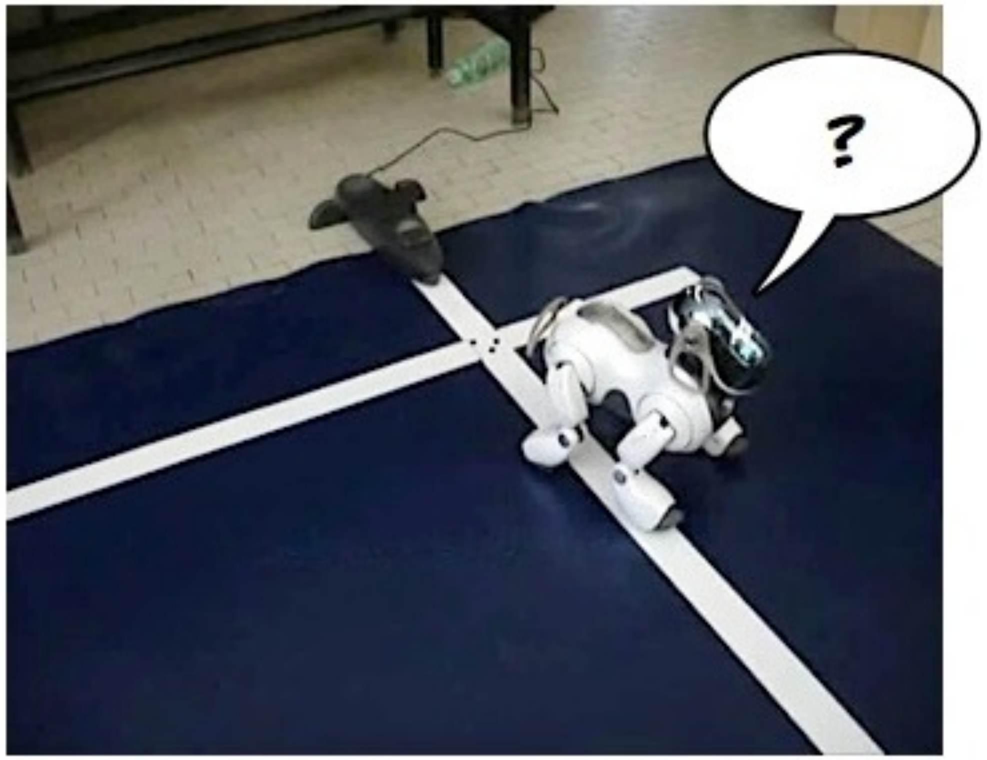
Duckietown

Robotis OP3

the key problems of mobile robotics

1. where am I?
2. how am I supposed to get to the goal?
3. how do I actually move?

(Durrant-Whyte 1991; slightly revised)



1: localization (with or without initial guess, map,...)

2: path/trajectory/motion planning (respectively: only geometric motion, with time, among obstacles)

3: motion control (feedback techniques)

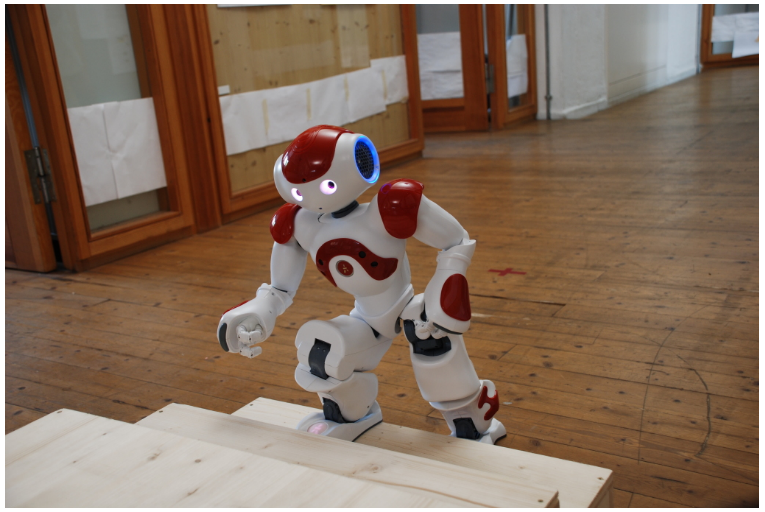
	fixed-base manipulators	single-body wheeled mobile robots
1. localization	easy (thanks to fixed-base and joint encoders)	difficult
2a. path/trajectory planning	easy (all paths are feasible)	difficult (not all paths are feasible)
2b. motion planning	difficult (many dof’s)	more difficult (not all paths are feasible)
3. motion control	difficult (due to inertial couplings)	more difficult (nonlinear & no smooth stabilizer)

