Humanoid Robotics

Introduction

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UNIVERSITÄT BONN

About This Lecture

- Introduction to **perception**, **manipulation**, and **locomotion** of humanoid robots
- Basic principles as well as selected state-of-the-art approaches
- Goal: students gain theoretical and practical knowledge in the area of humanoid robotics
- Slides will be provided on the web page

Content

- Sensing and perception
- World representations
- Active perception
- Inverse kinematics, arm motion planning
- Trajectory generation and optimization
- Grasping and pushing
- Visual servoing
- Interactive perception
- Balance control
- Walking
- Footstep planning

General Information

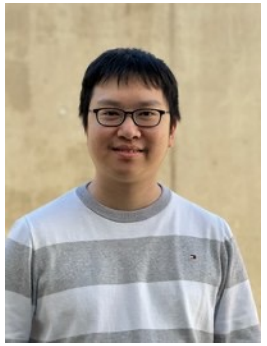
- **Lecture:** usually Thursdays (but exceptions, see schedule on webpage)
- **Tutorial:** two hours, usually Tuesdays
- **Exercise sheets**
  - **Ungraded**: Conceptual and programming problems
  - **Graded (3,6,9)**: Conceptual and numerical problems
- Prerequisite for exam attendance: **50%** of the maximum points from the **graded** sheets
- **Exam dates:** August 19 and September 29

Co-Organizers / Tutors

- Subham Agrawal
- Nils Dengler
- Shahram Khorshidi
- Rohit Menon
- Niklas Mueller-Goldingen
- Sicong Pan
- Ahmed Shokry
- Benno Wingender





https://www.hrl.uni-bonn.de/people

Tutorial / Exercise Sheets

- Weekly active participation highly recommended
- Focus on practical work and implementation of the approaches presented in the lecture
- Programming in Python
- Lecture+tutorial is a good preparation for the exam as well as for projects and theses in the area of humanoid robotics
- **Graded** sheets: Submission of solutions via IGG gitlab

Registration

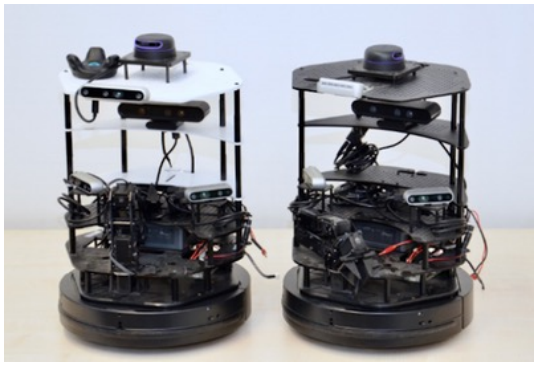
- Details on lecture webpage: https://www.hrl.uni-bonn.de/teaching/ss26/humanoid-robotics/
- Sign up on https://gitlab.igg.uni-bonn.de if no account
- Submit the registration form
  - Specify team partners
  - Provide Name, Matriculation Number and Gitlab ID
- Email hr_exercises@hrl.uni-bonn.de in case of any difficulties
- **Registration deadline: April 22, 2026**

Robot Taxonomy

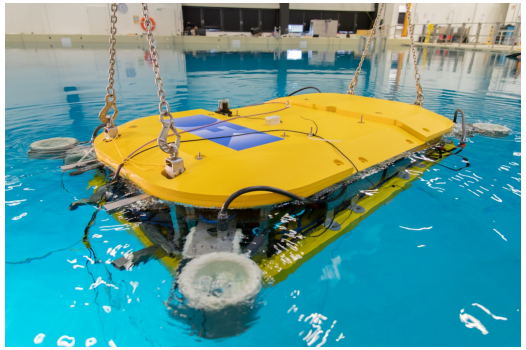
Robots differ along multiple dimensions:

