



THE UNIVERSITY *of* EDINBURGH
informatics

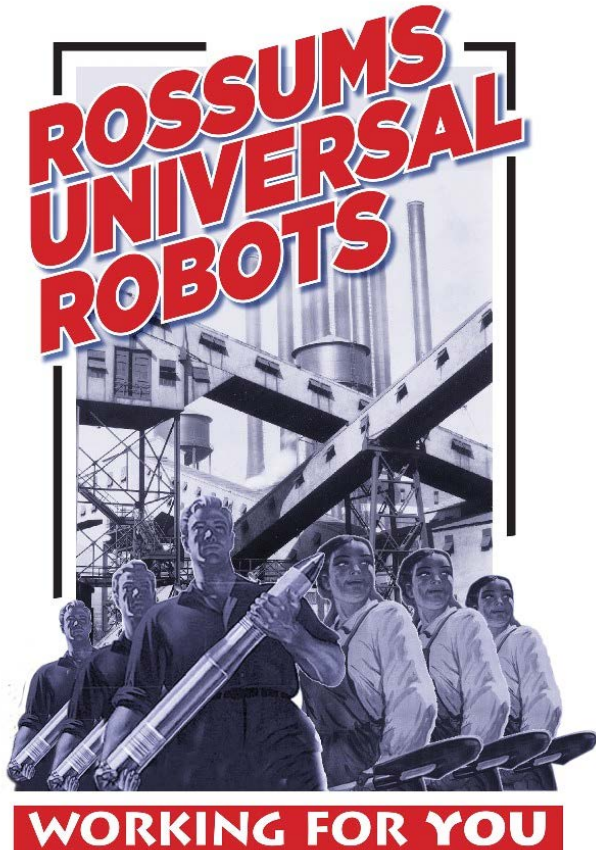
Advanced Robotics

1 - Overview of Robotics

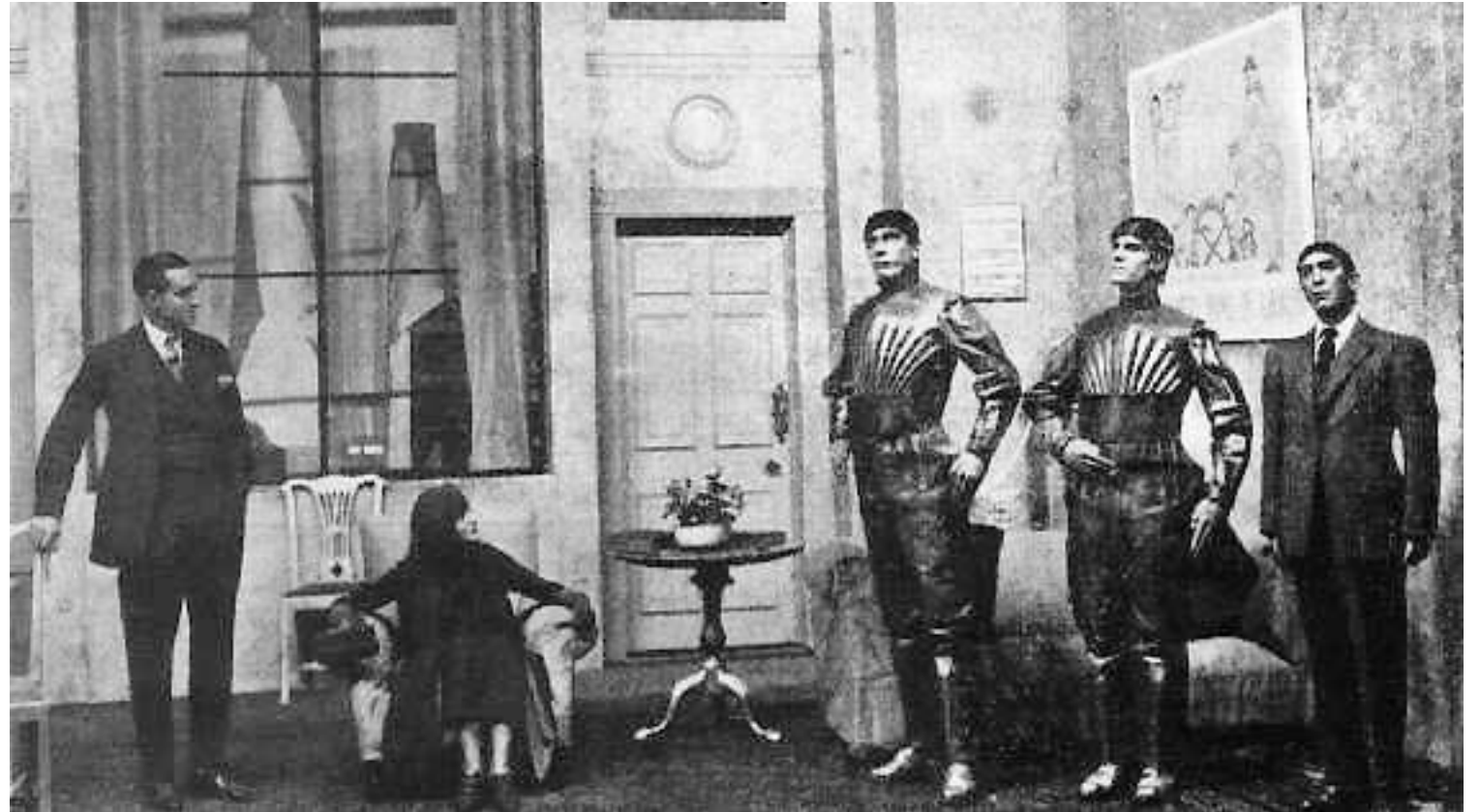
21 Sep 2026

Sethu Vijayakumar & Steve Tonneau
School of Informatics
University of Edinburgh

Rossum's Universal Robots



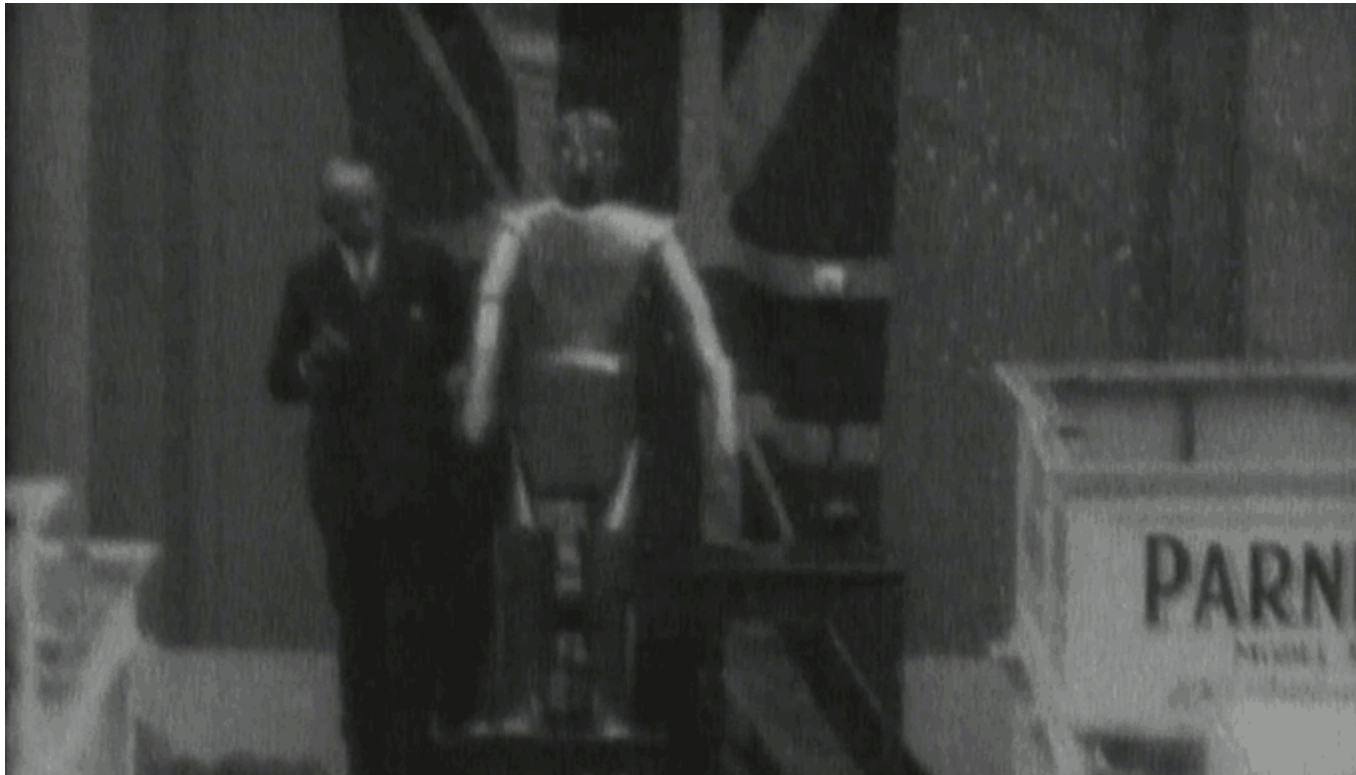
© Edward Alderton Theatre, image by Kevin Coward



© R.U.R. - Wikipedia

Eric: UK's first robot

UK's first robot, and most interestingly, it is a humanoid robot.



Built in 1928 by Captain Richards & A.H. Reffell

See more at: http://www.sciencemuseum.org.uk/visitmuseum/plan_your_visit/exhibitions/eric

