THE UNIVERSITY *of* EDINBURGH
informatics

Advanced Robotics

1 - Overview of Robotics
16 Sep 2025

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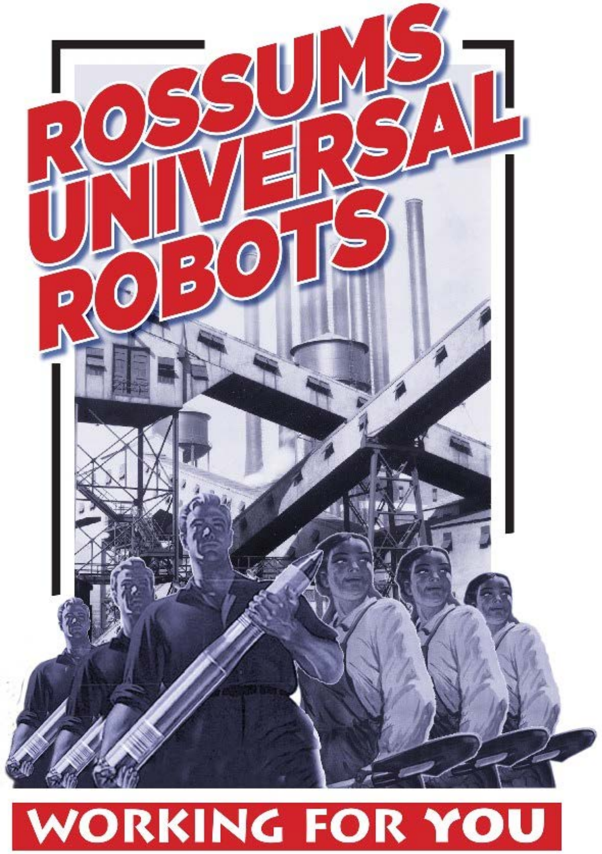
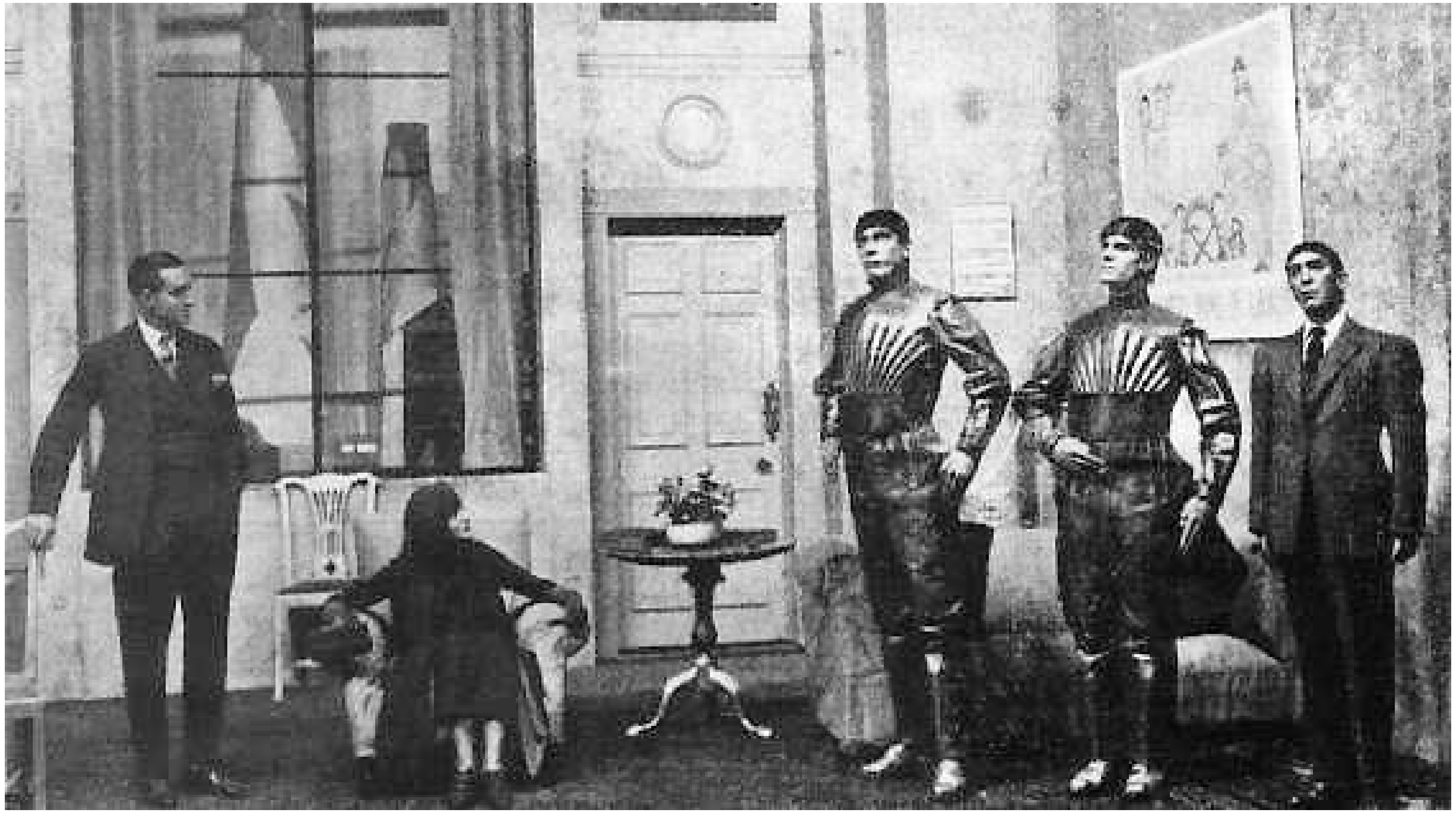
Rossum's Universal Robots