- Embodiment
- Environment
- Contact/manipulation capability
- Autonomy level

Hybrid Wheeled-Legged Quadruped

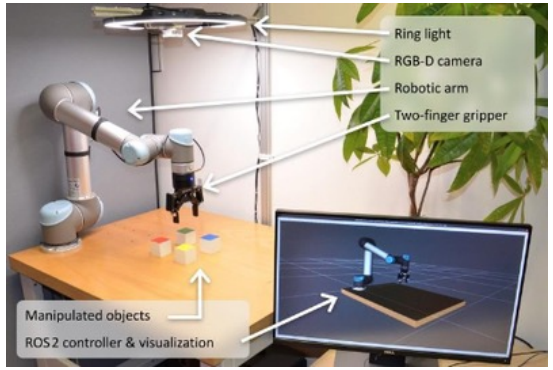


Wheeled Mobile Robot



Thruster based AUV

UAV/Drone



Fixed Manipulator

Wheeled Mobile Manipulator

Legged Quadruped

Bipedal Humanoid

Vision: Service Robots as Assistants in Domestic Environments

source: Tesla

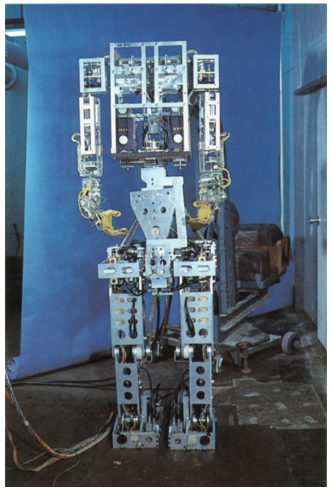
source: Honda

Why Humanoids?

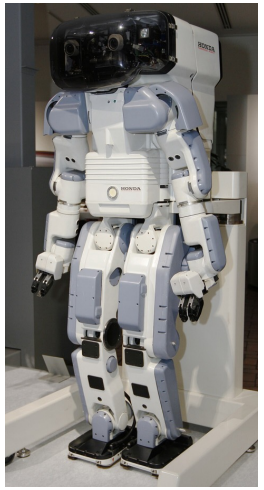
- Designed for **human environments** with existing infrastructure
- Enable **general-purpose task execution** across diverse scenarios
- Platform for integrated perception, planning, and control
- Study of whole-body control and dynamic balance
- **Natural interaction** in shared human environments
- **Humans empathize** with anthropomorphic forms

Early Humanoid Robots

- **1970s–1990s:** Early prototypes with limited locomotion
- **2000s:** Stable biped walking and basic interaction
- **2010s:** Dynamic control and improved perception
- **Late 2010s:** Agile behaviours in real-world environments



WABOT-1, 1973



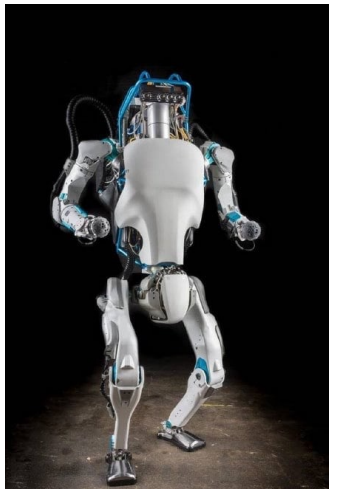
Honda P2, 1996

Honda ASIMO, 2005

Nao Robot, 2008

HRP-4, 2010

DLR TORO, 2013

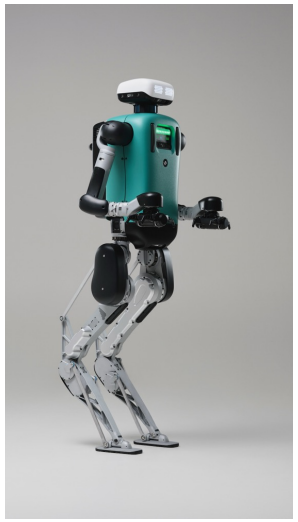


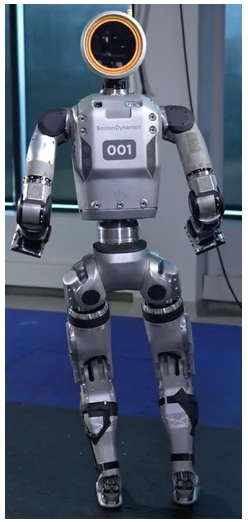
Boston Dynamics Atlas, 2016

The "Cambrian Explosion" of Humanoids

- **~2020–present:** Rapid increase in humanoid platforms
- Advances in **learning-based control** and **large-scale data**
- **Improved hardware:** actuators, batteries, sensing systems
- **Strong industrial push** for general-purpose service robots

