清華大學 交叉信息研究院
Tsinghua University Institute for Interdisciplinary Information Sciences

ISR Lab
Intelligent Systems and Robotics Lab

Advanced Topics for Robotics
智能机器人前沿探究

Lecture 1: Introduction

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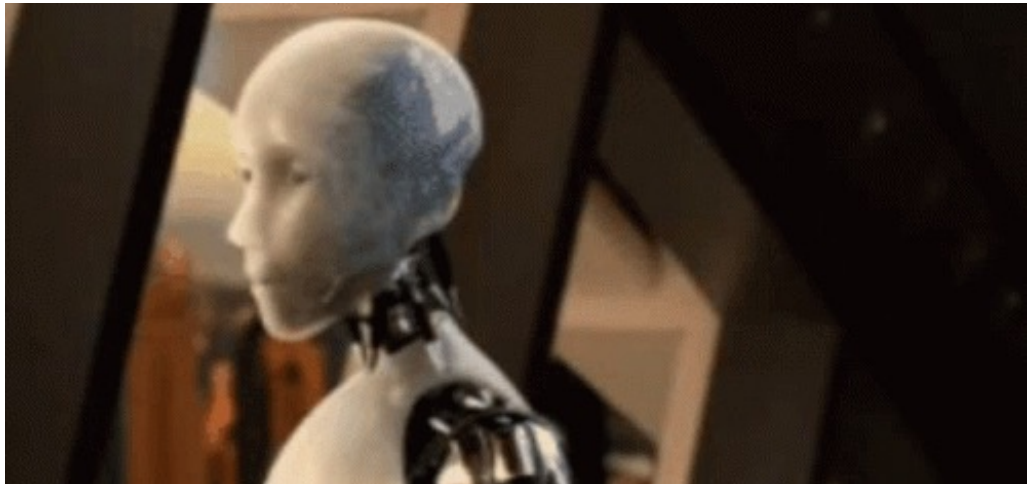
Course purposes

- Motivate you for robotics research
- Give you necessary theoretical and practical background to do robotics research
- Introduce advanced robotics research topics
- Practice doing robotics research on your own!

Contents

What is a robot?

- Robots in our imagination

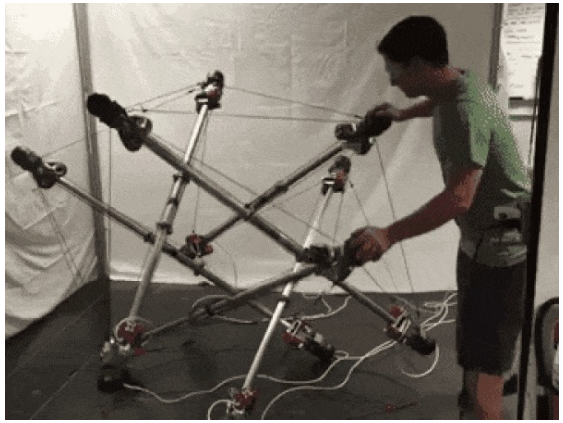


What is a robot?

- Robots in our real world

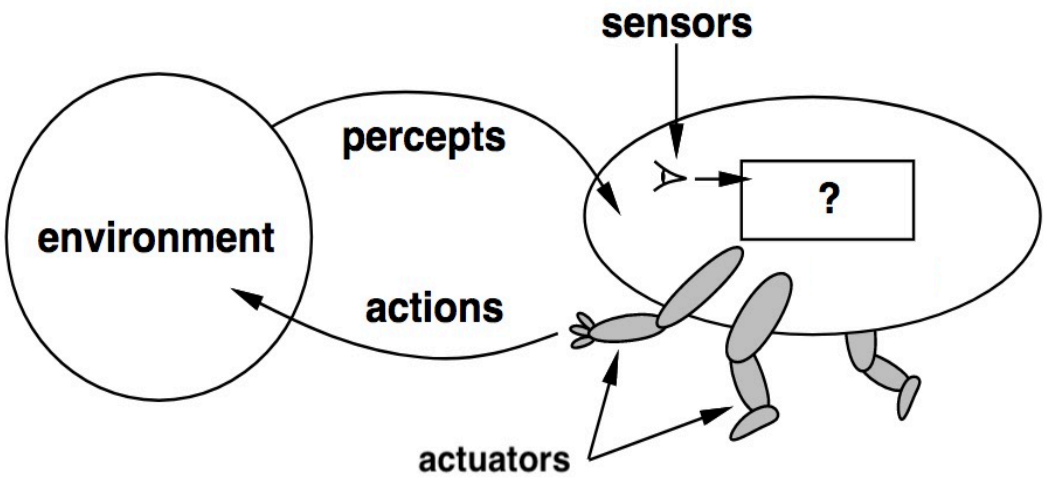
What is a robot?

- Robots in our real world



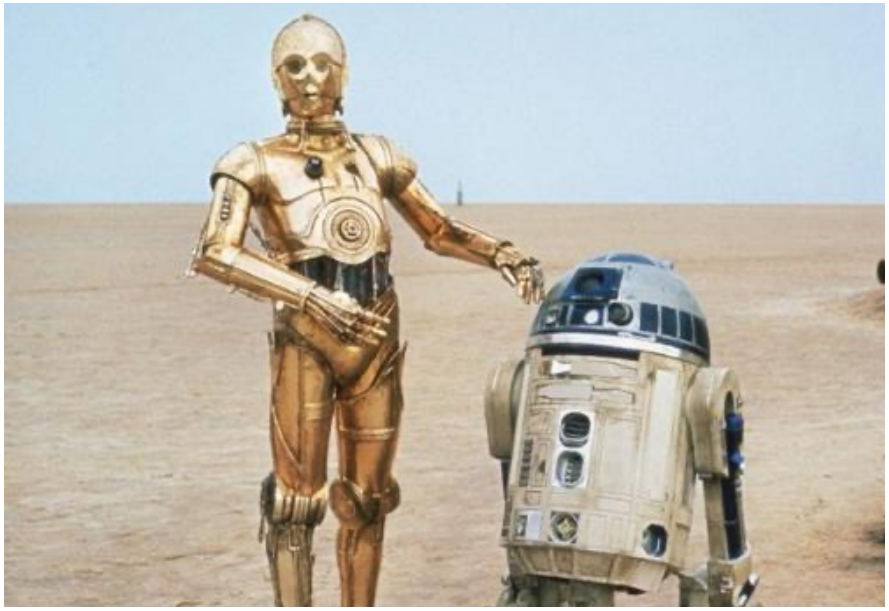
What is a robot?

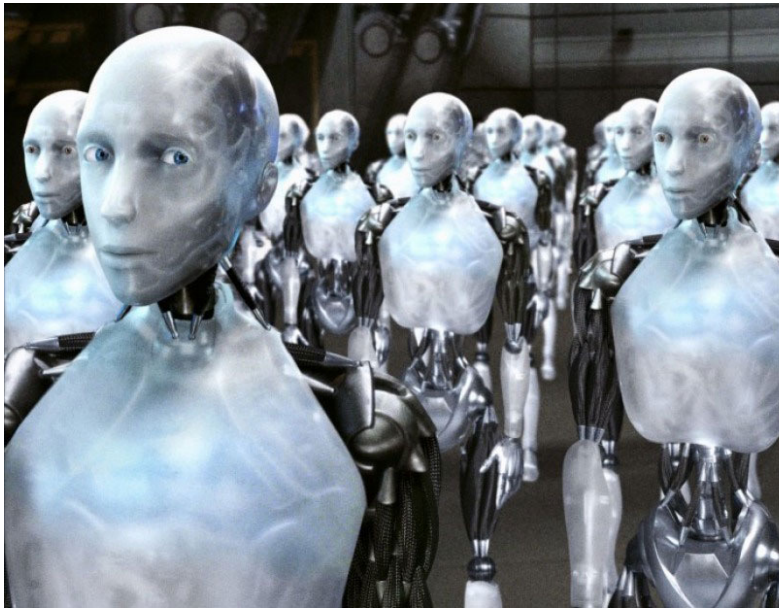
- What is a robot, really?
  - A robot is an automatic machine with **physical body** and **intelligence** which **interact with real world environment physically**



Why build robots?

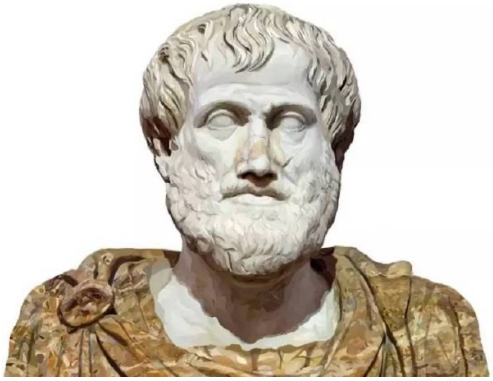
- Building intelligent machines, and being the ”god” of them is a dream of human





Why build robots?

- Key reason: human are lazy!
  - Keep building tools to extent their abilities and do the work for them
  - Components of robots are keep improving with human history

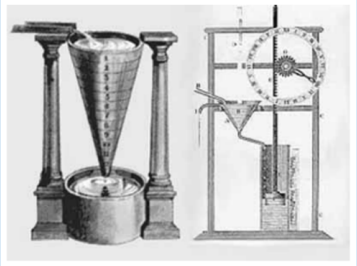


Aristotle

"If every tool autonomously does the work that is suited to them… then there would be no need for masters and apprentices anymore."

The long history of robotics

Mechanical age

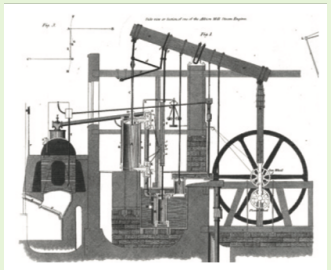


Mechanics

Leonardo da Vinci (1480)

Mechanical vehicle

Steam age

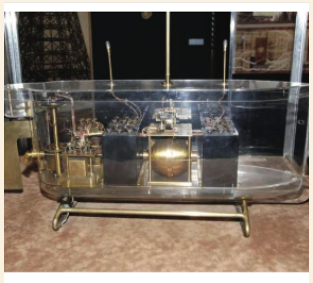


Electricity

J. Jaquard (1801)

Programmable automatic loom

Electrical age

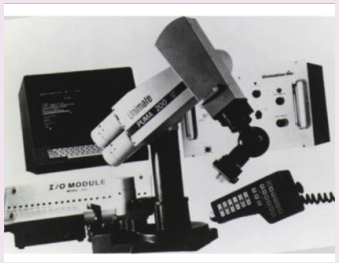


Modern Control

G. Brown (1952)

CNC machine

Information age



Computer Science

ABB (1990)

automotive factory

Intelligence age

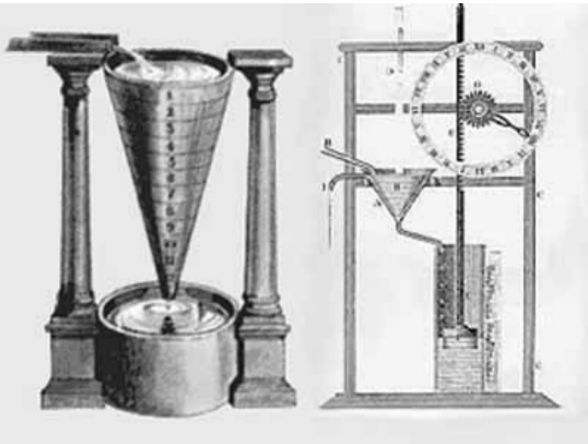
AI

Google (2009)

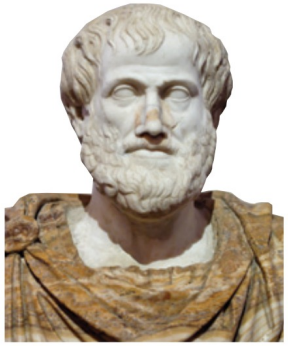
self-driving car

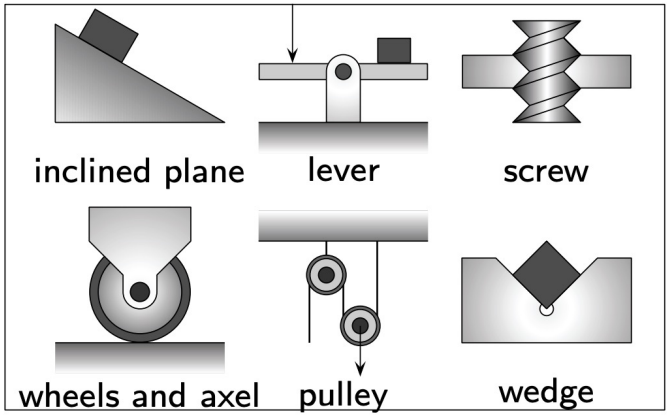
Ancient history (400 B.C.-1450 A.D.)

- Earliest machine designs



Ctesibius (270 B.C.): Water clock



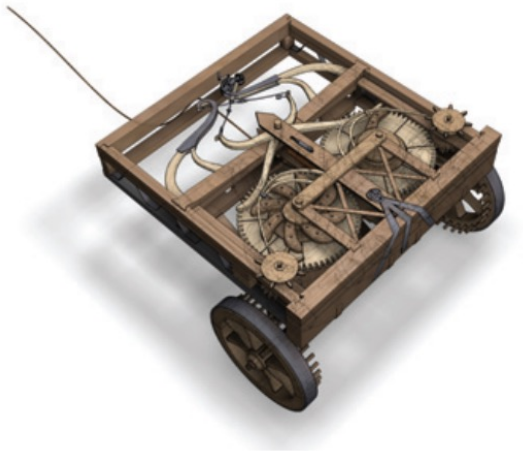


Aristotle (384-322 B.C.): Six basic machine elements

Zhang Heng (100 A.D.): Southpointing Chariot and automatic steering

Early history (1451 A.D.-1960)

- More deliberate machines

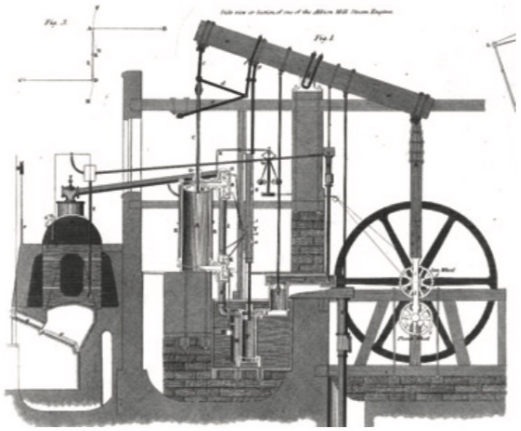


Leonardo da Vinci (1452-1519): Helicopter, hydraulic armor, simple "mechanically" pre-programmed vehicle

P. Ambroise (Paris 1564): First mechanical hand

Early history (1451 A.D.-1960)

- Early automata



J. Watt (1736-1819): Improved steam engine

P. Jaquet-Droz (1770): The programmed piano player with different music.

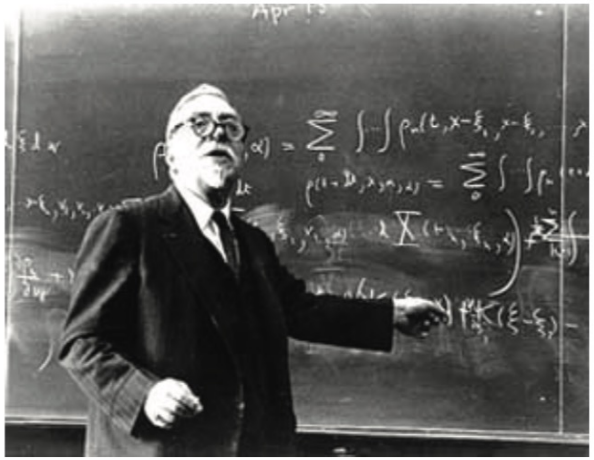
J. Jaquard (1801): First programmable loom with different patterns.

Early history (1451 A.D.-1960)

- Earliest robot and machine intelligence

Karel Capek (1921): Coined the word "ROBOT"in a play called "RUR"

A. Turing (1936): Machine Intelligence



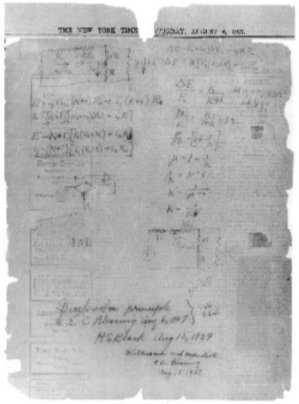
N. Wiener (1894-1964): Cybernetics

Early history (1451 A.D.-1960)

- Early control theory

Nyquist and Bode (1932, 1938): Classic control

R. Kalman (1930-): Modern control and Kalman filter



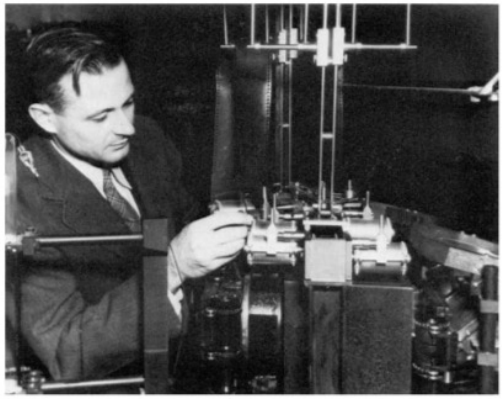
H. black (1898-1983): Negative feedback

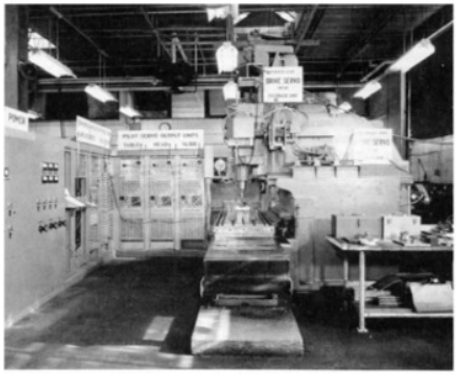
Early history (1451 A.D.-1960)

- Earliest computer and computer-aided machines

J. Eckert and J. Mauchley (1946): Developed ENIAC

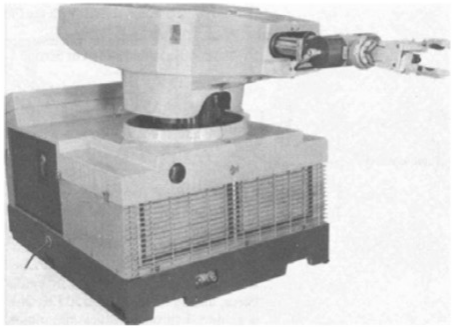
Von Neumann (1903-1957): Von Neumann architecture





The MIT numerically controlled milling machine.