Robots: machines that automate some behavior

The first industrial robot: Unimate



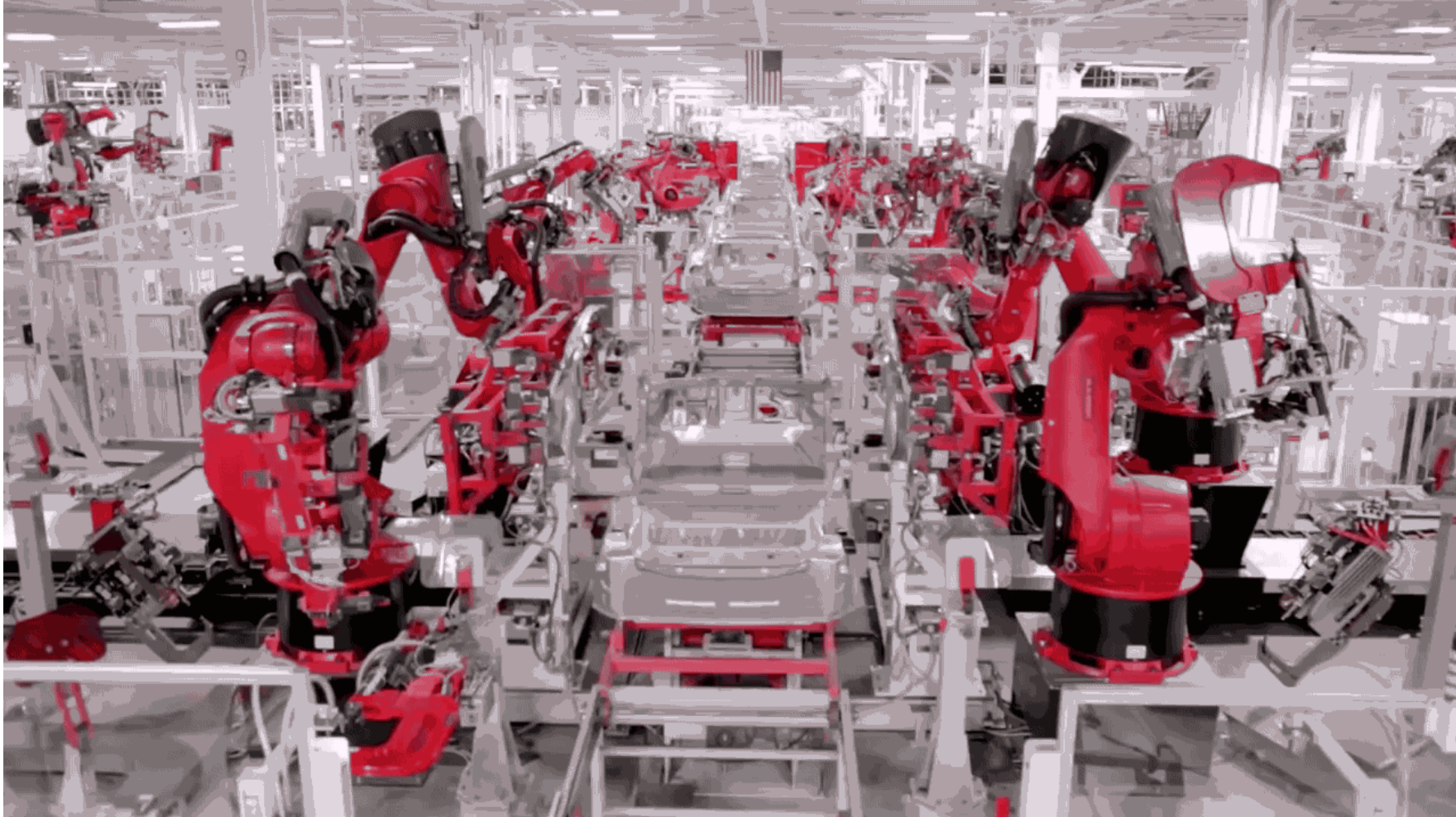
George Charles Devol developed the prototype of Unimate in 1950s, the first material handling robot employed in industrial production work.

The first Unimate robot was sold to General Motors in 1961.



Unimate Robot, © the history channel

Robots Today: Car assembly in Tesla



Picture source: [pinterest.com](https://www.pinterest.com)

What is (not) a Robot?



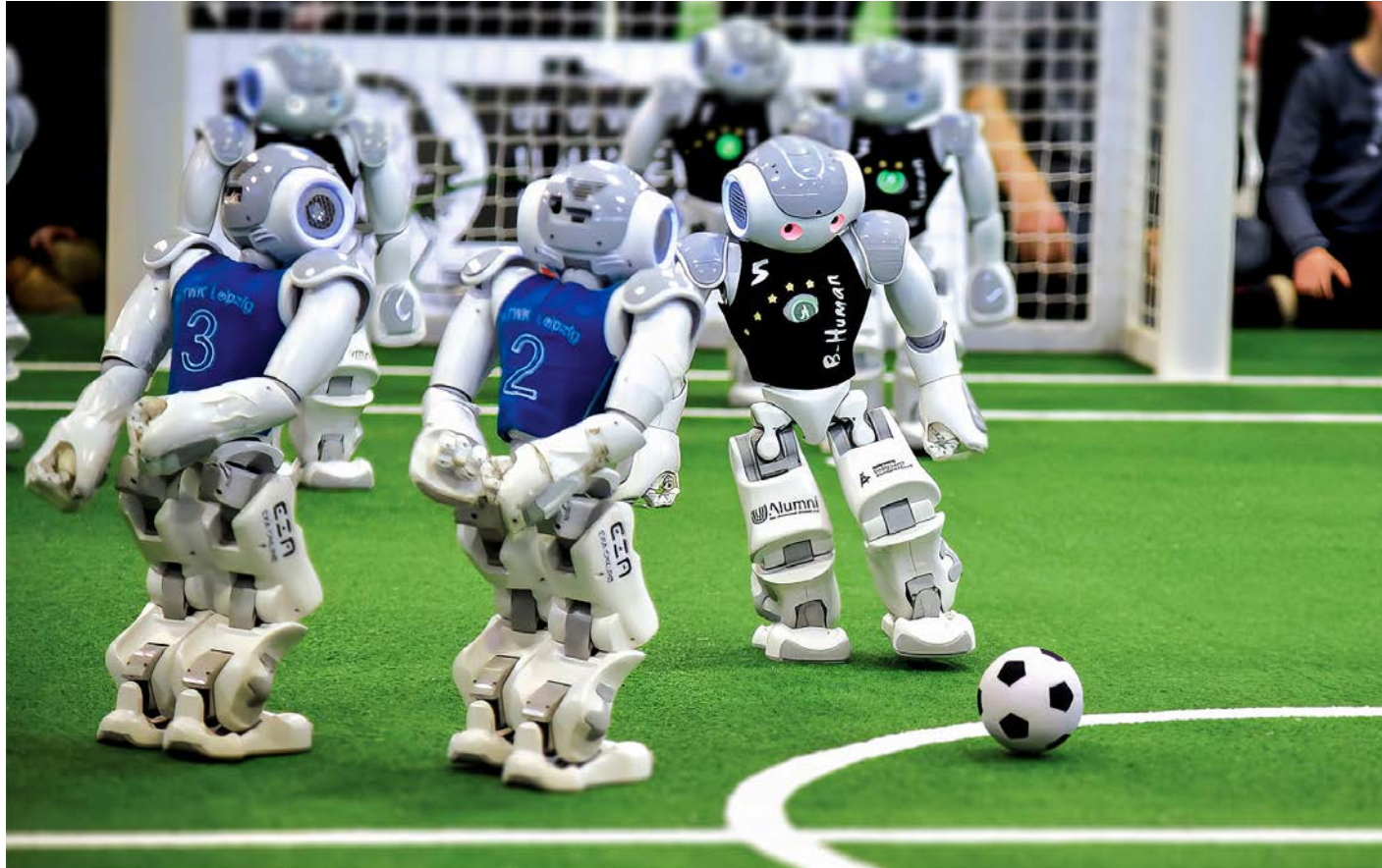
Source: <https://sabukaru.online/articles/professor-hiroshi-ishiguro-the-man-who-built-his-own-clone-to-understand-humankind>

What is (not) a Robot?



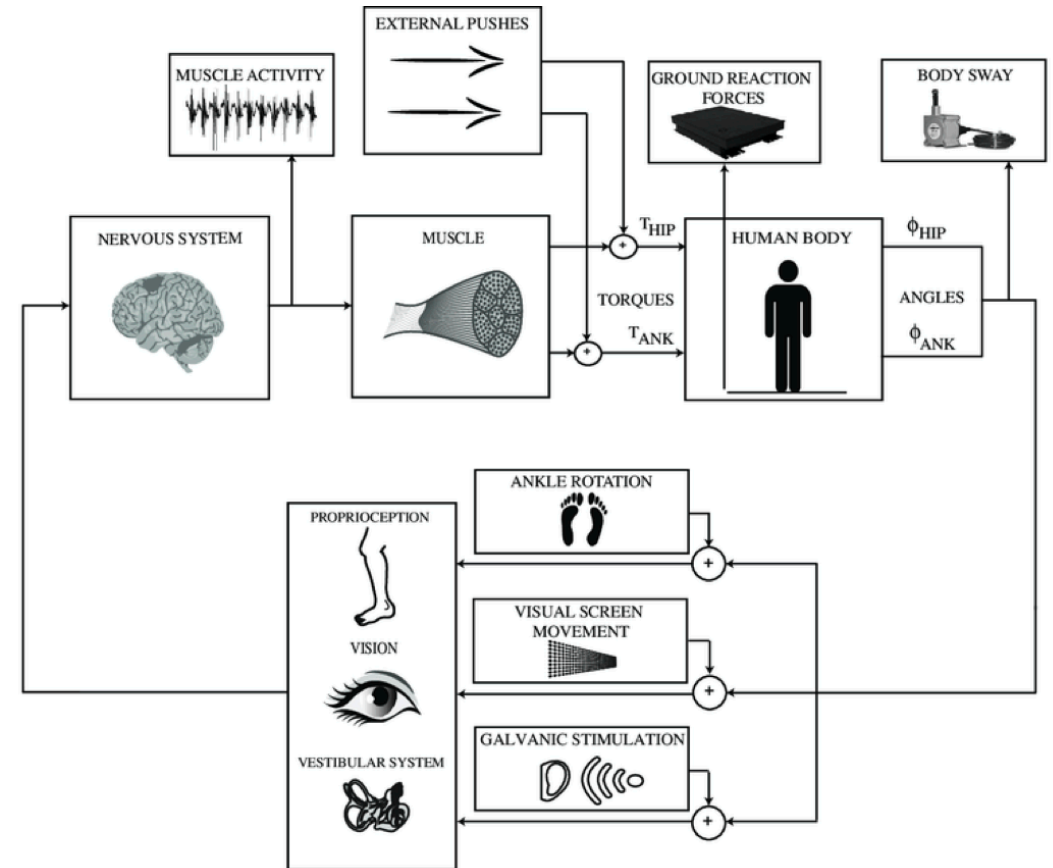
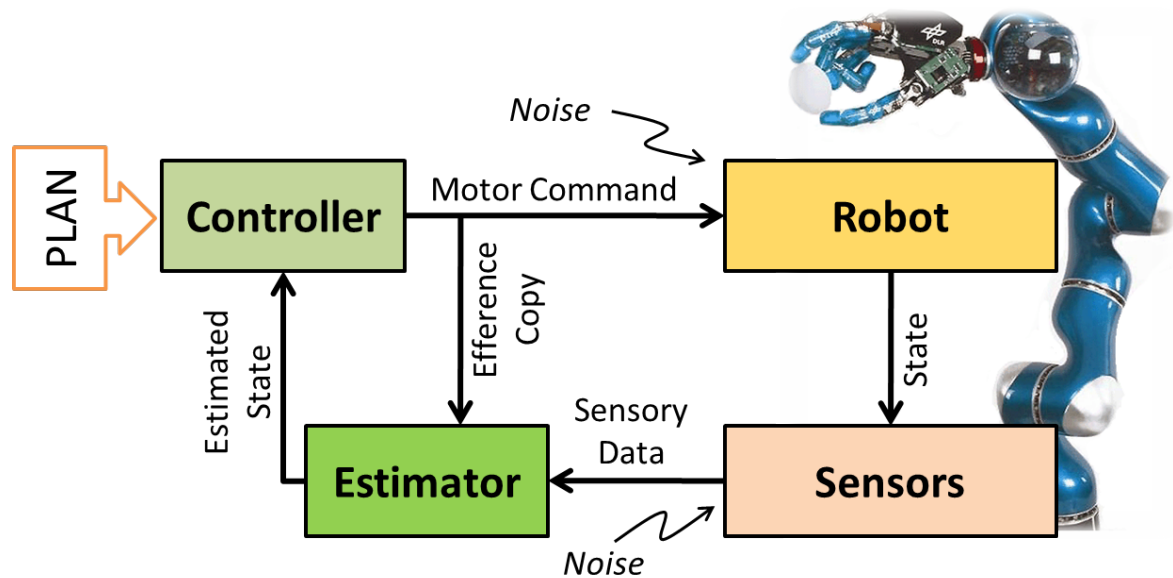
[Source: <https://waymo.com/blog/2023/07/doubling-down-on-waymo-one/>]

