上海科技大学
ShanghaiTech University

CS289: **Mobile Manipulation Fall 2026**

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ShanghaiTech University

Outline

- Mobile Manipulation Intro & Definition
- Course Overview
- Software
- Brief History
- 3D Geometry

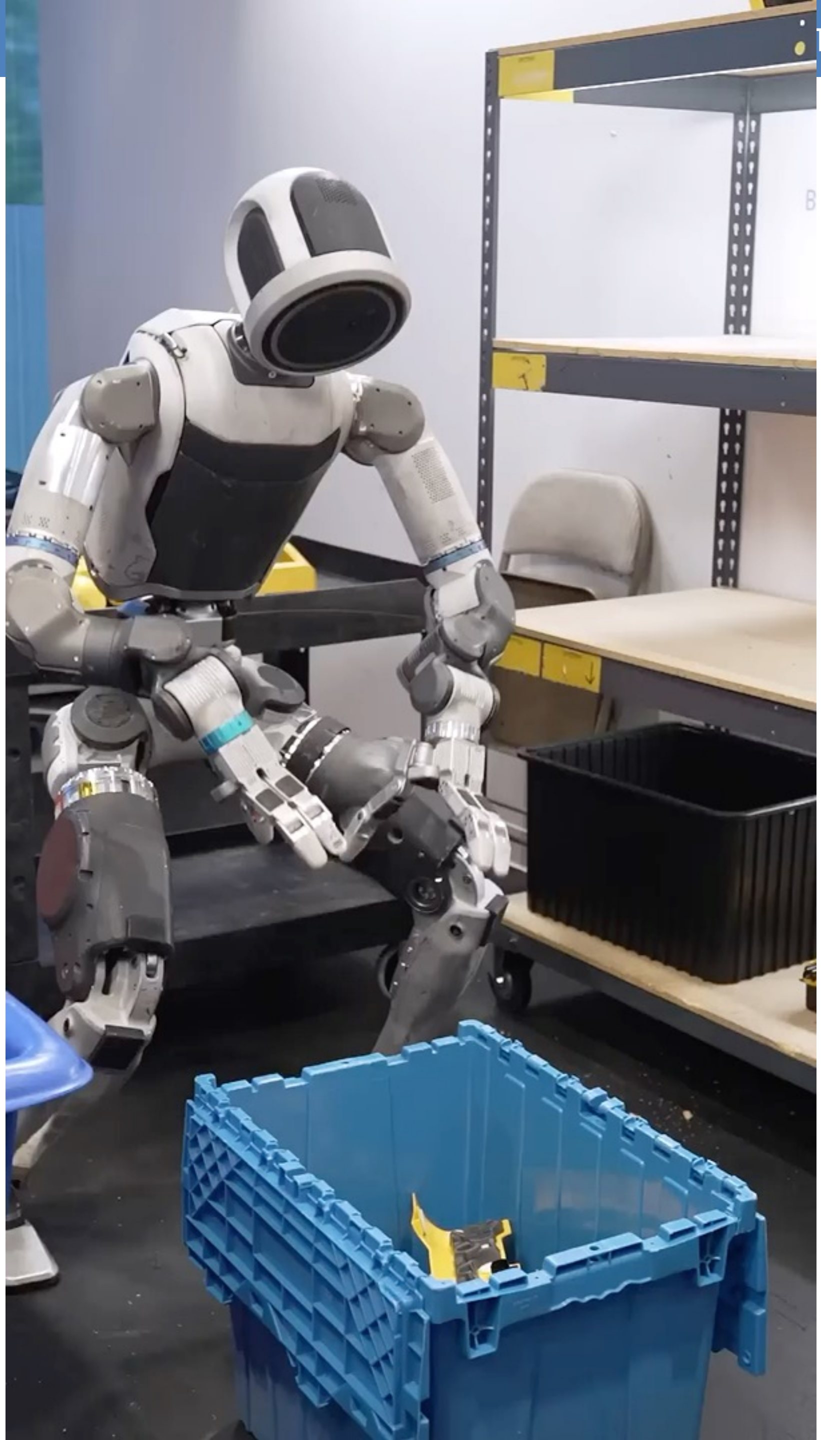
Mobile Manipulation

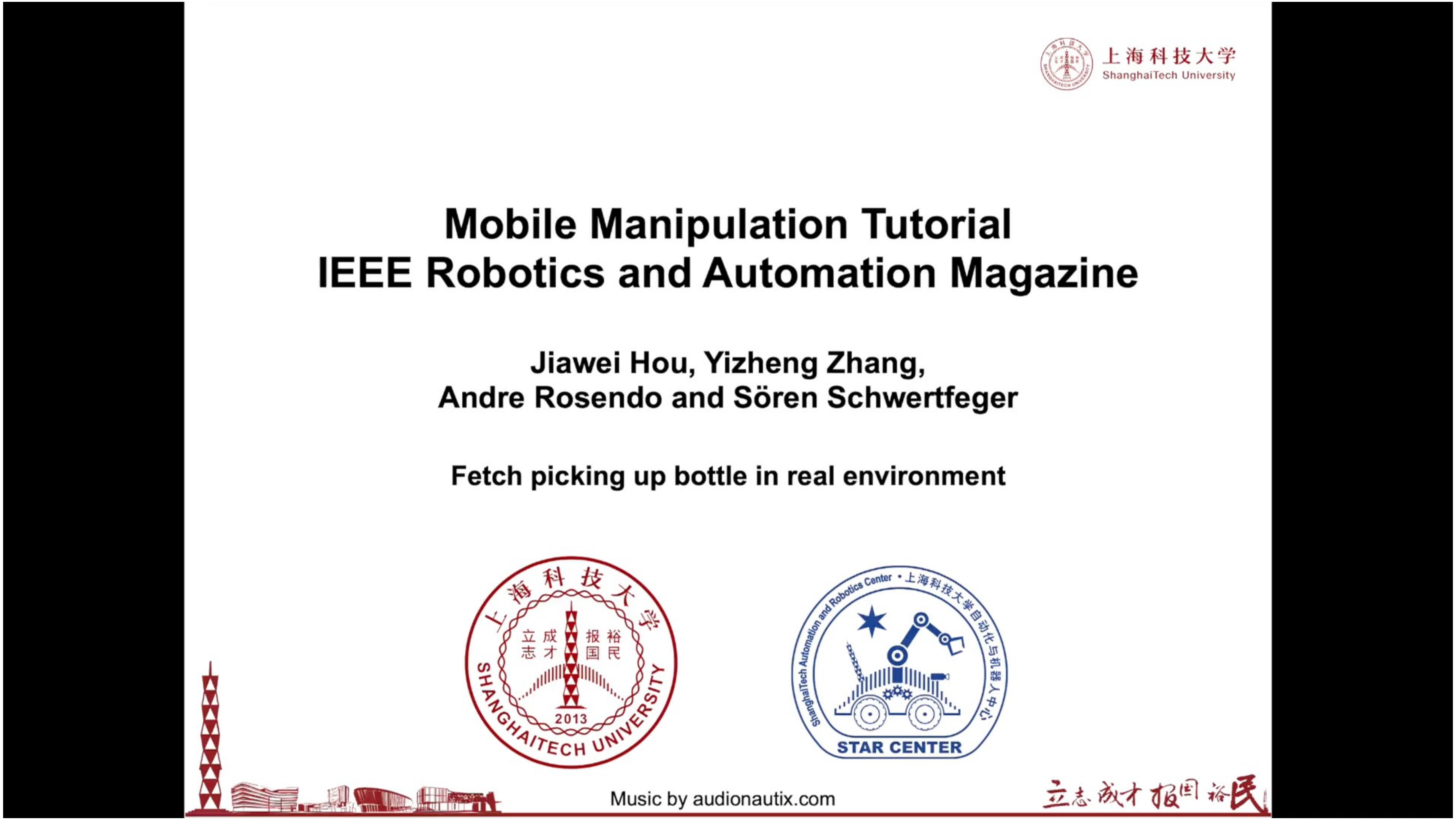
- A mobile robot …
  - A mobile base that can move in the environment
- that can change something in the environment
  - Typically with a robot arm/ robot manipulator

- Complex problem
  - This course: how to program/ control such a robot!