⇒ multi-body mobile robots are a real challenge!

articulated vehicles

mobile manipulators

humanoids

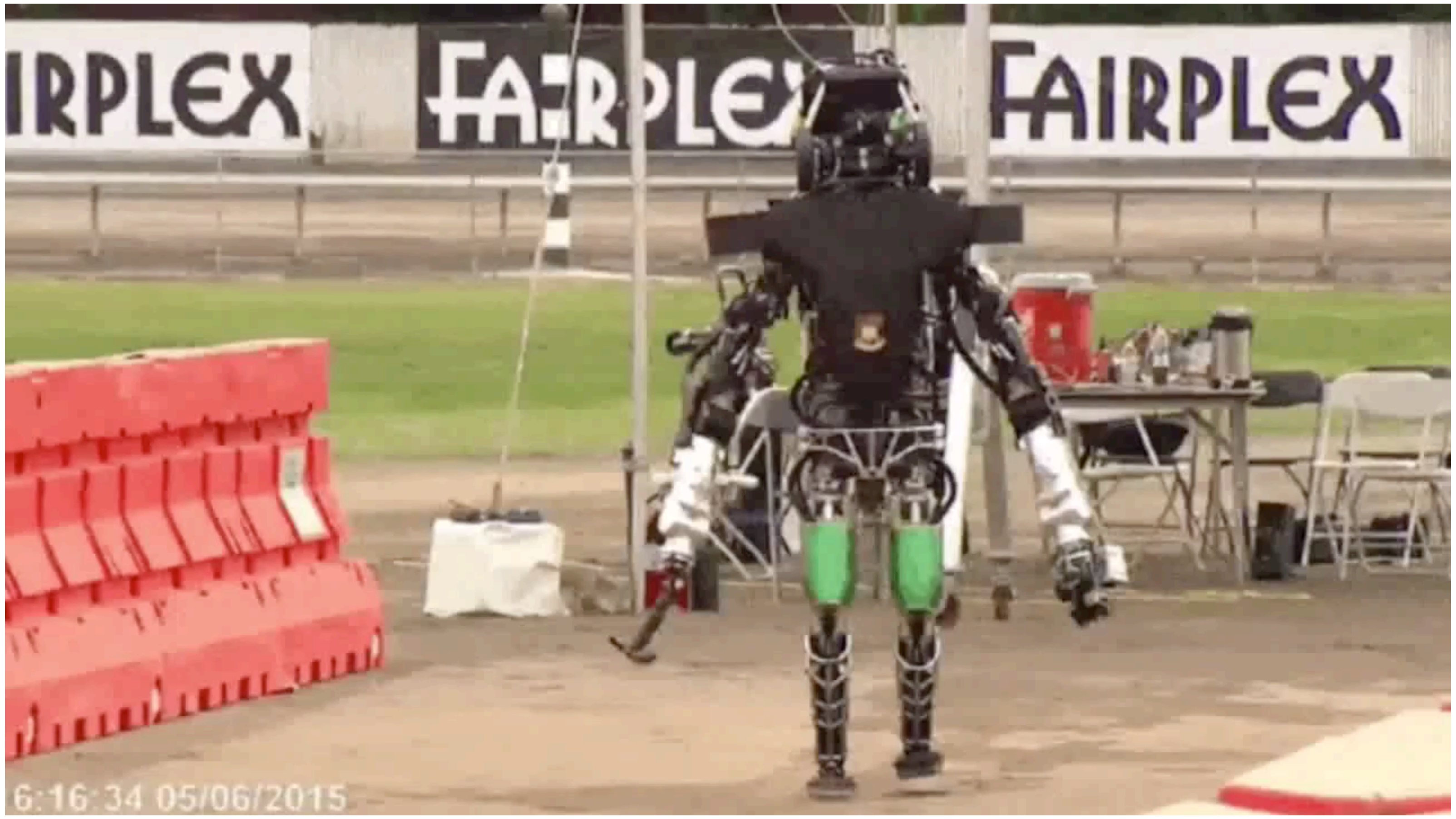


autonomy

can be defined as (or better, requires) the ability to solve problems 1, 2, 3 in unstructured environments and uncertain, possibly dynamic operating conditions