One Definition: Achieve Human-like *Behaviours*



[Source: <https://2024.robocup.org/leagues/robocupsoccer/>]

Example: Control Needed “Just” to Stand Still



[Pasma et al., Neurosci. 2014]

Often Robots Need Clever Body Designs



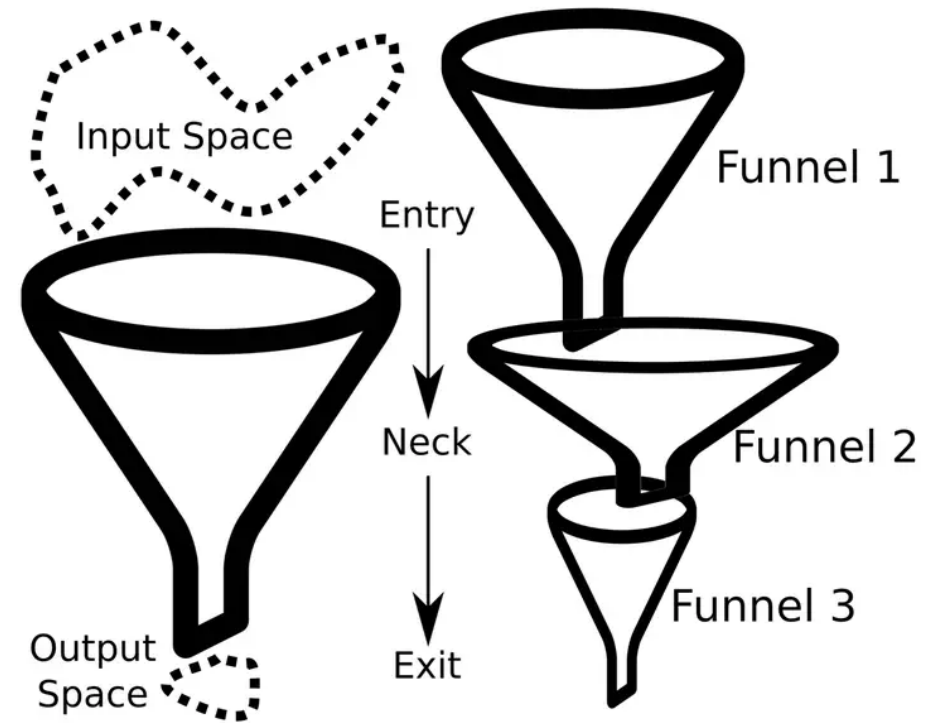
Biomimetics and Dexterous Manipulation Lab, Stanford

Efficient Mechanisms Yield Major benefits



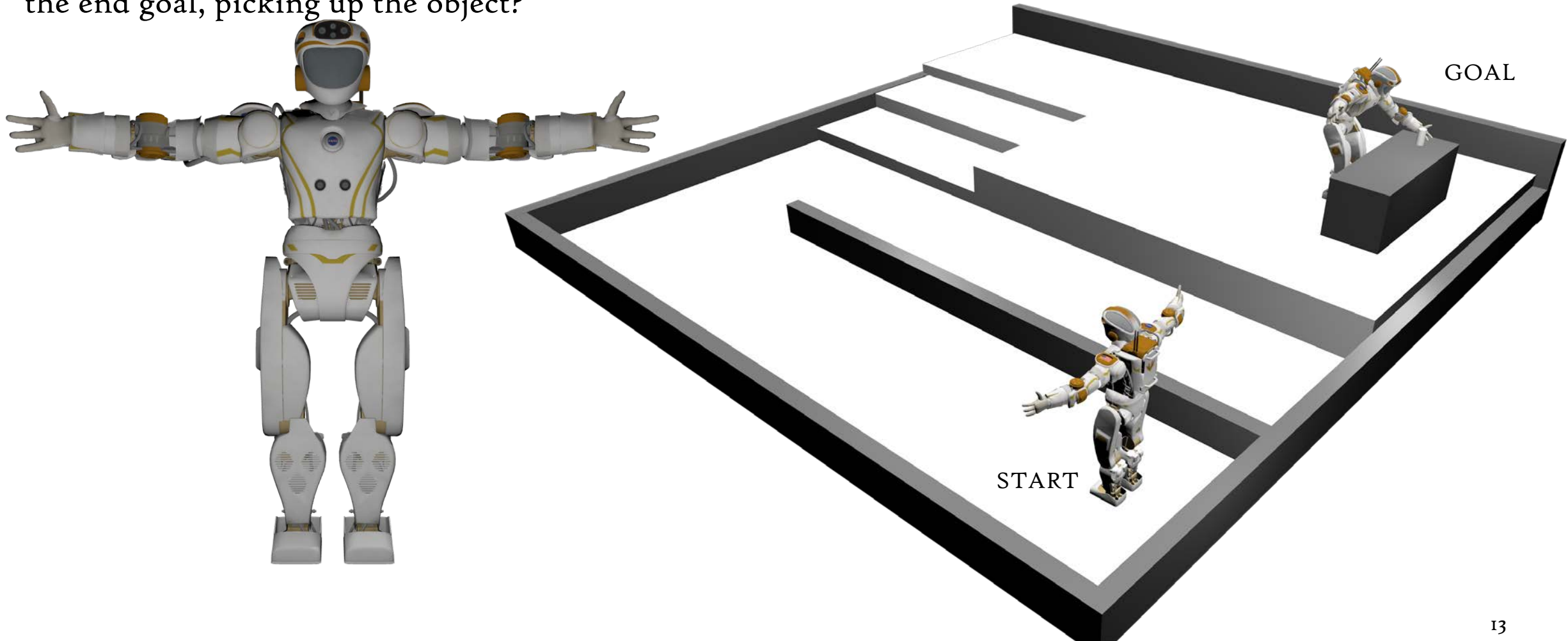
Our Focus: General Computational Principles

Control action =
Gain x Error signal

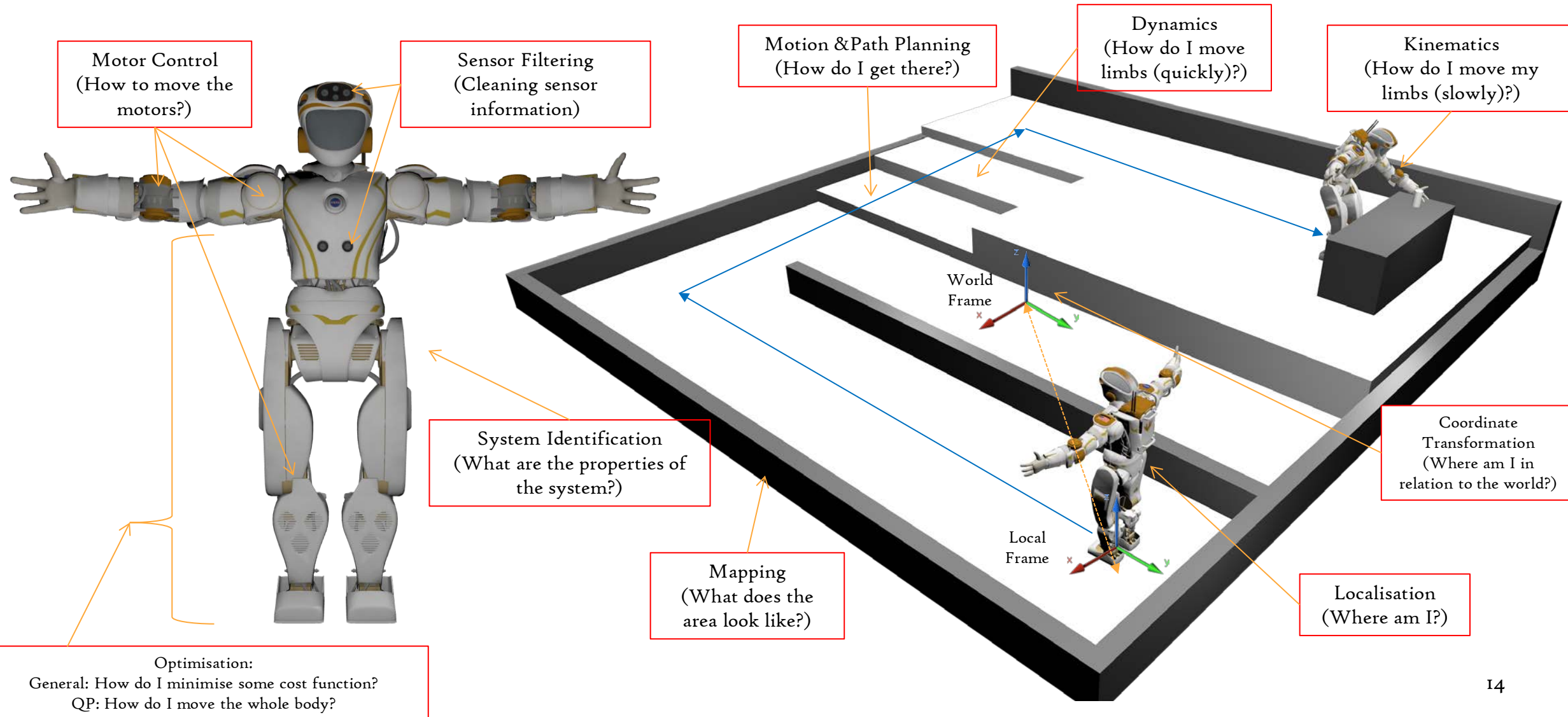


How do we control a Robot?

Can you name some of the things we need in order to move the Valkyrie robot from the start position to the end goal, picking up the object?



How do we control a Robot?



What do we learn in this course?