- Many different applications …


Boston Dynamics




上海科技大学
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Mobile Manipulation Tutorial
IEEE Robotics and Automation Magazine
Jiawei Hou, Yizheng Zhang,
Andre Rosendo and Sören Schwertfeger
Fetch picking up bottle in real environment
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https://momantu.github.io/

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Fetch picking up bottle in simulated environment

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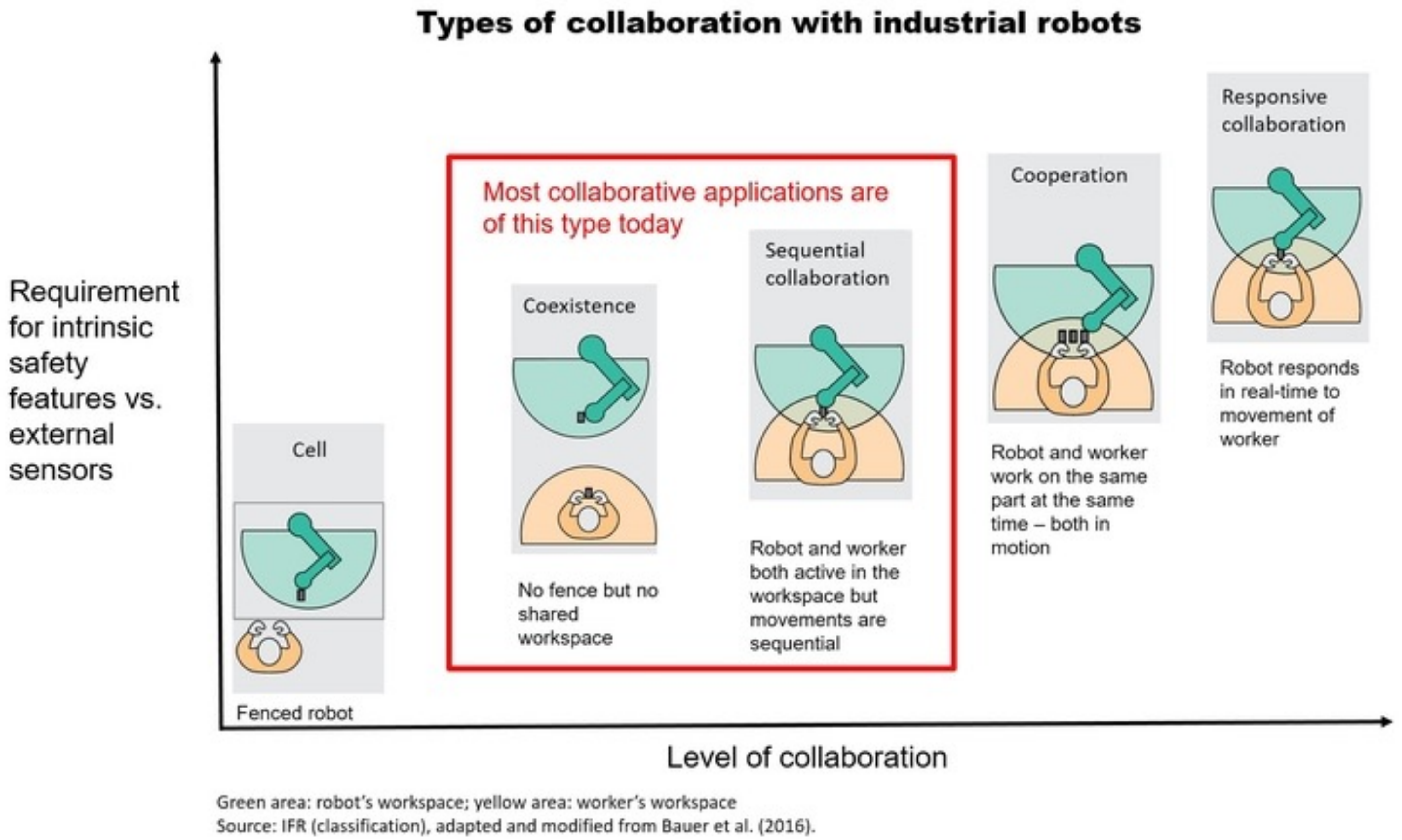
International Organization for Standardization: ISO 8373 Definition