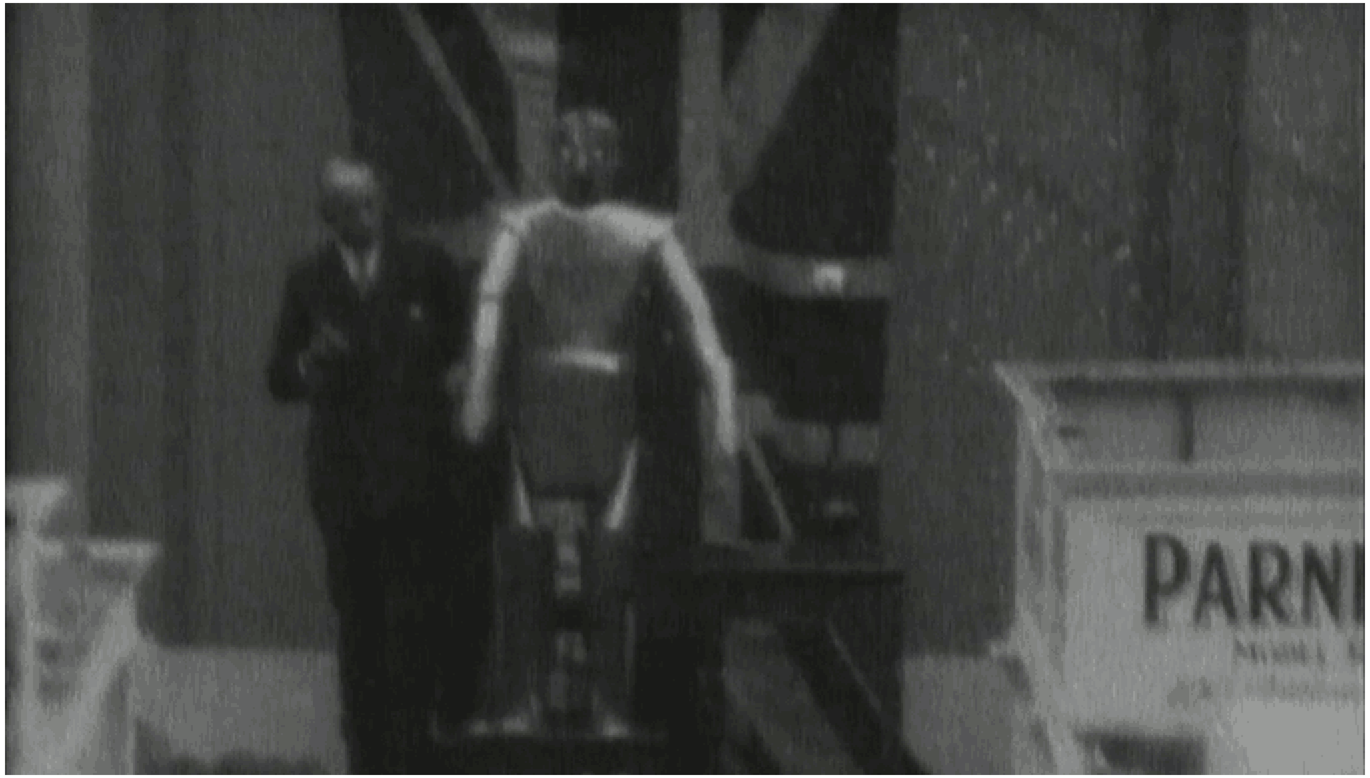
© Edward Alderton Theatre, image by Kevin Coward