- ❖ Knowledge of fundamental topics relevant to robotics:
 - Motion Planning
 - Dynamics, Kinematics and Control
 - Optimisation and more
- ❖ Experience (tutorial + practical) conceptualising a robotic solution to a problem
 - Build/run a simulated robot
 - Program it
 - Achieve dynamic tasks in the simulation

Robot *intelligence* – Levels of Autonomy

Level 5

Intelligently dealing with the
unexpected

Level 4

Task-level programming

Level 3

Structured programming

Level 2

Motion primitive programming

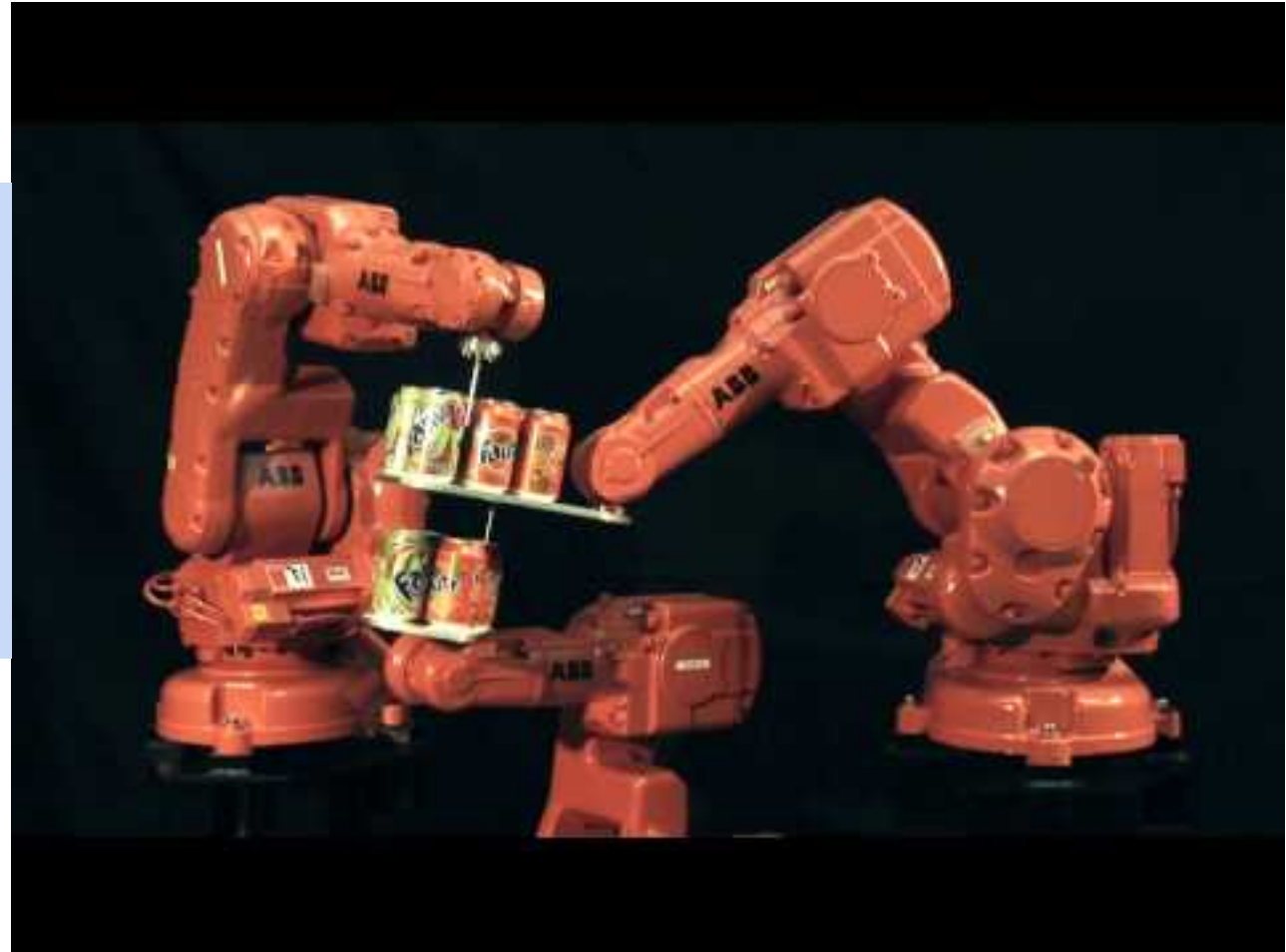
Level 1

Point to point programming

Robots: Mapping Behaviours to Concepts Needed

High-speed motion control

Robot Kinematics & Dynamics
System Identification
Kalman Filter
Digital System & control
Design of Advanced Controllers
Trajectory Planning and Motion Planning

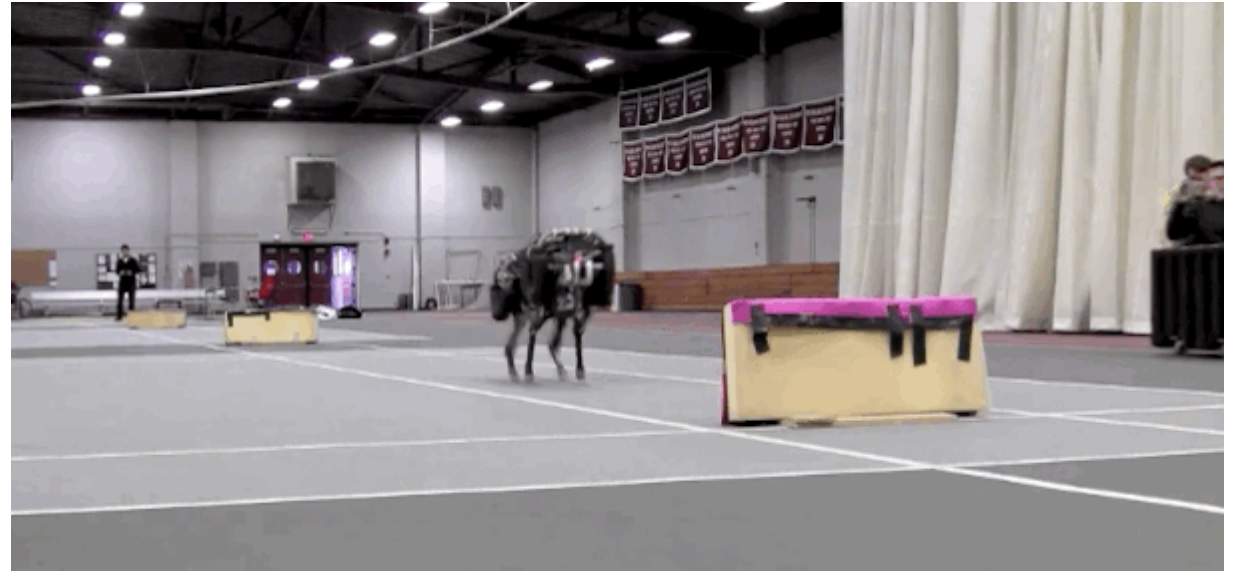


Robots: Mapping Behaviours to Concepts Needed

Tasks and performance that can only be achieved by dynamic motions



Source: Boston Dynamics (Atlas)



Source: MIT (Cheetah)

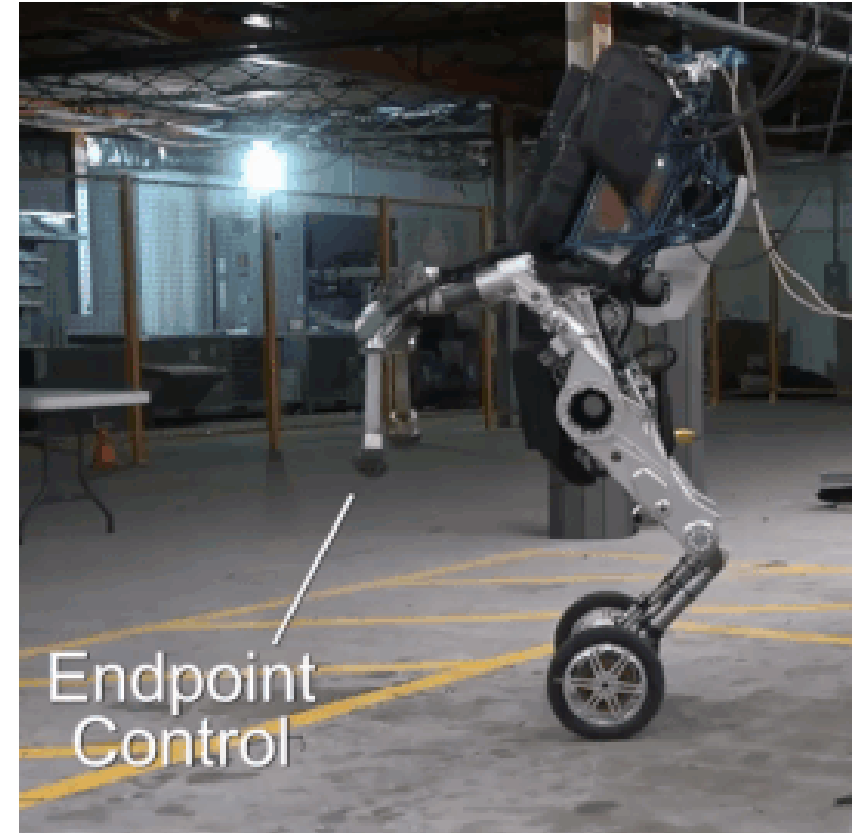
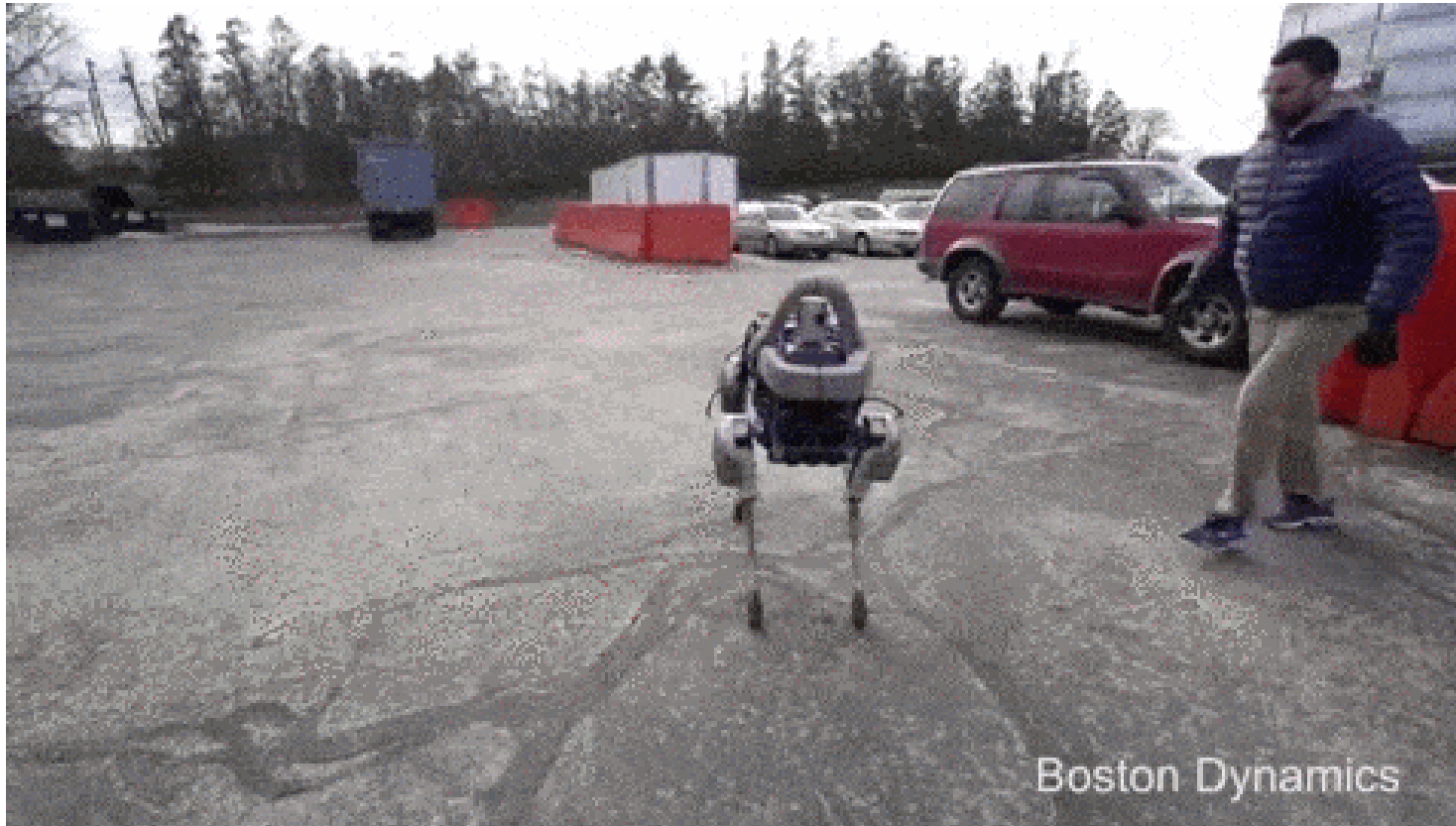
Robots: Mapping Behaviours to Concepts Needed