- https://www.iso.org/obp/ui/#iso:std:iso:8373:ed-2:v1:en
- Robot
  - actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks
- Industrial Robot
  - automatically controlled,
  - reprogrammable,
  - multipurpose
  - manipulator,
  - programmable in three or more axes
  - which can be either fixed in place or mobile for use in industrial automation applications
- Service Robot
  - robot that performs useful tasks for humans or equipment excluding industrial automation applications


Types of collaboration with industrial robots
Requirement for intrinsic safety features vs. external sensors
Cell
Fenced robot
Most collaborative applications are of this type today
Coexistence
No fence but no shared workspace
Sequential collaboration
Robot and worker both active in the workspace but movements are sequential
Cooperation
Robot and worker work on the same part at the same time – both in motion
Responsive collaboration
Robot responds in real-time to movement of worker
Level of collaboration
Green area: robot's workspace; yellow area: worker's workspace
Source: IFR (classification), adapted and modified from Bauer et al. (2016).

Mobile Manipulation

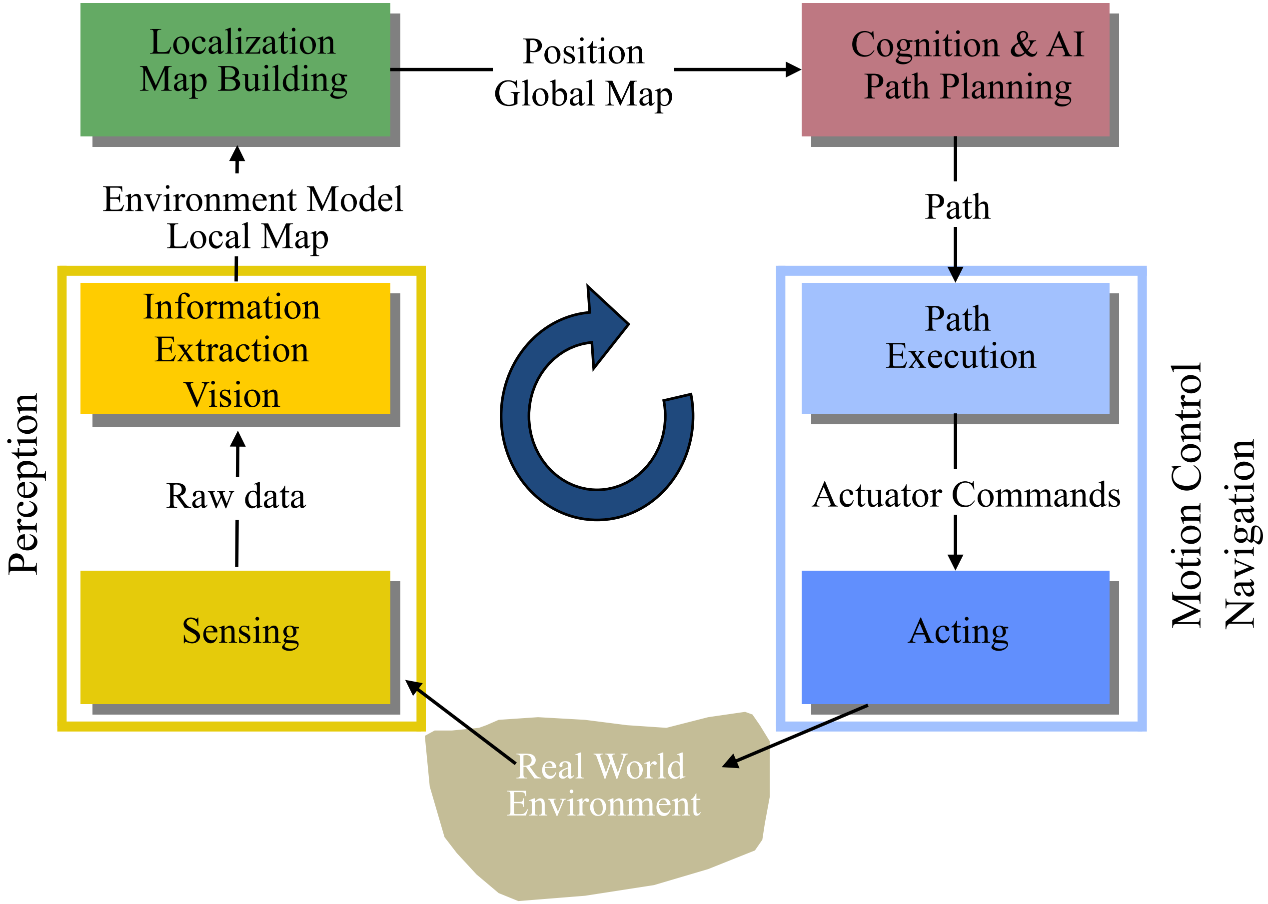
- Two problems
  - Mobile Robotics – move Robot from place A to place B
  - Manipulation – use a robotic manipulator to … manipulate something in the environment

- Two problems:
  - Can be solved sequentially:
    - First move the robot base to a goal position
    - Now use the robot arm to do something
    - easier
  - Can be solved together:
    - Plan for the task with moving the base and arm at the same time
    - Harder to do, more flexible solutions possible