© 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

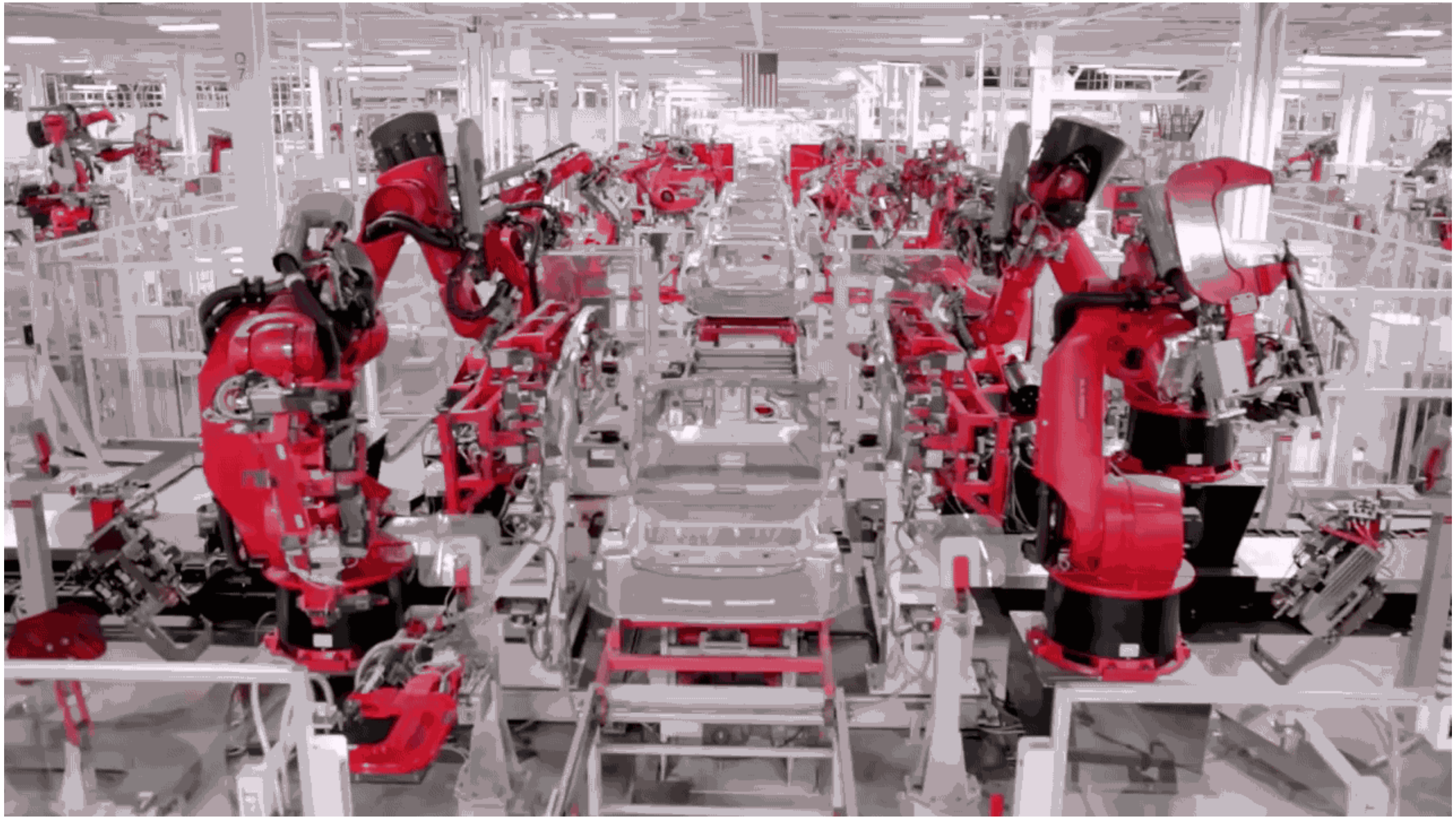
The first industrial robot: Unimate

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