Sorting parcels in warehouse application



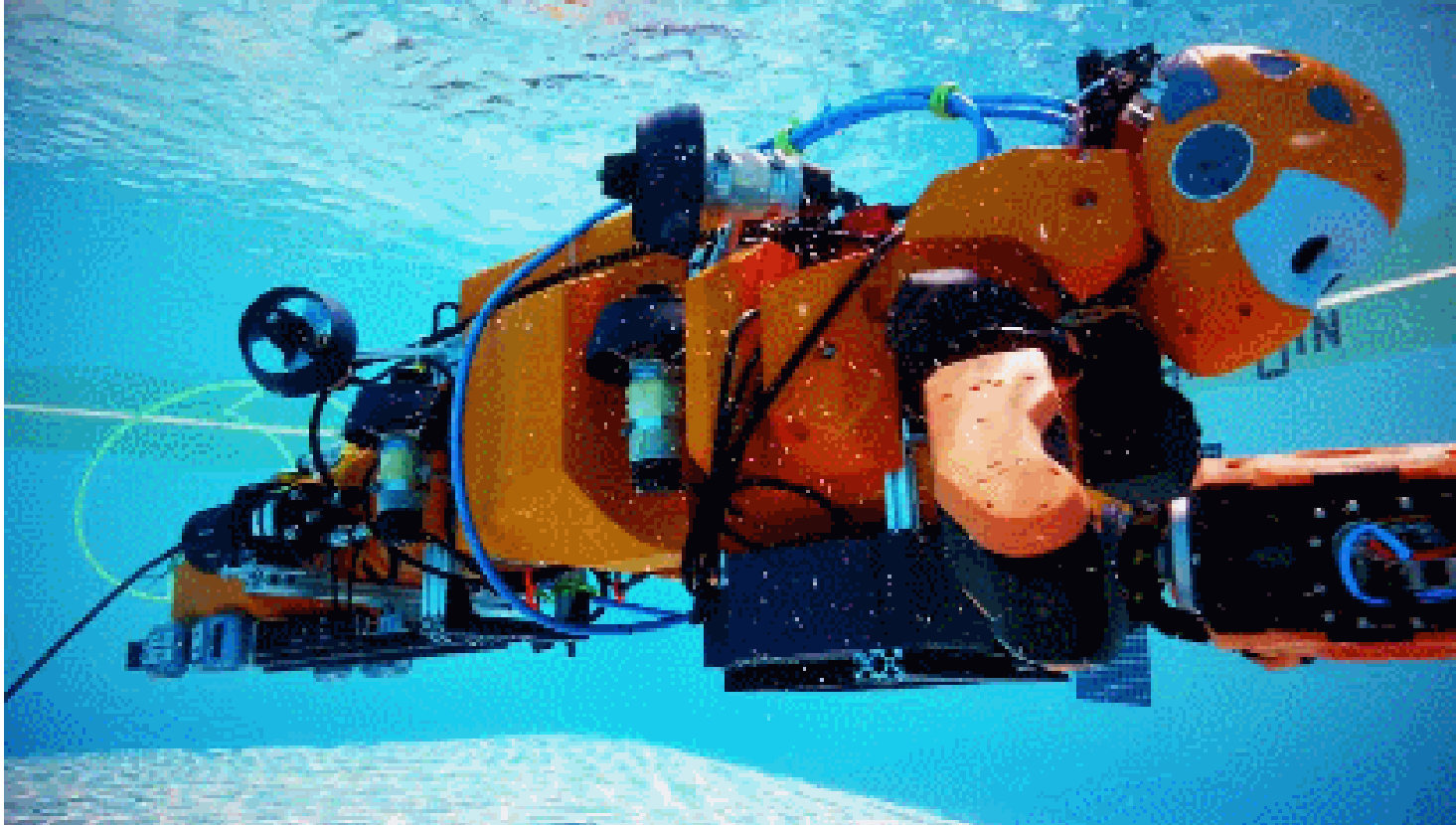
Digital System & control
Localization and Mapping
Path & Motion Planning

Robots: Mapping Behaviours to Concepts Needed



Spot-mini and Handle robots from Boston Dynamics

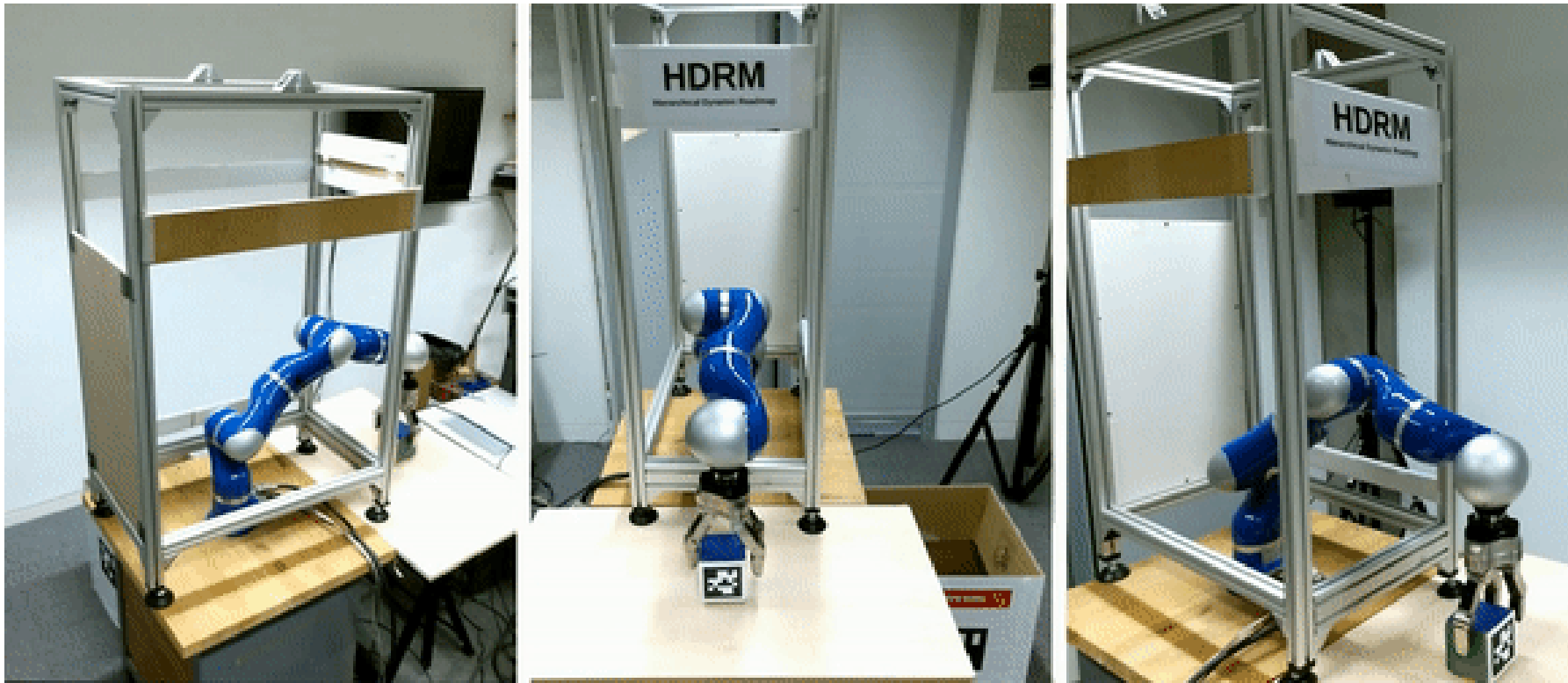
Robots: Mapping Behaviours to Concepts Needed



Ocean one, © Stanford University

Robots: Mapping Behaviours to Concepts Needed

What do robots need to know about their environment?



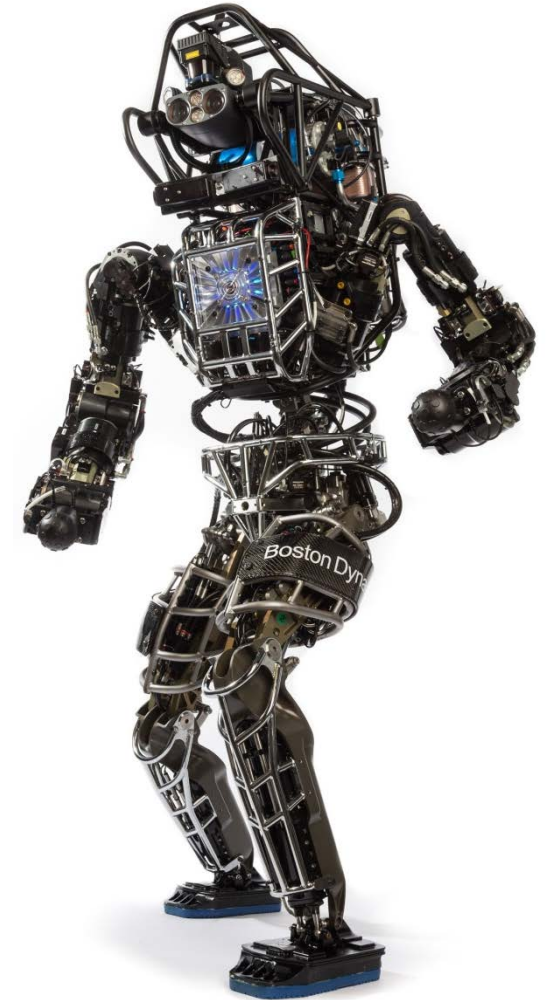
Yiming Yang, Wolfgang Merkt, Vladimir Ivan, Zhibin Li and Sethu Vijayakumar, **HDRM: A Resolution Complete Dynamic Roadmap for Real-Time Motion Planning in Complex Environments**, IEEE Robotics and Automation Letters, vol. 3(1), pp. 551-558(2018)

2005 DARPA Grand Challenge (Autonomous Driving)



The Stanford Racing Team's Stanley won the 2005 DARPA Grand Challenge. The race helped jump-start interest in self-driving cars. Credit: Division of Work and Industry/National Museum of American History/Smithsonian Institution