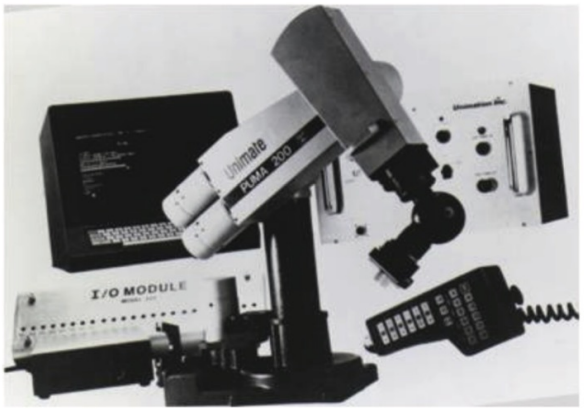
G. Brown (1952): First CNC machine



George Devol (1954): filed first robot patent

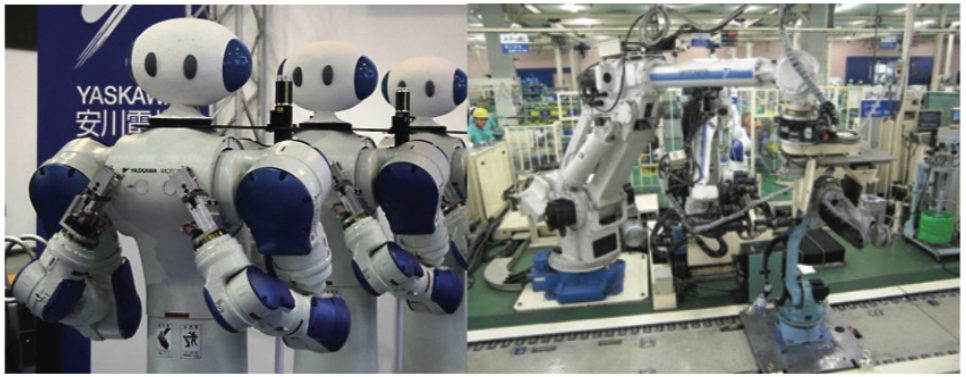
Traditional robotics (1961-2010s)

- Early robot industry



George Devol and **Joseph Engelberger** founded Unimation (1961), which installed the first industry robot at a GM plant in Trenton, New Jersy

Kawasaki robots in Japan with a patent from Unimation (1968)



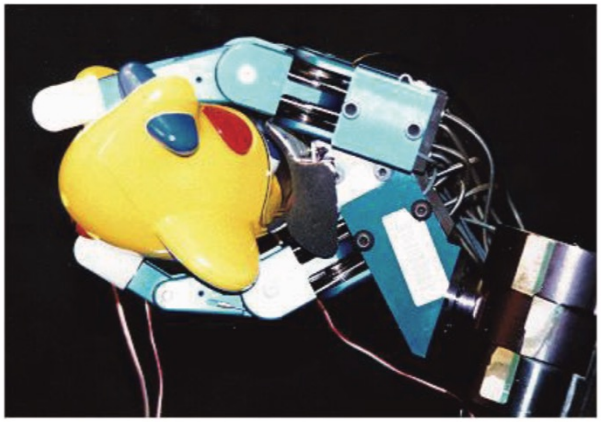
Yaskawa engineers coined the term ”Mechatronics” (1971)

Traditional robotics (1961-2010s)

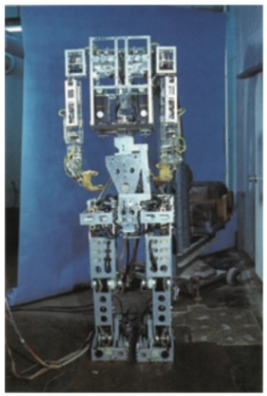
- The world's first autonomous robot

Traditional robotics (1961-2010s)

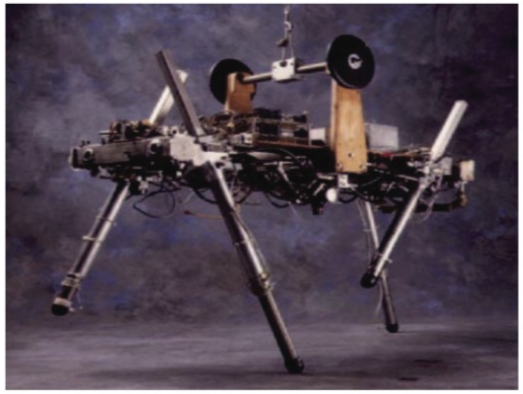
- Other types of robots

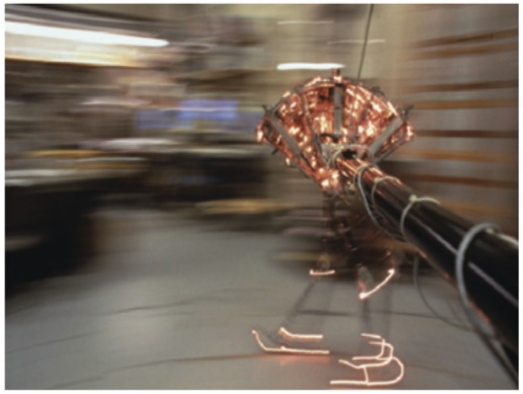


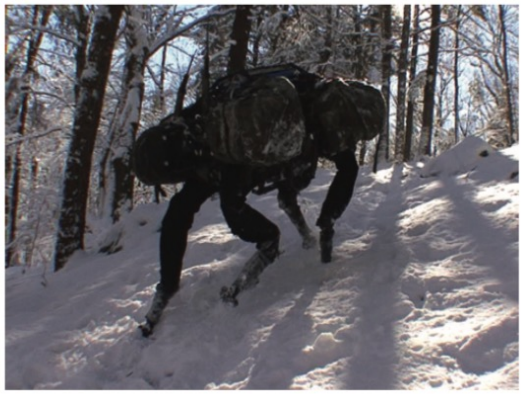
K. Salisbury (1981): Salisbury Hand



Waseda University develops Wabot-1 (1973) and Wabot-2 (1980)





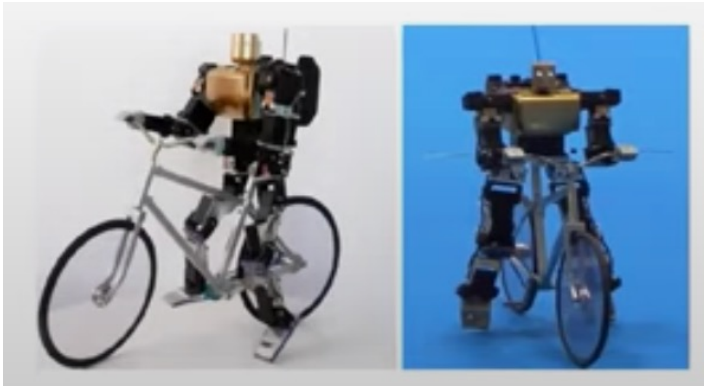


M. Raibert (1980) (RI, CMU & AI lab, MIT): Hopping, Robots, Monoped, biped and Quadpeds. Founded Boston Dynamics (1992)

Traditional robotics (1961-2010s)

- Robotic researches about kinematics, dynamics, and feedback control, and basic planning

Research on **robot kinematics** and design initiated by B. Roth (1964), D. Pieper (1968), K. J. Waldron (1972), etc.



Research on **robot dynamics** initiated by J. Luh (1980), T. Kane (1983), R. Featherstone (1983), etc.

Research on **robot control** initiated by J. Luh, M.W. Walker, R. Paul (1980), S. Arimoto (1984), etc.

Planning research initiated by J. Schwartz and M. Sharir (1983), Lozano-Perez (1983), J. Canny (1988), and O. Khatib (1986)

Traditional robotics (1961-2010s)

- The world first humanoid robot: WABOT (1970s)

Traditional robotics (1961-2010s)

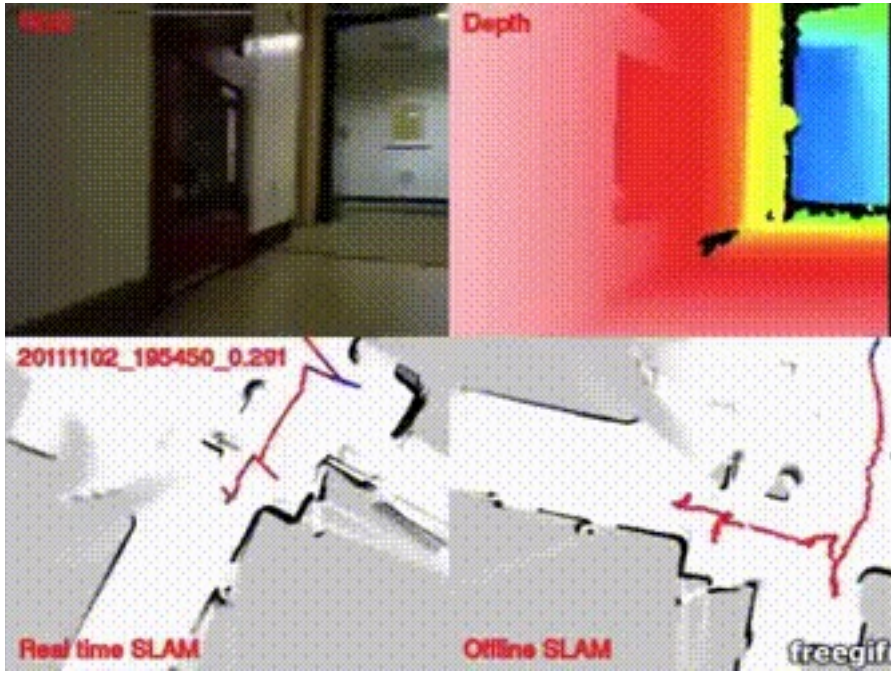
- Boston dynamics in the early stage (1970s)

Traditional robotics (1961-2010s)

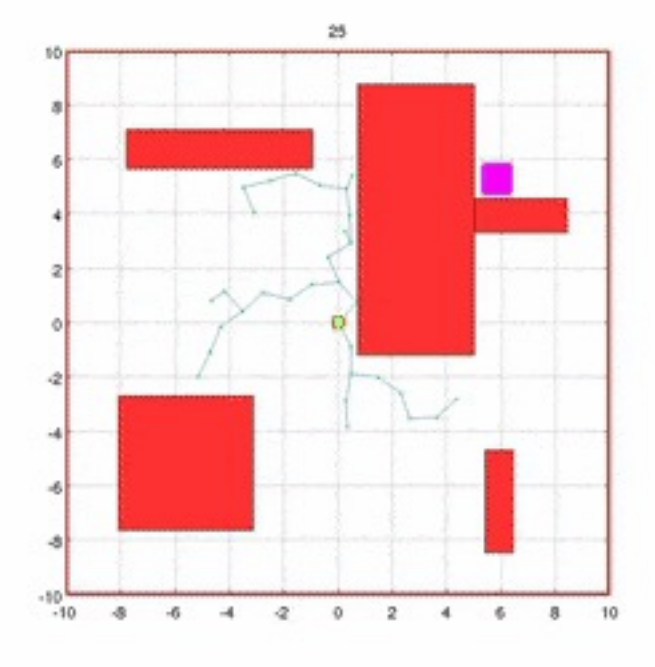
- Robots in the automotive factory (1990s)

Traditional robotics (1961-2010s)

- Perceptual localization and motion planning (2000s)



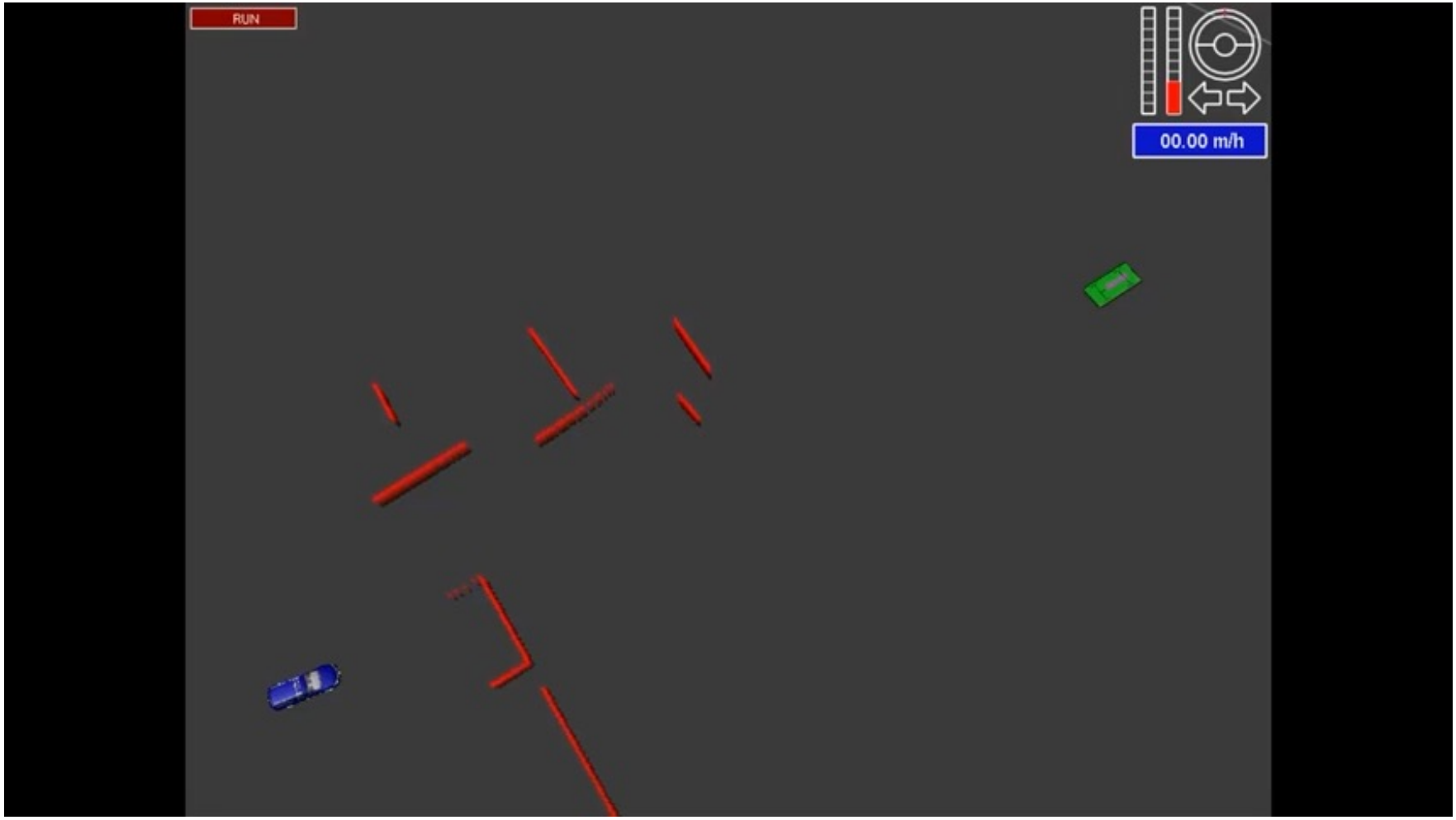
SLAM



Motion planning

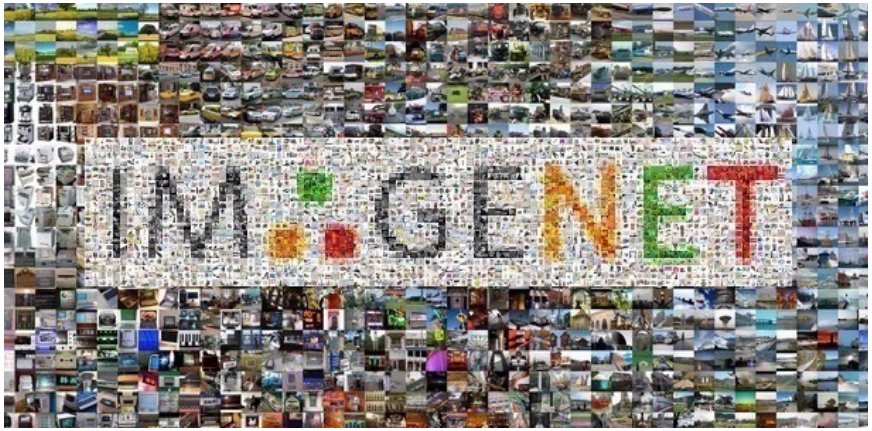
Traditional robotics (1961-2010s)

- Early autonomous driving (~2005)

