Autonomous and Mobile Robotics

Prof. Giuseppe Oriolo

Introduction:
Applications, Problems, Architectures

Dipartimento di Ingegneria Informatica
Automatica e Gestionale Antonio Ruberti

Sapienza
Università di Roma

practical information

- course timetable 2025/26: 25 Sept -18 Dec 2025, Mon 10-13, Thu 9-11, room B2
- 6 ECTS credits, 60 hrs
- office hours: by appointment only, room A209 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 or slides

grading

- 50% midterm test + 50% final project *(for midterm top grades)*
- 50% midterm test + 50% final test *(for those who pass midterm)*
- conventional exam *(everyone else)*

theses

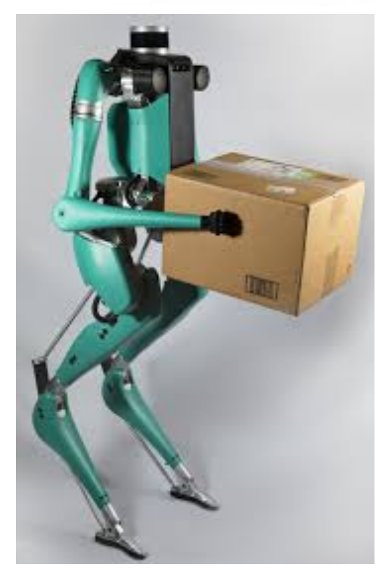
- Master Theses on the topics studied in this course are available at the DIAG Robotics Lab

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

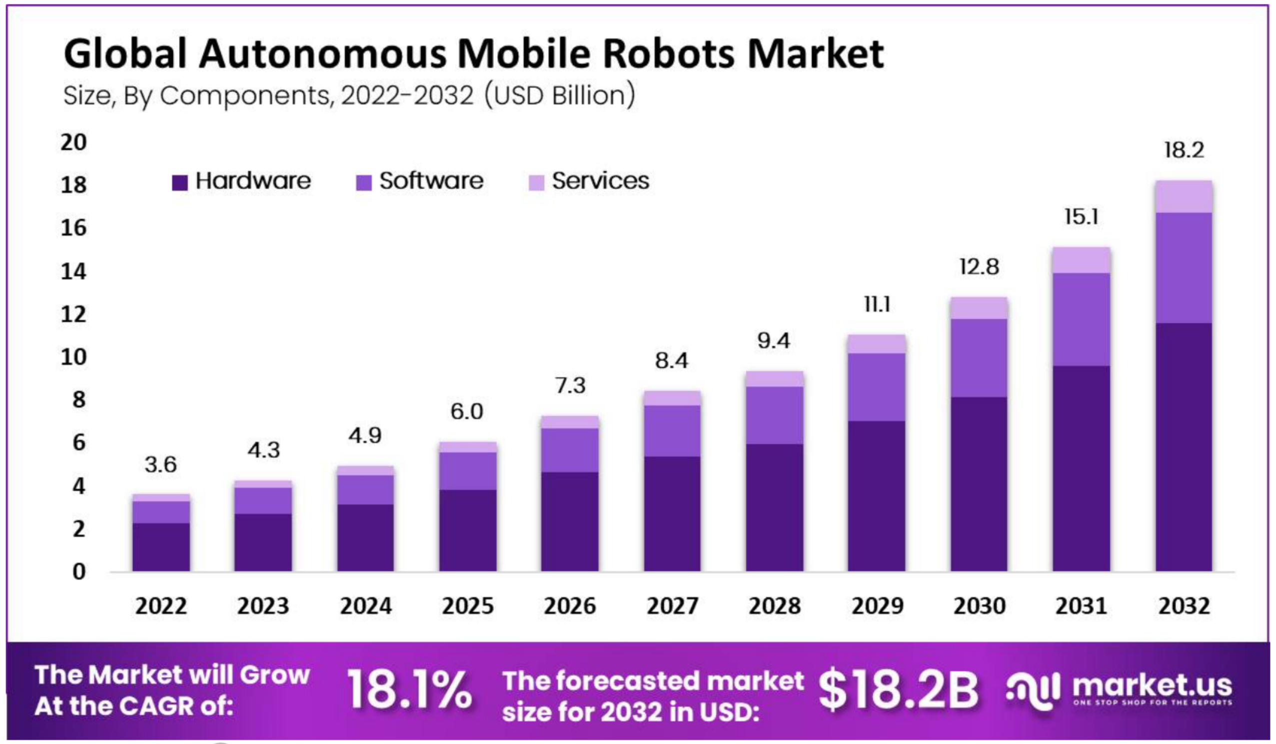
structured environments (service robots)

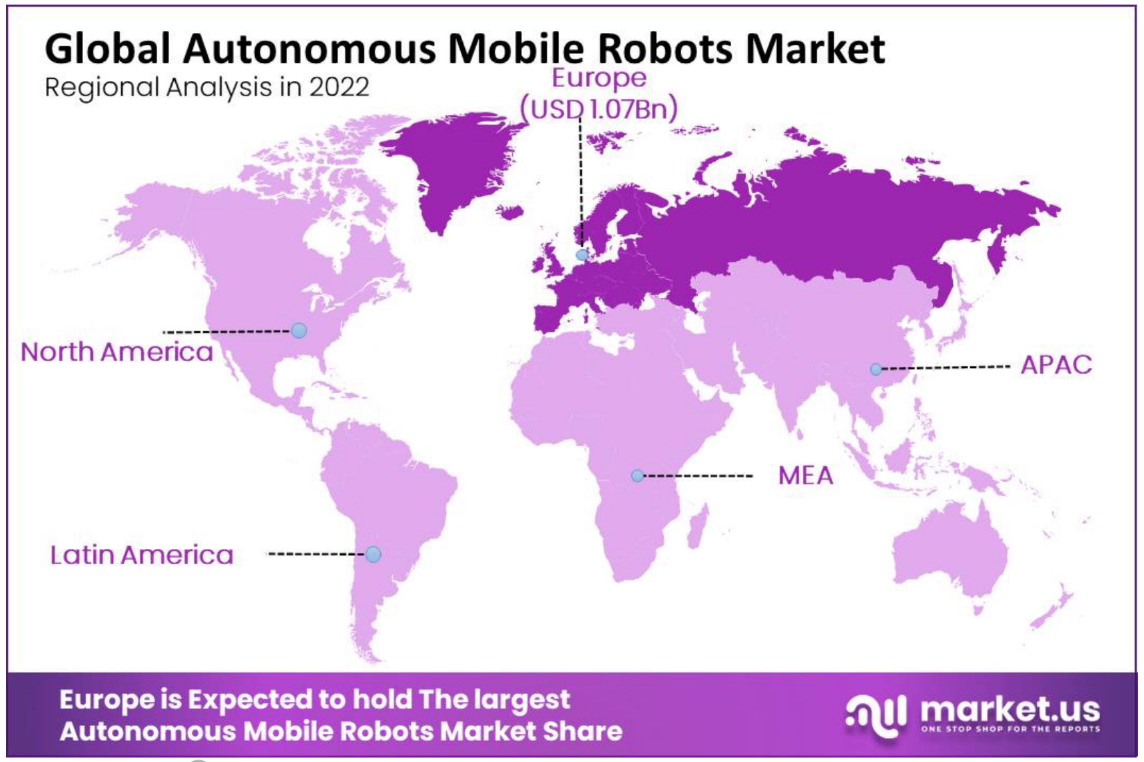
- transportation (industry, logistics)
- cleaning (homes, large buildings, cities)
- customer assistance (museums, shops)
- surveillance
- entertainment
- …

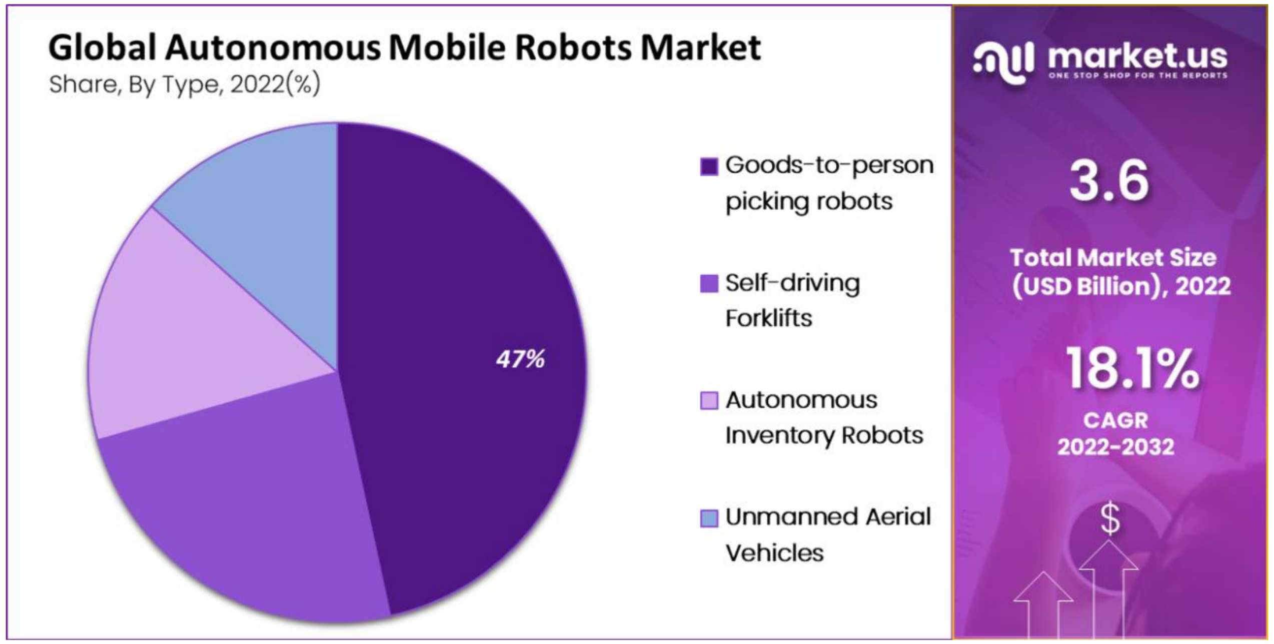
unstructured environments (field robots)