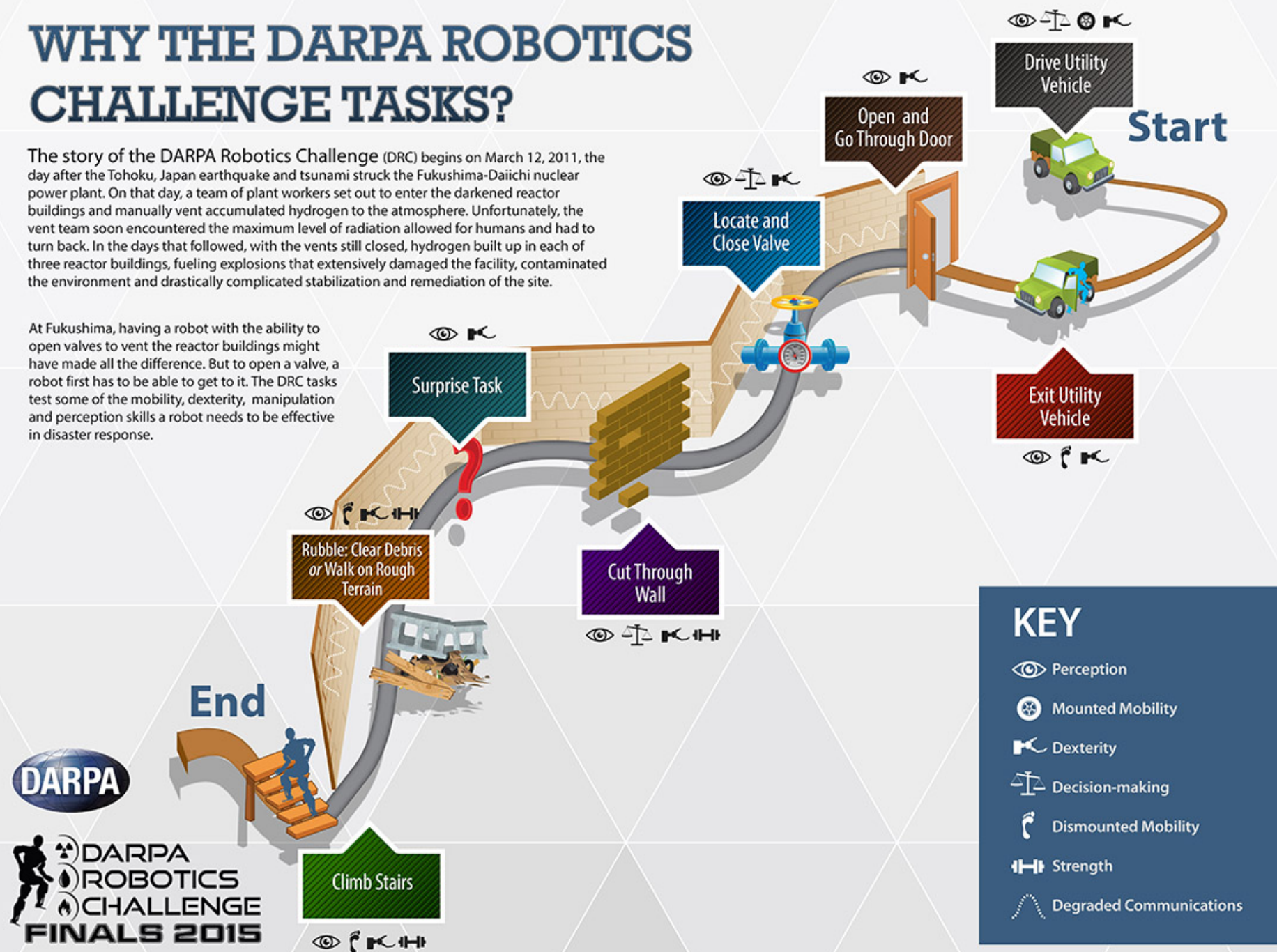
2015 DARPA Robotics Challenge (Humanoid Robotics)



WHY THE DARPA ROBOTICS CHALLENGE TASKS?

The story of the DARPA Robotics Challenge (DRC) begins on March 12, 2011, the day after the Tohoku, Japan earthquake and tsunami struck the Fukushima-Daiichi nuclear power plant. On that day, a team of plant workers set out to enter the darkened reactor buildings and manually vent accumulated hydrogen to the atmosphere. Unfortunately, the vent team soon encountered the maximum level of radiation allowed for humans and had to turn back. In the days that followed, with the vents still closed, hydrogen built up in each of three reactor buildings, fueling explosions that extensively damaged the facility, contaminated the environment and drastically complicated stabilization and remediation of the site.

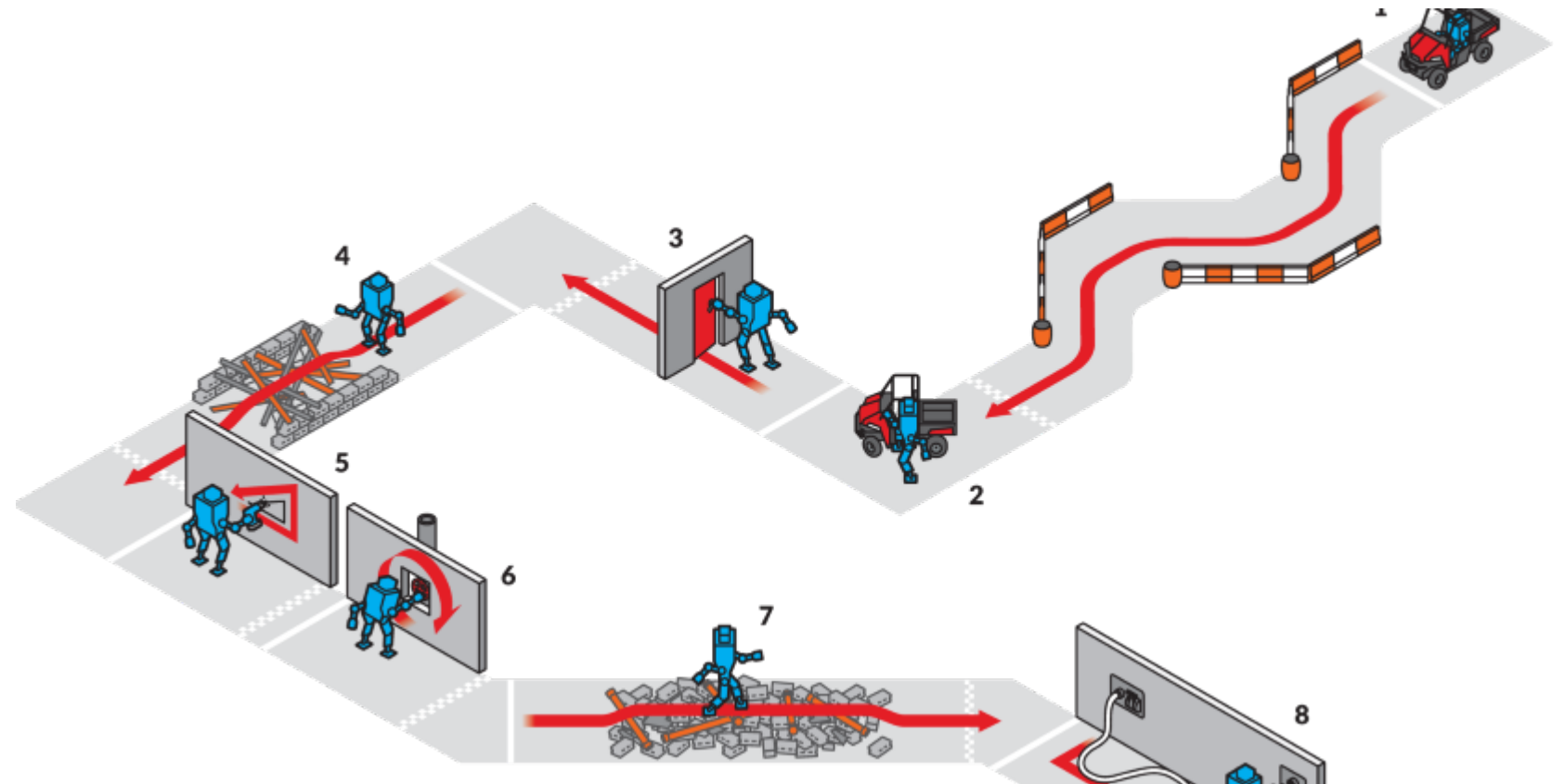
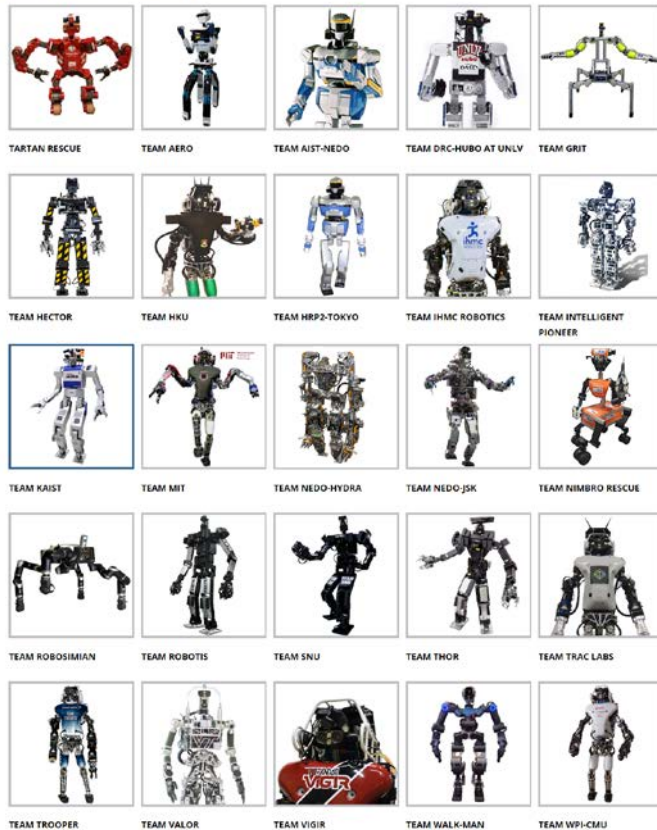
At Fukushima, having a robot with the ability to open valves to vent the reactor buildings might have made all the difference. But to open a valve, a robot first has to be able to get to it. The DRC tasks test some of the mobility, dexterity, manipulation and perception skills a robot needs to be effective in disaster response.