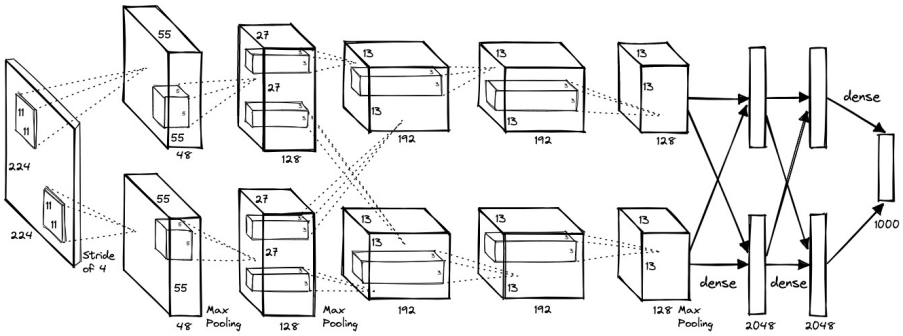


Modern robotics (2010-2020s)

- The deep learning era



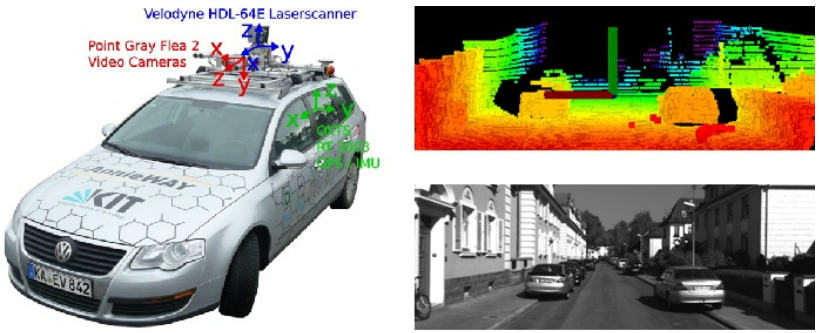
Feifei Li (2009): ImageNet dataset for deep learning based computer vision



AlexNet

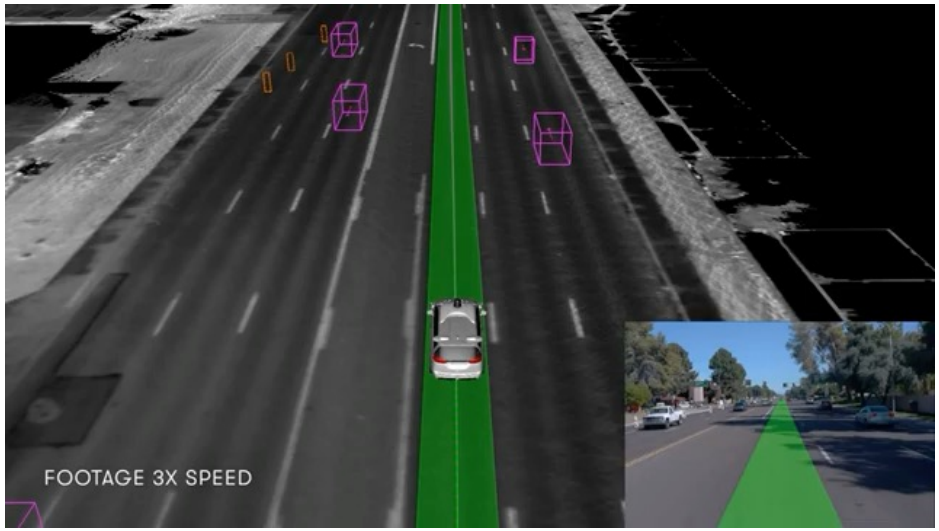
Modern robotics (2010-2020s)

- Perception for autonomous driving



(a) (b)

R. Urtasun (2012): KITTI dataset for autonomous driving perception



Modern robotics (2010-2020s)

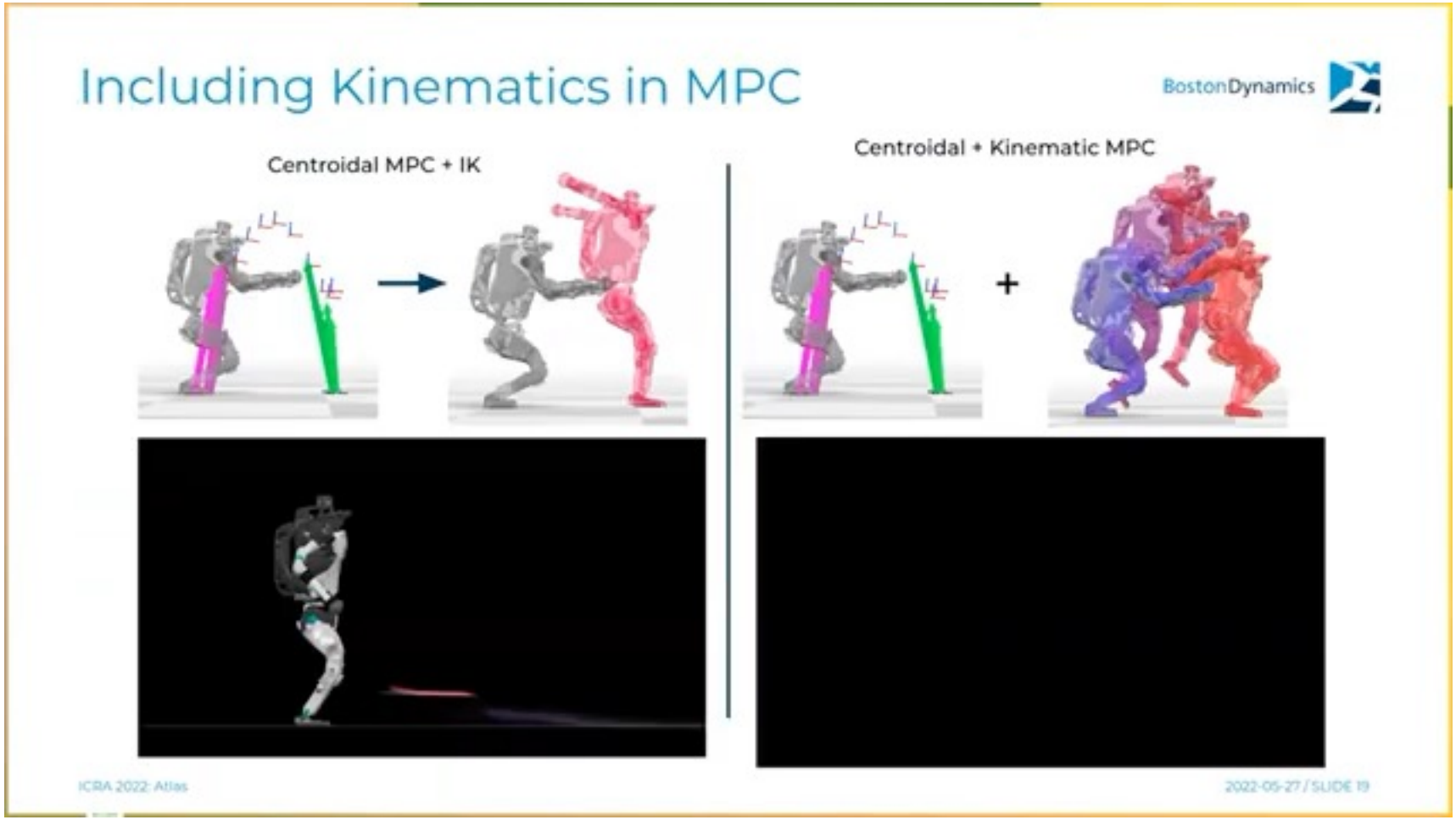
- DexNet (2017): supervised learning for robot grasping

Modern robotics (2010-2020s)

- Boston Dynamics Atlas: model predictive control for complex robot systems

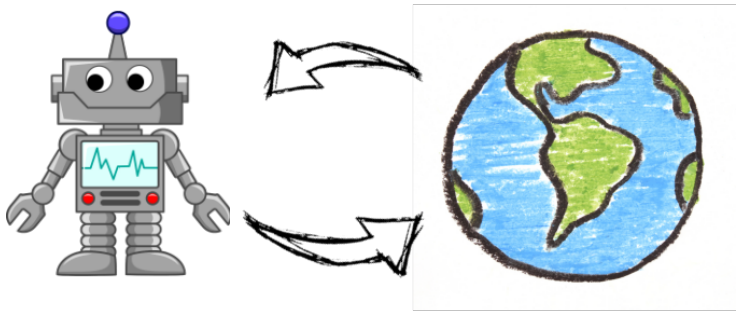
Modern robotics (2010-2020s)

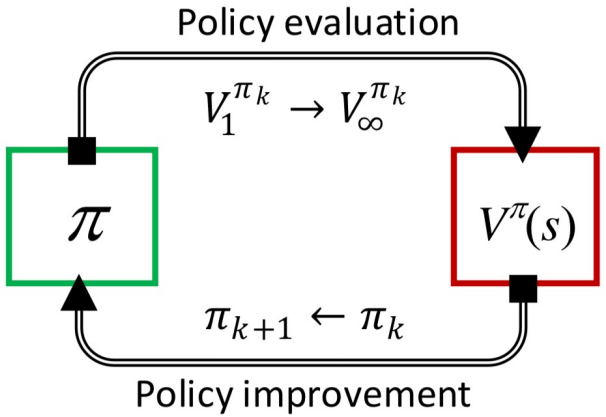
- Boston Dynamics Atlas: model predictive control for complex robot systems



Modern robotics (2010-2020s)

- Reinforcement learning and AlphaGo (2016)

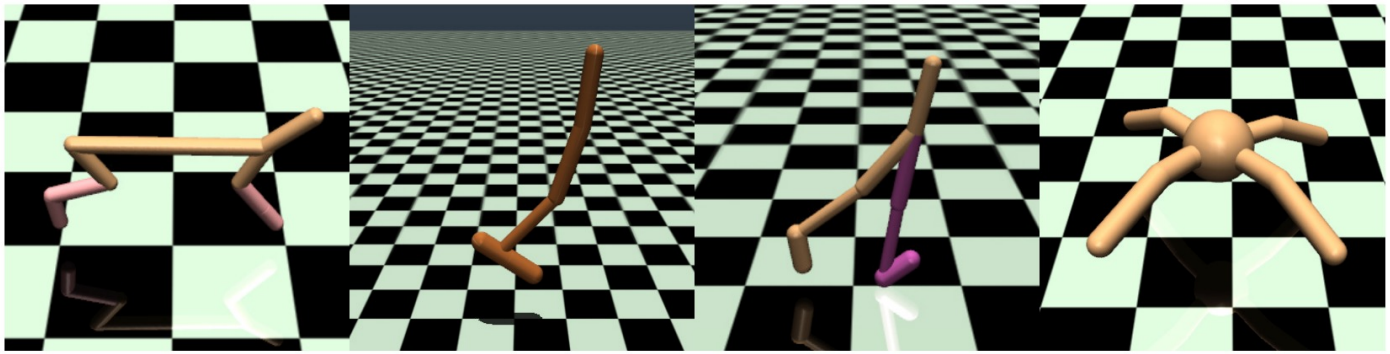




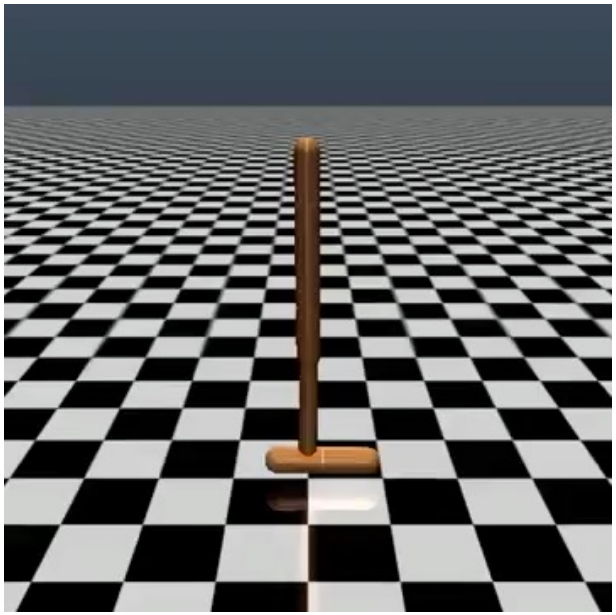
DeepMind (2016): Beat Go champion using reinforcement learning

Modern robotics (2010-2020s)

- Reinforcement learning for simulated systems

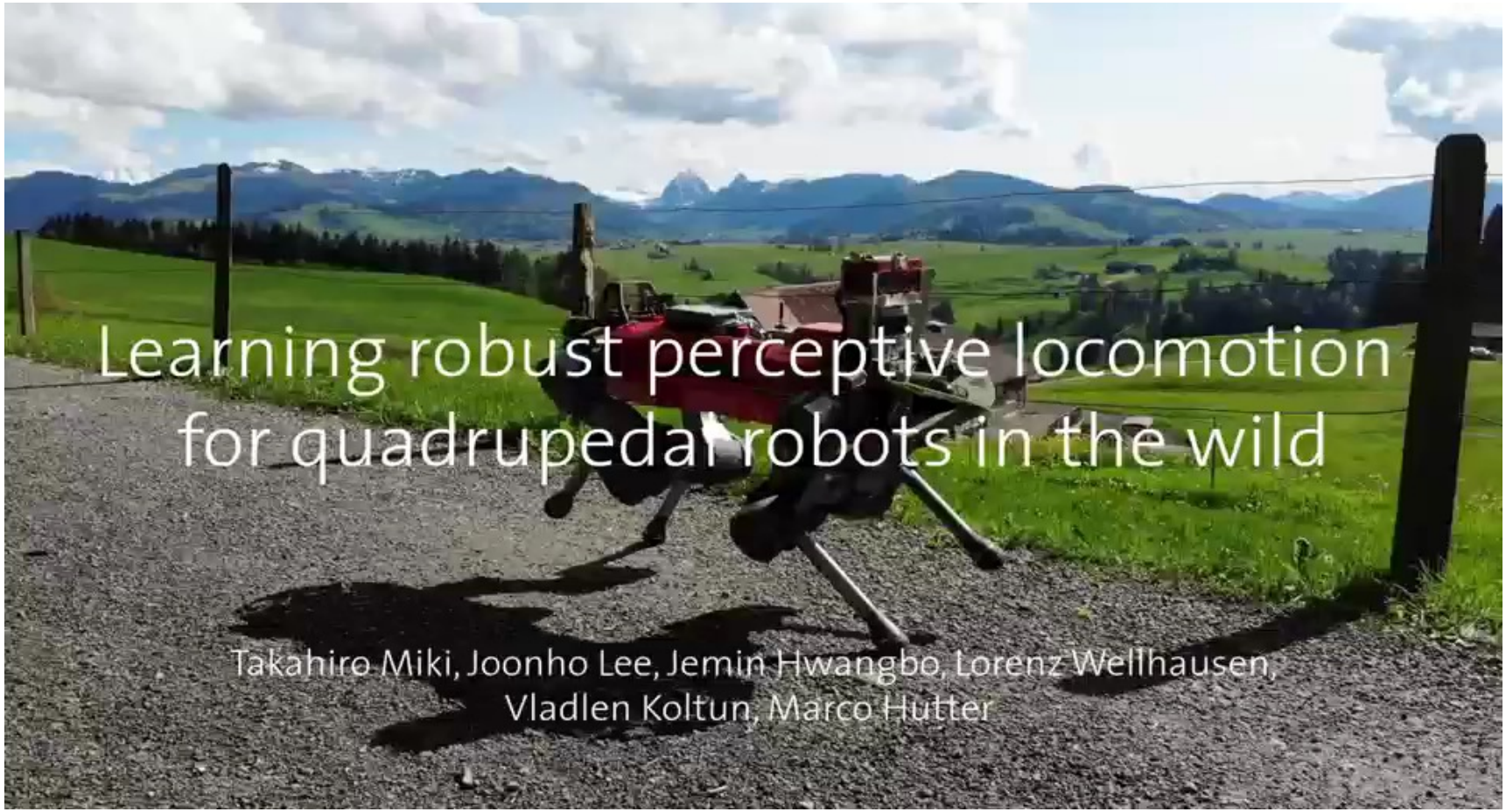


Mujoco simulation



Modern robotics (2010-2020s)

- Reinforcement learning for quadrupedal locomotion



ETH (2021): Climb Etzel

Modern robotics (2010-2020s)

- Reinforcement learning for dexterous manipulation

OpenAI (2018): Solving Rubik's Cube

Cooling down (~2020)

- Boston dynamics was sold three times

Google = SoftBank

HYUNDAI

2014（3 Billion） 2017 2020（1 Billion）

Boston Dynamics

Cooling down (~2020)

- ASIMO retired (2022)

Cooling down (~2020)

- OpenAI shutting down robotics team (2021)

News

OpenAI Shuts Down Its Robotics Team Due To Lack Of Data

By **Dipayan Mitra** July 21, 2021

The rise of humanoid robots

- Elon Musk announces working on humanoid robots (2021)

The Guardian

The rise of humanoid robots

- MIT Humanoid (2021): Highly dynamic humanoid robot (but only in simulation then)