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

market

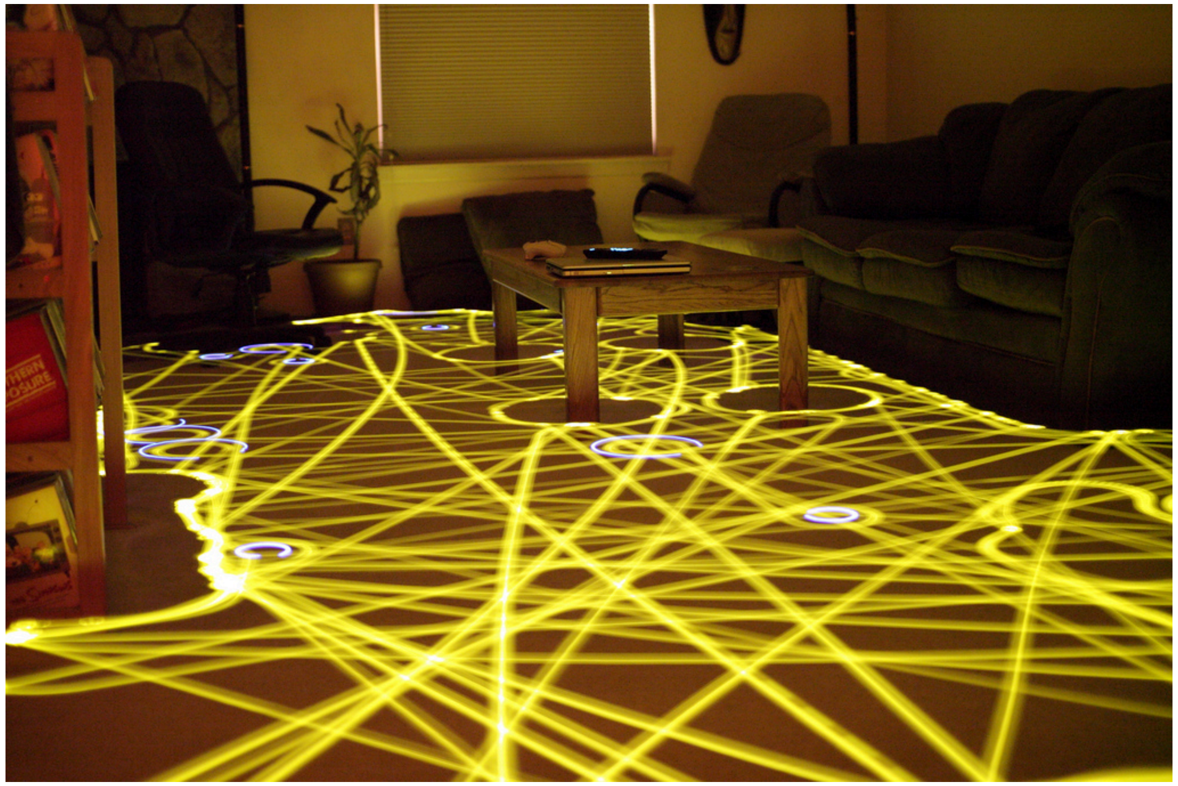

Global Autonomous Mobile Robots Market
Size, By Components, 2022-2032 (USD Billion)
Hardware
Software
Services
3.6
4.3
4.9
6.0
7.3
8.4
9.4
11.1
12.8
15.1
18.2
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
The Market will Grow At the CAGR of:
18.1%
The forecasted market size for 2032 in USD:
$18.2B
market.us


Global Autonomous Mobile Robots Market
Regional Analysis in 2022
Europe
(USD 1.07Bn)
North America
APAC
MEA
Latin America
Europe is Expected to hold The largest Autonomous Mobile Robots Market Share
market.us


Global Autonomous Mobile Robots Market
Share, By Type, 2022(%)
47%
Goods-to-person picking robots
Self-driving Forklifts
Autonomous Inventory Robots
Unmanned Aerial Vehicles
market.us
3.6
Total Market Size (USD Billion), 2022
18.1%
CAGR
2022-2032

gallery

on wheels/1

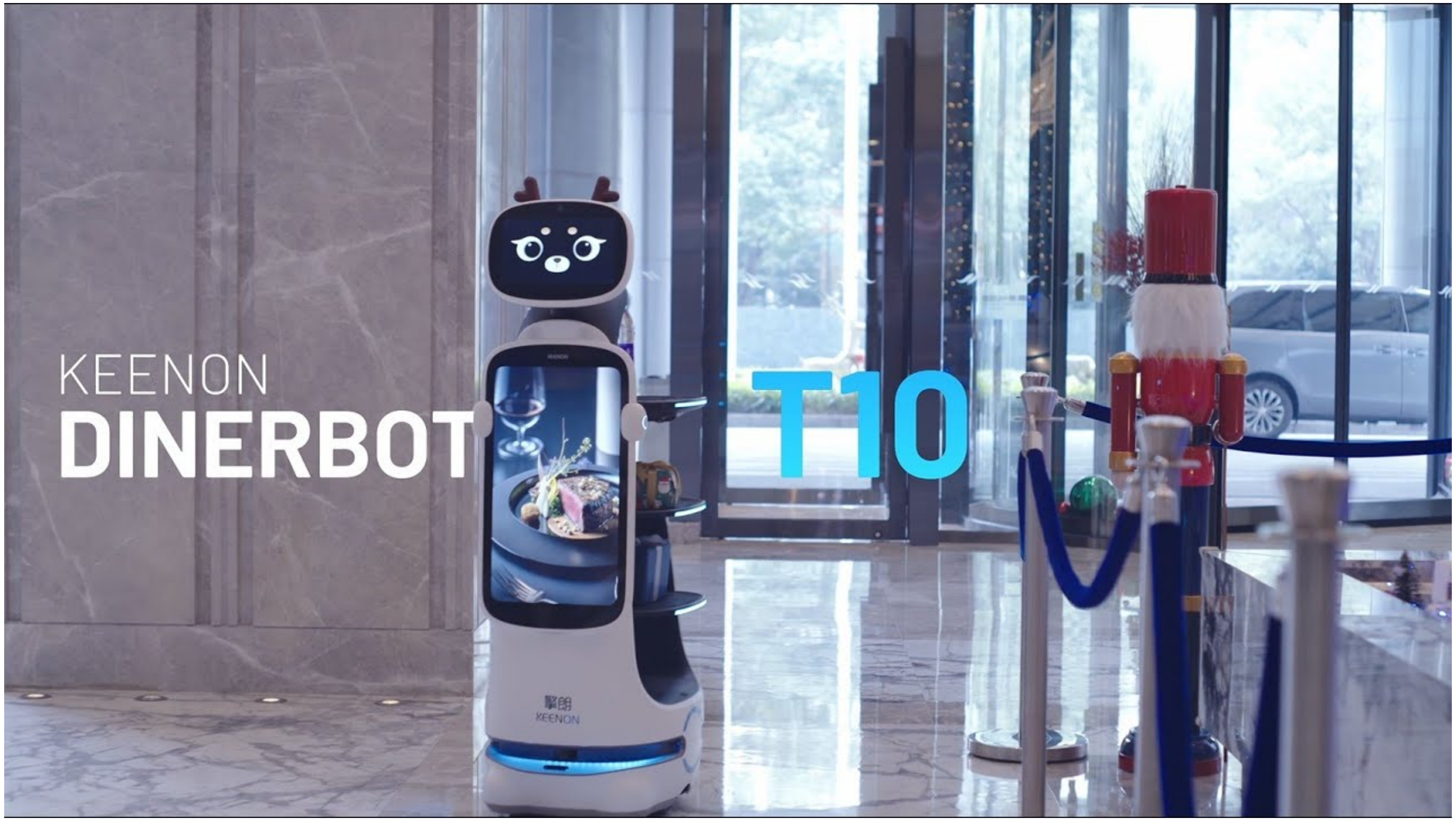


Roomba by iRobot
(cleaning)

gallery

on wheels/2

https://www.keenon.com

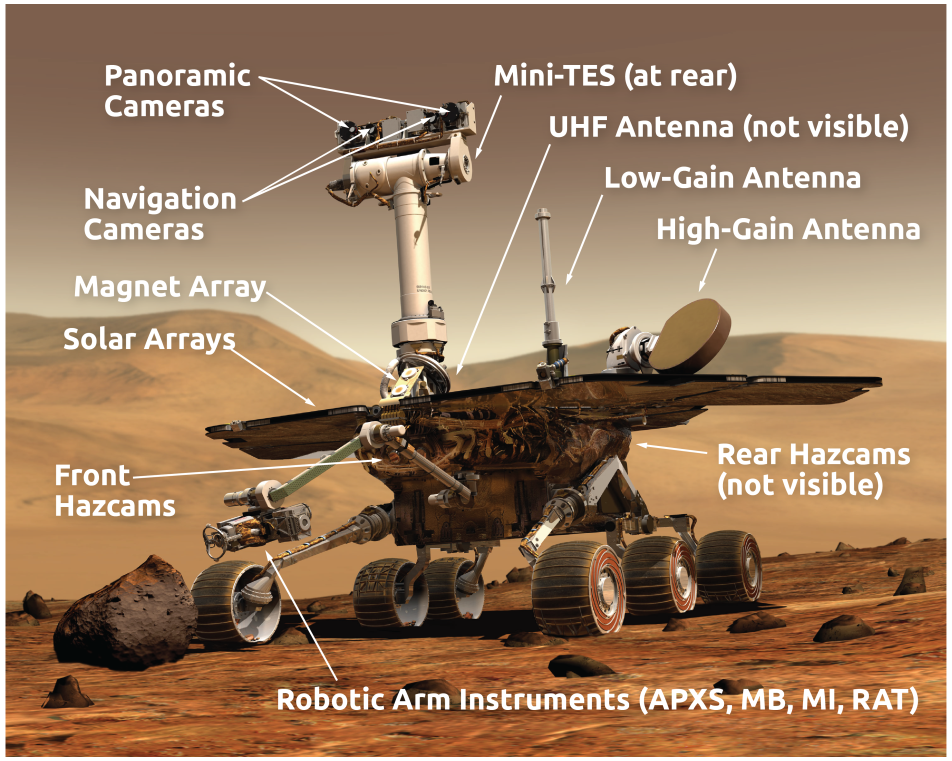


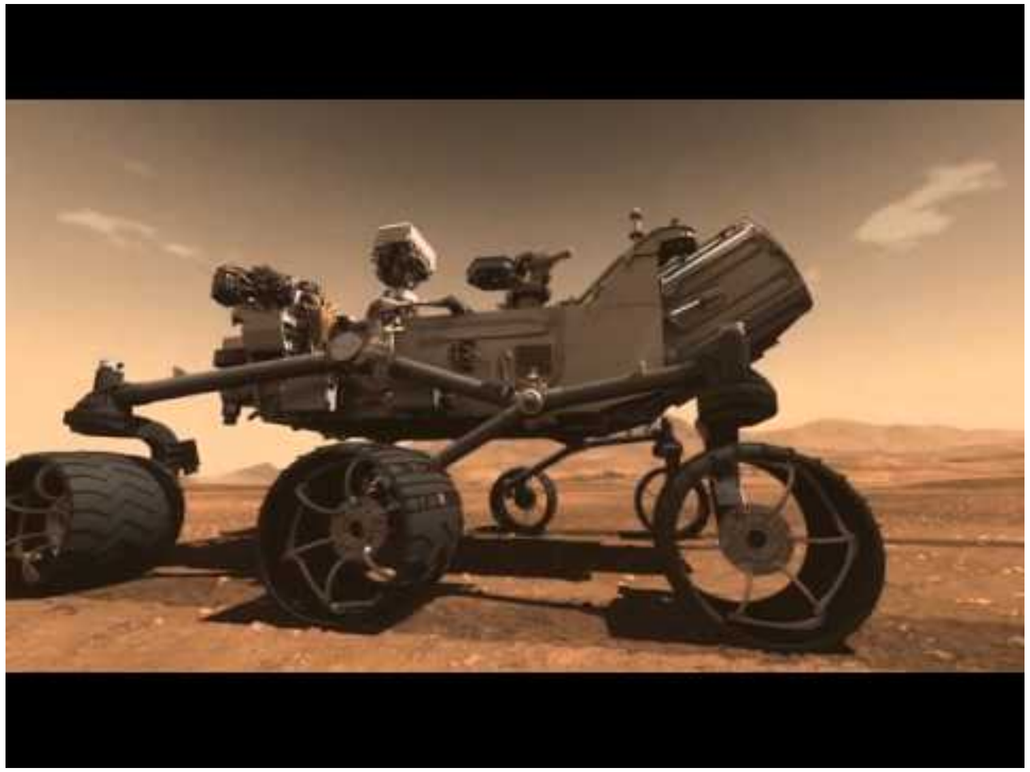
Dinerbot by Keenon
(catering)