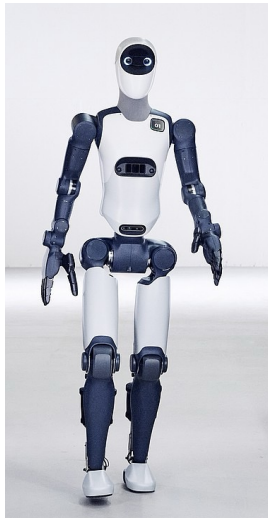
Unitree G1, 2023


Agility Robotics Digit, 2023



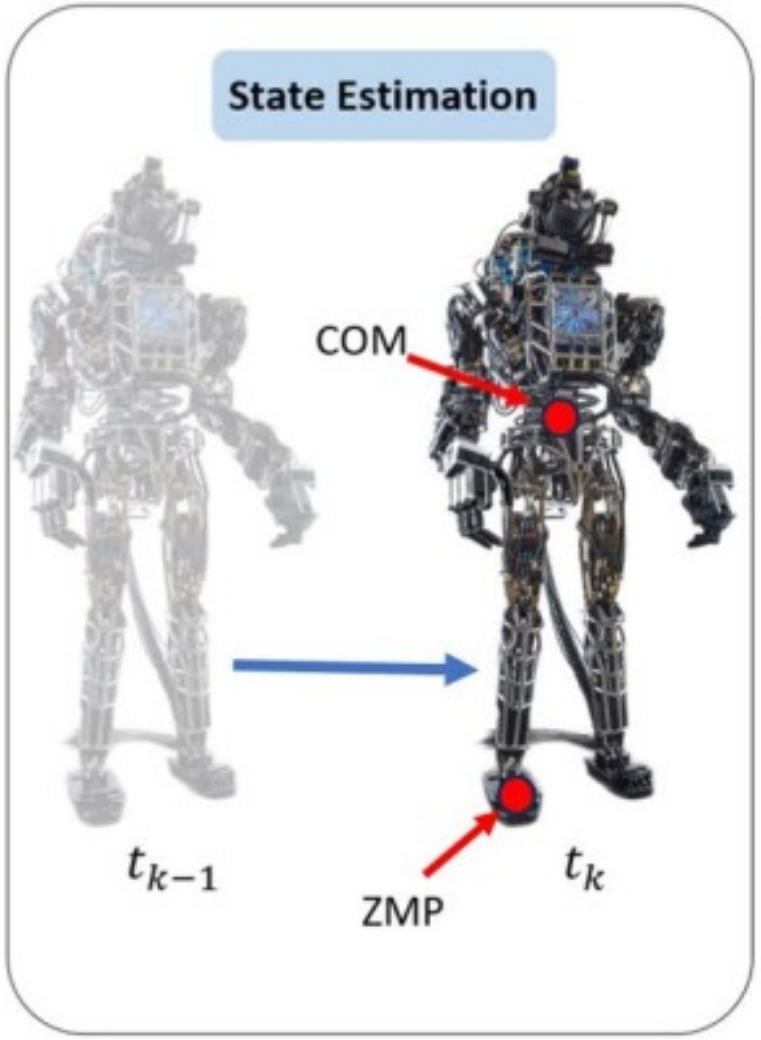
Boston Dynamics Atlas 02, 2024


Figure 03, 2025


Agile One, 2025

Challenges