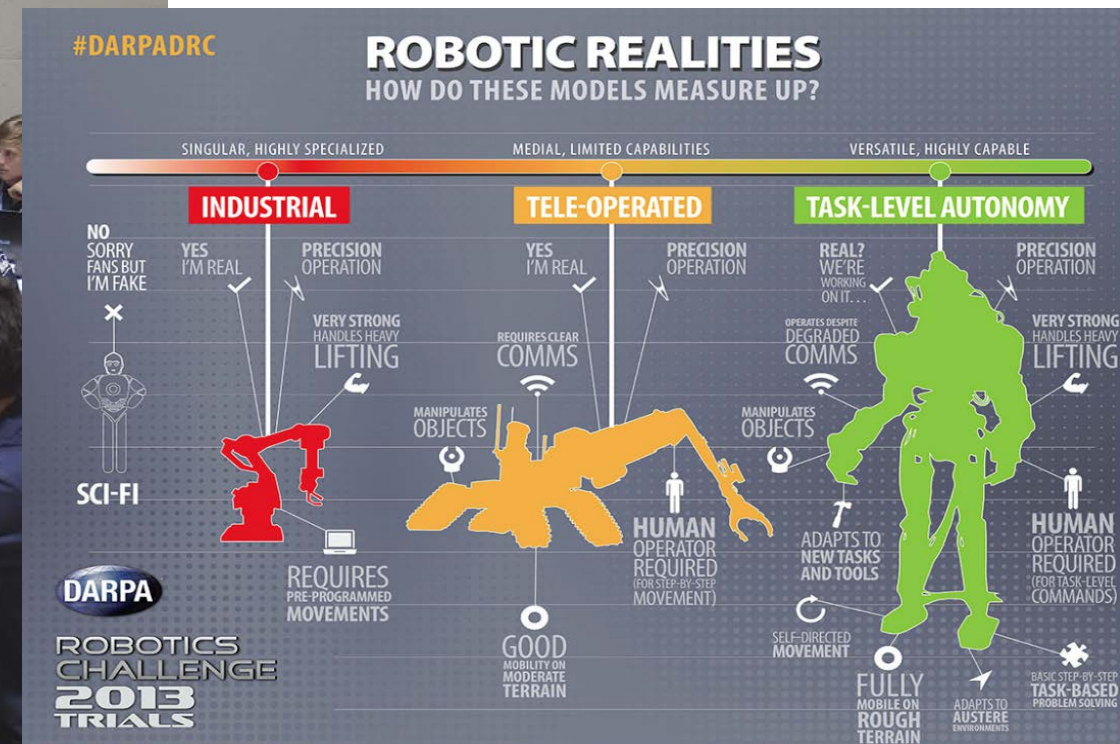
**DARPA
ROBOTICS
CHALLENGE
FINALS 2015**

Towards Autonomy in General Environments

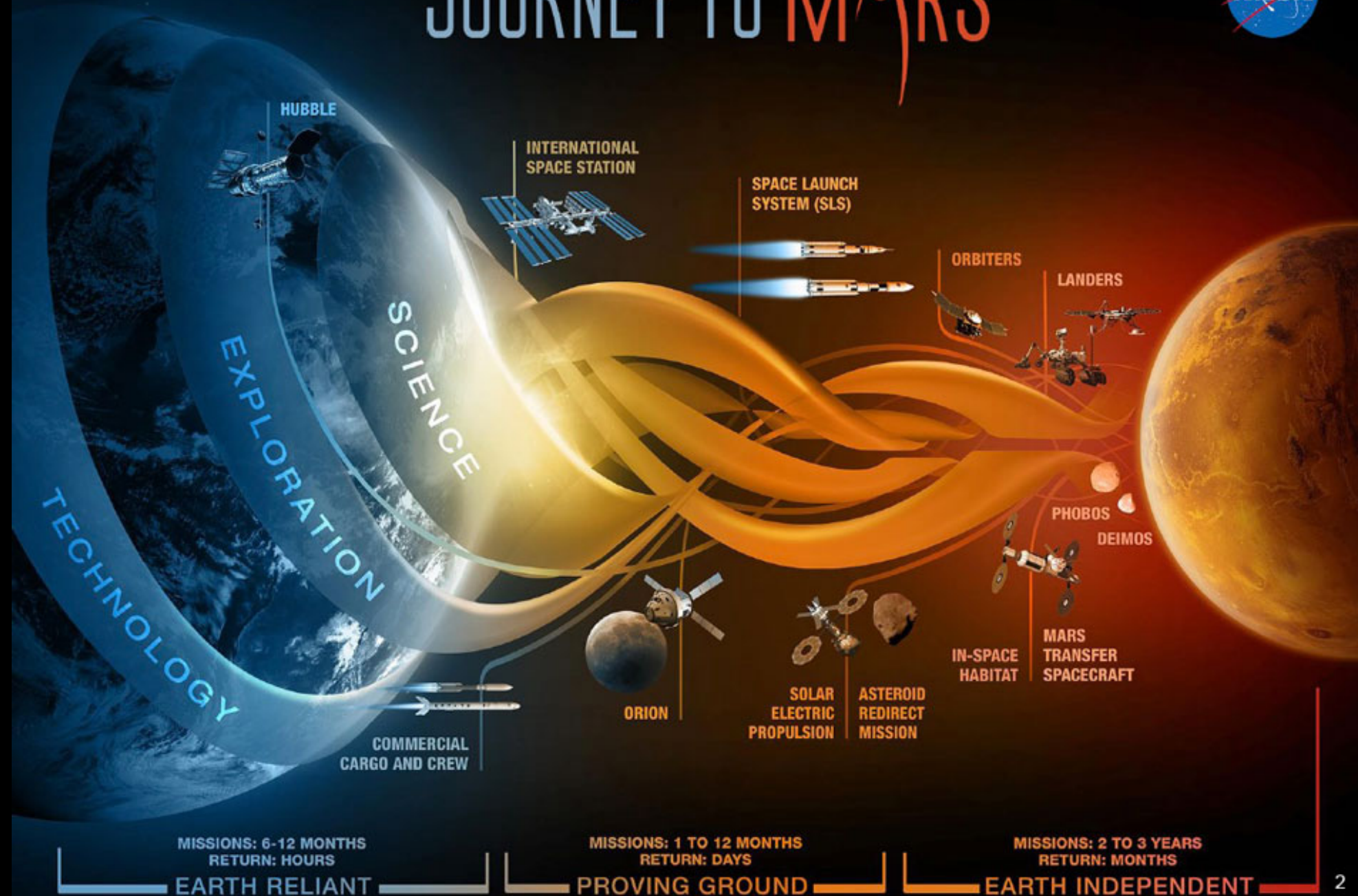
DRC Finals - Qualified Teams



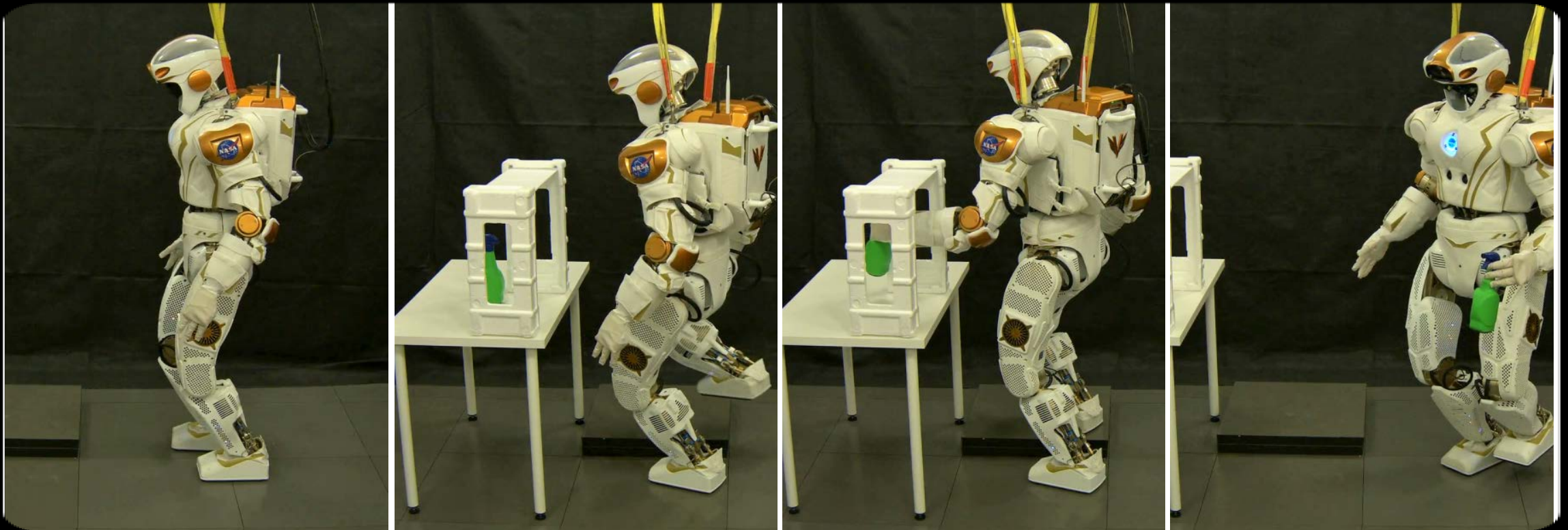
Human Intervention & Supervision in DRC 2015



JOURNEY TO MARS



NASA Valkyrie Humanoid Robot @U. Edinburgh

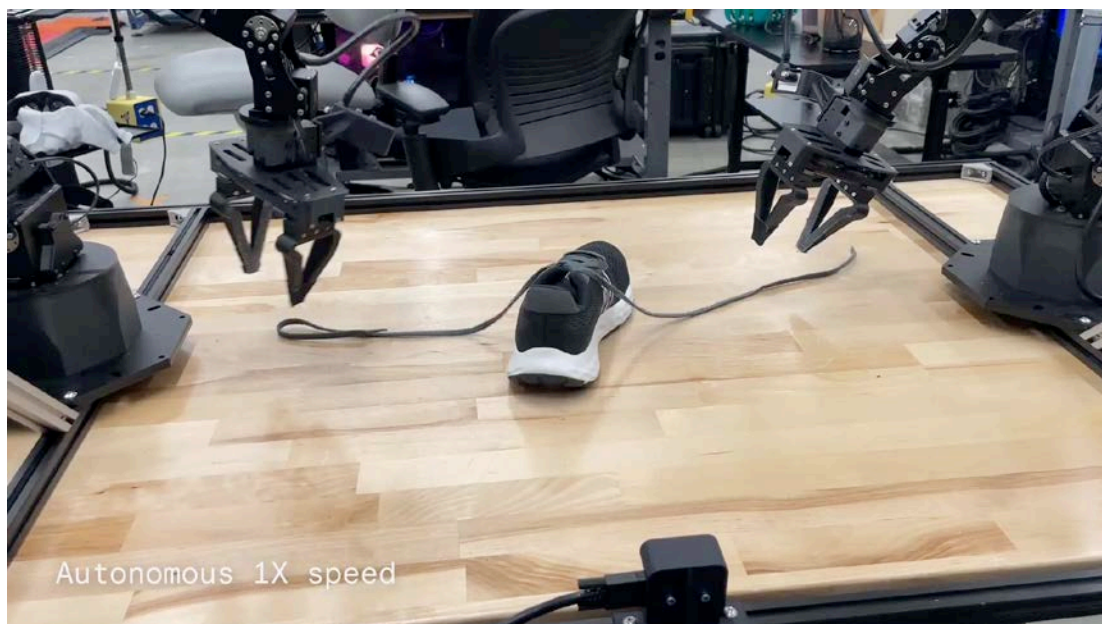


Towards task level autonomy, today...