Classical Robotics vs. Modern AI

- Modern AI very powerful & breathtaking pace of development
- Huge impact on Robotics & Manipulation
- Novel AI often bypasses the need for classical approaches, e.g.:
  - Reinforcement Learning replaces Control
  - Vision (Language) Models replace computer vision
  - Imitation Learning replaces coding task (planning) by hand
  - Robotic Foundation Models aim to integrate many components end to end
- But: For developers & researchers to fully understand the problem & properly develop the solution, we need to understand the underlying problem & its classical (attempts at) solutions
- This course is introducing the fundamental challenges of Mobile Manipulation & their classical solutions & introduces some of the novel AI methods
- Some HW & (if you want) your project focus more strongly into new AI

General Control Scheme for **Mobile** Robot Systems Emphasis of CS283 Robotics



With material from Roland Siegwart and Davide Scaramuzza, ETH Zurich

Manipulation: Grasp an Object: Steps

1. Startup robot and sensors
2. Detect object & its pose
3. Select grasping points on the object
4. Scan the scene and environment (for collision checking later)
5. Use IK to check if grasping point can be reached – checks for collisions – may try thousands of possibilities (before concluding that there is always a collision)
6. Use motion planning to plan from current pose to goal pose: Lots of collision checks! Might realize that it is impossible after a long time
7. Execute that trajectory: Check if we reached the intermediate pose (within the time constraint) and command the next
8. Controller: take dynamics into account to move to the next intermediate pose
9. Once goal is reached close fingers.
10. Check if object is in fingers
11. Add the object to the collision description of the robot
12. Plan the path to the goal pose…

ADMINISTRIVIA

Teaching Plan

- Lectures
- Homework
  - Allow AI to use for HW!
  - Presentation about robotics paper (related to your project)
  - Oral Exam on HW!
    - TA will be present to help with the English…
- Final Exam
- Project…

Project

- 1 credit point!
- Work in groups, min 2 students, max 3 students – maybe 4 students.

- Some topics will be proposed later…
  - You can also do your own topic, but only after approval of Prof. Schwertfeger
    - Prepare a short, written proposal till next Tuesday!
  - Choose/ suggest a topic that is in line with your graduate research!
  - We are flexible w.r.t. the topics – as long as they are involved with manipulation or complex mobile robotics.

- One graduate student from my group will co-supervise your project
- Weekly project meetings!

- Oral ”exams” to evaluate the contributions of each member
- No work on project => bad grade of fail

Grading

- Grading scheme is not 100% fixed
- Approximately:
  - Lecture: 66%
    - Homework: 36%
      - HW Assignments 15%
      - Oral HW Exam (2 randomly chosen HW, 10 min each) 16%
      - Paper presentation 5%
    - Final: 30%
  - Project: 34%
    - Project Proposal: 5%
    - Weekly project meetings: 6%
    - Final Report: 10%
    - Final Demo: 10%
    - Final Webpage: 3%

Getting Help

- Piazza:
  - For discussions and announcements
  - You have been enrolled already
  - Ask questions regarding your reading assignments and homewor
  - You are not allowed to give the solutions – just guidance
- Ask questions during the lecture!
- Upon request we can organize a tutorial session
- Ask general questions in our wechat group:
- Only if everything else fails: write e-mails
- Office Hours Prof. Schwertfeger: Tuesday afternoon
- Office Hours TA: make appointment via email

Group: MoMa 2026

Valid until 9/22 and will update upon joining group

TA: Li Pingcong

lipc2024@shanghaitech.edu.cn

Policy on Plagiarism

- The homework are individual tasks!
- You may discuss the ideas and algorithms of homework with others but:
  - At no time should you read the source code or possess the source files of any other person, including people outside this course.
  - We will **detect plagiarism** using automated tools and will **prosecute** all violations to the fullest extent of the university regulations, including failing this course, academic probation, and expulsion from the university.

- Homework, project submissions, etc. will be submitted through git – using gitlab. We will create accounts on our gitlab for you.

Mobile Manipulation

- Topic: Mobile Manipulation Robots and how to program them

- **Literature:**
- P. Corke, Robotics, Vision & Control.
  3rd edition!
  “Fundamental Algorithms in Python” !

  Available as open access:
  https://link.springer.com/book/10.1007/978-3-031-06469-2

Material

- Webpage
  - https://robotics.shanghaitech.edu.cn/teaching/moma2026
  - Slides will be available on the webpage
- Message Board
  - tbd
- Where to find us:
  Office: SIST 1D 201.A
  Lab: SIST 1D 203
- E-Mail:
  - soerensch@ShanghaiTech.edu.cn

Schedule

- Rough plan:
  - Lectures: Sep, Oct & Nov;
  - Project: December & January
  - Oral HW Exam Beginning of December
  - Final in week 18
- May change – take a look at webpage for most recent version!