What is (not) a Robot?

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

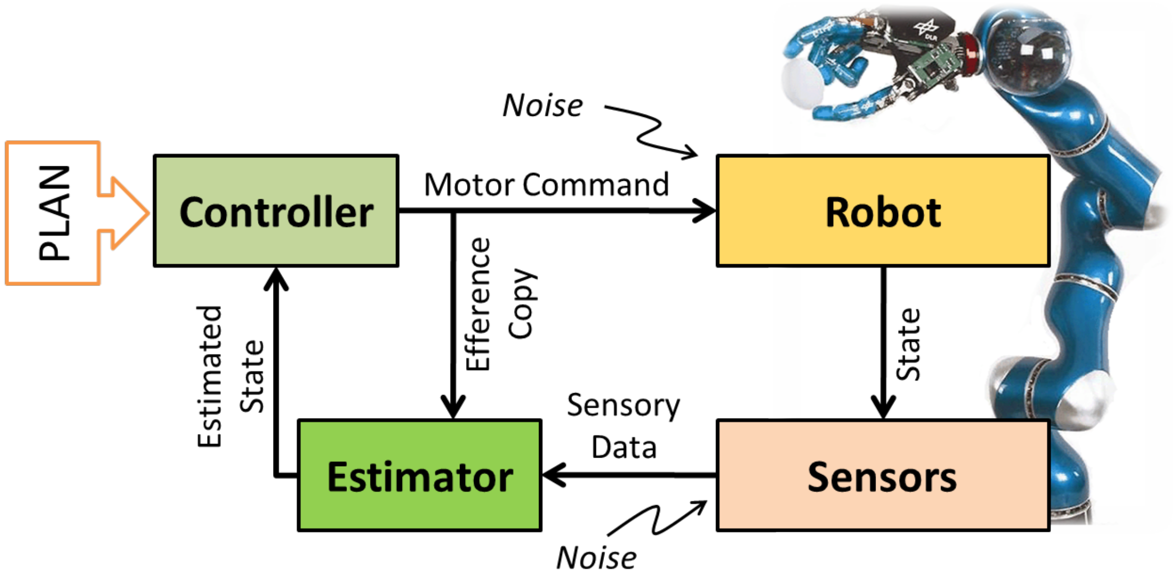
What is (not) a Robot?