DARPA
Grand Challenge
2005

that was 2005, this is one decade later



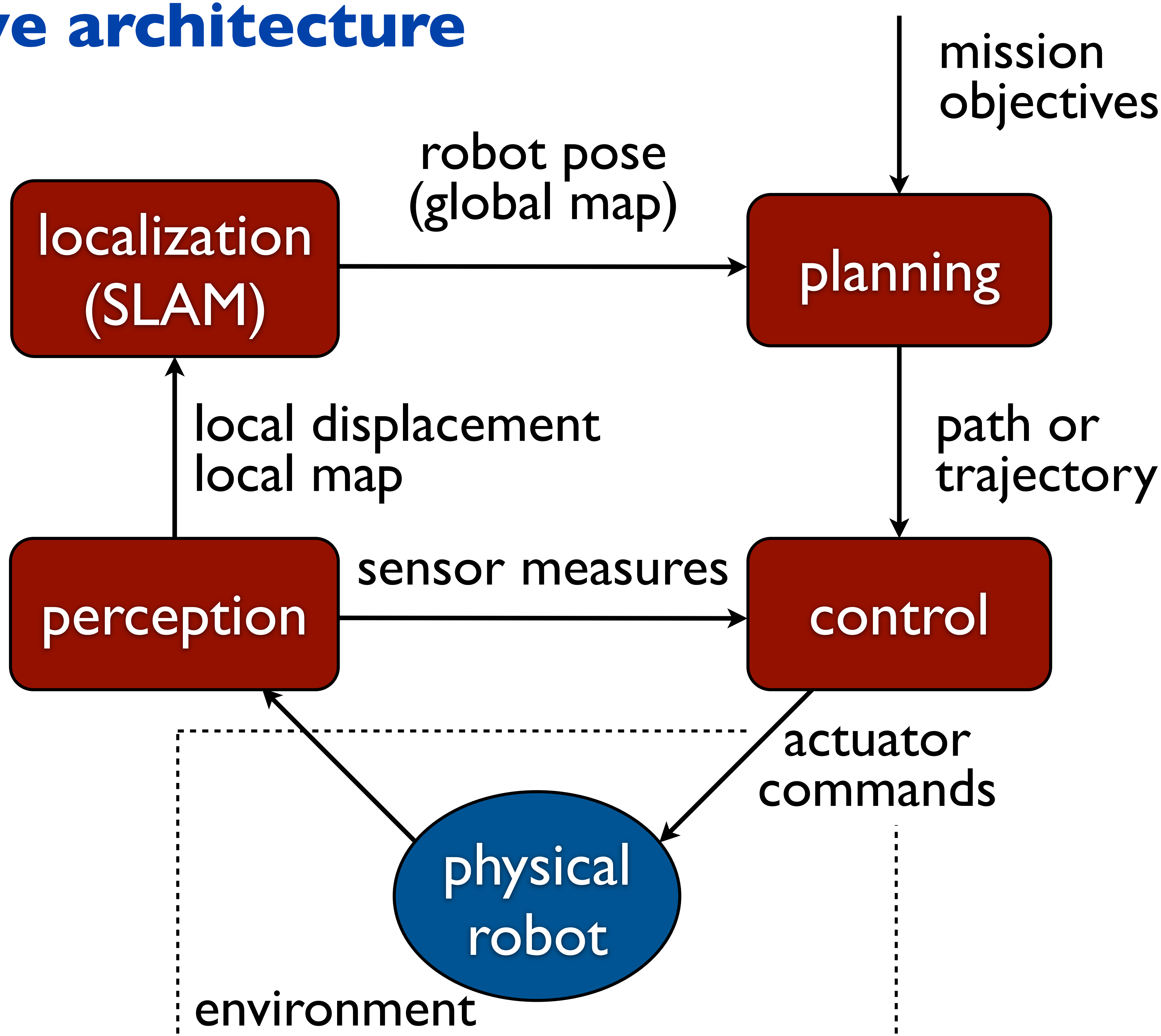
DARPA Robotics Challenge 2015

real autonomy (especially if you want to do more than drive) is not around the corner: still a long way to go

a basic underlying functionality: perception

- sensing + interpretation
- proprioceptive: perception of the robot itself (position, orientation, velocity, etc, in a certain frame)
- exteroceptive: perception of the environment surrounding the robot (obstacles, robots, people, etc)
- essential in unstructured environments
- performed via a variety of sensors:
  - encoders, IMUs, GPS (proprioception)
  - rangefinders, cameras, tactile sensors (exteroception)