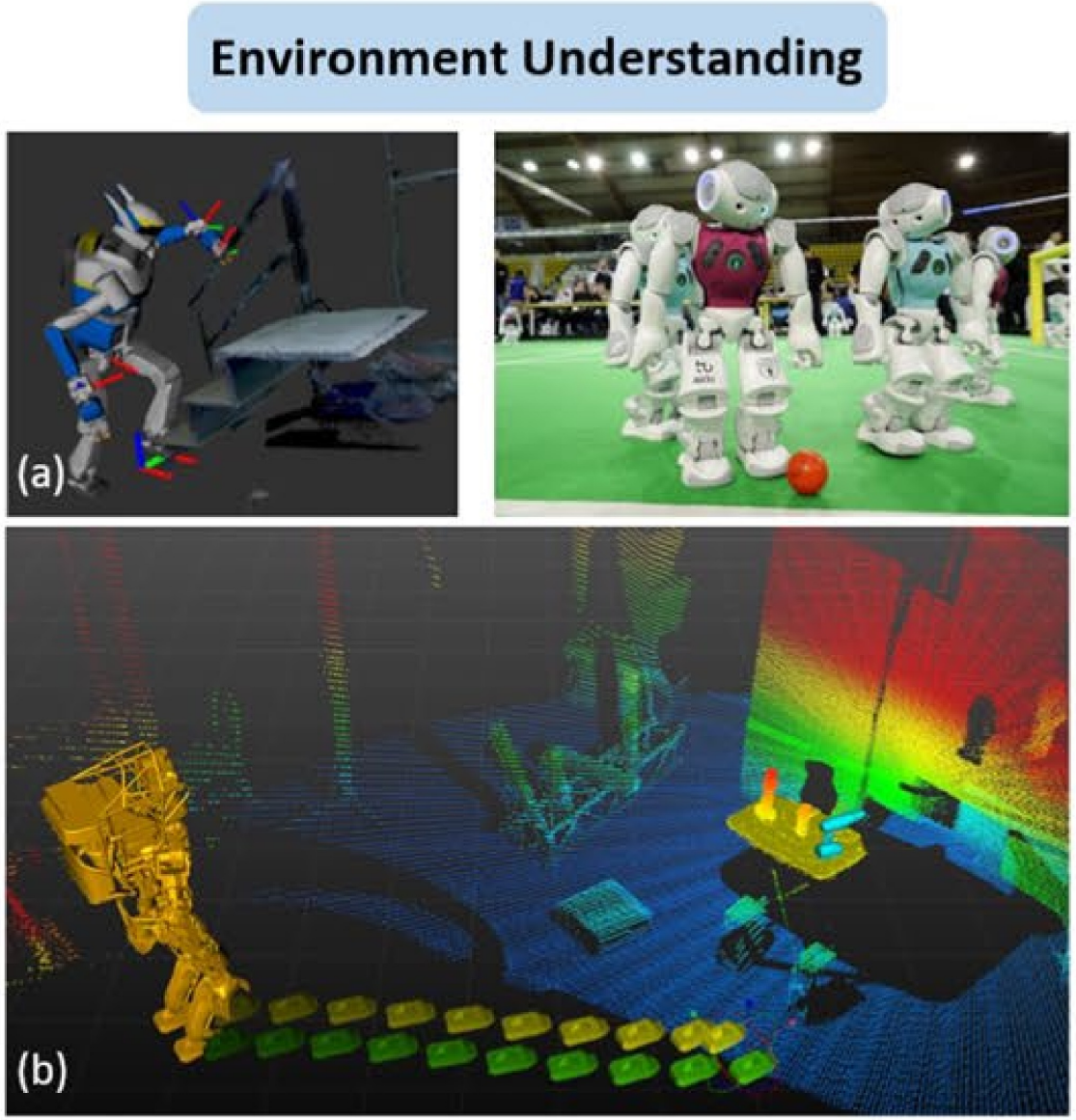
- Internal state estimation



Roychoudhury et al., 2023

Challenges

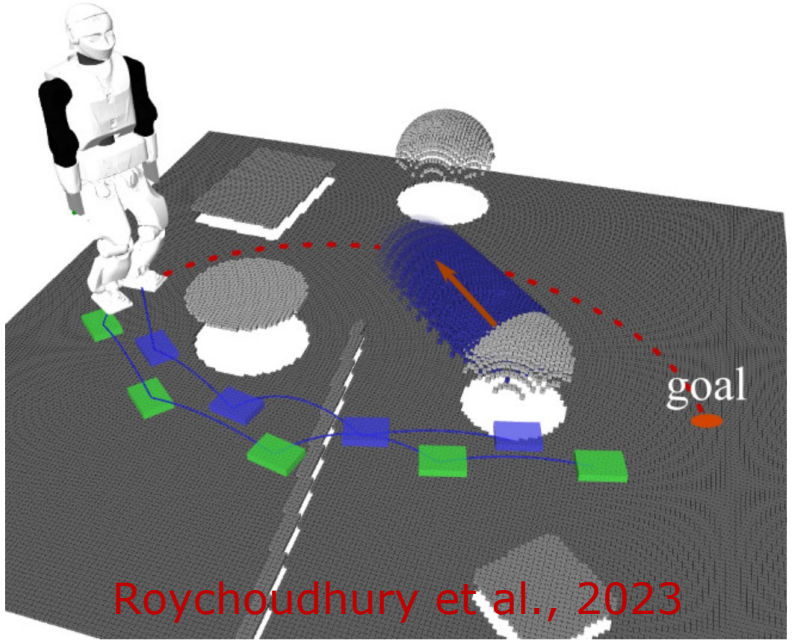
- Internal state estimation
- Environment perception and understanding