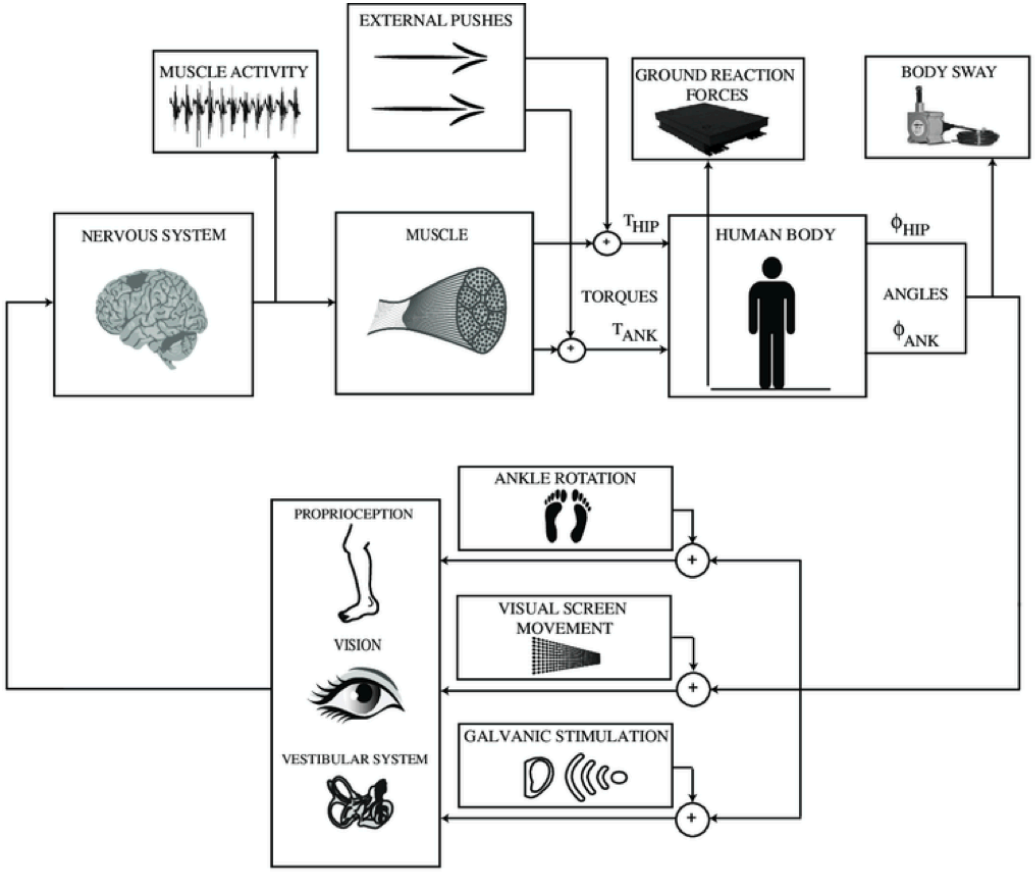
[Source: https://waymo.com/blog/2023/07/doubling-down-on-waymo-one/]