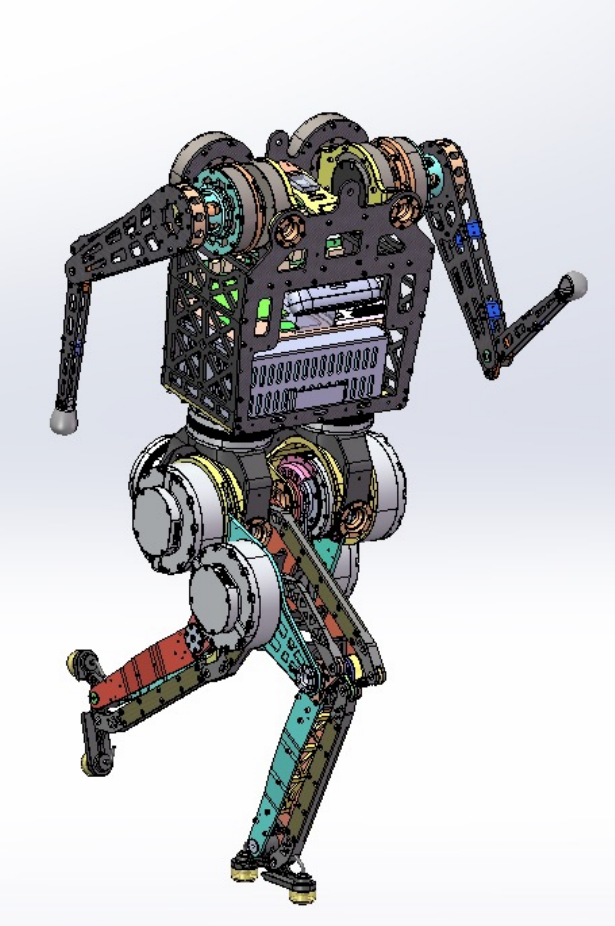
The MIT Humanoid Robot:
Design, Motion Planning, and Control For Acrobatic Behaviors

Matthew Chignoli, Donghyun Kim, Elijah Stanger-Jones, Sangbae Kim

Massachusetts Institute of Technology
Biomimetic Robotics Lab
UMassAmherst | College of Information & Computer Sciences

The rise of humanoid robots

- The prototype of our “Xiaoxing” robot (2022)



The rise of humanoid robots

- The prototype of our “Xiaoxing” robot (2022)

The rise of humanoid robots

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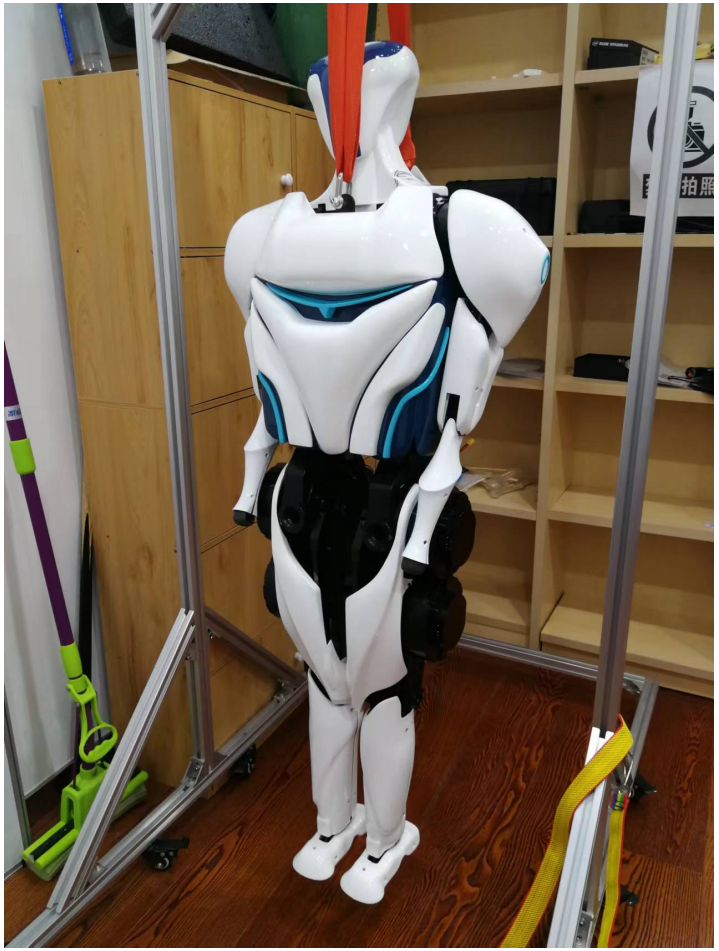
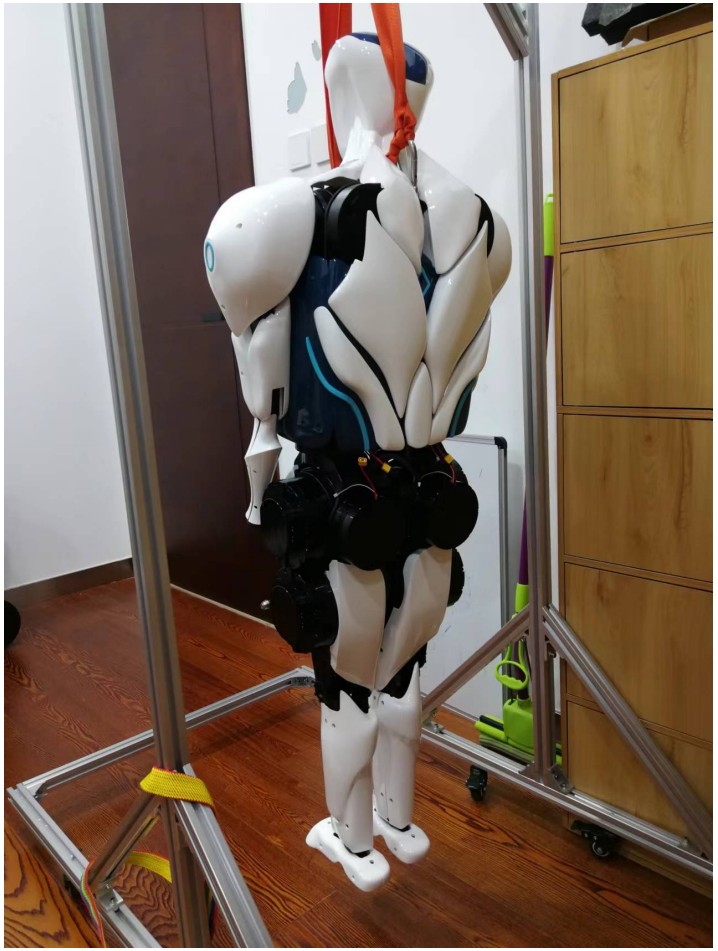
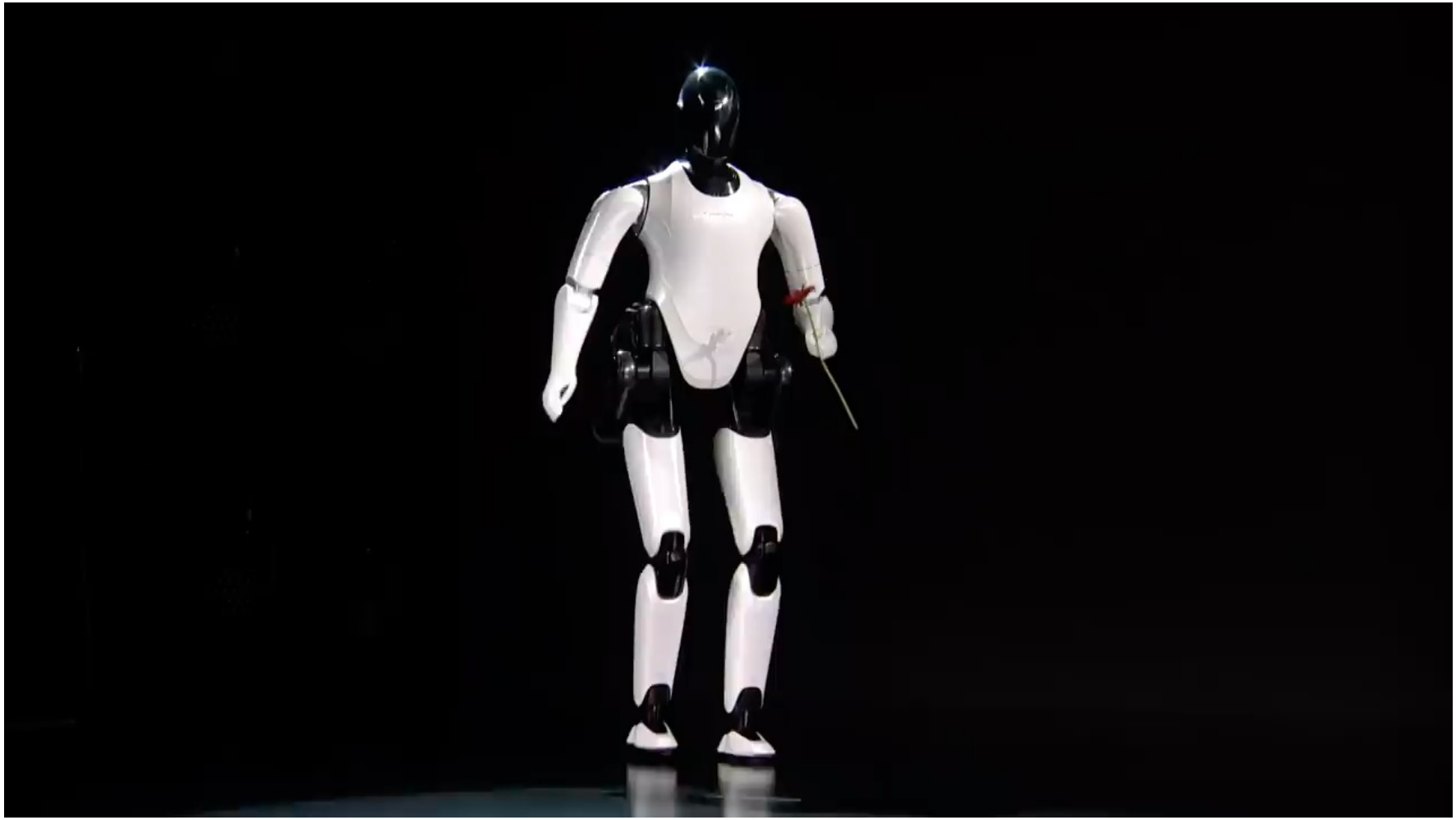




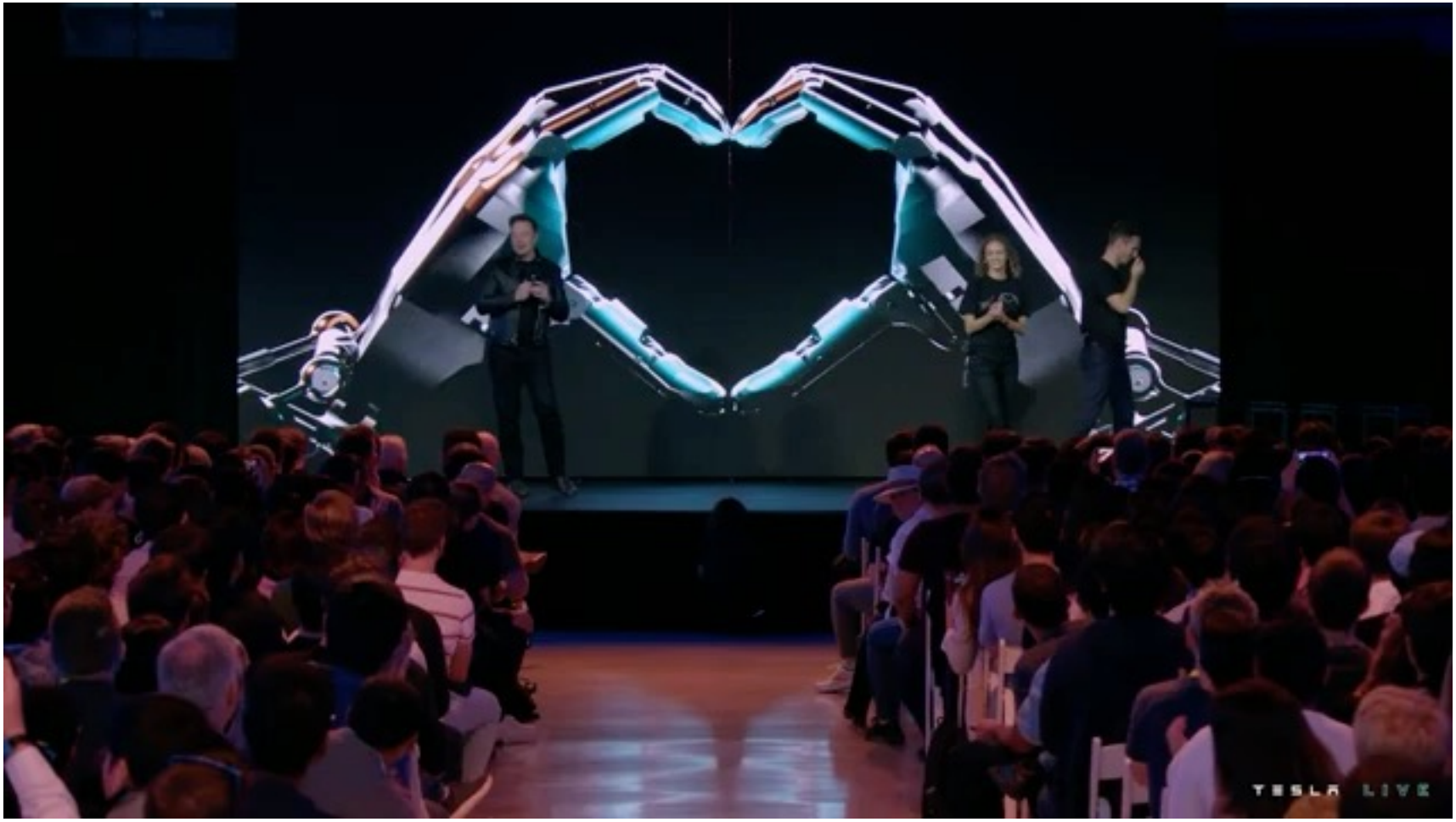
The rise of humanoid robots

- Xiaomi “CyberOne” (2022.08)



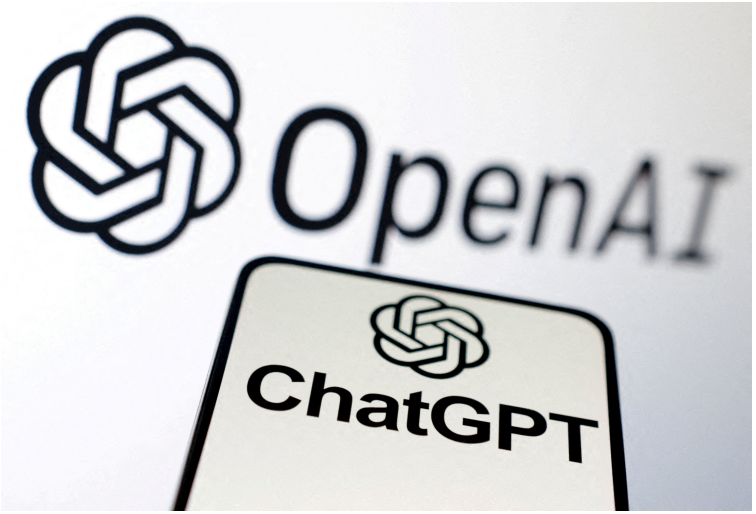
The rise of humanoid robots

- Tesla Optimus (2022.10)



Embodied AI era

- ChatGPT gives the hope of building general purpose intelligence



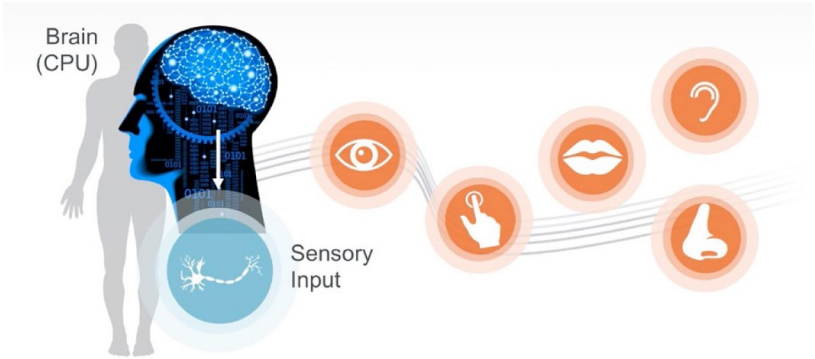
Embodied AI era

- My talk at 2023.03

通用人工智能的最佳物理载体

- ChatGPT是“缸中大脑”
- 通用人工智能需要更好的物理载体
- 人形机器人是AGI的最佳载体
  - 人类是世界上唯一真实存在的通用智能体

ChatGPT



AGI+物理载体

Embodied AI era

- My talk at 2023.03

广阔的应用前景

- 继智能手机的下一代通用智能终端

虚拟交互 → 物理交互

过去

现在

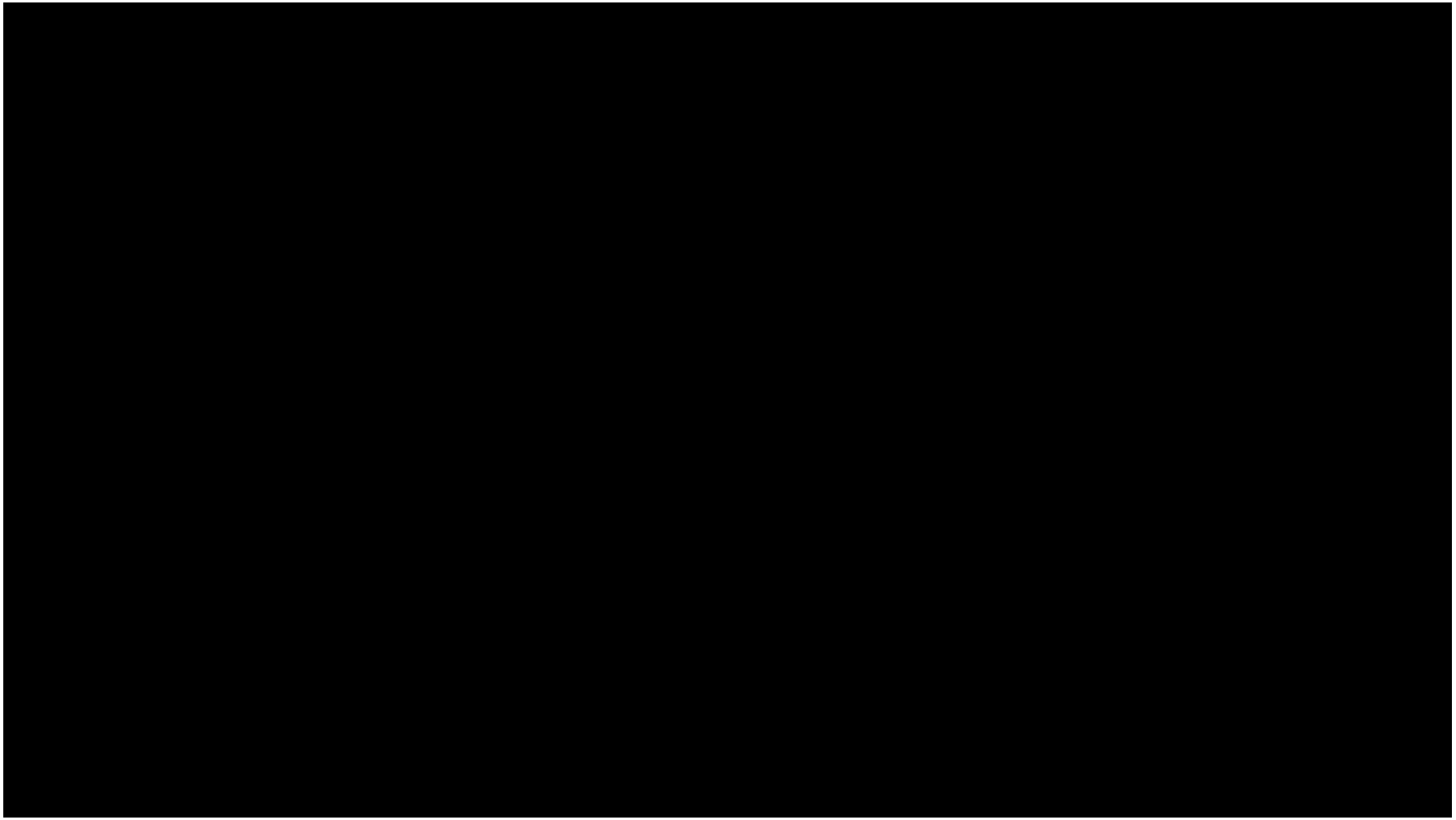
智能手机

通用机器人

未来

Embodied AI era

- The first generation of “Xiaoxing” (2023.07)