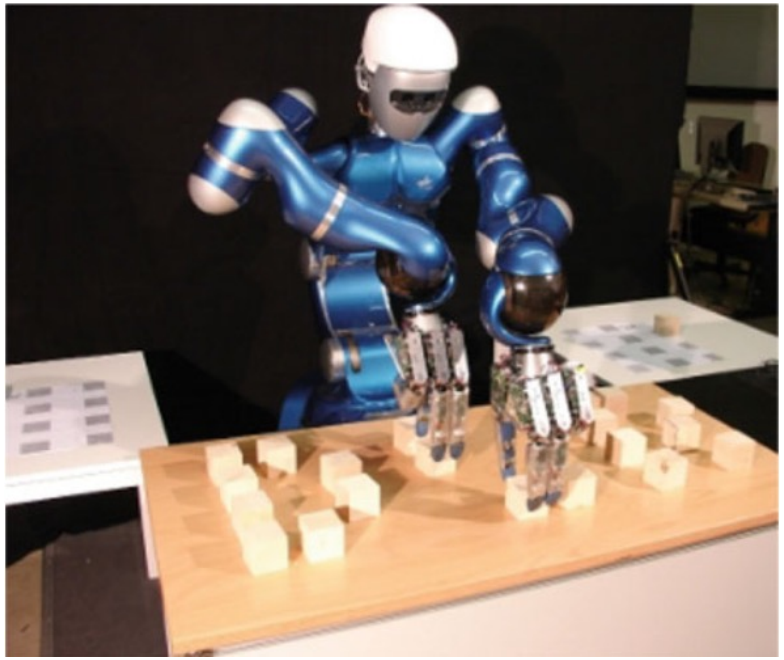


Roychoudhury et al., 2023

Challenges

- Internal state estimation
- Environment perception and understanding
- Planning navigation, locomotion and manipulation actions

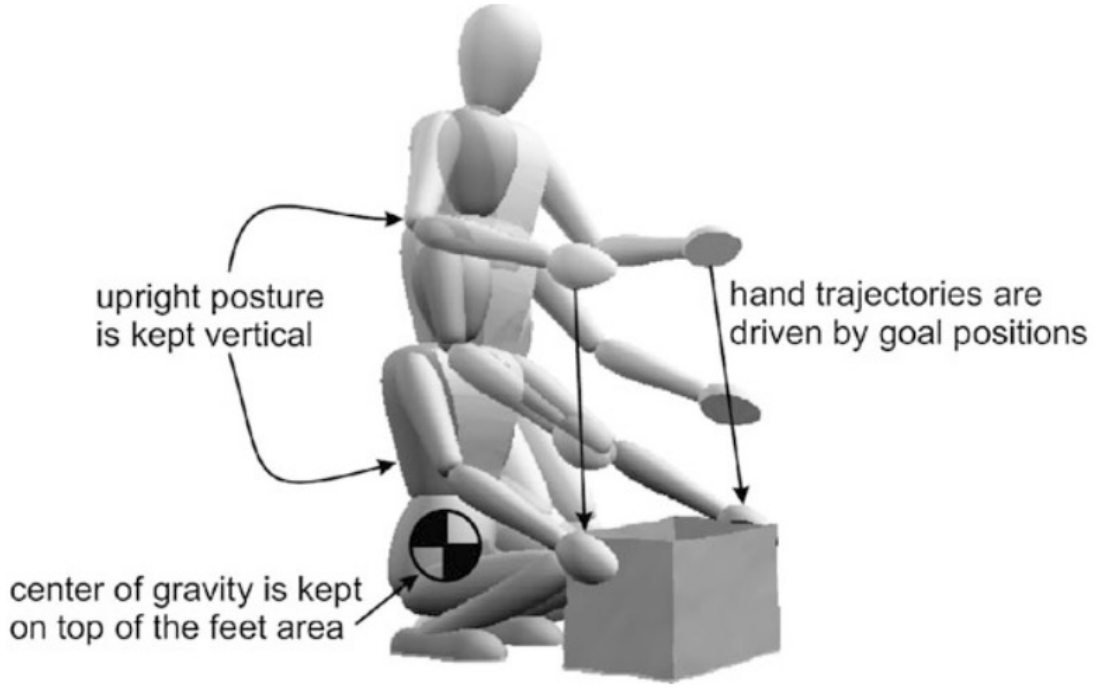




Goswami et al., 2019

Challenges

- Internal state estimation
- Environment perception and understanding
- Planning navigation, locomotion and manipulation actions
- Whole-body planning and control for dexterous motions and stability