One Definition: Achieve Human-like *Behaviours*

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

Example: Control Needed "Just" to Stand Still



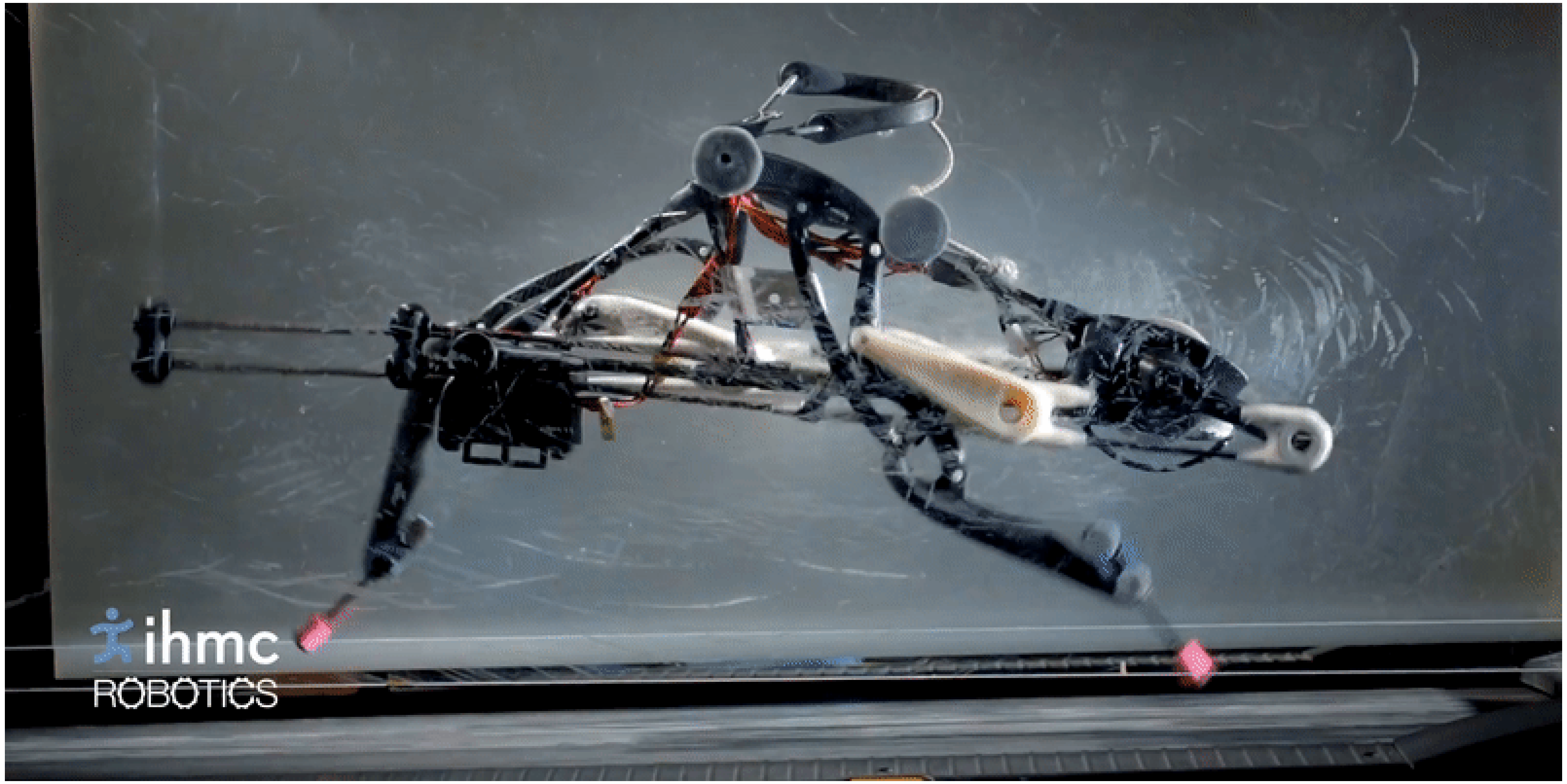


[Pasma et al., Neurosci. 2014]