gallery

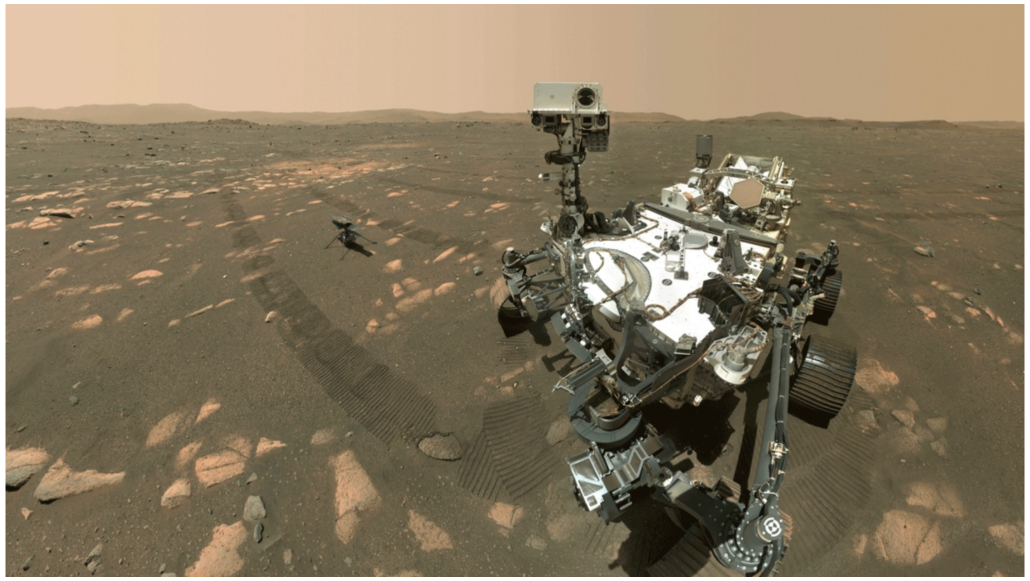
on wheels/3

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





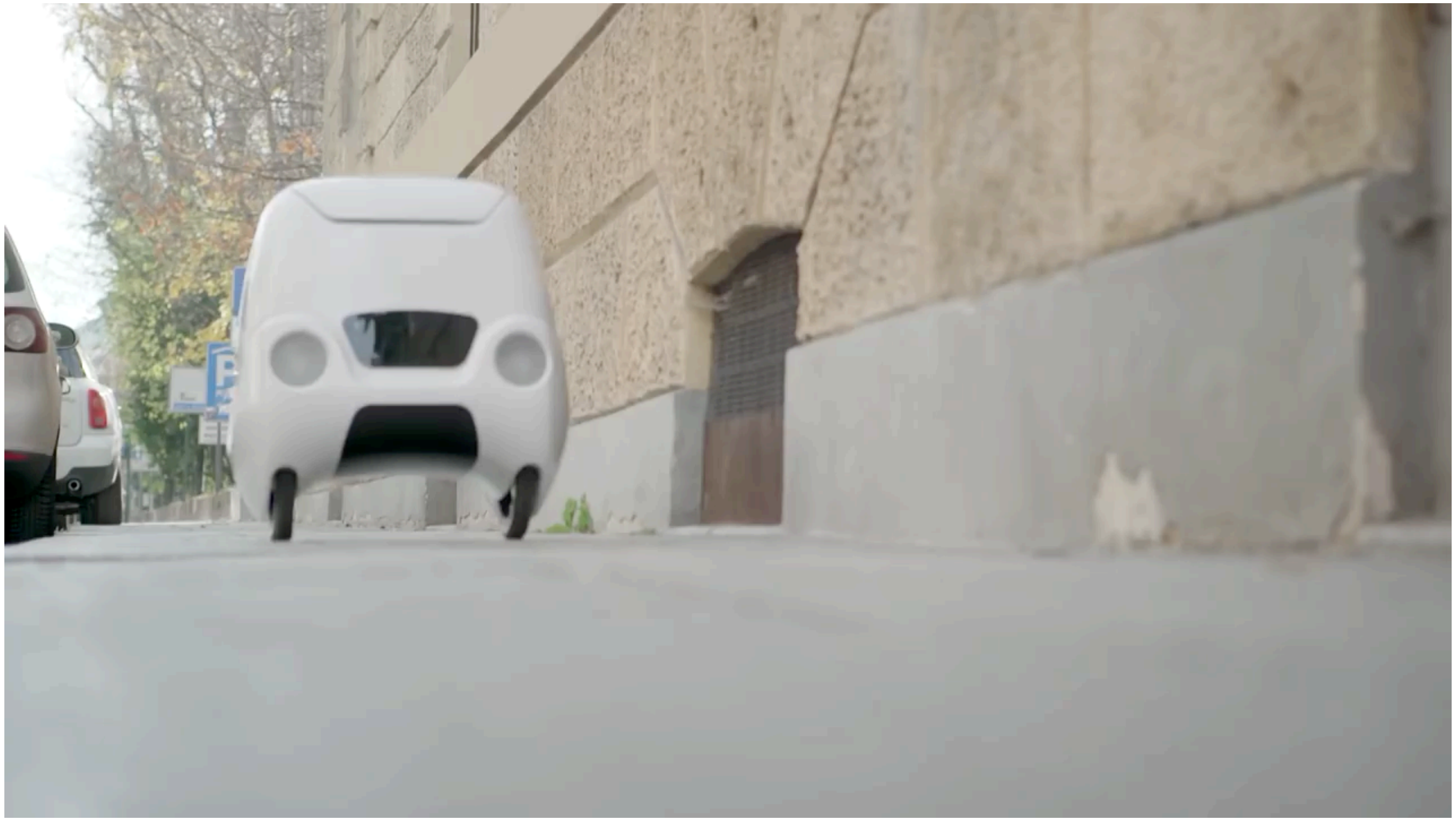
Spirit+Opportunity, Curiosity,
Perseverance+Ingenuity
by NASA
(planetary exploration)



gallery

on wheels/4

https://yapemobility.it



Yape by e-Novia
(urban transportation)

gallery

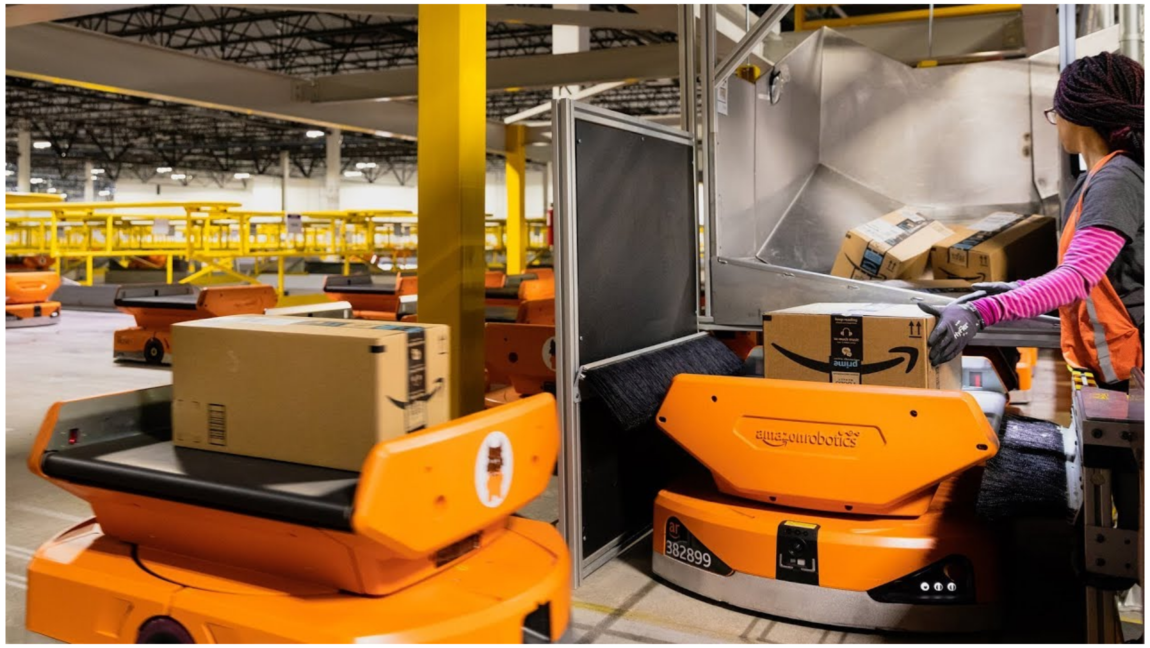
on wheels/5

https://mygita.com

Gita by Piaggio
(urban transportation)