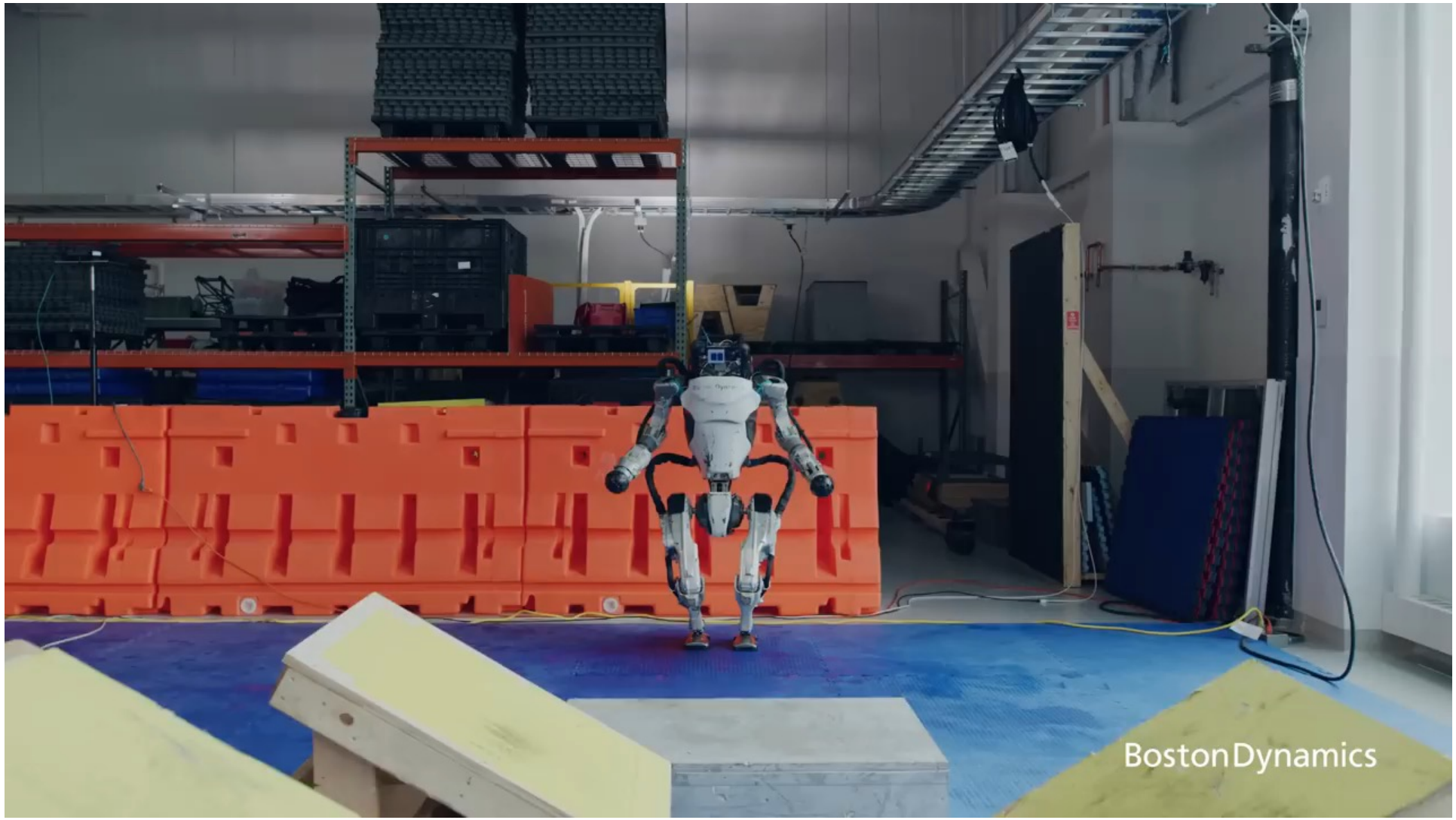
Goswami et al., 2019

Challenges

- Internal state estimation
- Environment perception and understanding
- Planning navigation, locomotion and manipulation actions
- Whole-body planning and control for dexterous motions and stability
- Safe and trustworthy human-robot interaction