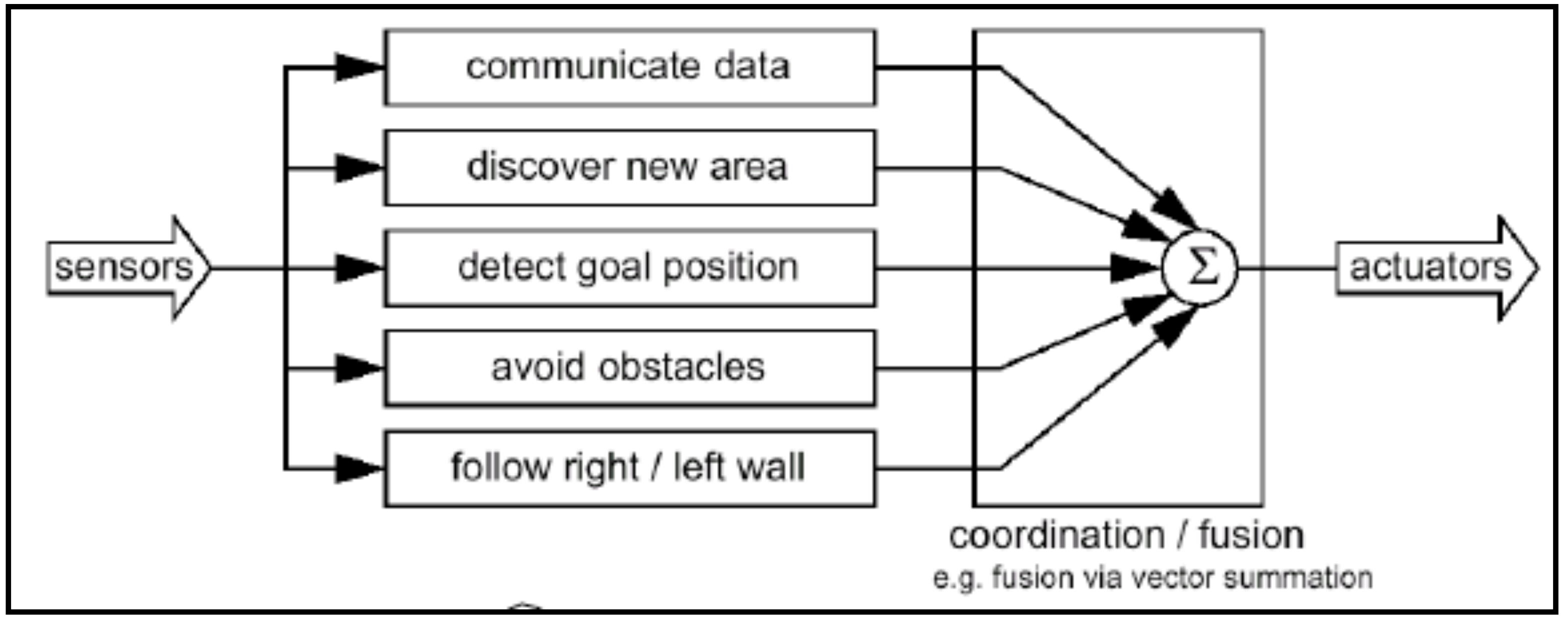
deliberative architecture



"think, then act"

other architectures

- reactive architecture ("don't think, (re)act")
- hybrid architecture ("think and act concurrently")
- behavior-based architecture ("think the way you act"), e.g.