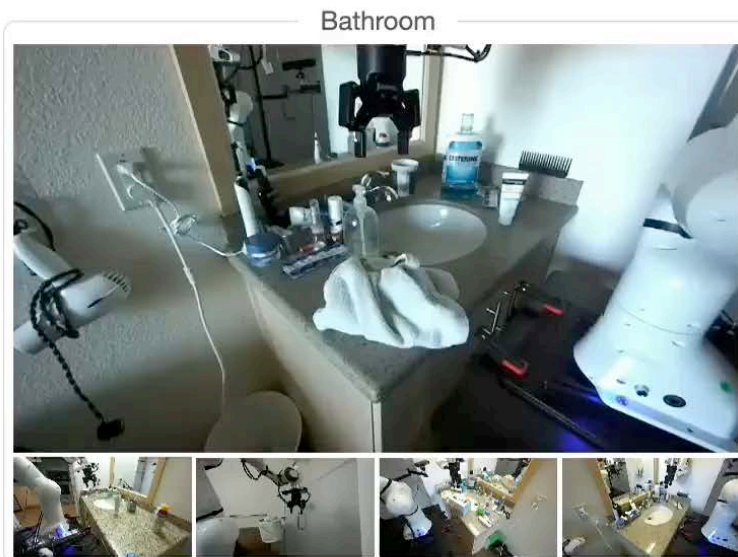
ALOHA Unleashed: A Simple Recipe for Robot Dexterity

**Tony Z. Zhao*, Jonathan Tompson, Danny Driess, Pete Florence,
Kamyar Ghasemipour, Chelsea Finn, Ayzaan Wahid***

Google DeepMind



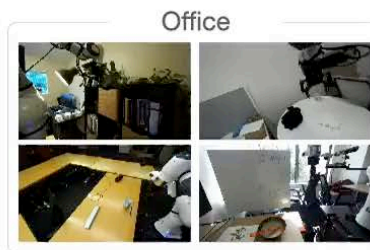
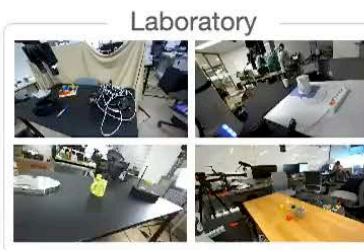
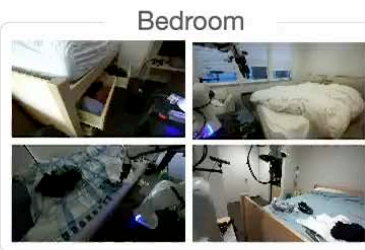
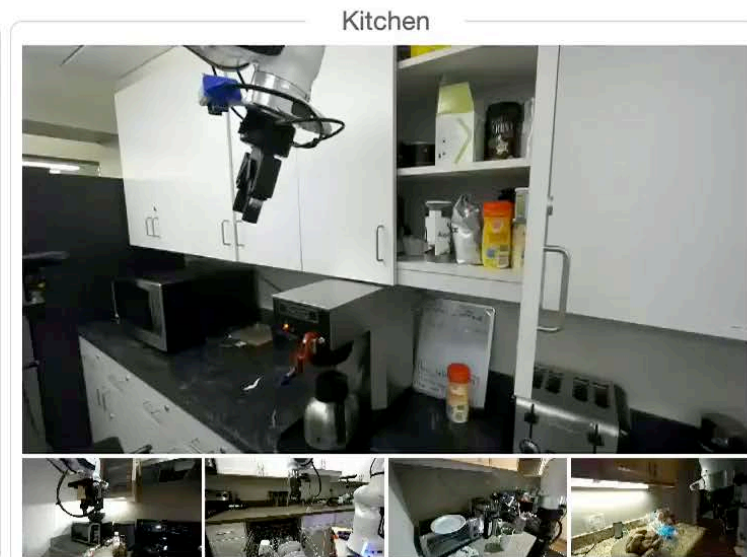
Role of Data



DROID

Distributed Robot Interaction Dataset

-  76k Episodes
-  564 Scenes
-  52 Buildings
-  13 Institutions
-  86 Tasks / Verbs



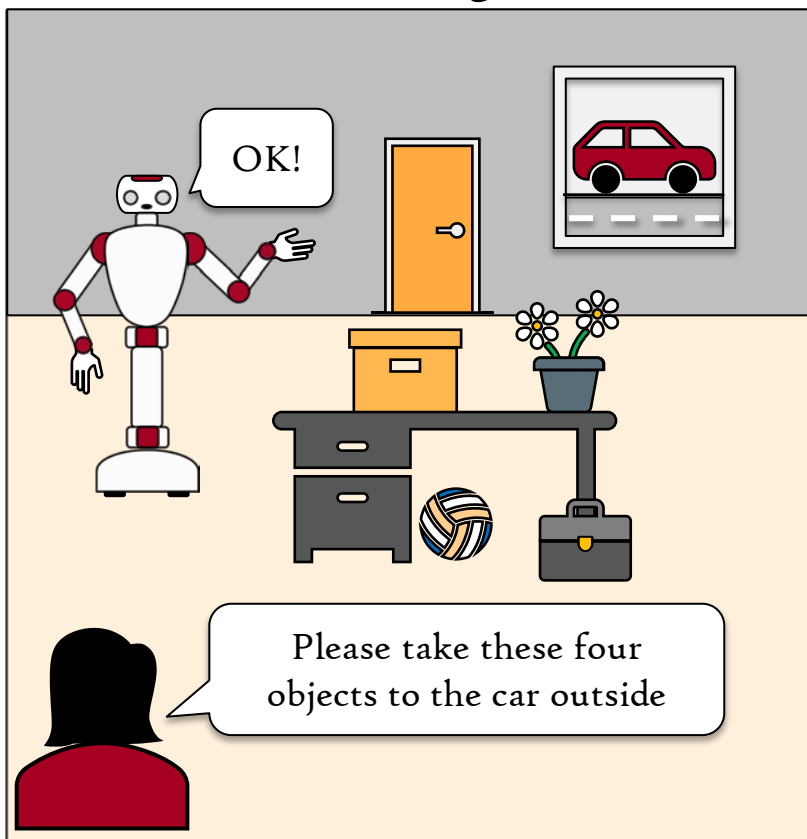
Are we there yet?



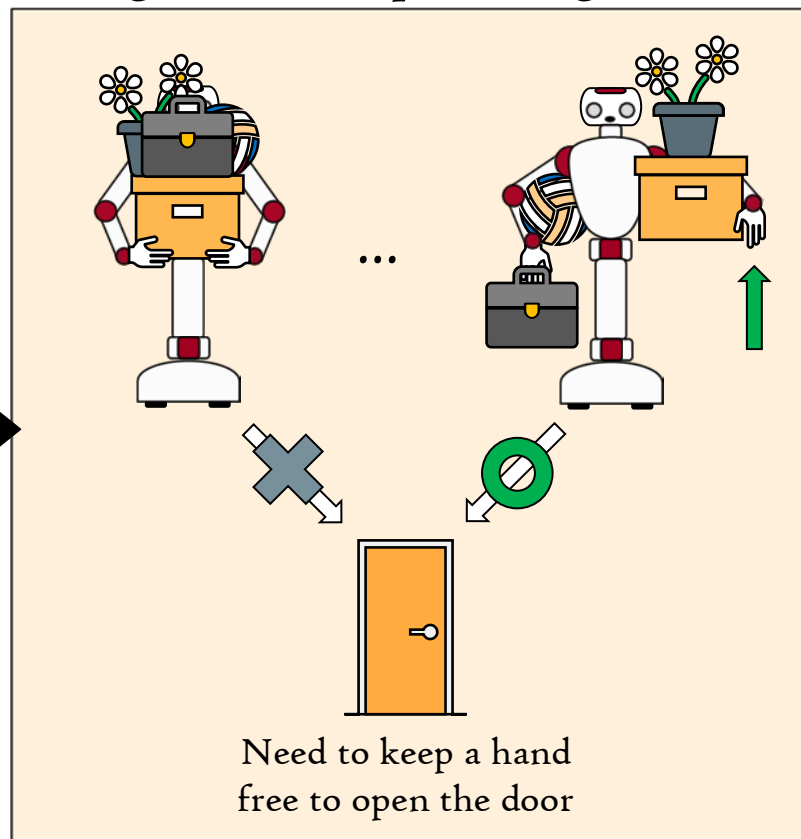
<https://earlyarts.co.uk/blog/using-clay-to-nurture-young-childrens-development>

Next Challenge: Whole-body Manipulation

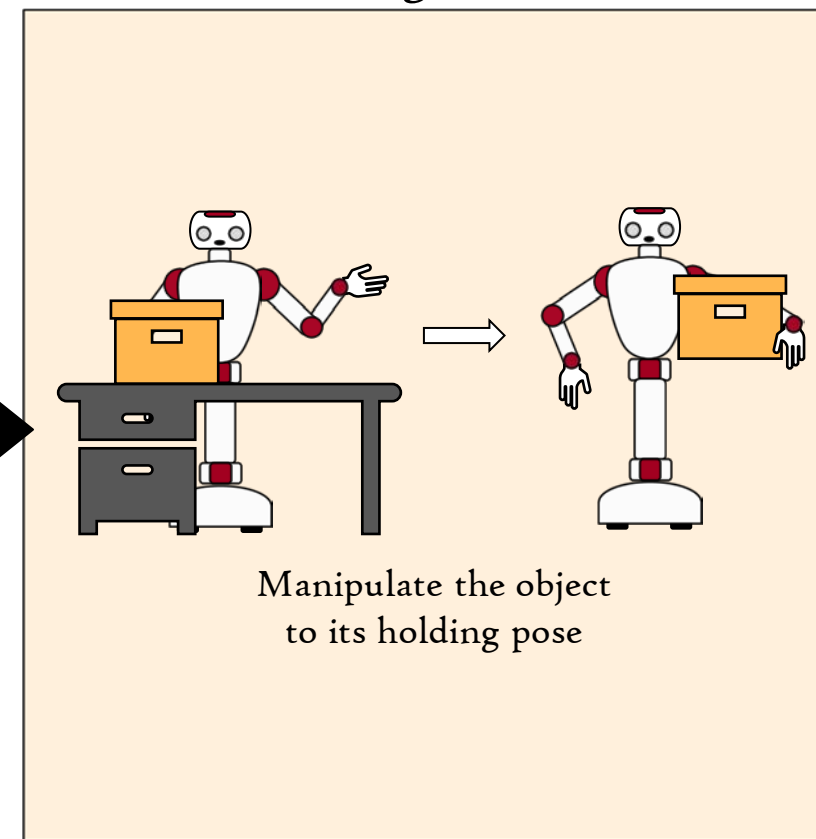
Overall task setting



Long-Horizon planning



WBM Planning & Control



Next Challenge: Shared Autonomy



Henrique Ferrolho, Vladimir Ivan, Wolfgang Merkt, Ioannis Havoutis and Sethu Vijayakumar, RoLoMa: Robust Loco-Manipulation for Quadruped Robots with Arms, *Autonomous Robots*, vol. 77(8), pp. 1463-1481 (2023).

Chris Mower, Joao Moura, Aled Davies and Sethu Vijayakumar, **Modulating Human Input for Shared Autonomy in Dynamic Environments**, Proc. 28th IEEE Intl. Conf. on Robot and Human Interactive Comm.(ROMAN 2019), New Delhi, India (2019).

Selected Readings (Optional)

	Additional reading
Trajectory Planning and Motion Planning (articulated)	Siciliano, B., Sciavicco, L., Villani, L., Oriolo, G., Robotics: Modelling, Planning and Control, Springer Verlag
Design of Advanced Controllers	H. Choset, K.M. Lynch, S. Hutchinson, G. Kantor, Principles of Robot Motion: Theory, Algorithms, and Implementations. Franklin, Gene F., et al. Feedback control of dynamic systems. Vol. 3. Reading, MA: Addison-Wesley, 1994.
Optimization	Jorge Nocedal, Stephen Wright – Numerical optimization
Model Predictive Control	J.M. Maciejowski, Predictive control : with constraints.
Machine Learning for Robot Control	Ian Goodfellow, et al., Deep Learning.