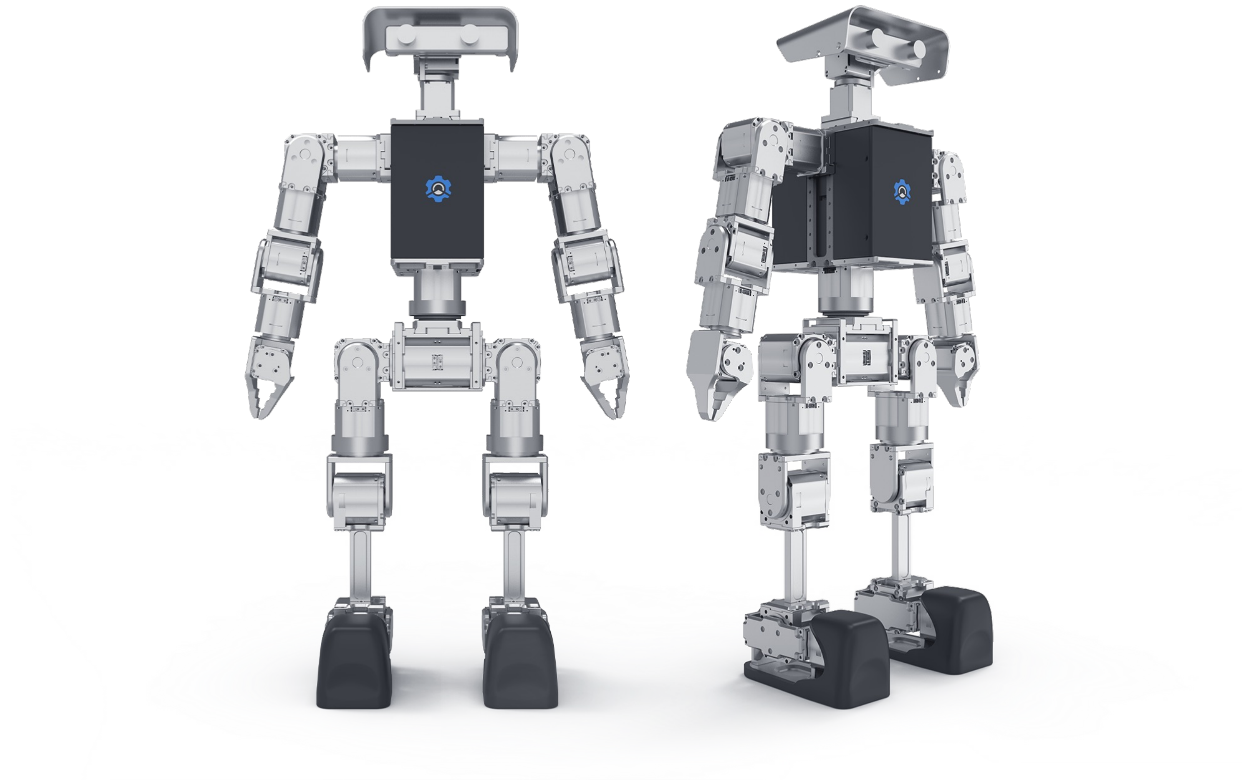
Date	Week	Topic	Robotics Conference	Lecture #	HW		
2026-09-15	1	Introduction		1			
2026-09-17		Kinematics		2			
2026-09-22	2	Kinematics & Planning		3	HW1 due		
2026-09-24		Planning		4		project selection	
2026-09-29	3	Project	IROS				
2026-10-01		Holiday	IROS				
2026-10-06	4	Holiday	IROS			paper selection	
2026-10-08		Mobile Robotics		5	HW 2 due		
2026-10-13	5	Simulation		6			
2026-10-15		Perception		7			
2026-10-20	6	BT & State Machines		8			
2026-10-22		LLM & Calibration		9	HW 3 due		
2026-10-27	7	Paper Presentation I		10			
2026-10-29		Paper Presentation II		11			
2026-11-03	8	Project	SSRR				
2026-11-05		Project	SSRR		HW 4 due		
2026-11-10	9	Grasping		12			
2026-11-12		Visual Servoing		13			
2026-11-17	10	Control & Whole Body Contol		14			
2026-11-19		Robot Learning		15	HW 5 due		
2026-11-24	11	Foundation Models		16			Lecture
2026-11-26		Project					Project
2026-12-01	12	Project					
2026-12-03		Project			HW 6 due		
2026-12-08	13	**Oral HW Exam**					
2026-12-10		Project					
2026-12-15	14	Project	IEEE ROBIO				
2026-12-17			IEEE ROBIO				
2026-12-22	15						
2026-12-24							
2026-12-29	16						
2026-12-31							
2027-01-05	17						
2027-01-07							
2027-01-12	18	**Final**		**Project Demo**			

ToDo:

- Join the lecture on piazza
- Organize access to the text book
- For your project you quite likely need ROS – ROS 1 or ROS 2, depending on robot…
  - => review ROS …

Think about projects – with real robots…

2x Fetch Robots



High Torque
Mini Pi+ (1x)

Think about projects – with real outdoor robots…

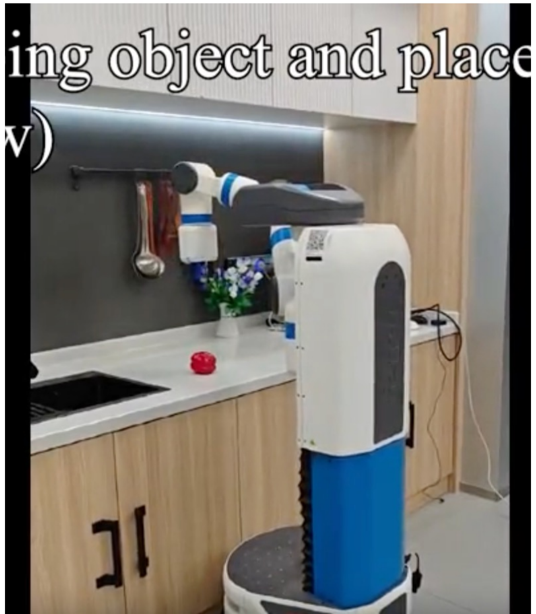
Unitree Go2-w
with and without arm!

Jackal Mobile Platform with
Kinova Robot Arm

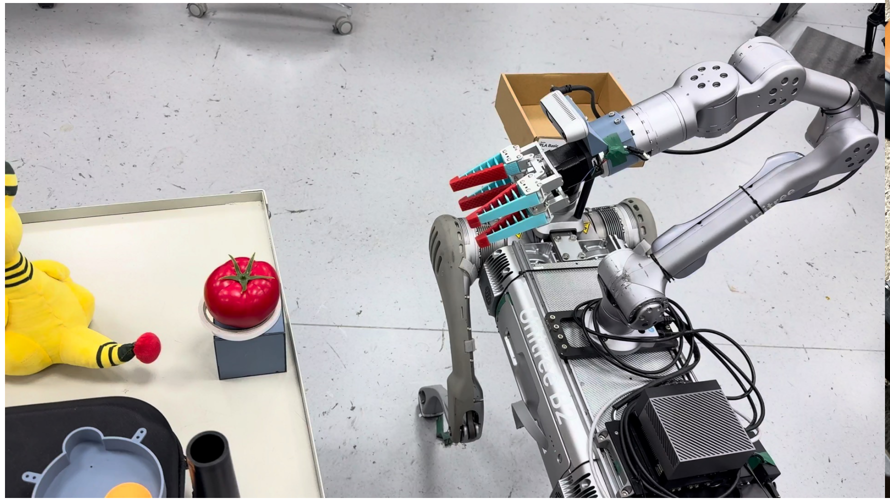
Husky Mobile Platform with
AUBO Robot Arm

Some of previous year's projects

- Human Robot Interaction with Fetch
- Face Manipulation with Sophia Robot
- Use water brush to paint characters on the ground
- Tablet balancing
- Fetch Kitchen Manipulation



- Legged Manipulation



Quick Introduction Round!