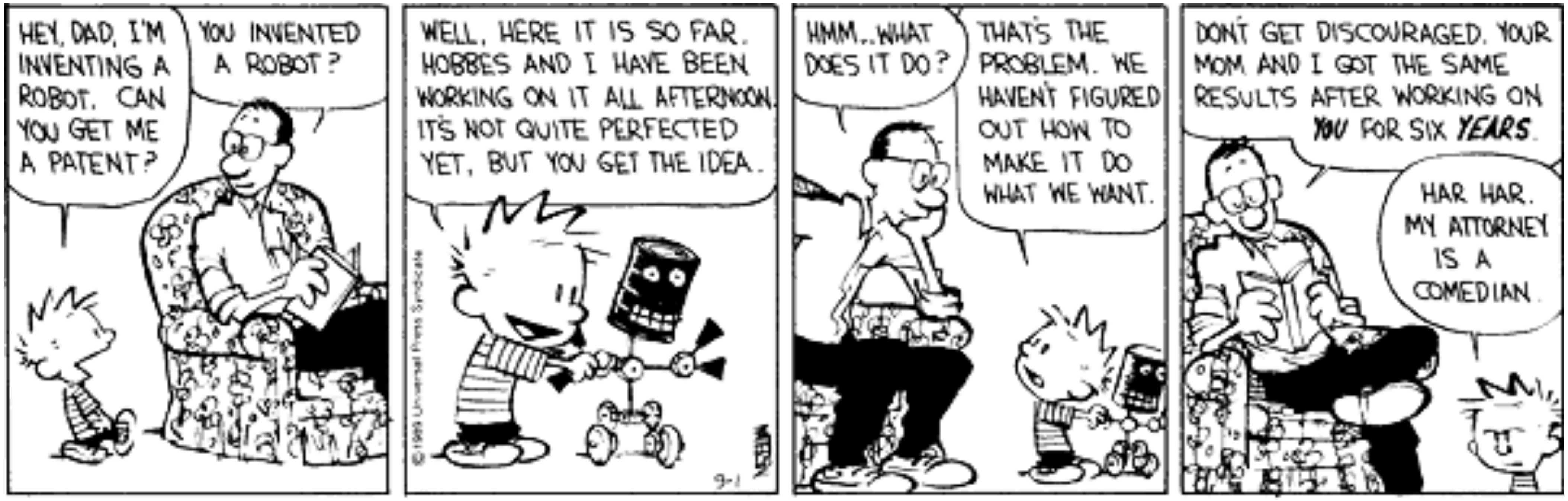
taken from "Introduction to Autonomous Mobile Robots"

course contents

- modeling (essential: model-based approach!)
- planning
- control
- localization

…mainly (but not only) for wheeled mobile robots (WMRs) the focus of this course is on methodologies that can be applied on any robotic platform rather than on specific hw/sw realizations

robotics is not about building robots!



syllabus (preliminary)

1. Introduction: Applications, Problems, Architectures
2. Configuration space
3. Wheeled Mobile Robots 1: Mechanics of mobile robots
4. Wheeled Mobile Robots 2: Kinematic models of mobile robots
5. Wheeled Mobile Robots 3: Path/trajectory planning
6. Wheeled Mobile Robots 4: Trajectory tracking
7. Wheeled Mobile Robots 5: Regulation
8. Perception: Sensors for mobile robots
9. Localization 1: Odometric localization
10. Localization 2: Kalman Filter
11. Localization 3: Landmark-based and SLAM
12. Motion Planning 1: Retraction and cell decomposition
13. Motion Planning 2: Probabilistic planning
14. Motion Planning 3: Artificial potential fields
15. Humanoid Robots 1: Introduction
16. Humanoid Robots 2: Dynamic modeling
17. Humanoid Robots 3: Gait generation
18. Case study 1, 2, 3: to be defined

textbooks and other material

- Siciliano, Sciavicco, Villani, Oriolo, *Robotics: Modelling, Planning and Control*, 3rd Edition, Springer, 2010 (also available in Italian by McGraw-Hill)
  [chapters 11 and 12 cover lectures 2-9 and 11-14]

- Choset, Lynch, Hutchinson, Kantor, Burgard, Kavraki, Thrun, *Principles of Robot Motion: Theory, Algorithms and Implementations*, MIT Press, 2005
  [a useful reference for the whole course; chapter 8 covers lectures 10-11]

- Siciliano, Khatib, Eds., *Handbook of Robotics*, 2nd Edition, Springer, 2016
  [a useful reference for the whole course]

additional material (slides, papers, code etc) available on the AMR website (already there but may be updated during the course)

other sources of information

- https://spectrum.ieee.org/robotics
- https://robotsguide.com
- https://mars.nasa.gov/mer/, https://mars.nasa.gov/msl/home/, https://mars.nasa.gov/mars2020/
- https://asimo.honda.com
- https://www.bostondynamics.com
- https://www.youtube.com/user/RoboticsLabSapienza