Embodied AI era

- The first generation of “Xiaoxing” (2023.07)

Embodied AI era

- WAIC Embodied AGI forum (2023.07)

Embodied AI era

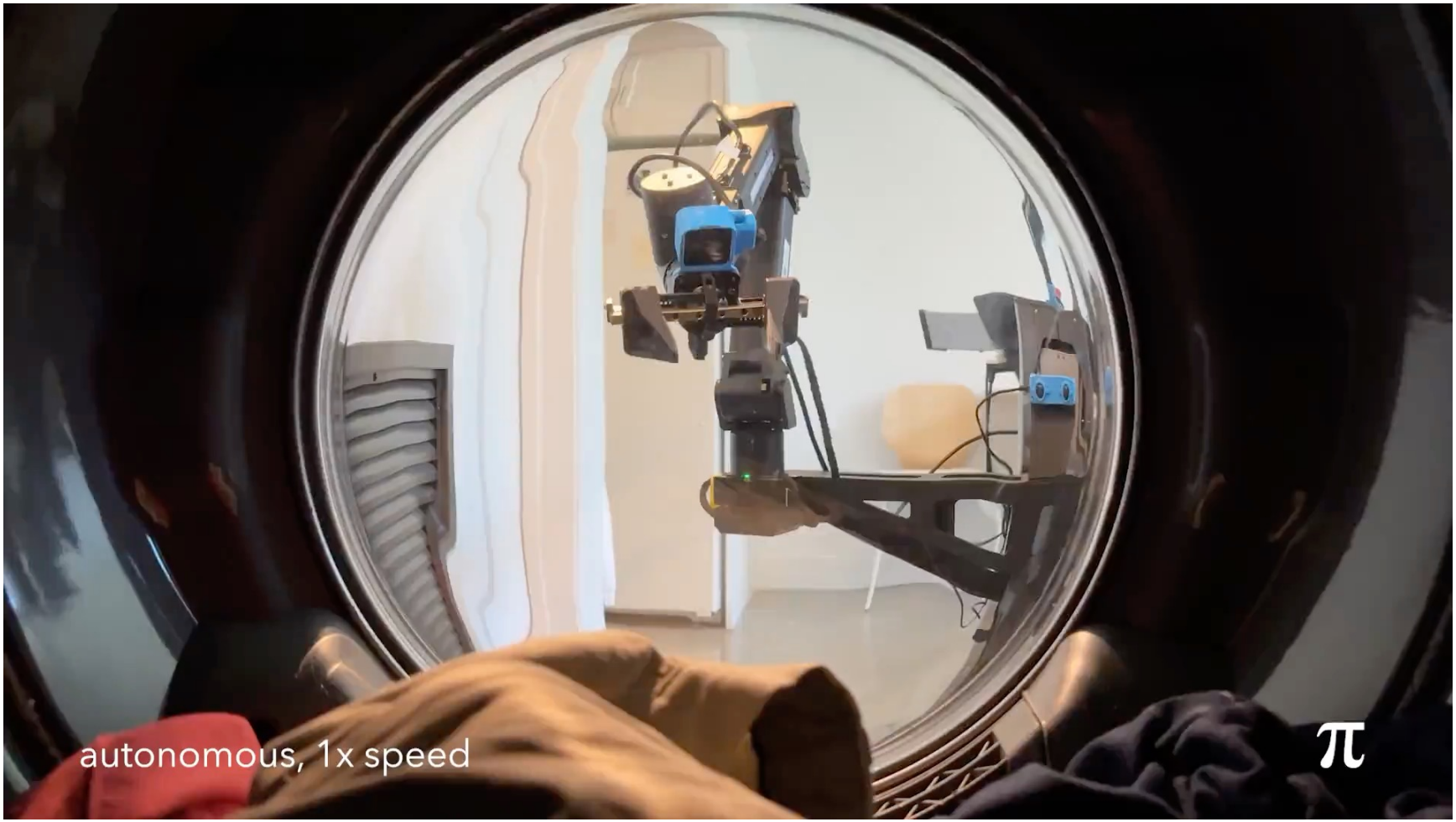
- Google Robot-Transformer

Embodied AI era

- Stanford Aloha

Embodied AI era

- Pi zero



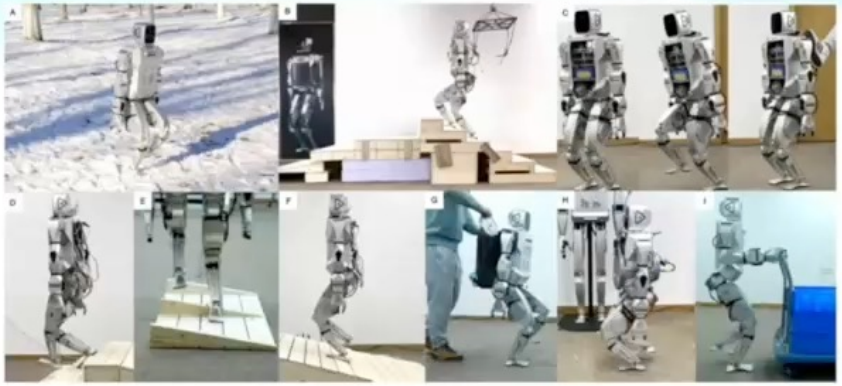
Embodied AI era

- Xiaoxing locomotion on challenging terrain (RSS best paper)

Advancing Humanoid Locomotion: Mastering Challenging Terrains with Denoising World Model Learning

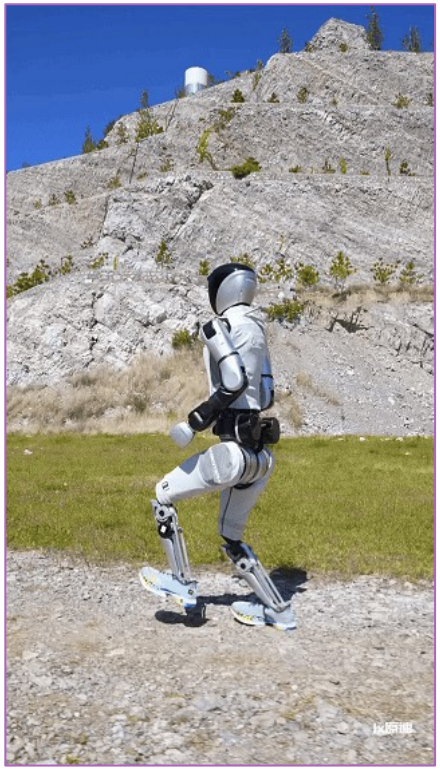
Supplementary Videos

The policy we trained was successfully deployed in all scenarios using a zero-shot sim-to-real approach, without any need for fine-tuning.



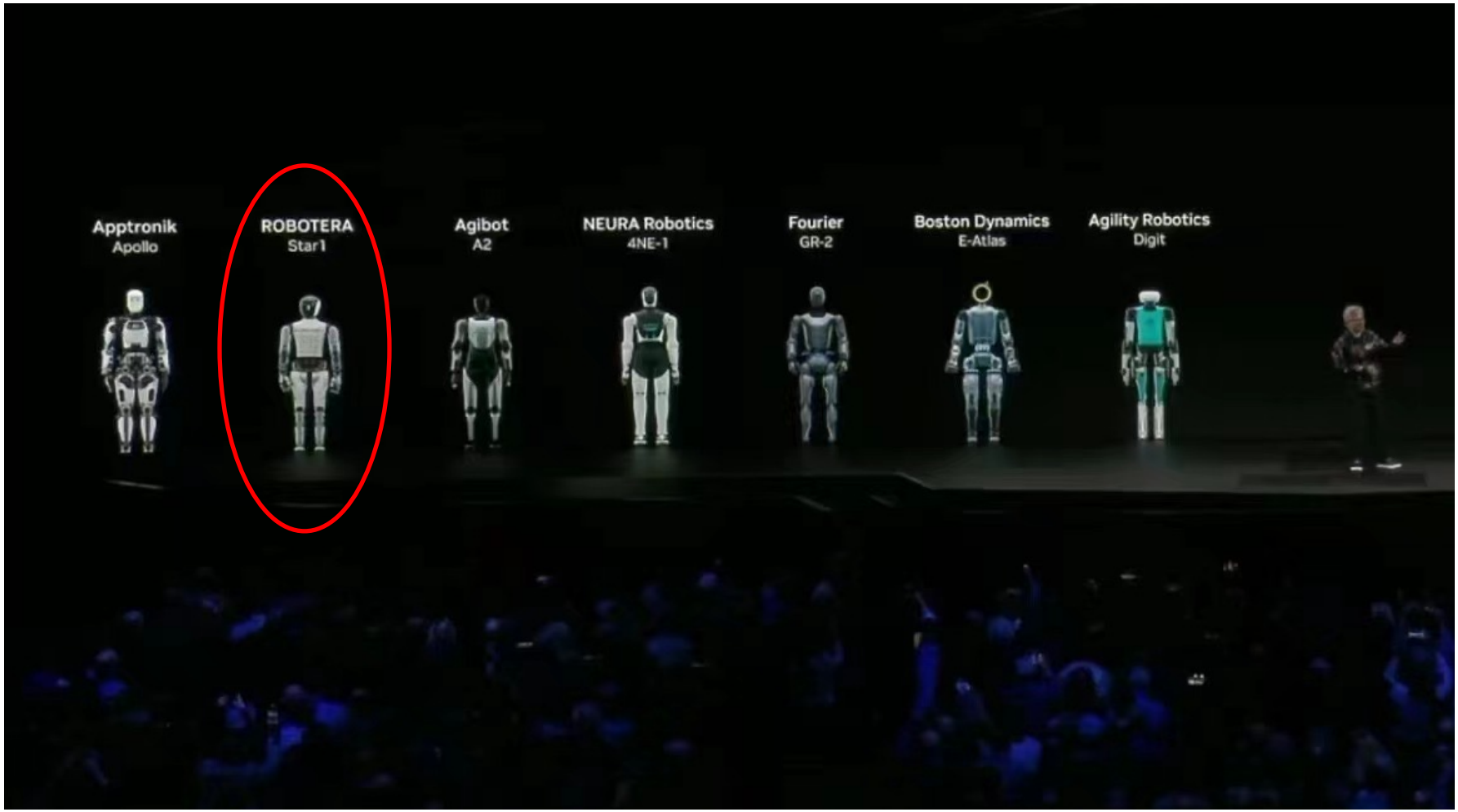
Embodied AI era

- Xiaoxing fast running (3.6m/s, world record)