- Name
- Graduate or Undergraduate student
- Did you take CS283 Robotics or CS183 Introduction to Robotics or any other Robotics course?
- CS student?
- Do you know ROS?
- Graduate Instructor
- Research Topic

SOFTWARE

Robot Software: Tasks/ Modules/ Programs (ROS: node)

Support

- Communication with Micro controller
- Sensor drivers
- Networking
  - With other PCs, other Robots, Operators
- Data storage
  - Store all data for offline processing and simulation and testing
- Monitoring/ Watchdog

Robotics

- Control
- Navigation
- Planning
- Sensor data processing
  - e.g. Stereo processing, Image rectification
- Mapping
- Localization
- Object Recognition
- Mission Execution
- Task specific computing, e.g.:
  - View planning, Victim search, Planning for robot arm, …

Software Design

- Modularization:
  - Keep different software components separated
  - ☺ Keep complexity low
  - ☺ Easily exchange a component (with a different, better algorithm)
  - ☺ Easily exchange multiple components with simulation
  - ☺ Easily exchange dada from components with replay from hard disk instead of live sensor data
  - ☺ Multiple programming teams working on different components easier
  - Need: Clean definition of interfaces or exchange messages!
  - Allows: Multi-Process (vs. Single-Process, Multi-Thread) robot software system
  - Allows: Distributing computation over multiple computers

Programming techniques for you to review!

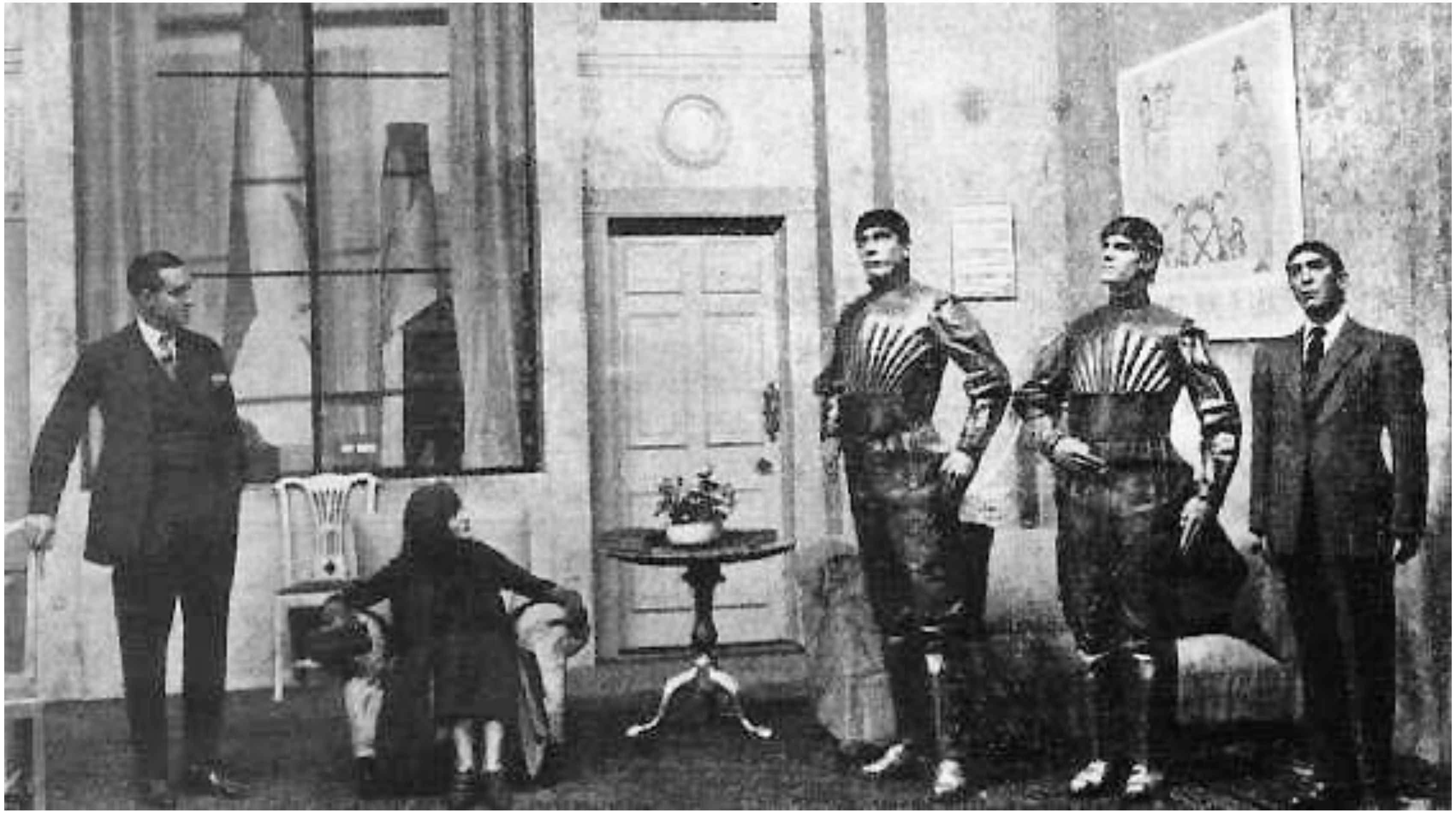
- Process vs. Thread
- C++ Object Orientation
- Constant Variables
  - const-correctness
- C++ Templates
- Shared Pointer

- Objective:
  - Prerequisites for understanding ROS.
  - Understand how we can efficiently retrieve and transfer data in ROS.
  - We may use ROS 1 and ROS 2
  - We may use C++ and Python
  - Homework will be in Python & ROS 2!