gallery

on wheels/6

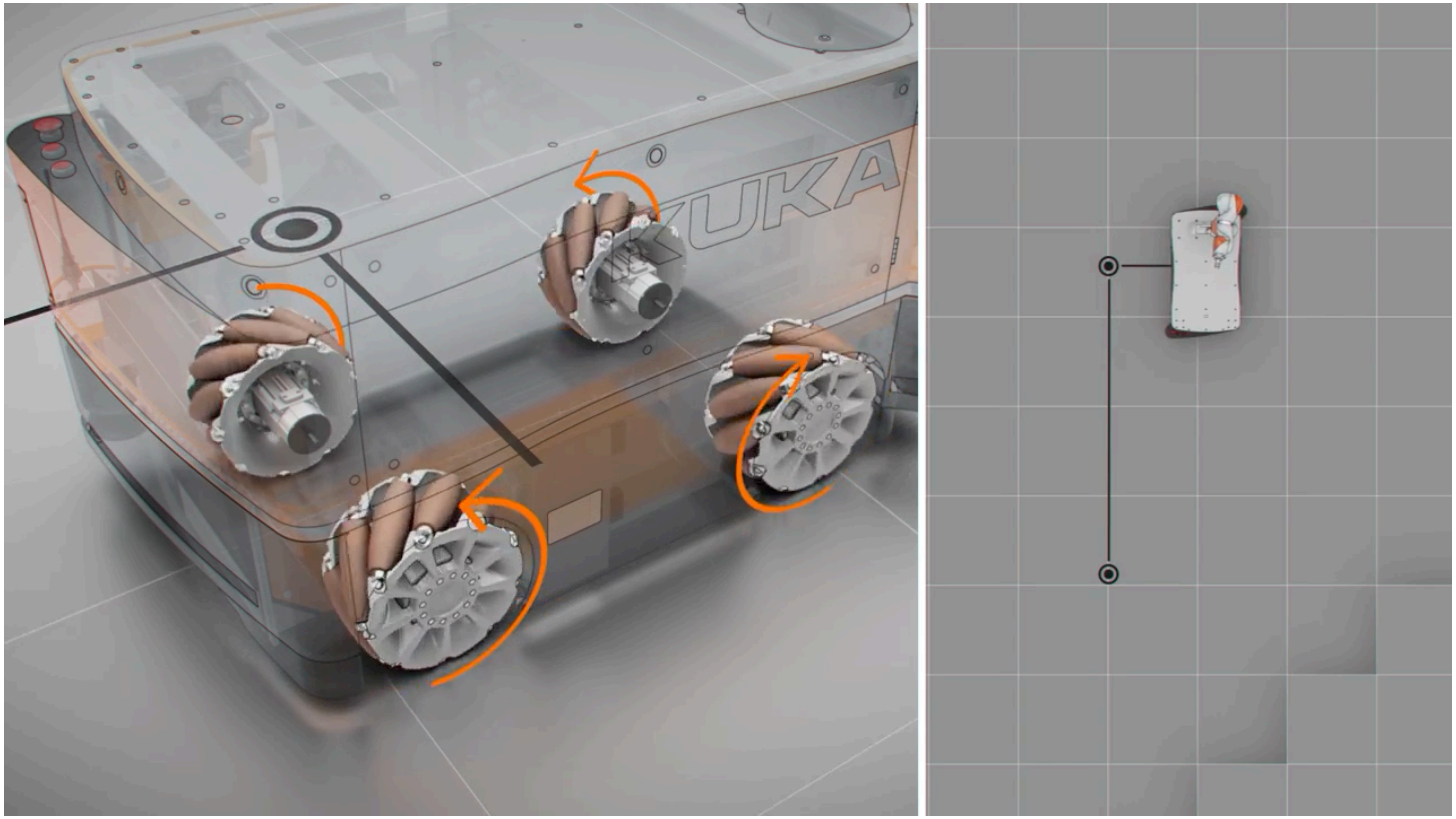


Amazon Robotics
ex-KIVA
(internal logistics)

gallery

on wheels/7

https://www.kuka.com

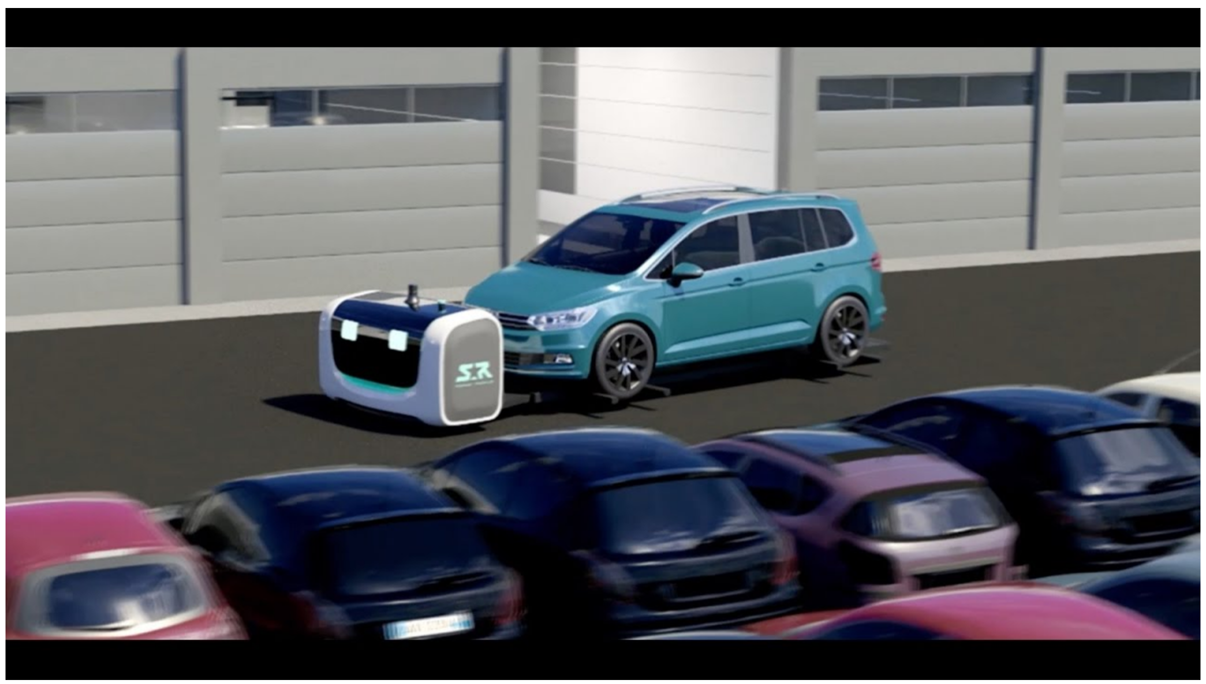


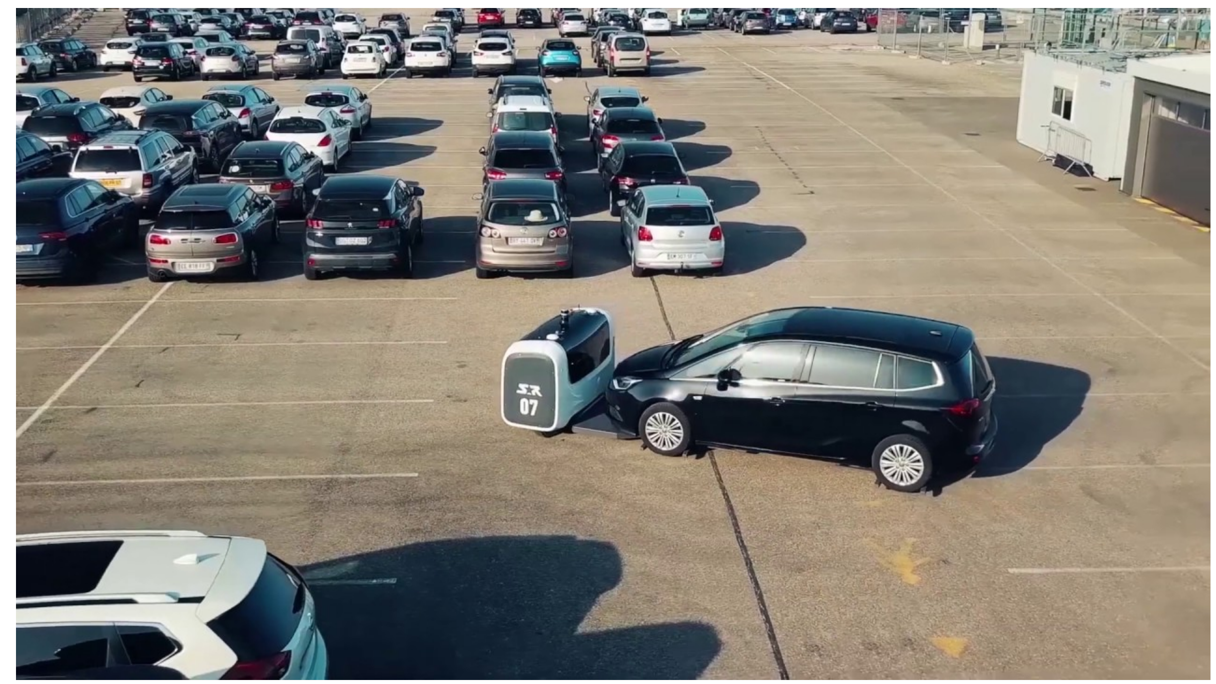
omniMove by KUKA
(internal logistics)

gallery

on wheels/8

https://stanley-robotics.com

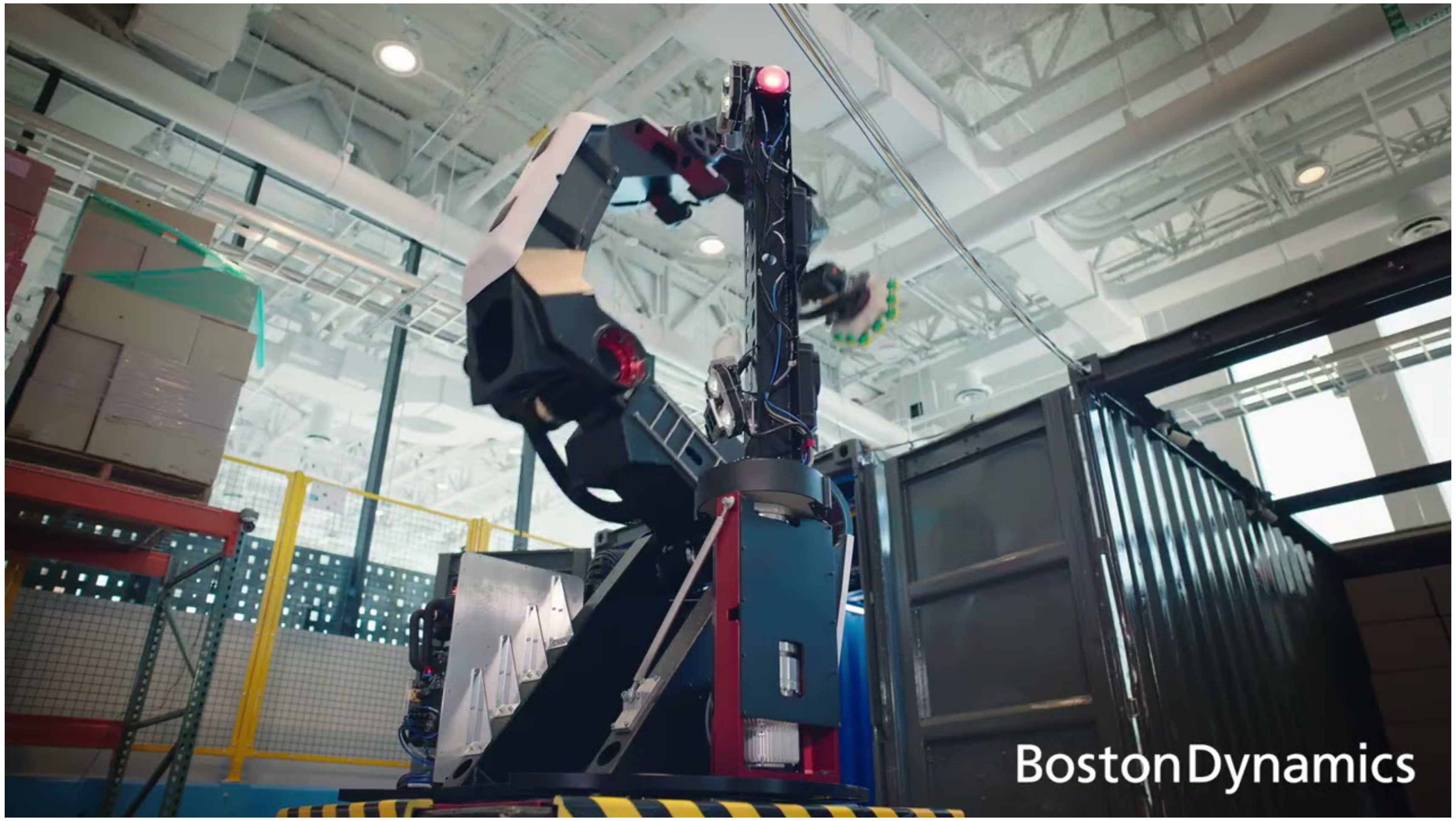




Stan by Stanley Robotics
(automated parking)

gallery

on wheels/9



Stretch by Boston Dynamics
(internal logistics)