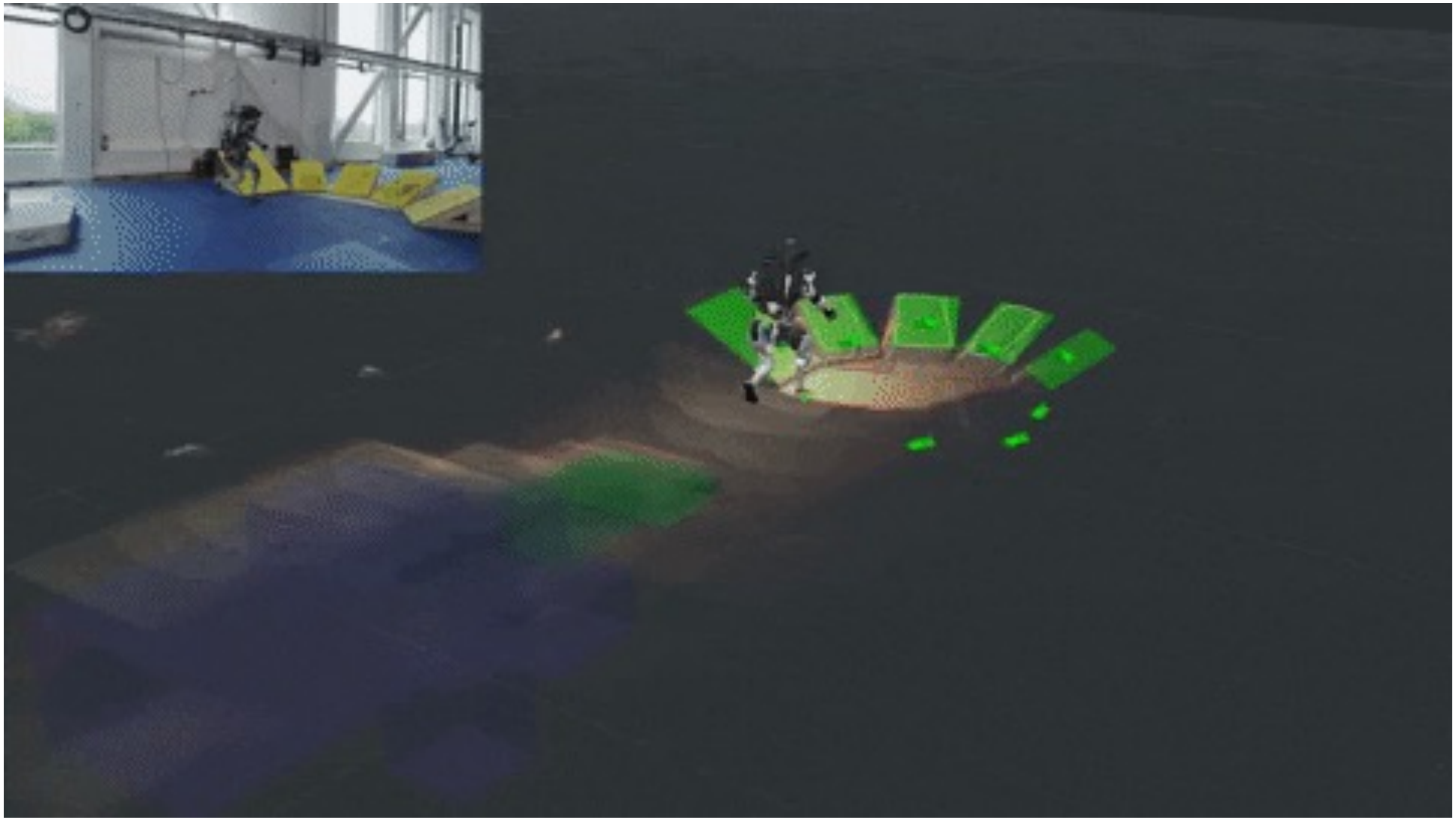
Goswami et al., 2019

Atlas Performing a Challenging Parkour



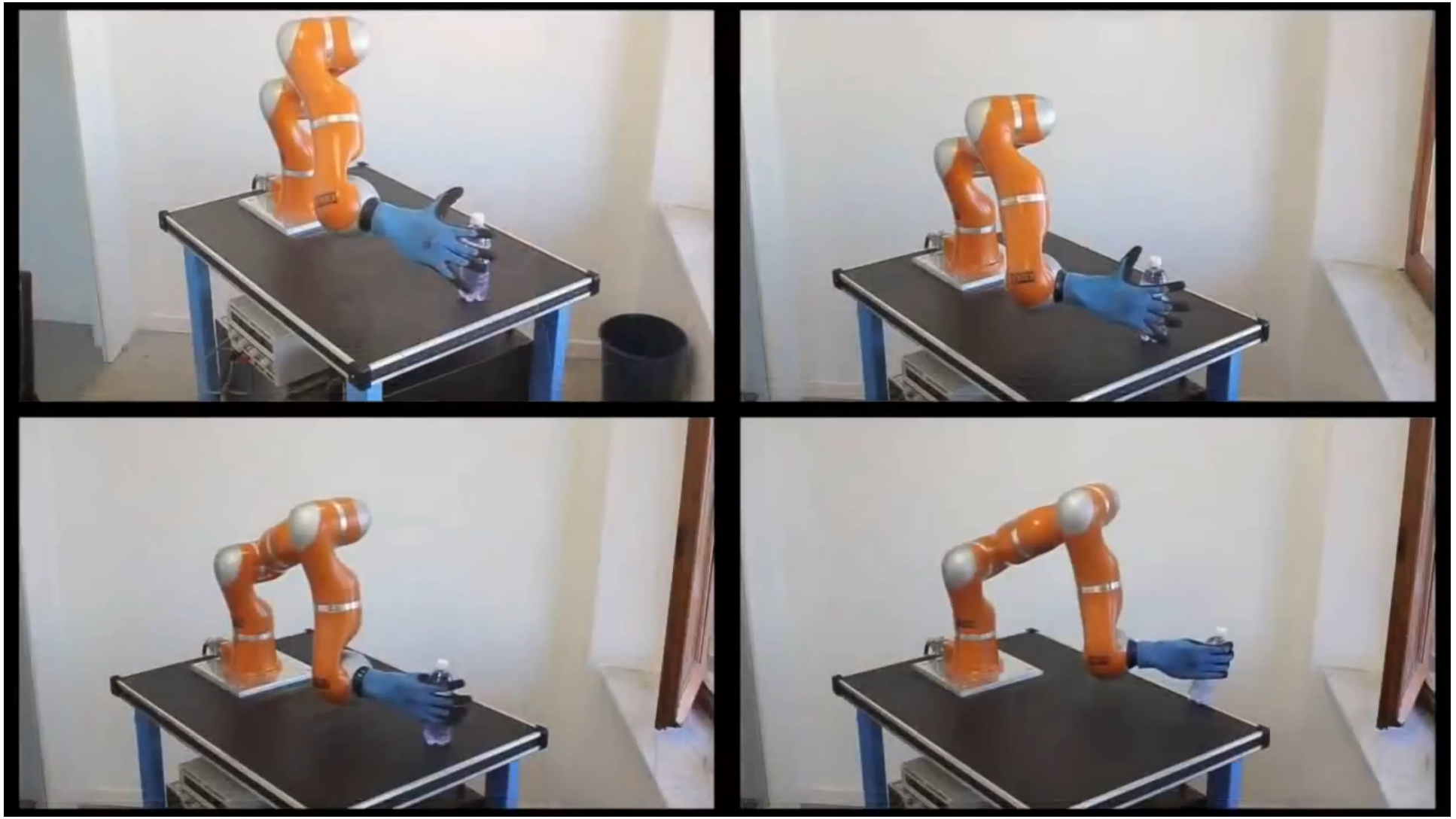
courtesy of Boston Dynamics

Environment Representation



courtesy of Boston Dynamics

Object Grasping and Manipulation



courtesy of IIT

Object Retrieval

About This Lecture

- Human-like robots are an exciting and active research area
- In this lecture, you will learn
  - How humanoid robots **perceive** the environment
  - How they **plan manipulation** actions and **execute** them
  - How they realize **walking** and **path planning**
  - …

Next Steps for You

- Register for the tutorial via website registration form
- Download the first exercise sheet from the web page
- Enjoy the lecture!