BRIEF HISTORY

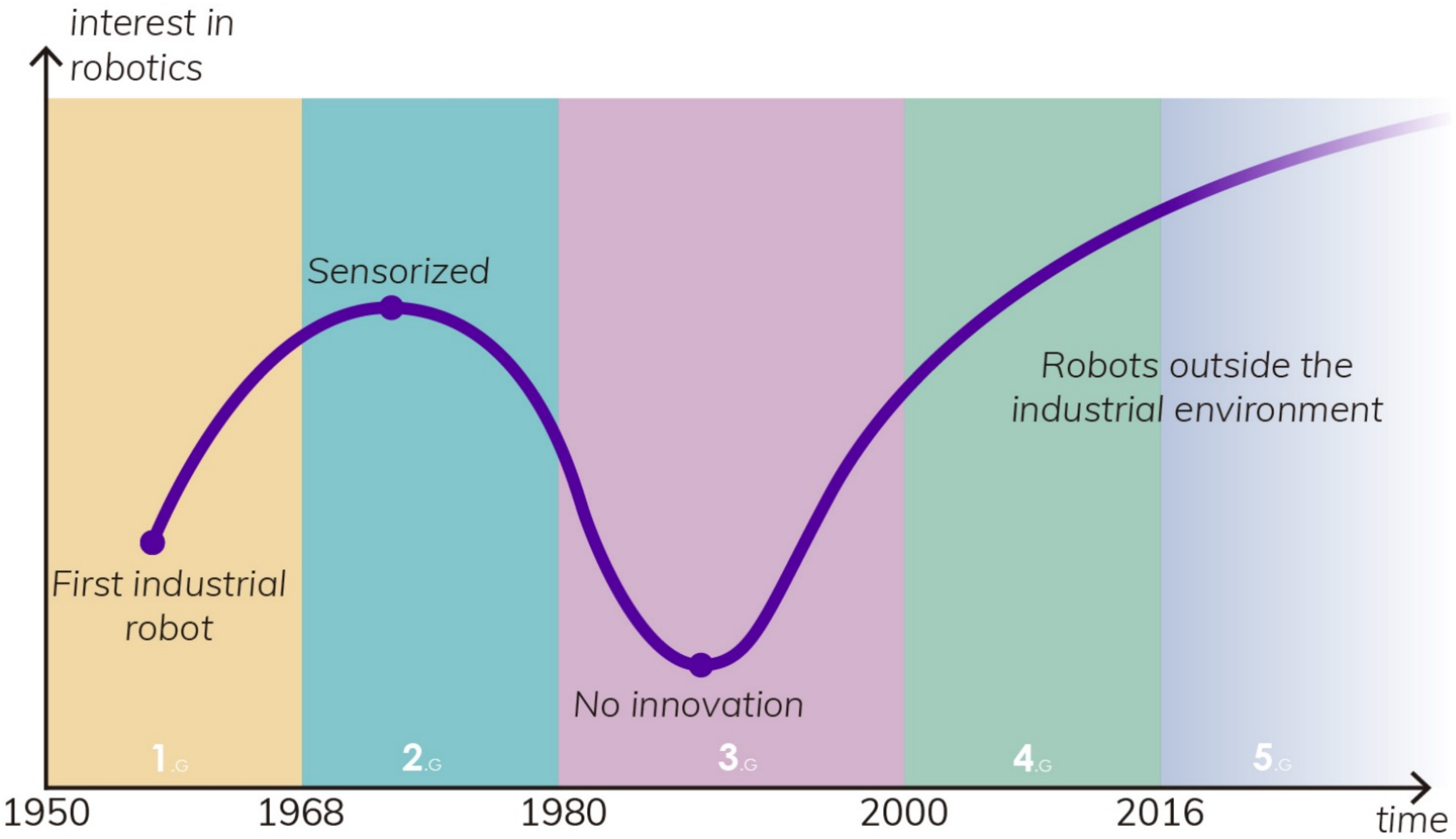
Brief History

Robota “forced labor”: Czech, Karel Čapek R.U.R. 'Rossum's Universal Robots' (1920).