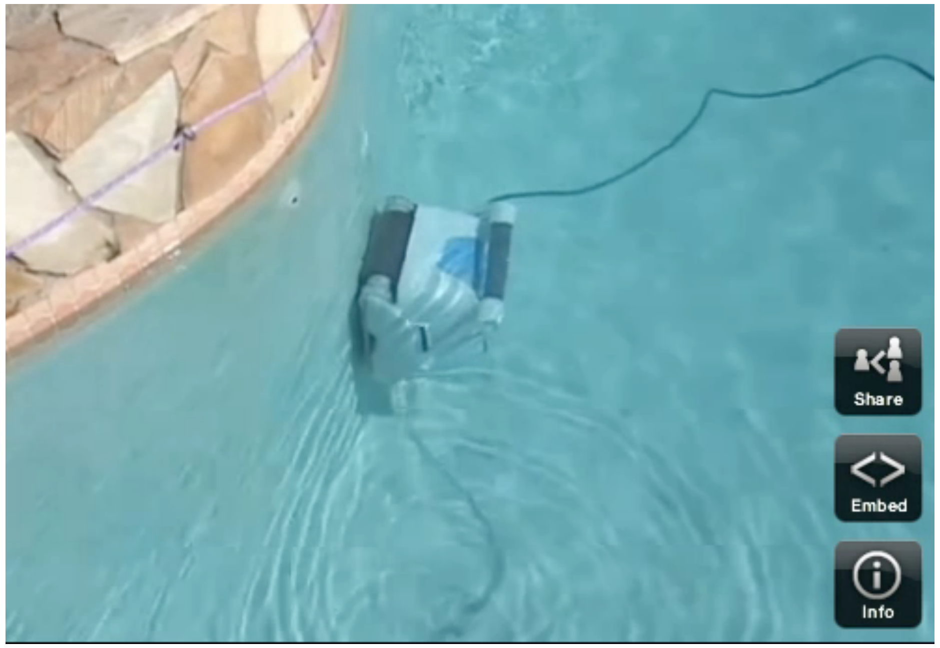
gallery

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

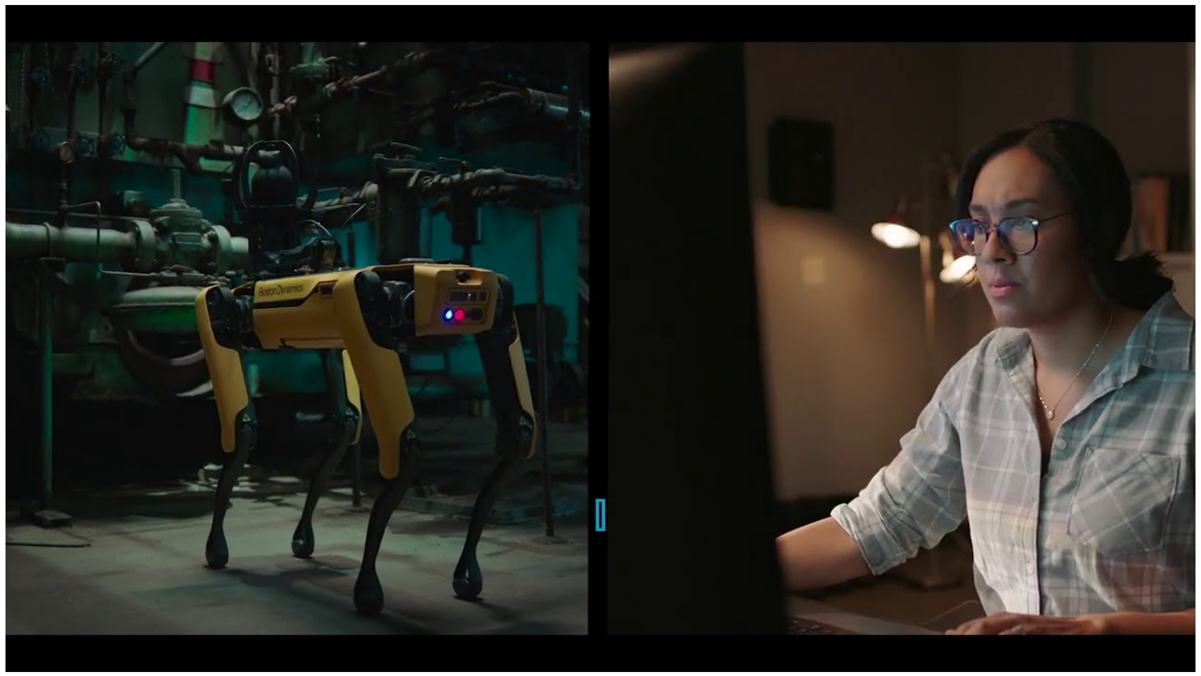
BigDog and LS3
by Boston Dynamics
(military transportation)

https://bostondynamics.com/legacy/

gallery

on legs/2

https://bostondynamics.com/products/spot/



Spot by Boston Dynamics
(remote monitoring
and intervention)

gallery

on legs/3

Cheetah
by MIT
(research)

ANYmal
by ANYbotics
(inspection)

gallery

on legs/4

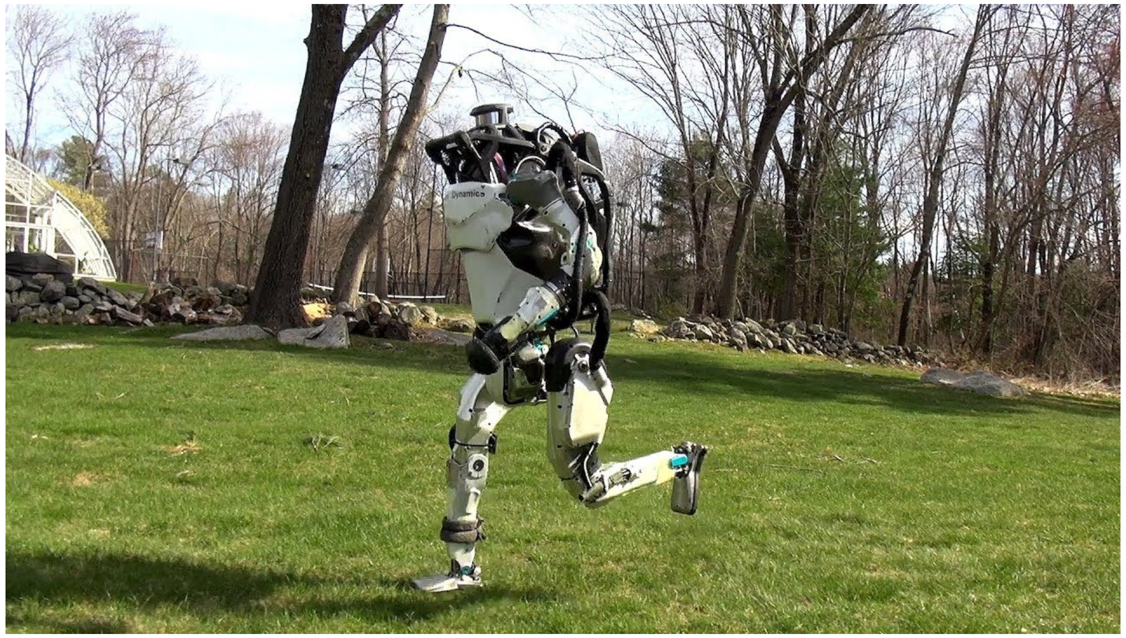
https://global.honda/en/robotics/

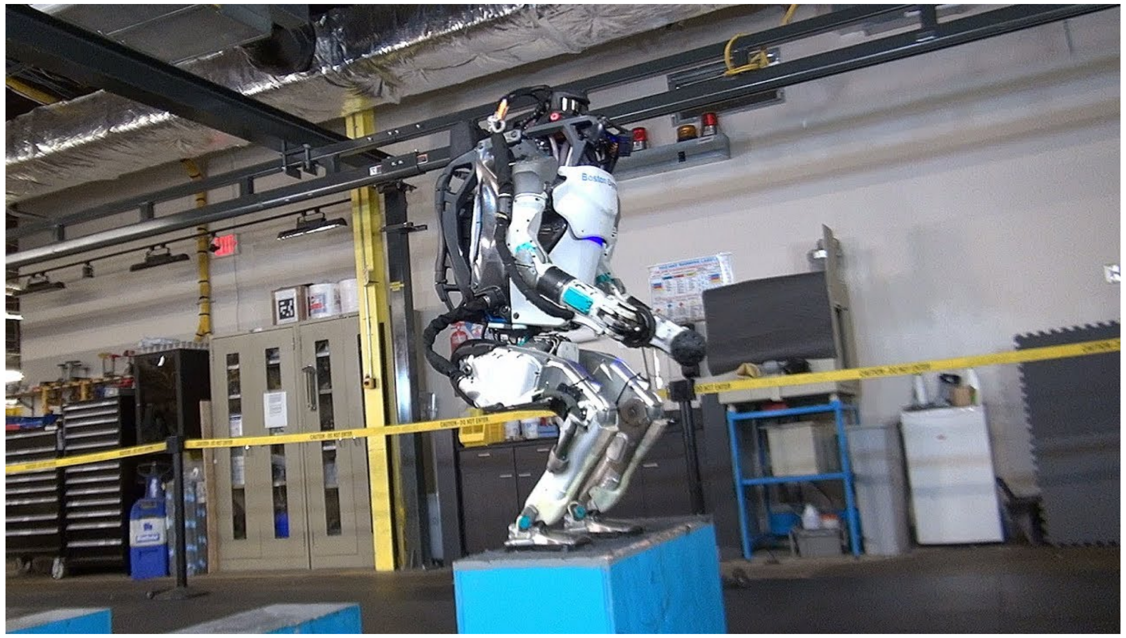
ASIMO by Honda
(research)