Embodied AI era

- CES 2025 Nvidia talk

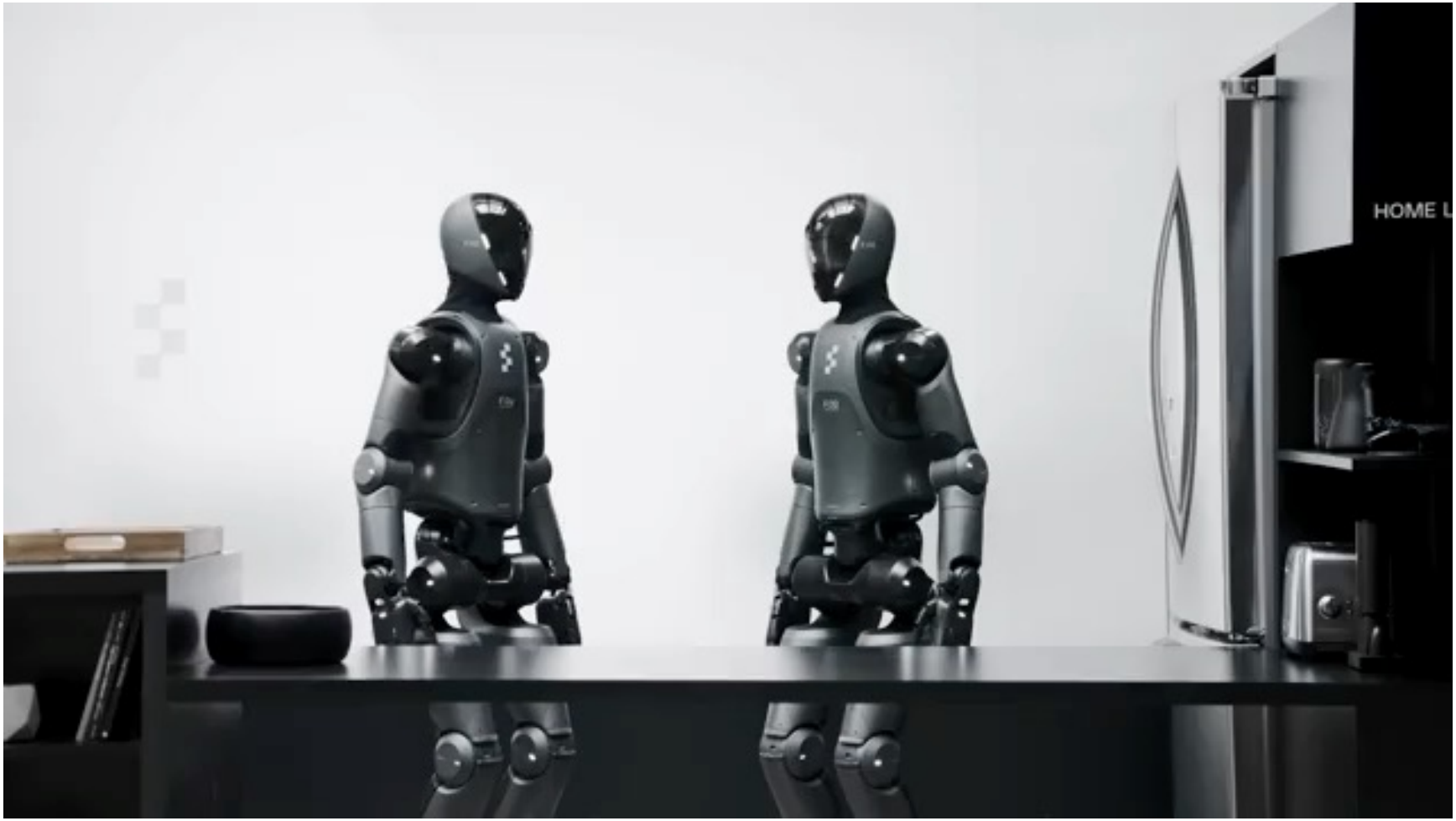


Foundation dexterous manipulation model

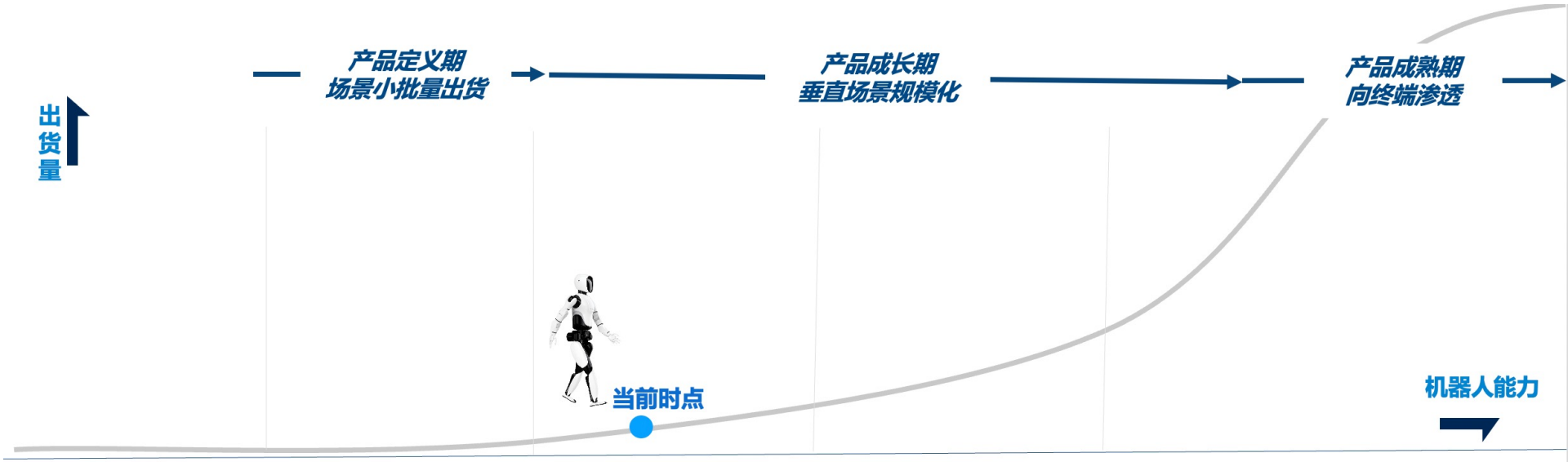
Foundation dexterous manipulation model

Unitree

Figure AI



The levels for embodied AI and robotics

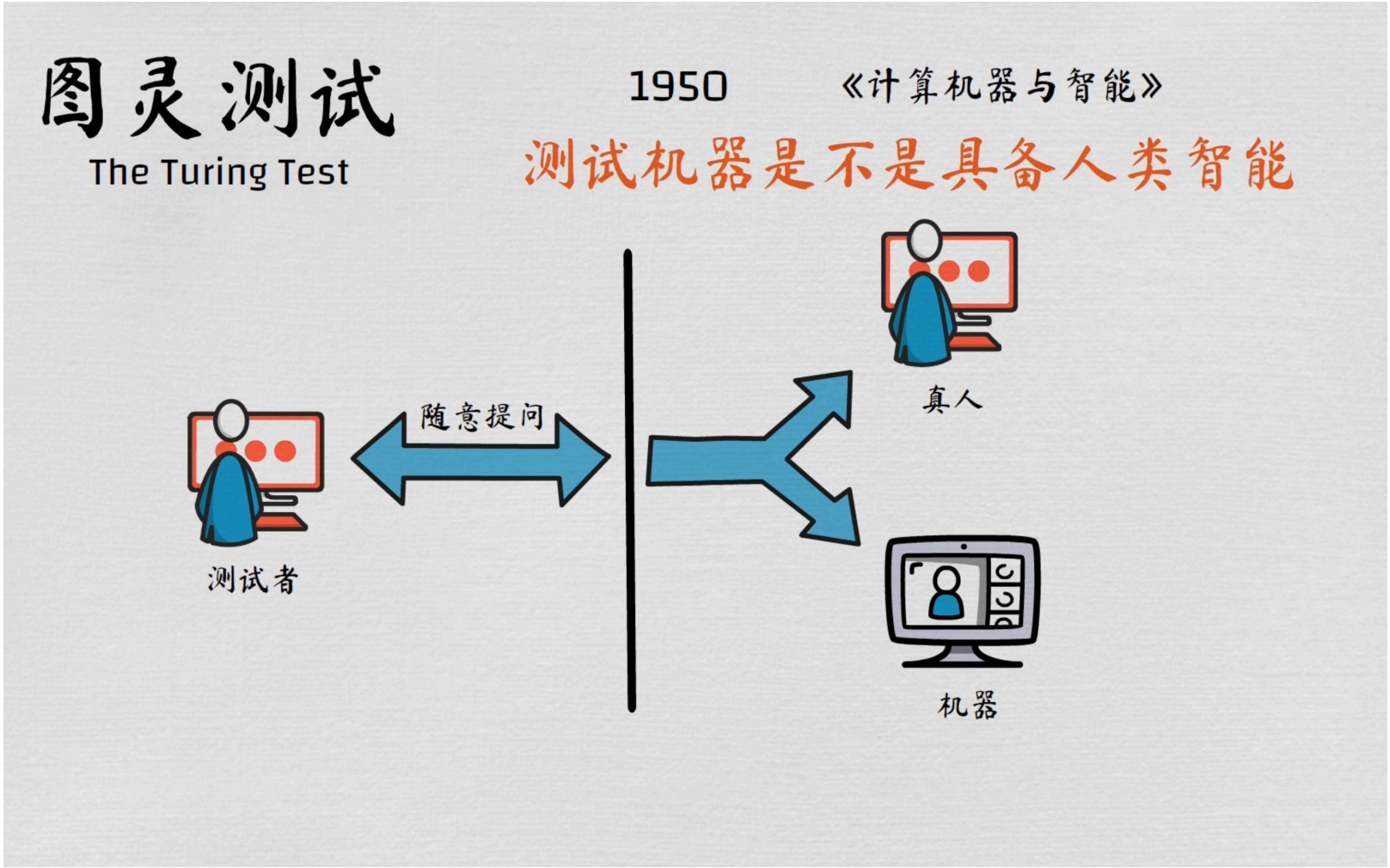


等级	L1	L2	L3	L4	L5
能力	固定动作与轨迹跟踪	单一移动与操作任务泛化实现	多任务泛化，复杂决策，人机交互	具备通用常识和快速学习能力	与人类等同的能力

工具 **服务** **共生**

Turing tests for robots?

- Autonomous or tele-operation?



Robots with self-conscious?

- The development of human intelligence is closely related to social relationships

"Wolf" child

The Truman Show

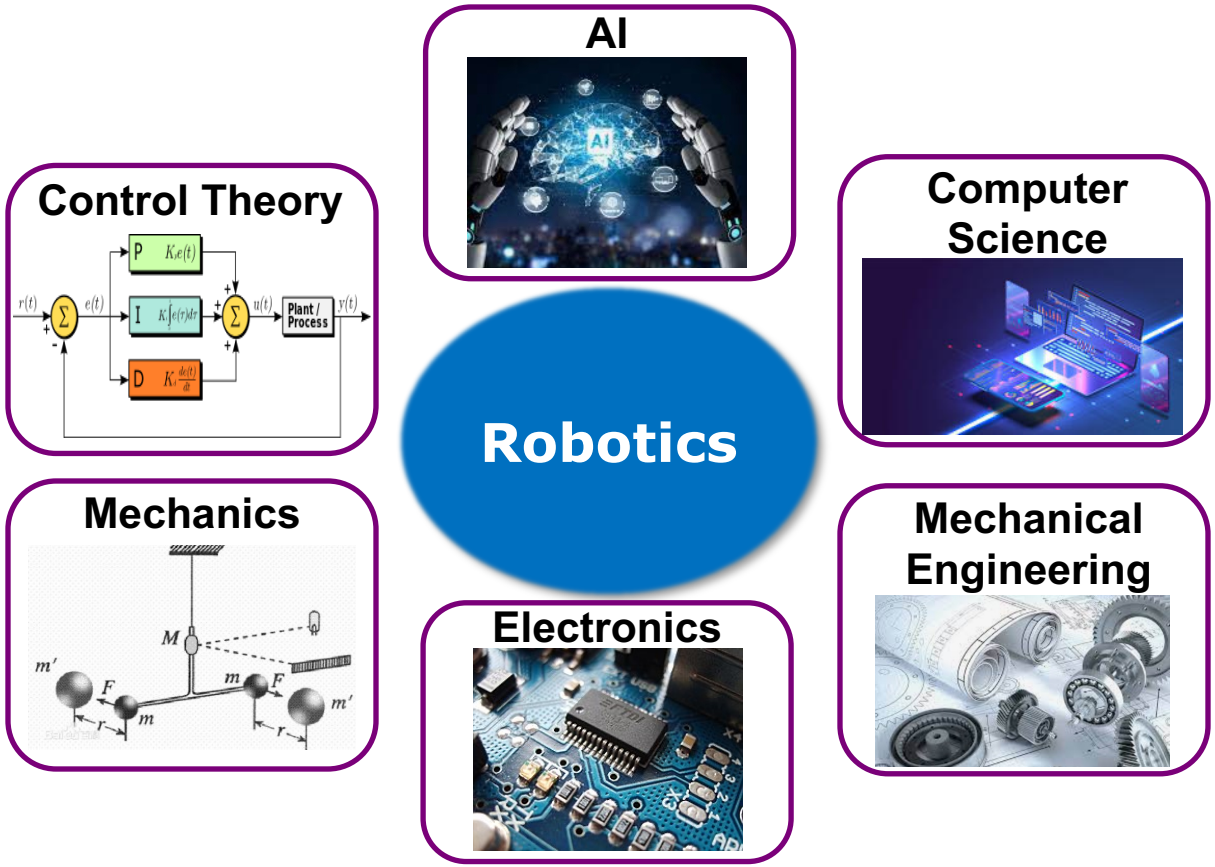
Contents

What is robotics?

- Definition: Robotics
  - Science and technology of robots.

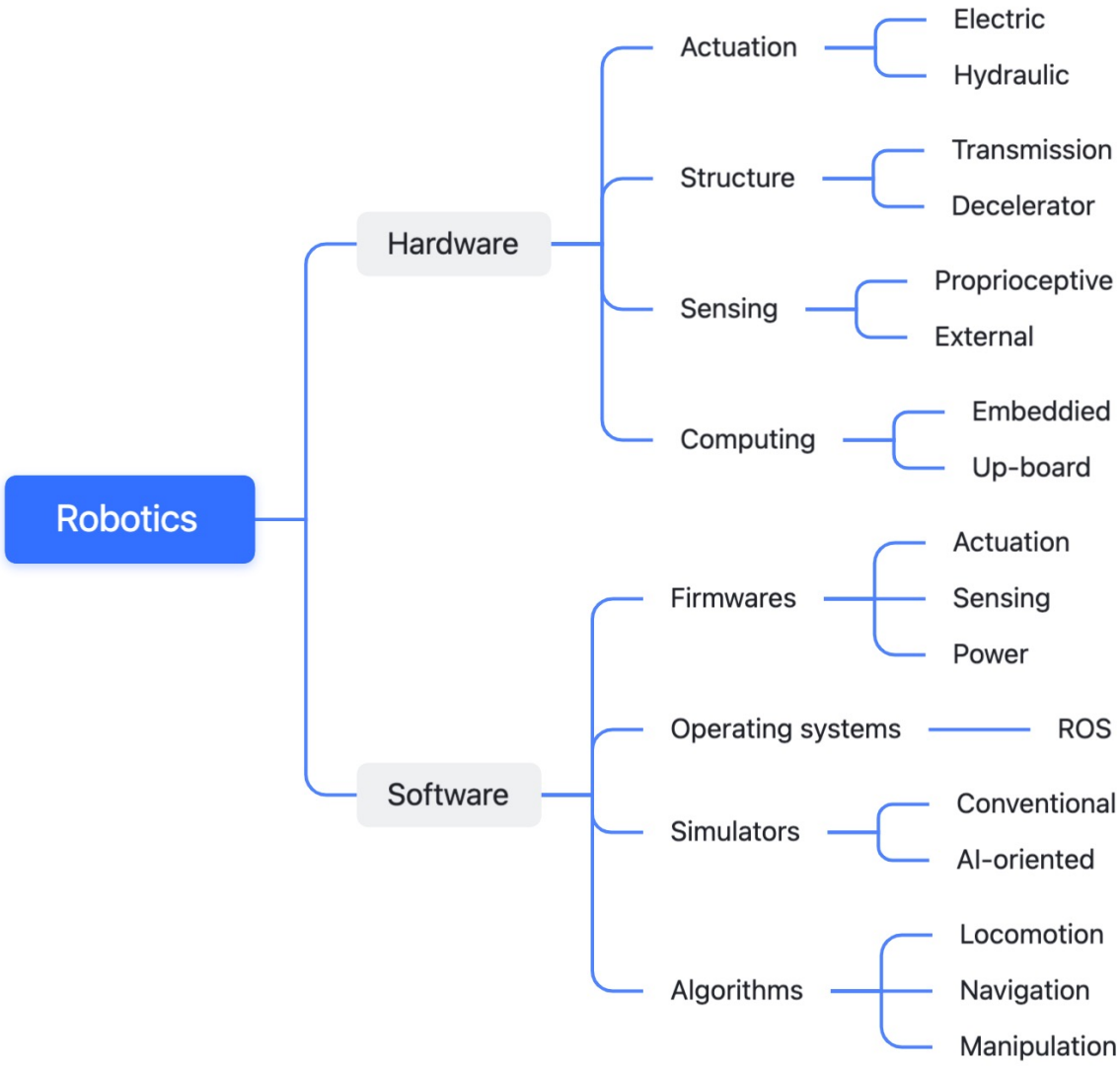
---S. Shankar Sastry

  - Robotics is an interdisciplinary science

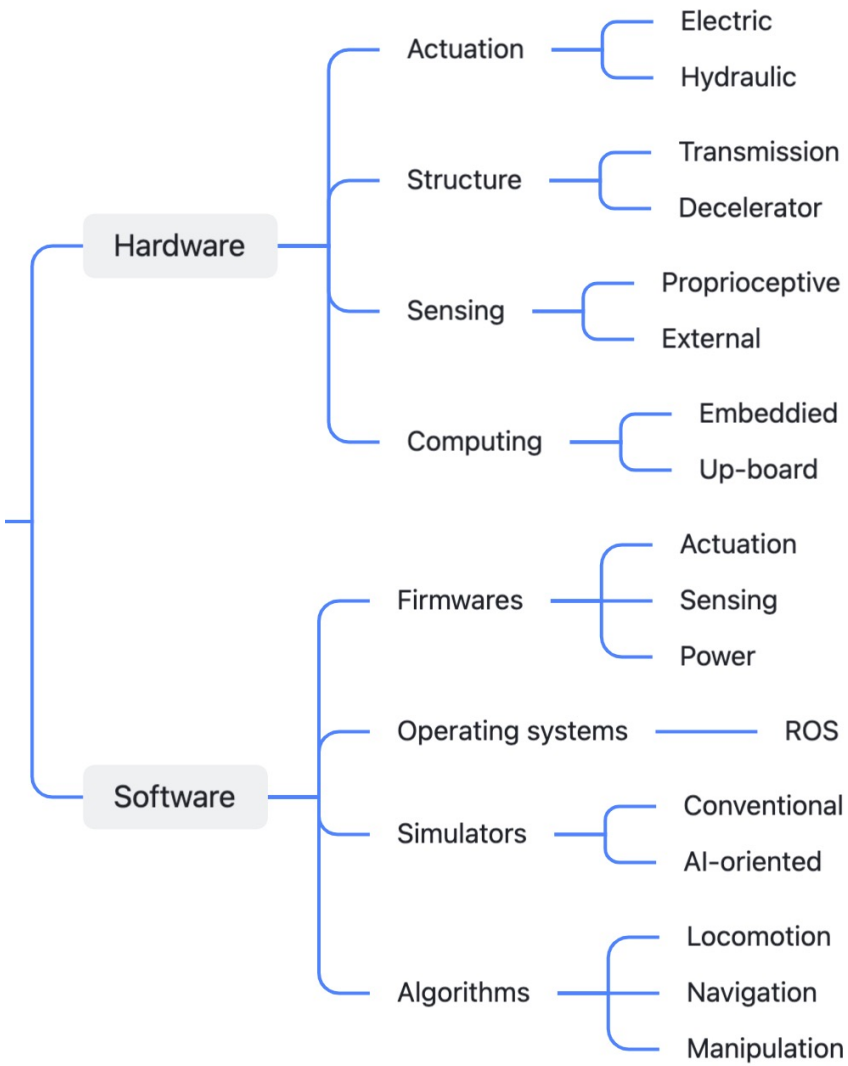


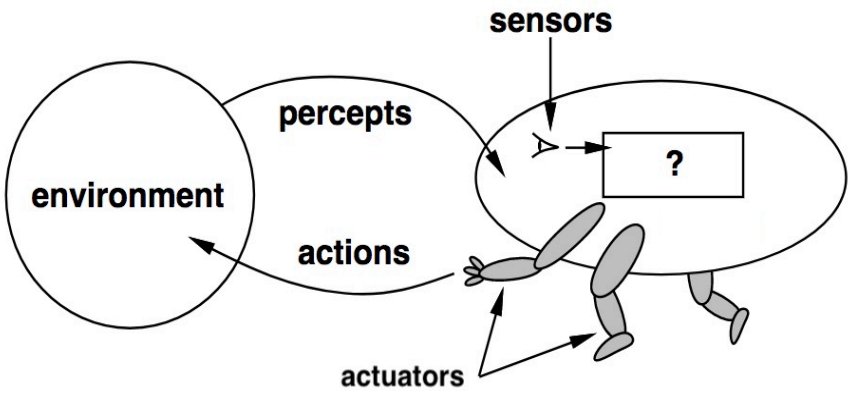
Technology overview

- Robotics covers a huge range of technologies



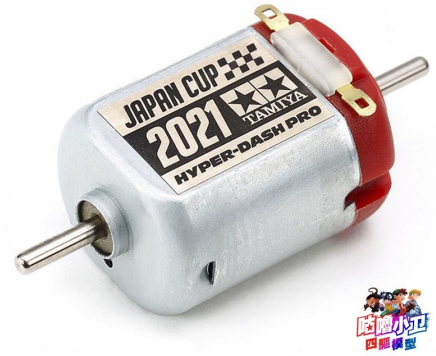
Technology overview





Actuation

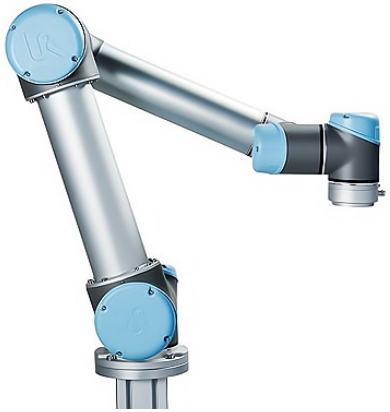
- Convert electric energy to kinetic energy
- Electric motors