History

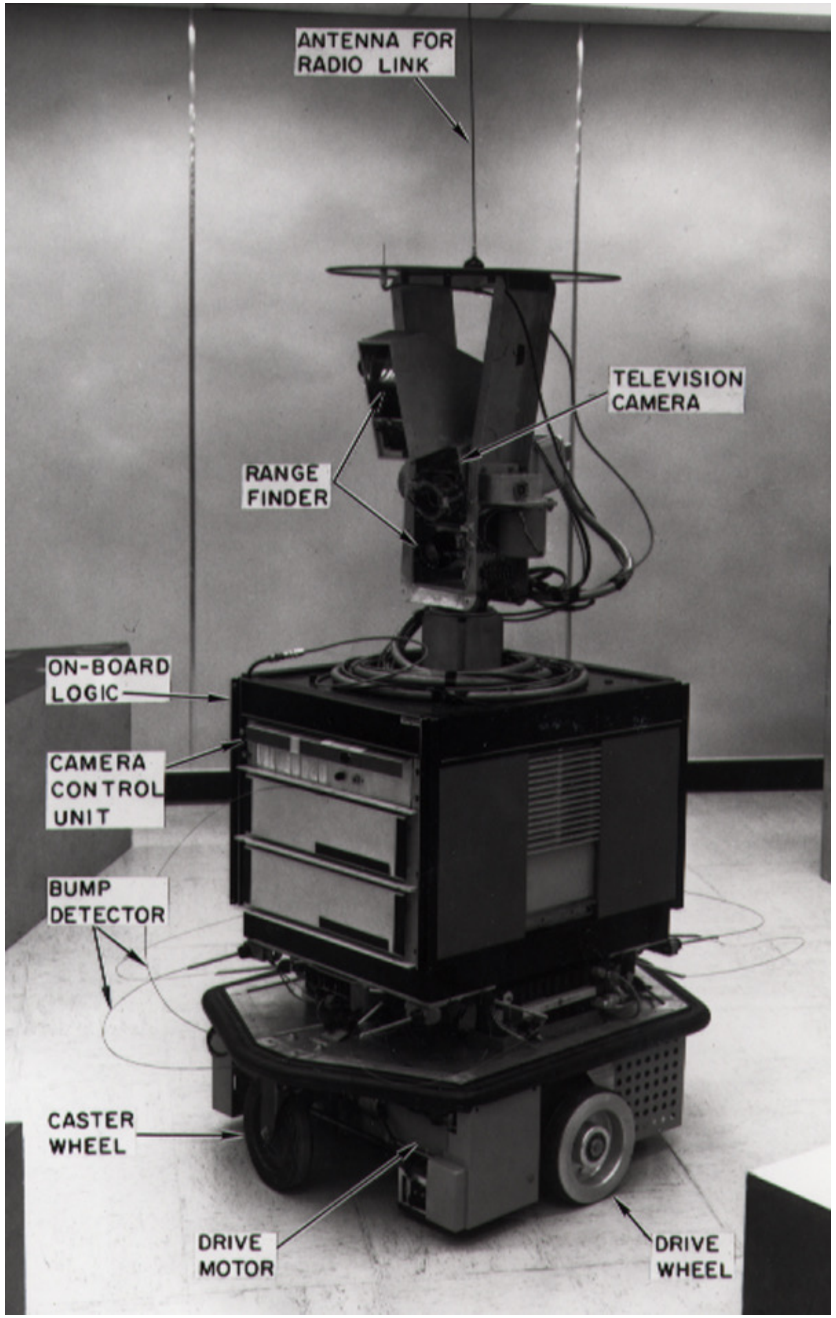
- First electronic autonomous robots 1949 in England (William Grey Walter, Burden Neurological Institute at Bristol)
  - three-wheeled robots: drive to recharging station using light source (phototaxis)
- Turing Test: 1950 (British mathematician Alan Turing)
- Unimate: 1961 lift hot pieces of metal from a die casting machine and stack them. First industry robot. Inventor: George Devol, user: General Motors.
- Lunokhod 1: 1970, lunar vehicle on the moon (Soviet Union)
- Shakey the robot: 1970
- 1989: Chess programs from Carnegie Mellon University defeat chess masters
- Aibo: 1999 Sony Robot Dog
- ASIMO: 2000 Honda (humanoid robot)



https://arxiv.org/pdf/1704.08617.pdf

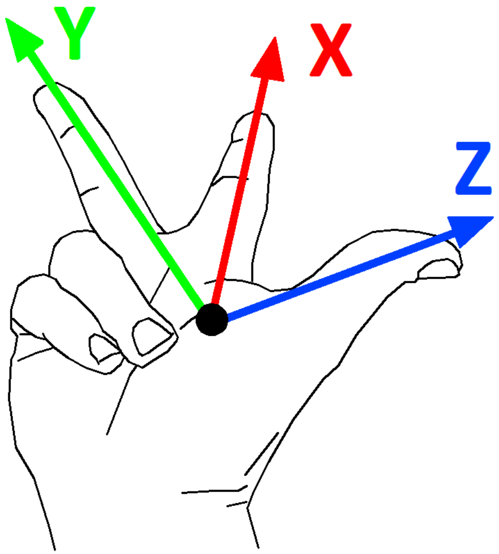
Shakey the robot (1970)

- First general-purpose mobile robot to be able to reason about its own actions
- Advanced hardware:
  - radio communication
  - sonar range finders
  - television camera
  - on-board processors
  - bump detectors
- Advanced software:
  - Sensing and reasoning
- Very big impact
- https://robotics.shanghaitech.edu.cn/static/videos/Shakey.mp4

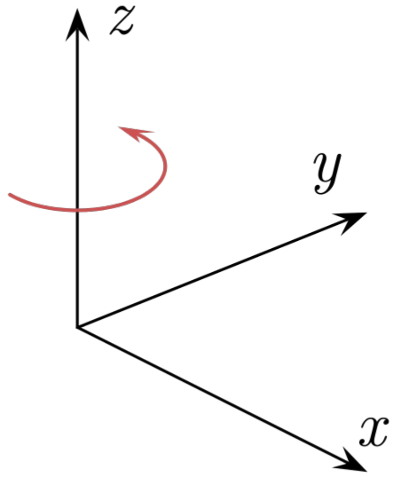


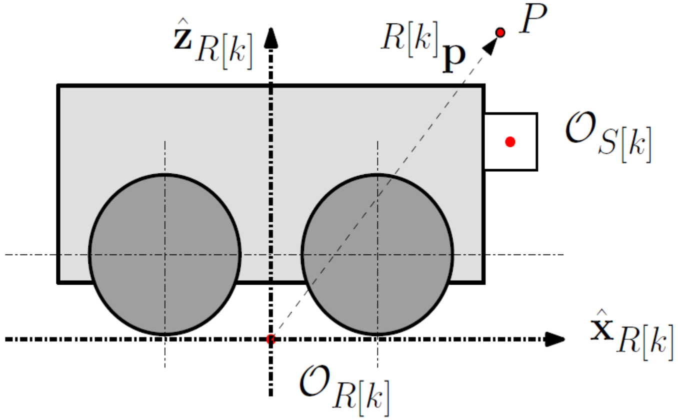
COORDINATE SYSTEM

Right Hand Coordinate System



- Standard in Robotics
- Positive rotation around X is anti-clockwise
- Right-hand rule mnemonic:
  - Thumb: z-axis
  - Index finger: x-axis
  - Second finger: y-axis
  - Rotation: Thumb = rotation axis, positive rotation in finger direction
- Robot Coordinate System:
  - X front
  - Z up (Underwater: Z down)
  - Y ???





Right Hand Rule http://en.wikipedia.org/wiki/Right-hand_rule