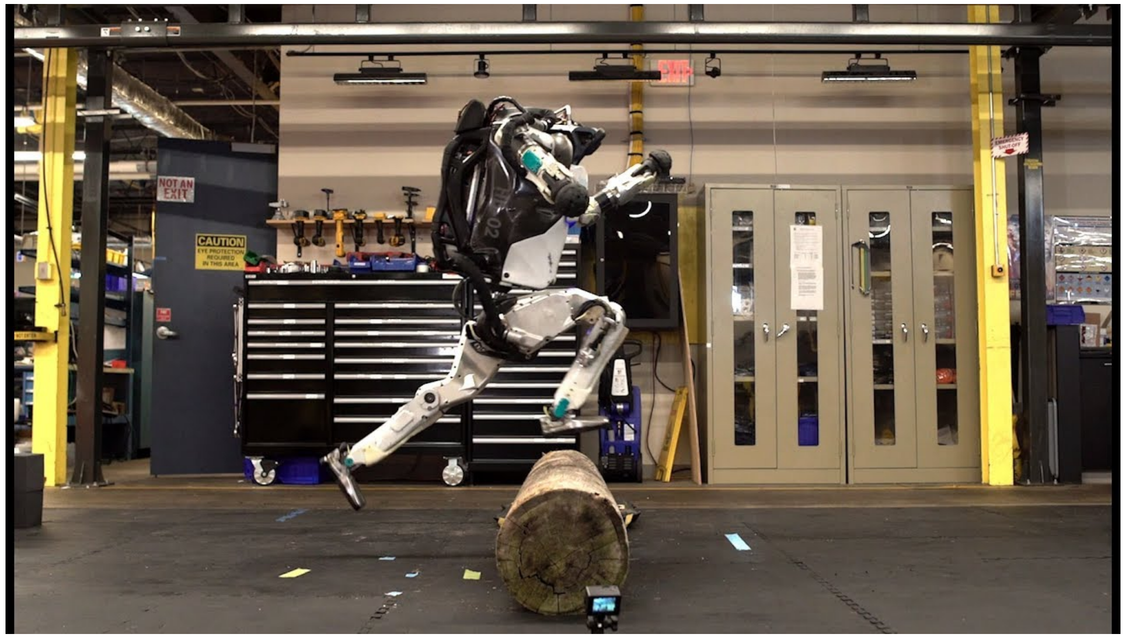
gallery

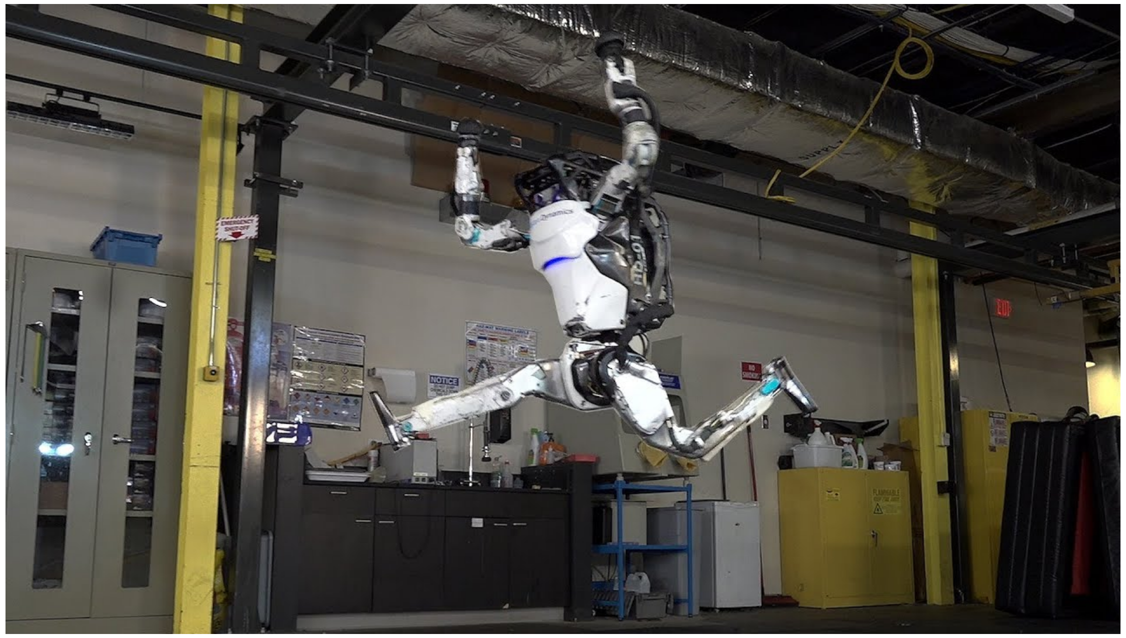
on legs/5

ATLAS by Boston Dynamics
(research)









gallery

flying

Skydio 2 by Skydio
(aerial cinematography)

Amazon Prime Air
(delivery)

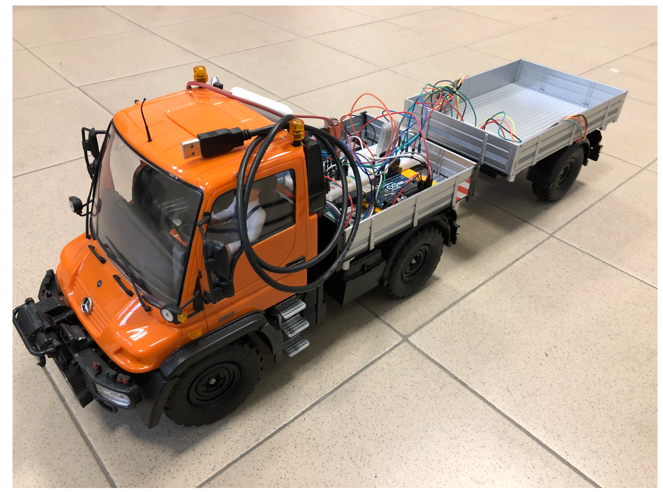
gallery

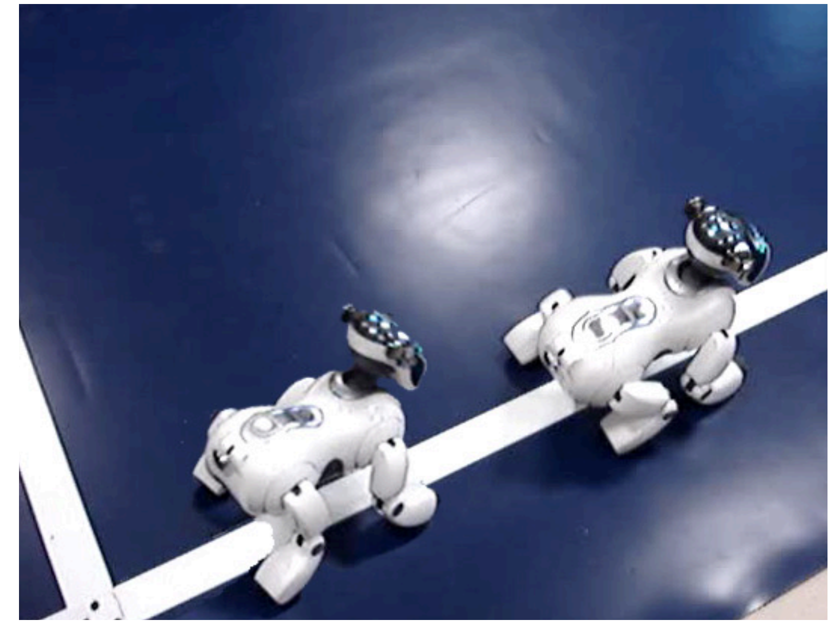
underwater

Seagoo ROV
(inspection)

Aquanaut by
Houston Mechatronics
(underwater operation)

at DIAG Robotics Lab





Kheperas

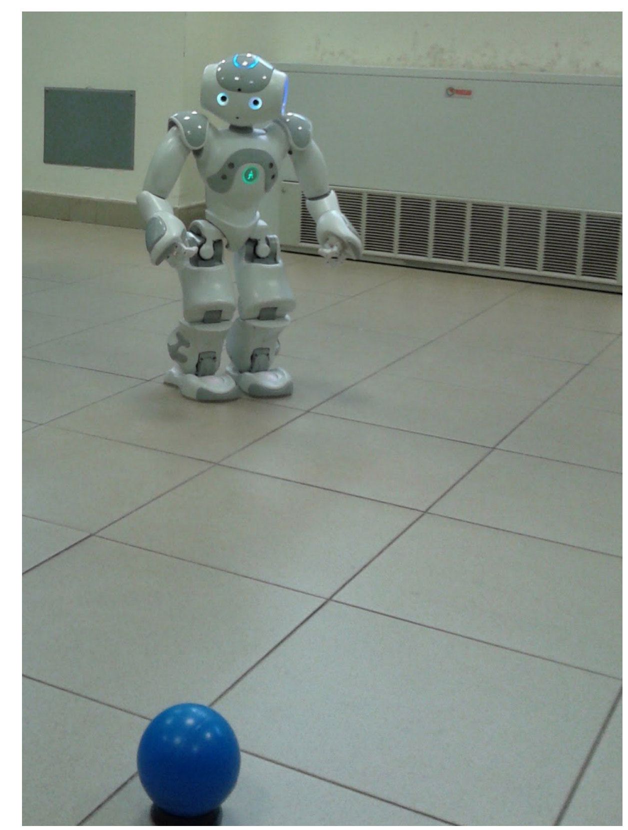
tractor-trailer prototype

AIBOs

NAOs

MagellanPro

Hummingbird, Pelican



at DIAG Robotics Lab

TIAGo

Duckietown

OP3

at DIAG Robotics Lab

G1

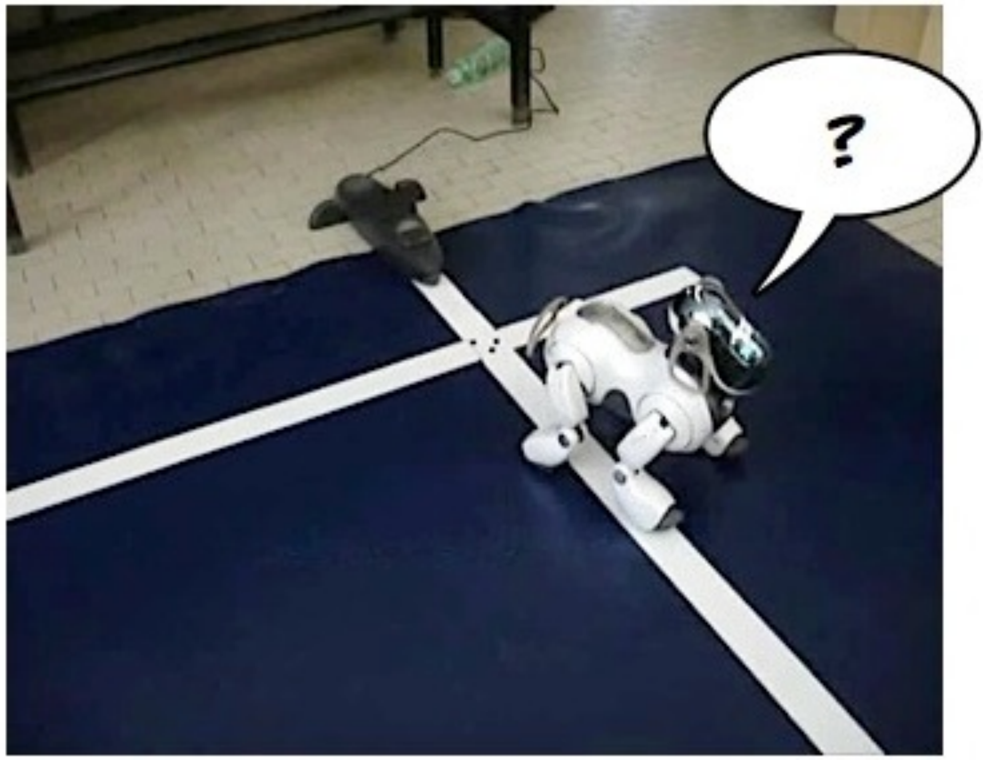
TITA

Lite3

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)