DC brush motor

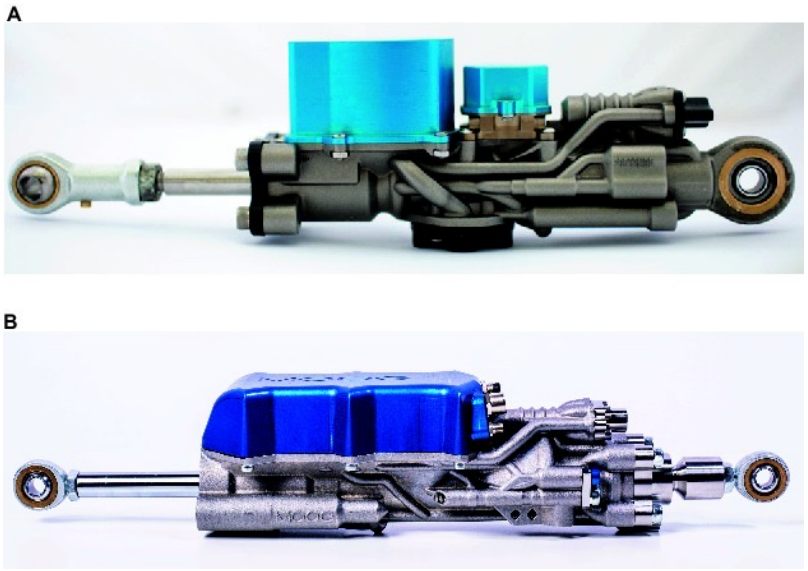
Steering engine

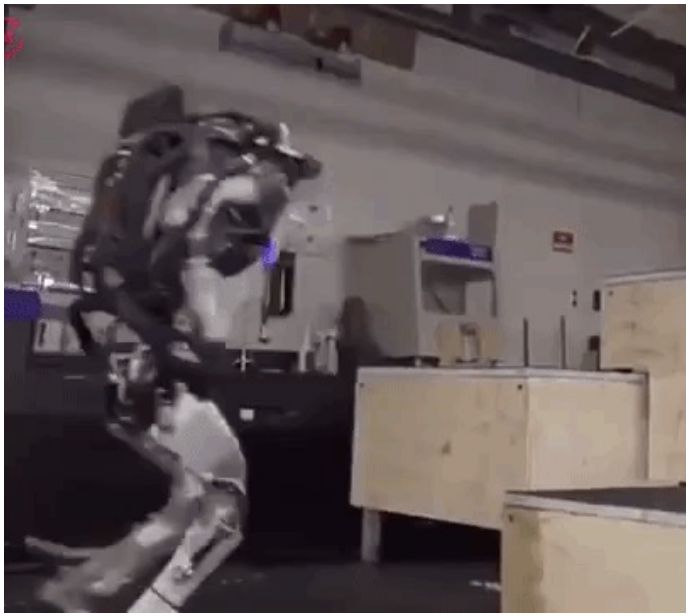
Torque motor



Actuation

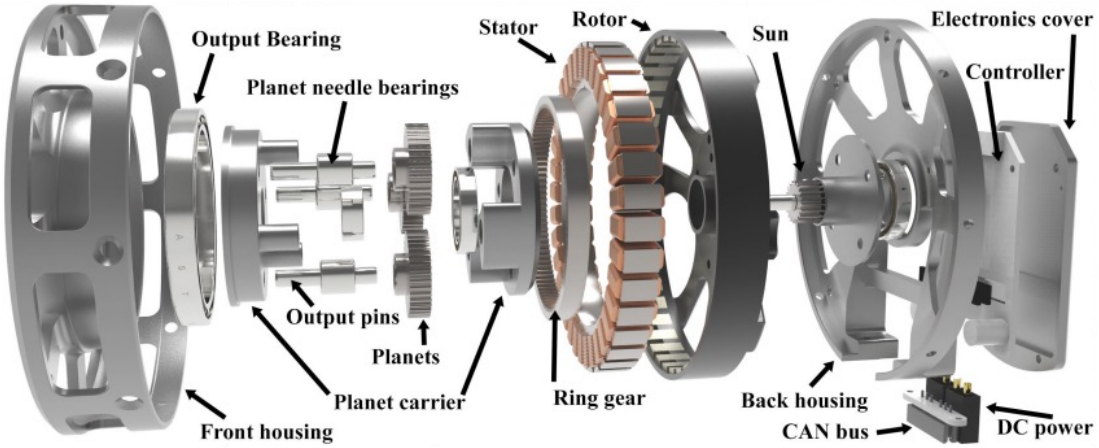
- Hydraulic motors
  - Can provide large power





Mechanics

- Decelerator
  - Output torque = Motor torque x ratio
  - Output speed = Motor speed / ratio



Planet gear

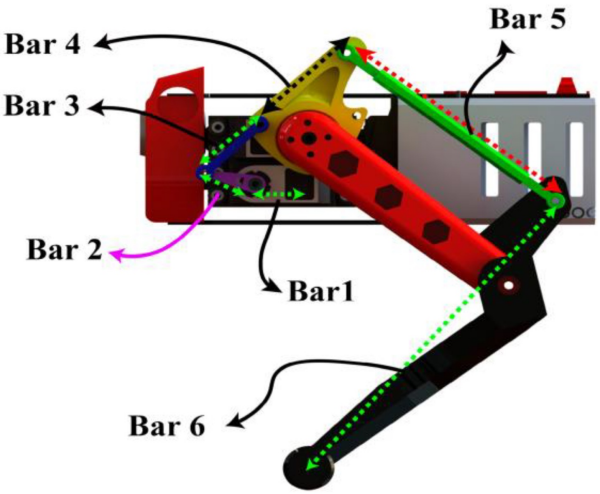
Mechanics

- Decelerator
  - Output torque = Motor torque x ratio
  - Output speed = Motor speed / ratio

Harmonic drive

Mechanics

- Transmission
  - Allow actuator and actuated links at different locations



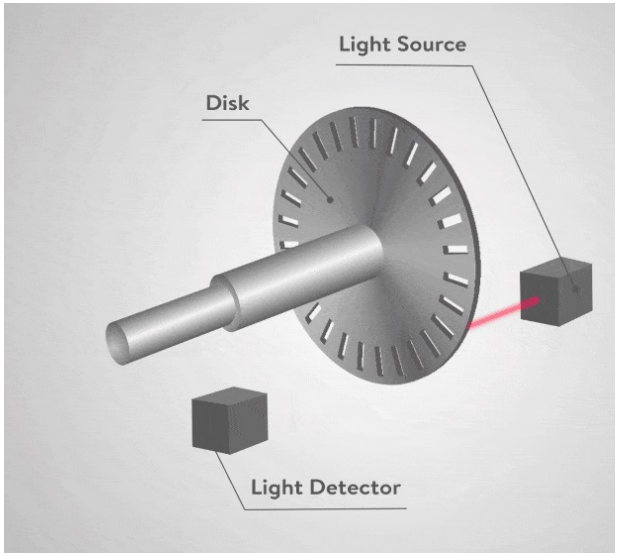
Bar linkage

Belt drive

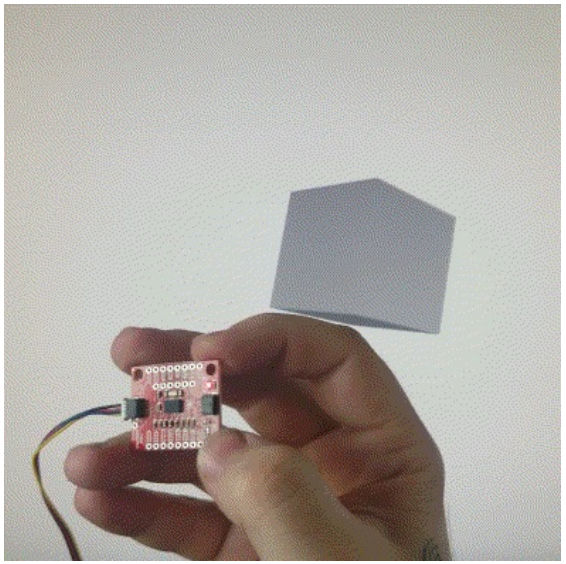
Ball screw

Sensing

- Proprioceptive



Encoder



IMU

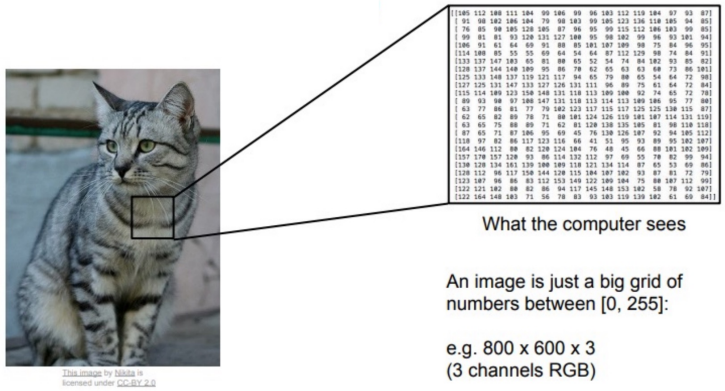
Sensing

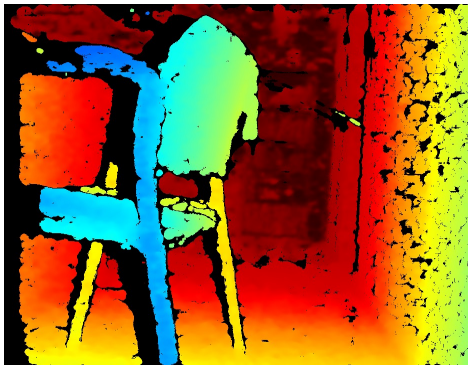
- External

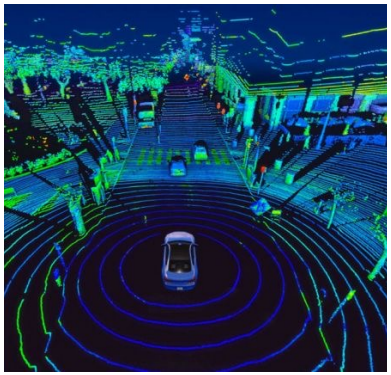
Camera

Depth

Lidar

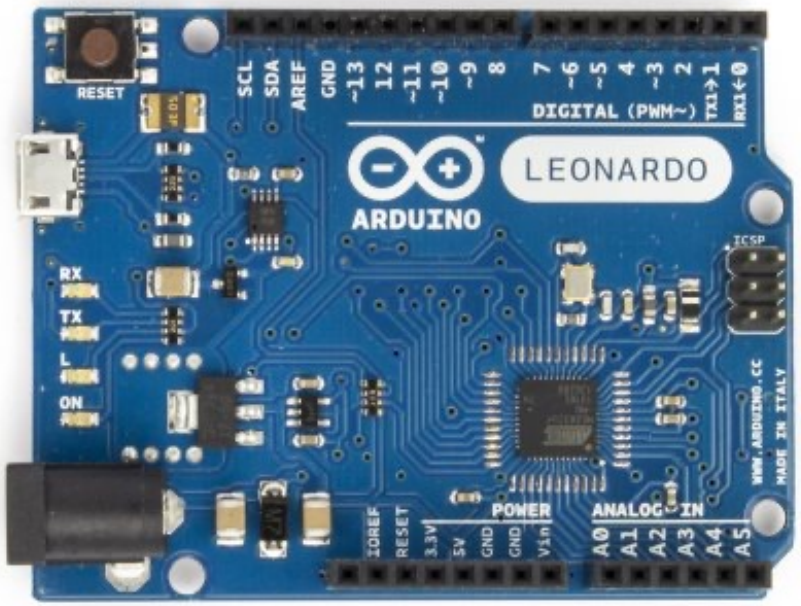






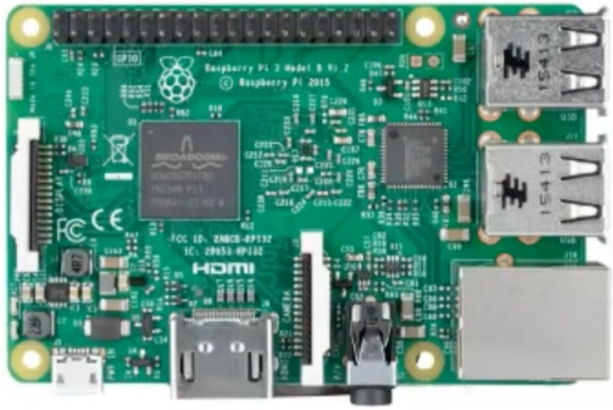
Computing

- Embedded: drive the hardware
  - Motors
  - Sensors
  - Power management



Computing

- Up-board
  - Run robot algorithms
  - Hardware for implementing robot intelligence
  - Basically a PC