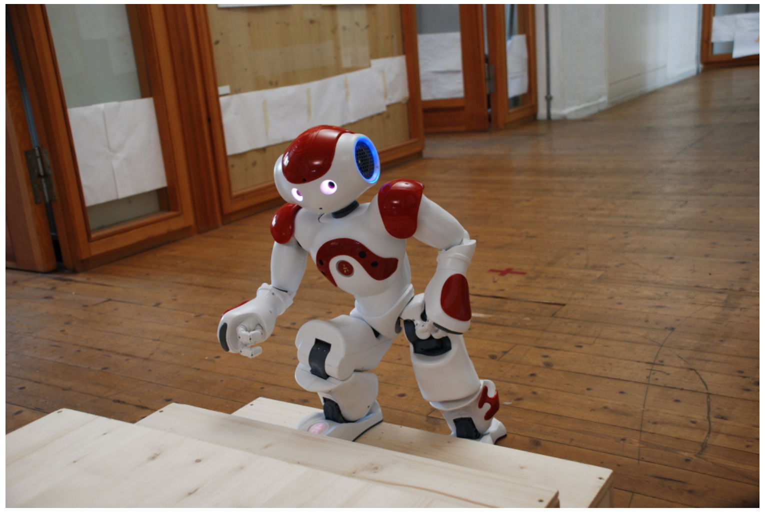
	fixed-base manipulators	single-body wheeled mobile robots
1. localization	easy (thanks to fixed-base and joint encoders)	difficult
2a. path/trajectory planning	easy (all paths are feasible)	difficult (not all paths are feasible)
2b. motion planning	difficult (many dof's)	more difficult (not all paths 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

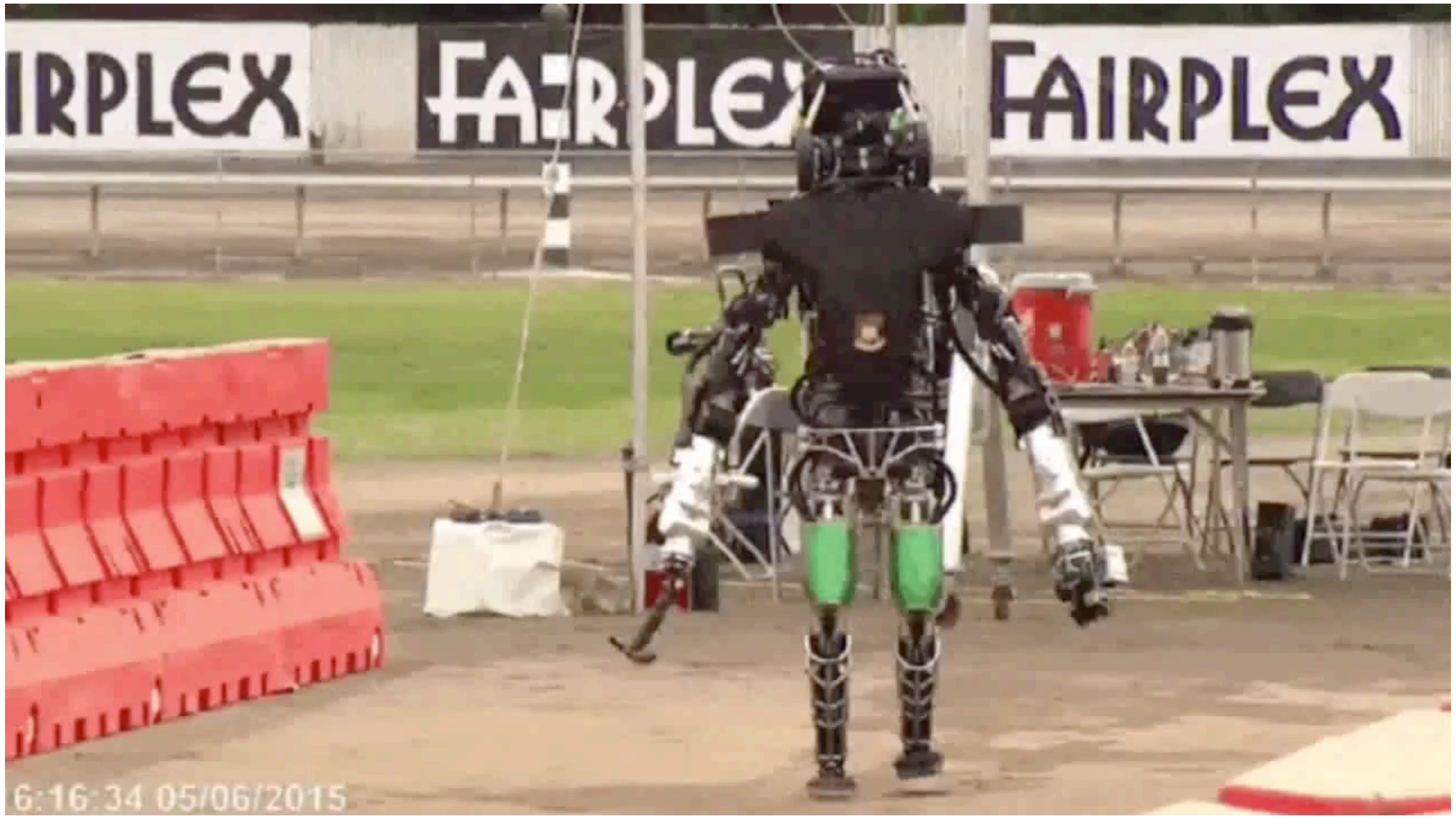


autonomy

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



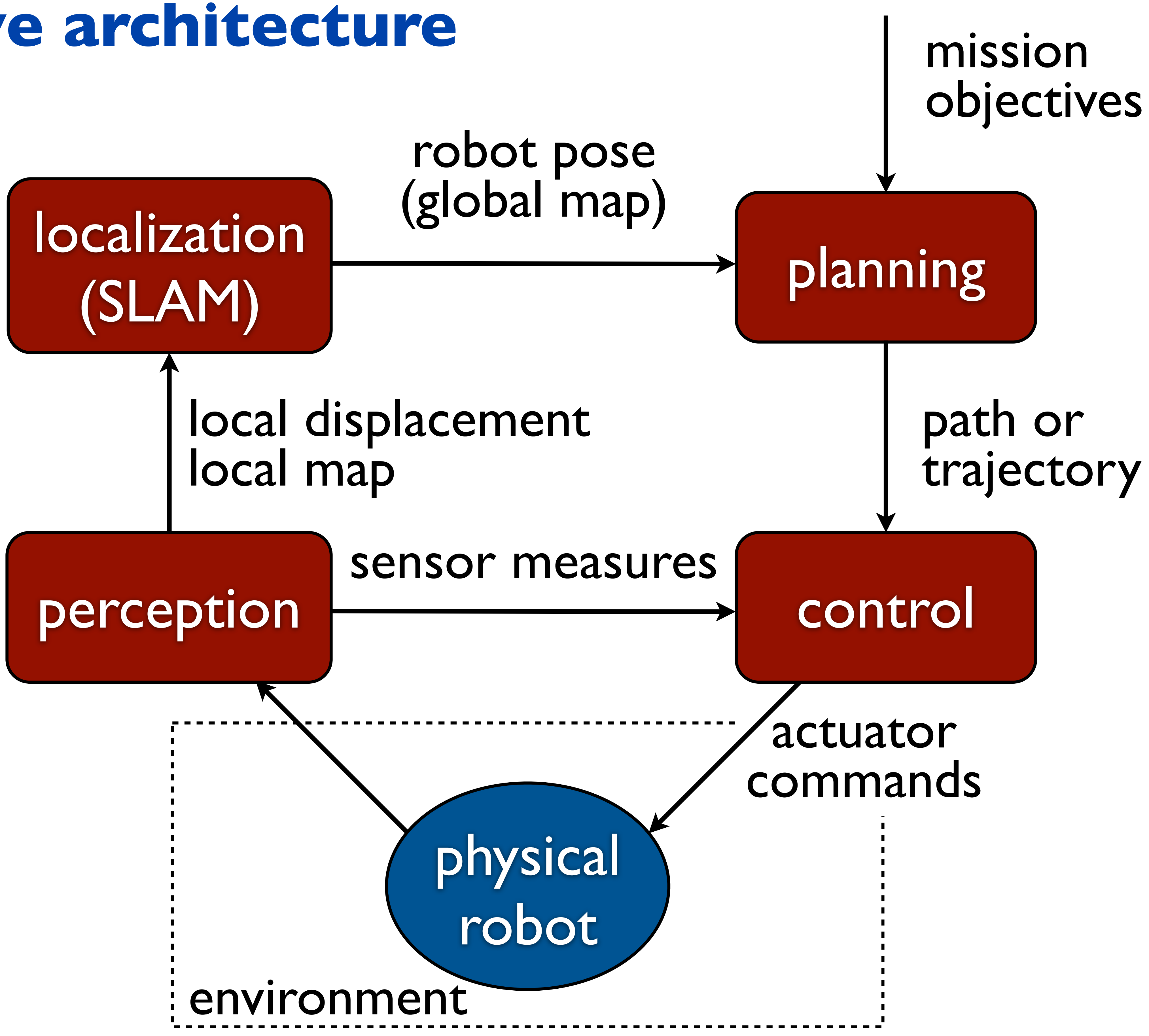
DARPA
Robotics
Challenge
2015

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)

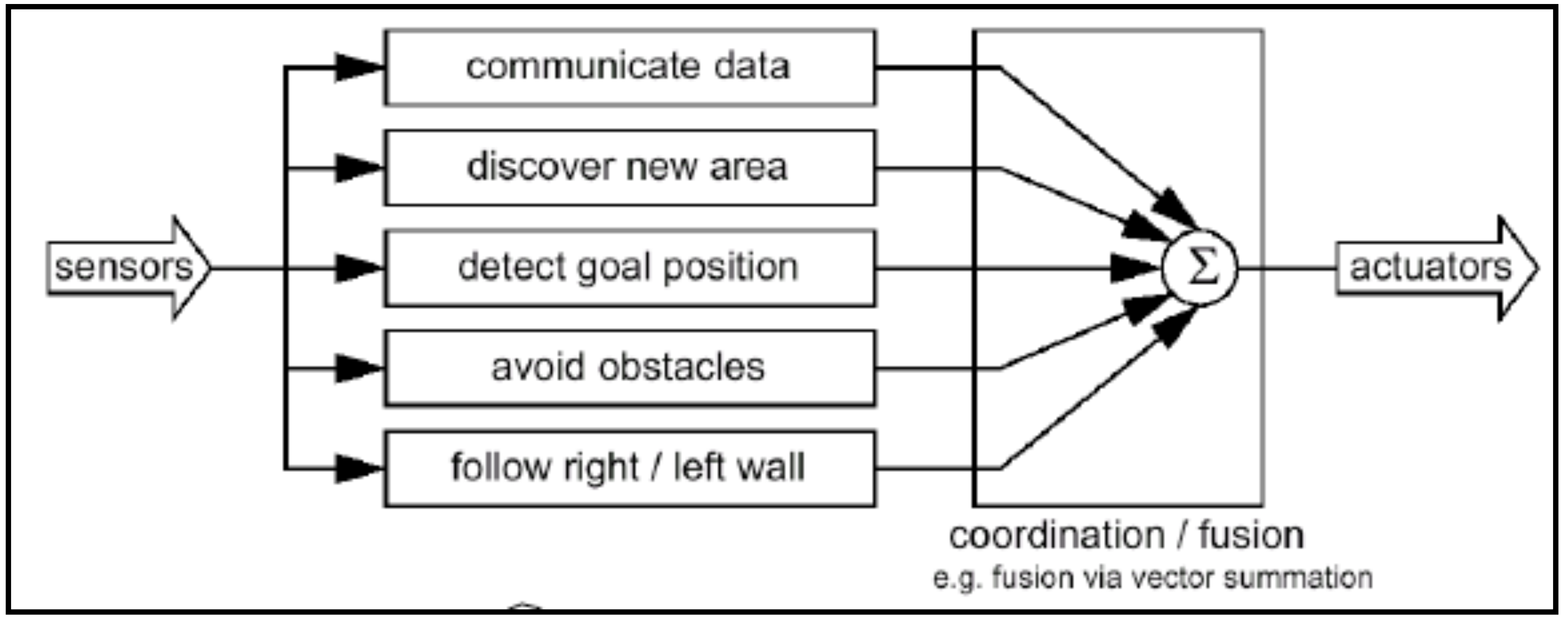
deliberative architecture



"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.



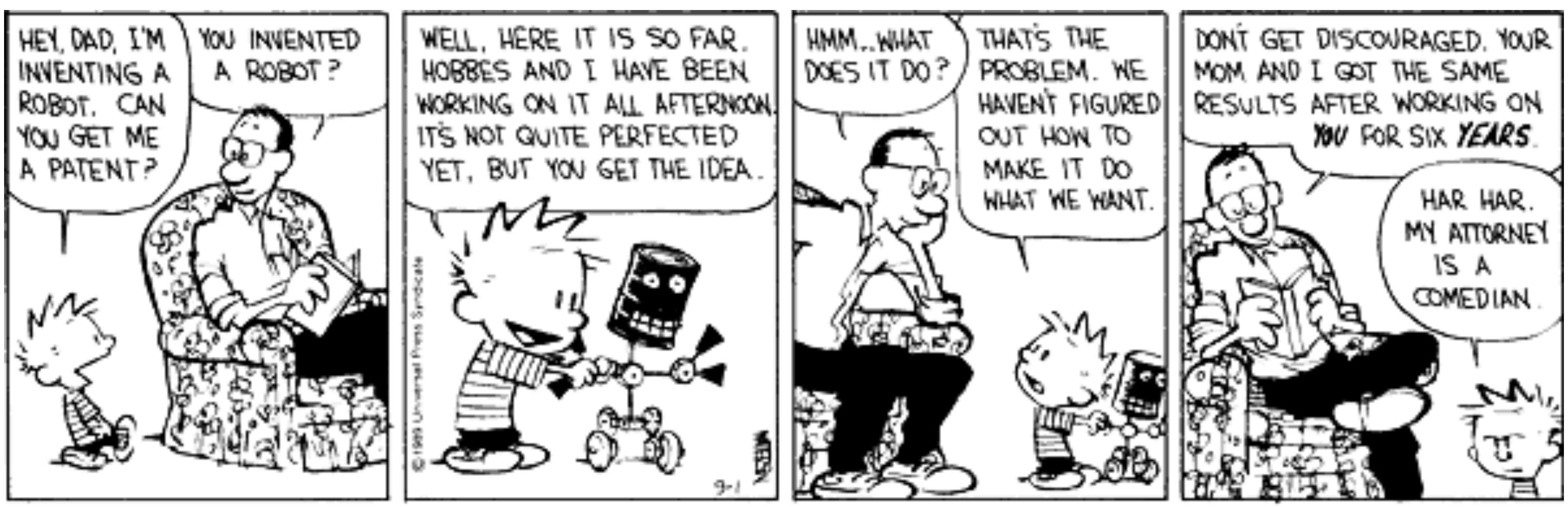
taken from "Introduction to Autonomous Mobile Robots"

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!

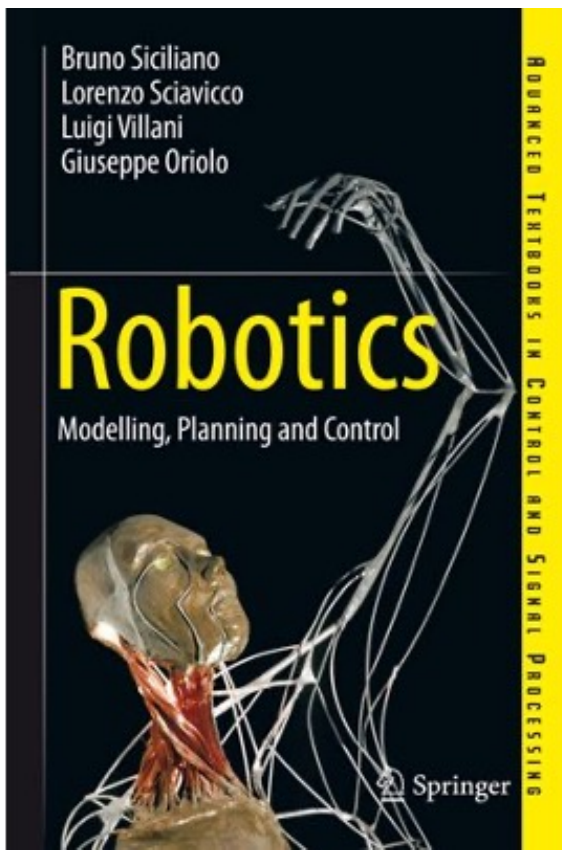


syllabus (preliminary)

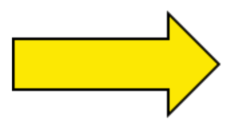
1. Introduction: Applications, Problems, Architectures
2. Configuration space
3. Wheeled Mobile Robots 1: Mechanics of mobile robots
4. Wheeled Mobile Robots 2: Kinematic models of mobile robots
5. Wheeled Mobile Robots 3: Path/trajectory planning
6. Wheeled Mobile Robots 4: Trajectory tracking
7. Wheeled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

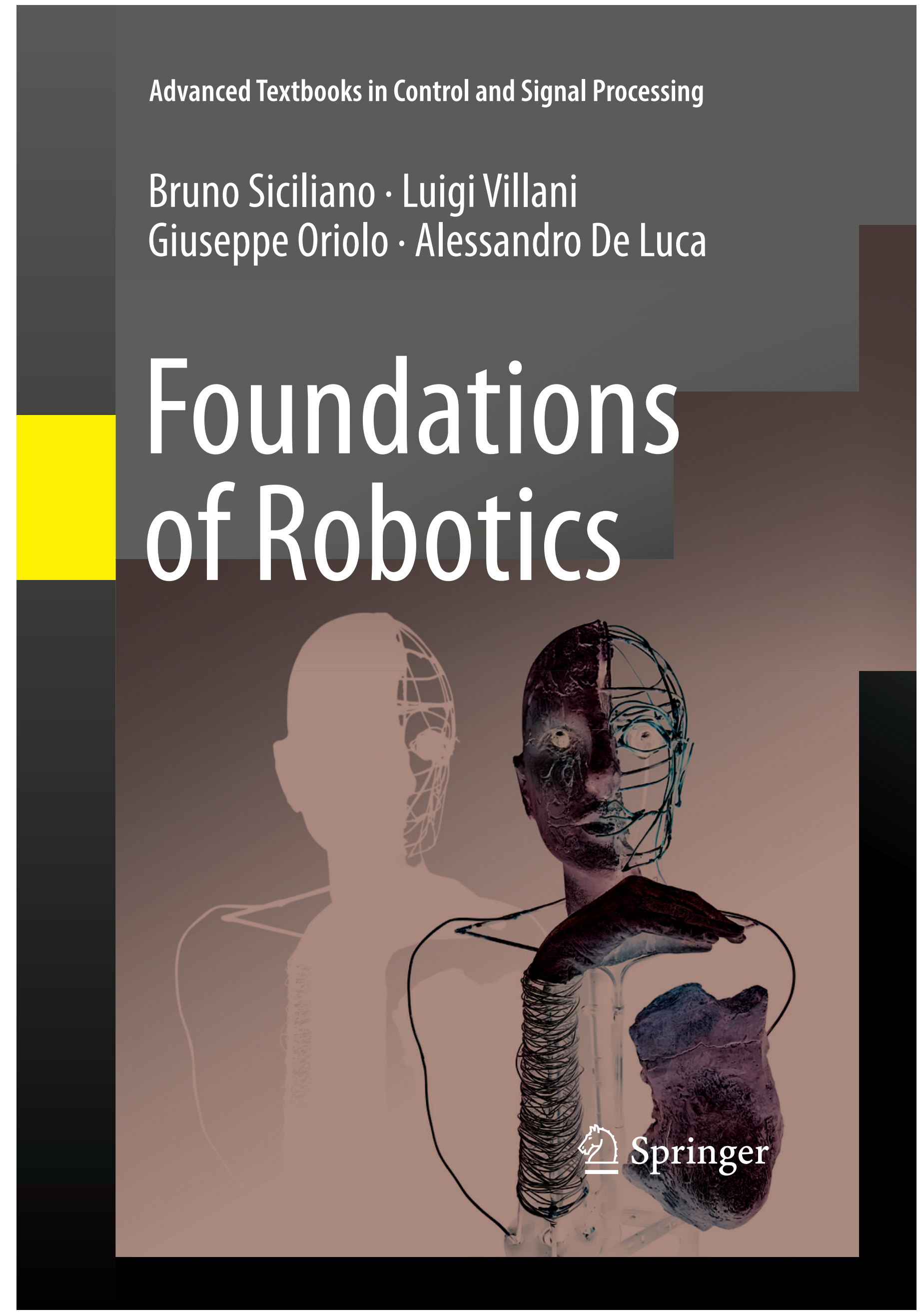
a new textbook!

https://link.springer.com/book/10.1007/978-3-031-85523-8



worldwide best seller since 2009
(with Italian, Chinese, Greek editions)





published on
September 6, 2025
(eBook, Hardcover, Softcover)

textbooks and other material

- Siciliano, Villani, Oriolo, De Luca, *Foundations of Robotics*, Springer, 2025
  [the main reference for the whole course]

- Choset, Lynch, Hutchinson, Kantor, Burgard, Kavraki, Thrun, *Principles of Robot Motion: Theory, Algorithms and Implementations*, MIT Press, 2005
  [a useful reference for selected topics]

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

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.therobotreport.com/
- https://www.youtube.com/user/RoboticsLabSapienza