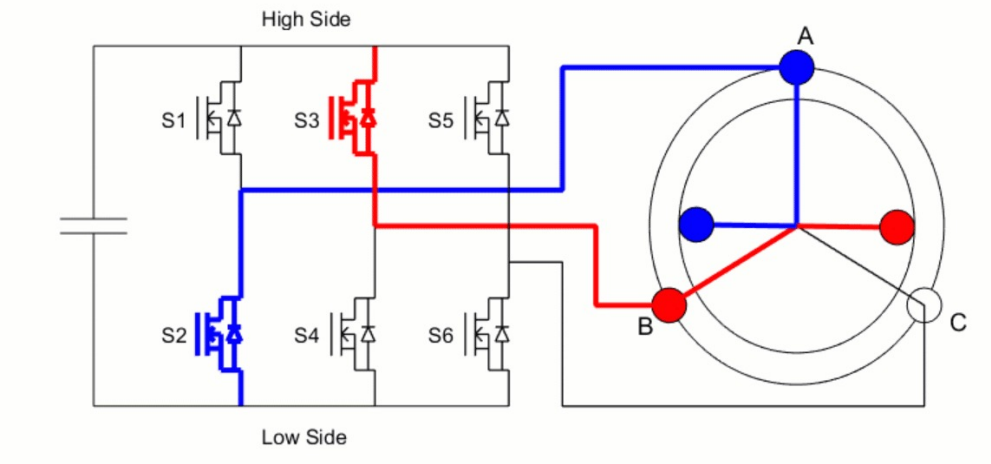
Raspberry Pi

Intel NUC

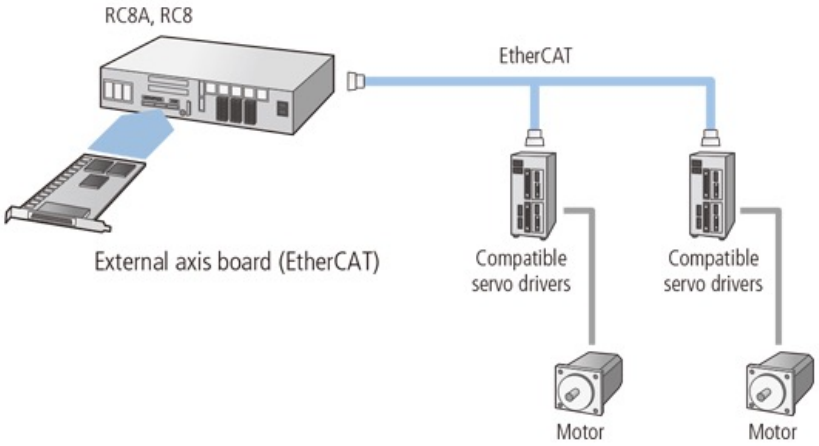
Nvidia Jetson

Softwares

- Hardware-level softwares



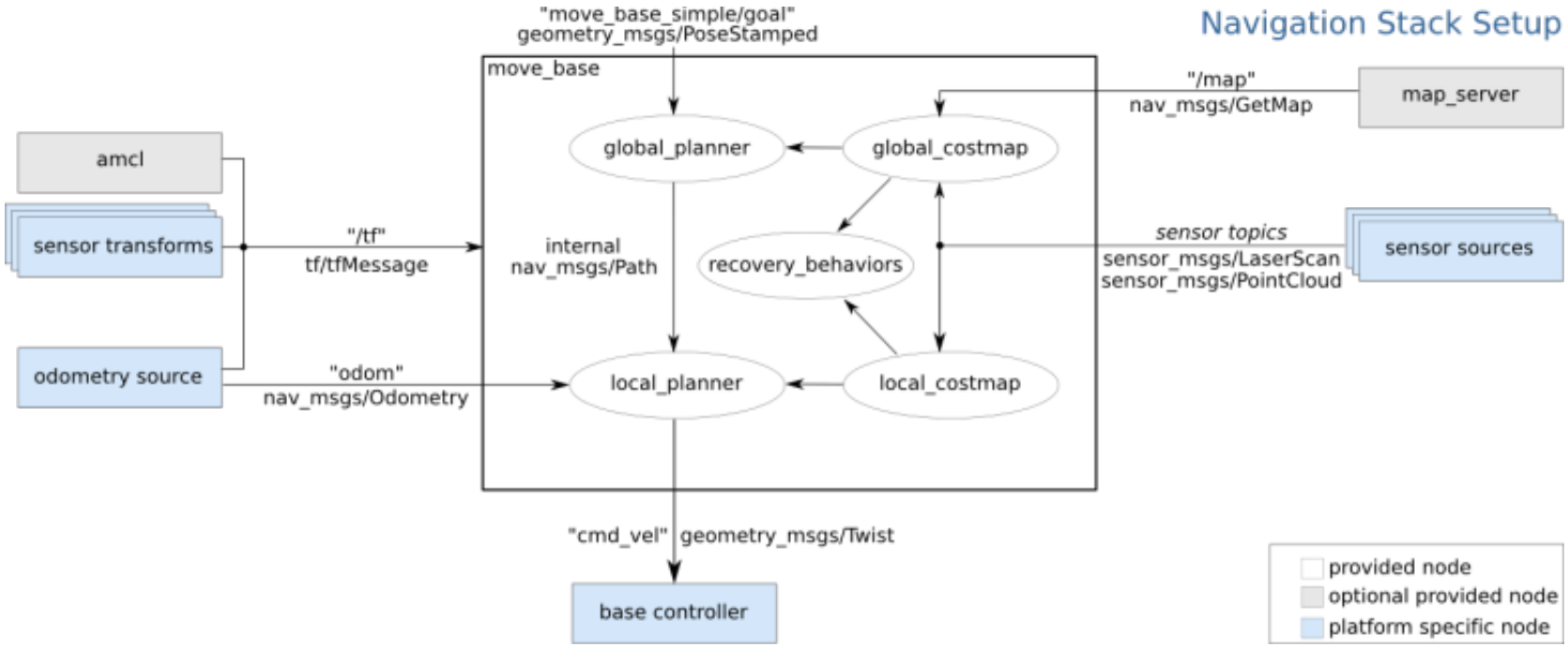
Motor control



Communications

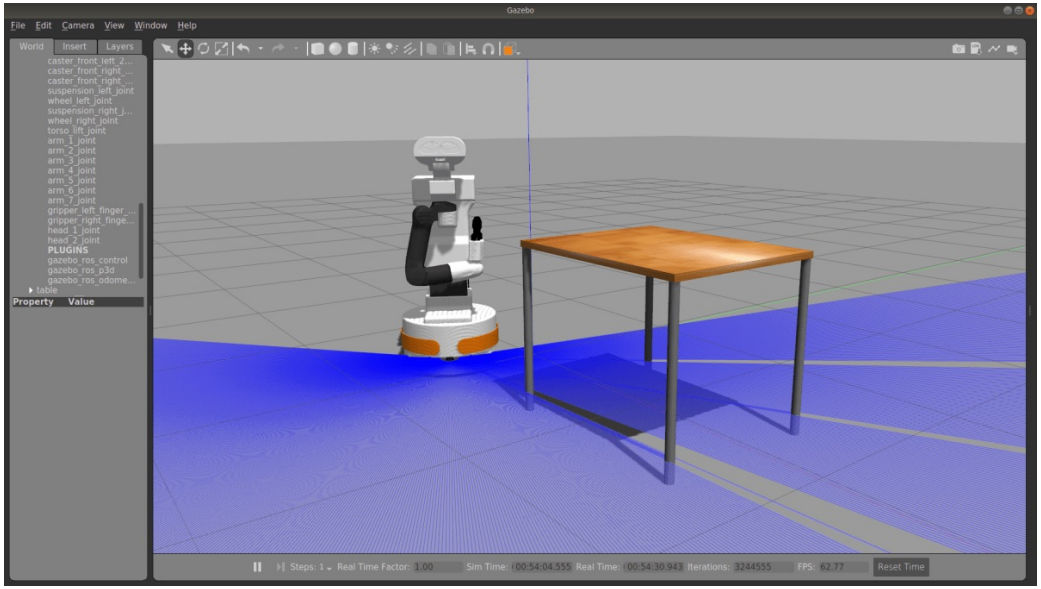
Softwares

- ROS (Robot Operating System)
  - Manage information sharing among multiple hardwares and software packages
  - A software ecosystem



Simulators

- Conventional robotics

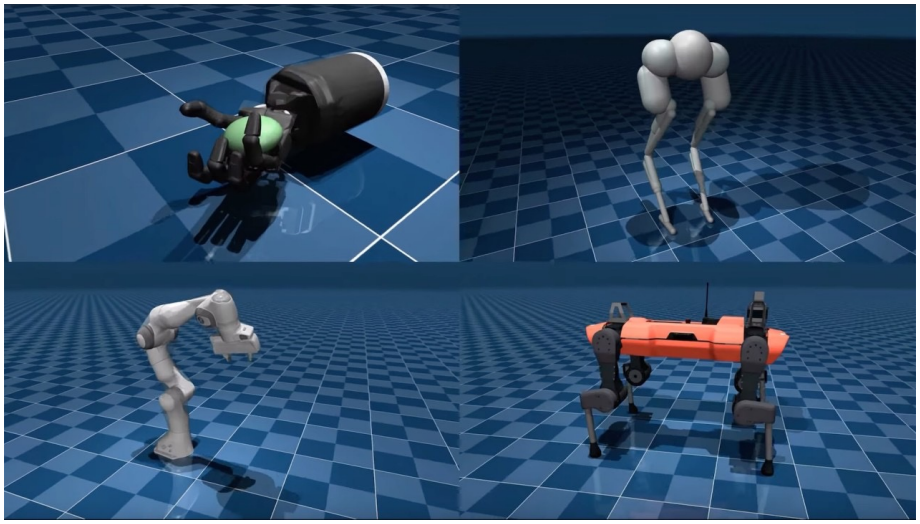


Gazebo

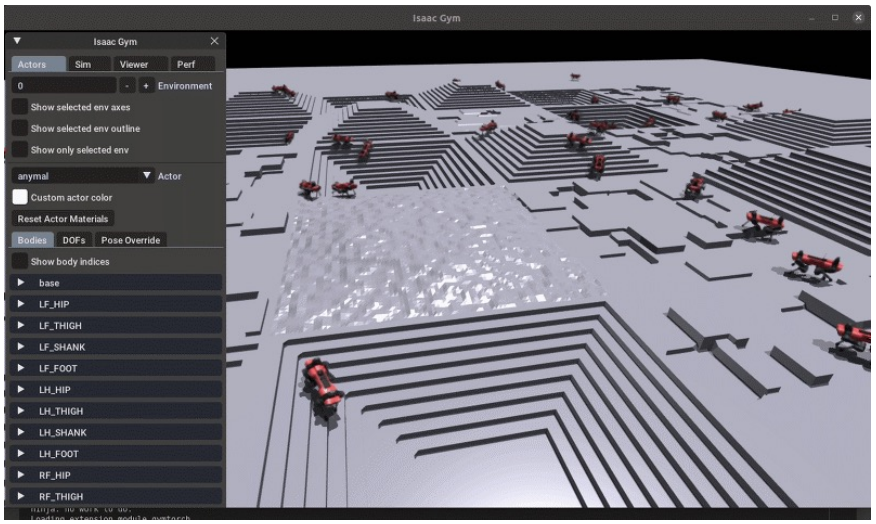
Webots

Simulators

- AI-oriented



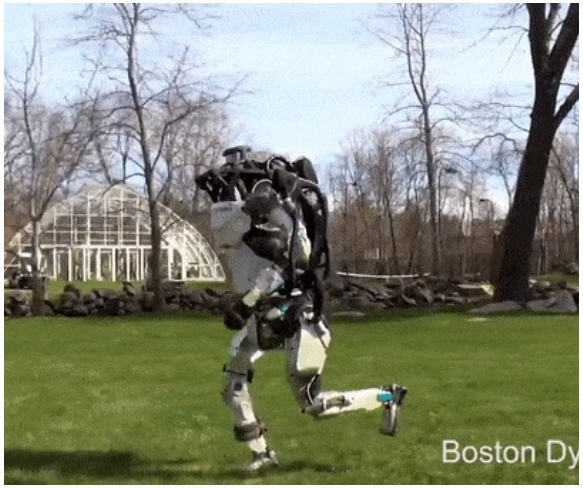
Mujoco



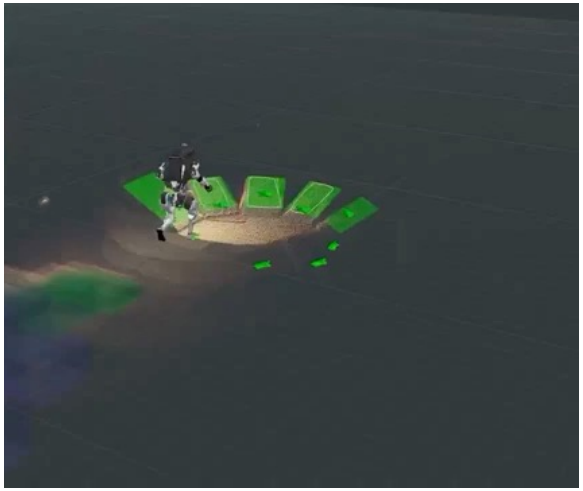
Isaac gym

Algorithms

- Kinematics, dynamics
- Control, planning
- Reinforcement learning, imitation learning
- Perception, localization



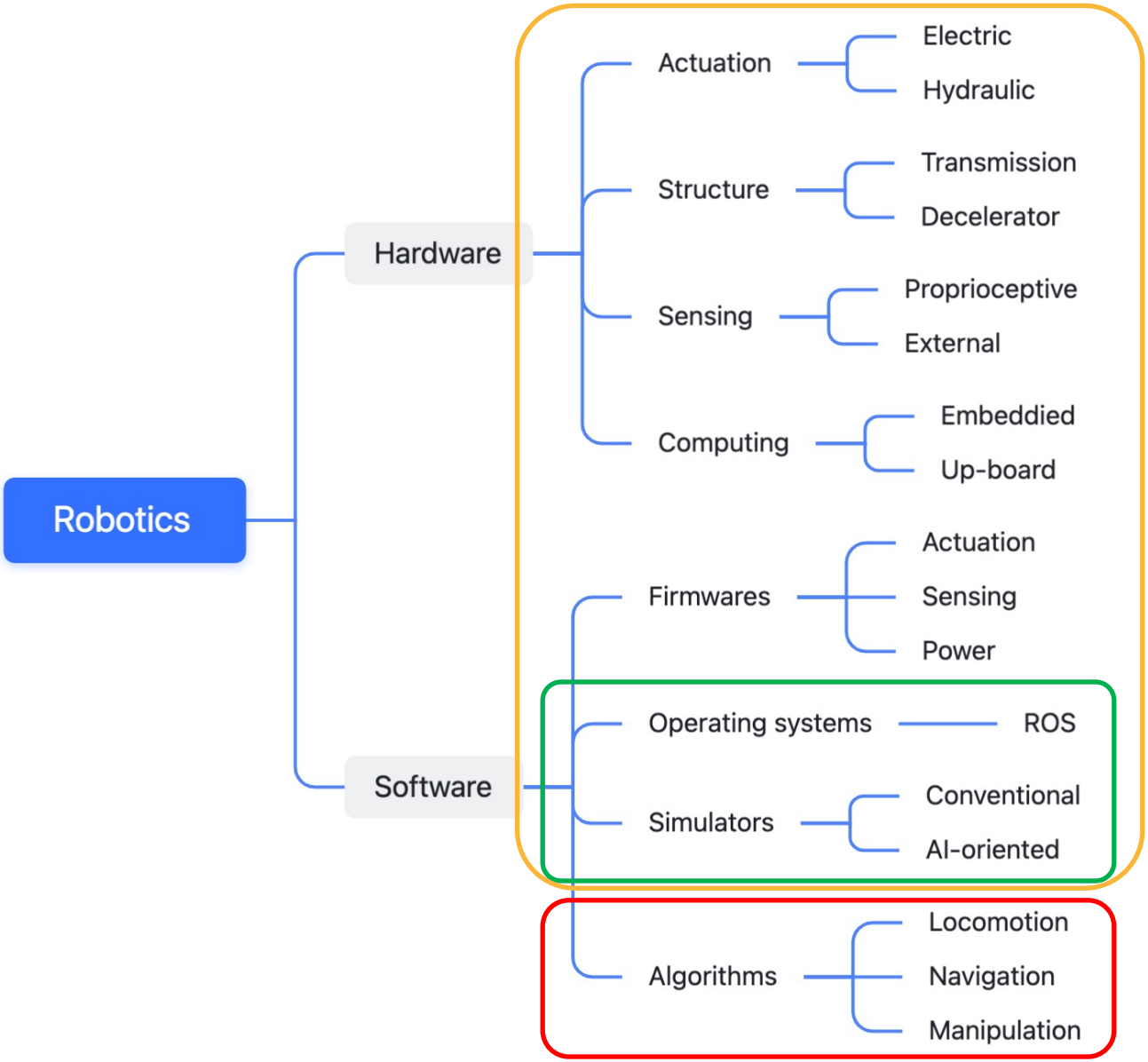
Locomotion



Navigation

Manipulation

Course coverages



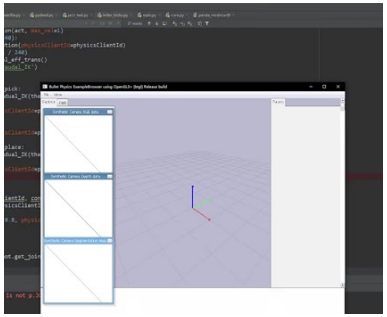
Use as it is

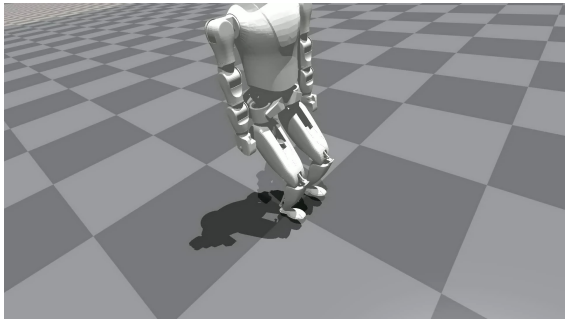
Need to practice in projects and HWs

Lecture mainly covers

Course policy

- **Grading policy**
  - Homeworks 40%
  - Paper reading 20%
  - Final project 35%
  - Class behavior 5%



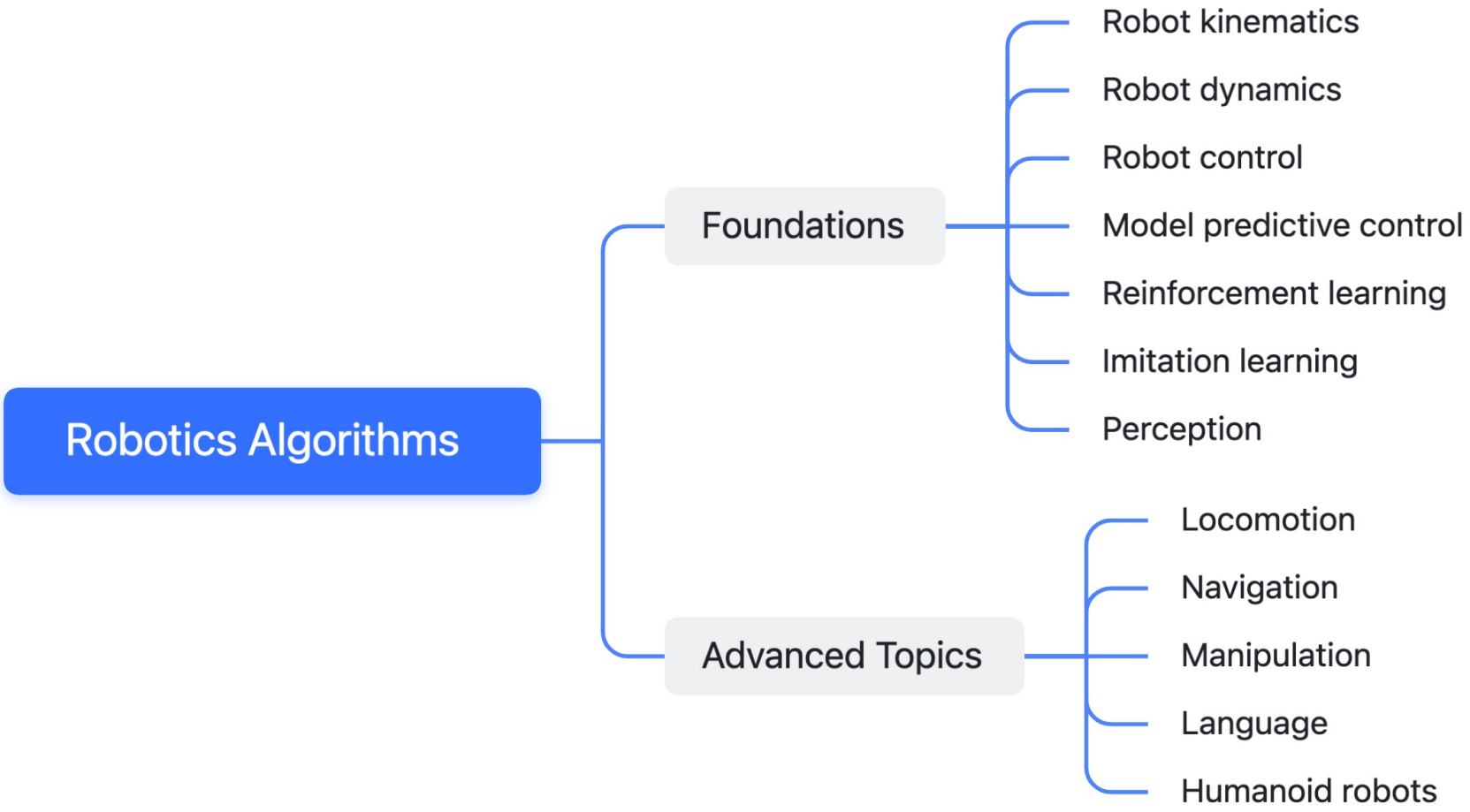


- **Final project**
  - 1~2 students per team
  - 10% proposal (Due around the 10th week)
  - 25% final project presentation (The last week)
  - Simulations or real robot

Intelligent Systems and Robotics Lab

- **Intelligent systems and robotics lab (ISRLab)**

Lecture topics



Thank you!

清華大學 交叉信息研究院

Institute for Interdisciplinary Information Sciences, Tsinghua University

ISR Lab

Intelligent Systems and Robotics Lab