Often Robots Need Clever Body Designs

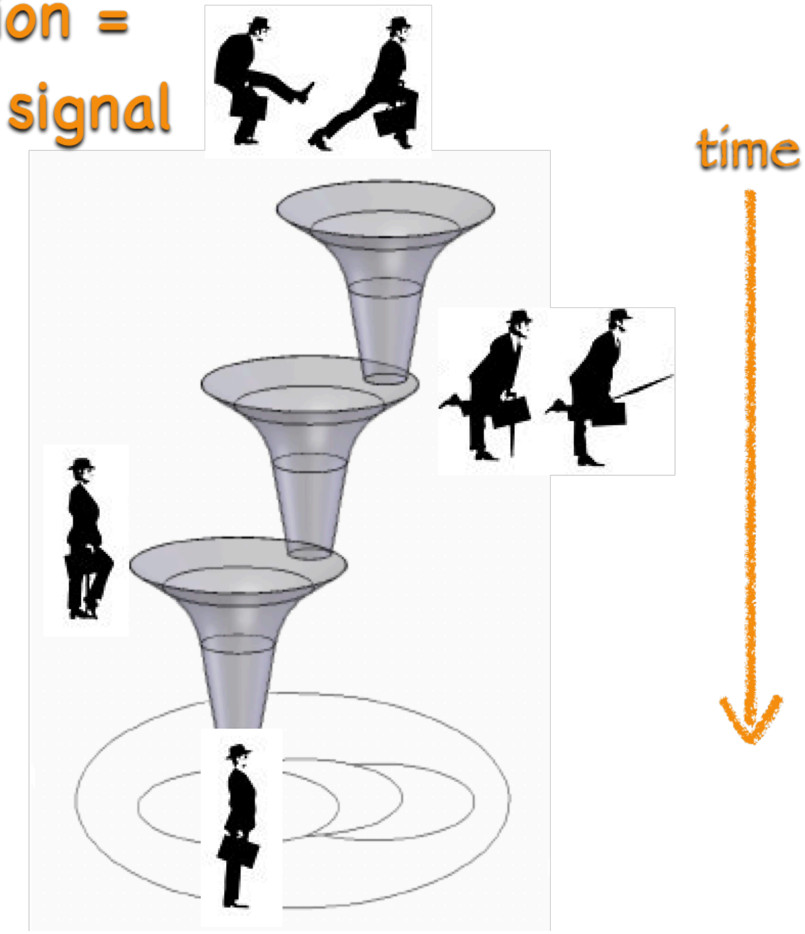
Biomimetics and Dexterous Manipulation Lab, Stanford

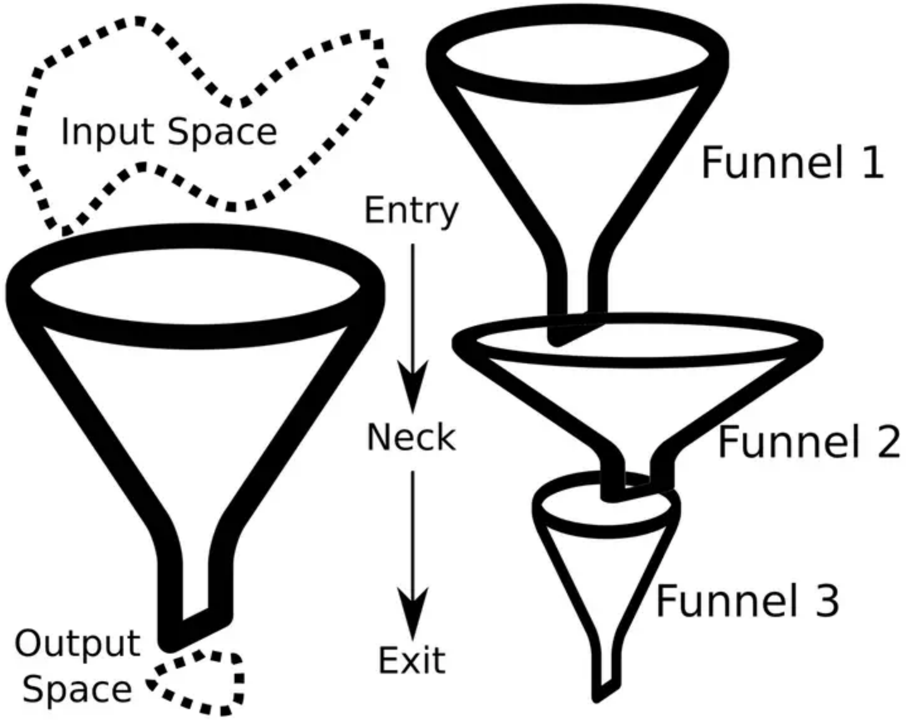
Efficient Mechanisms Yield Major benefits



Our Focus: General *Computational* Principles

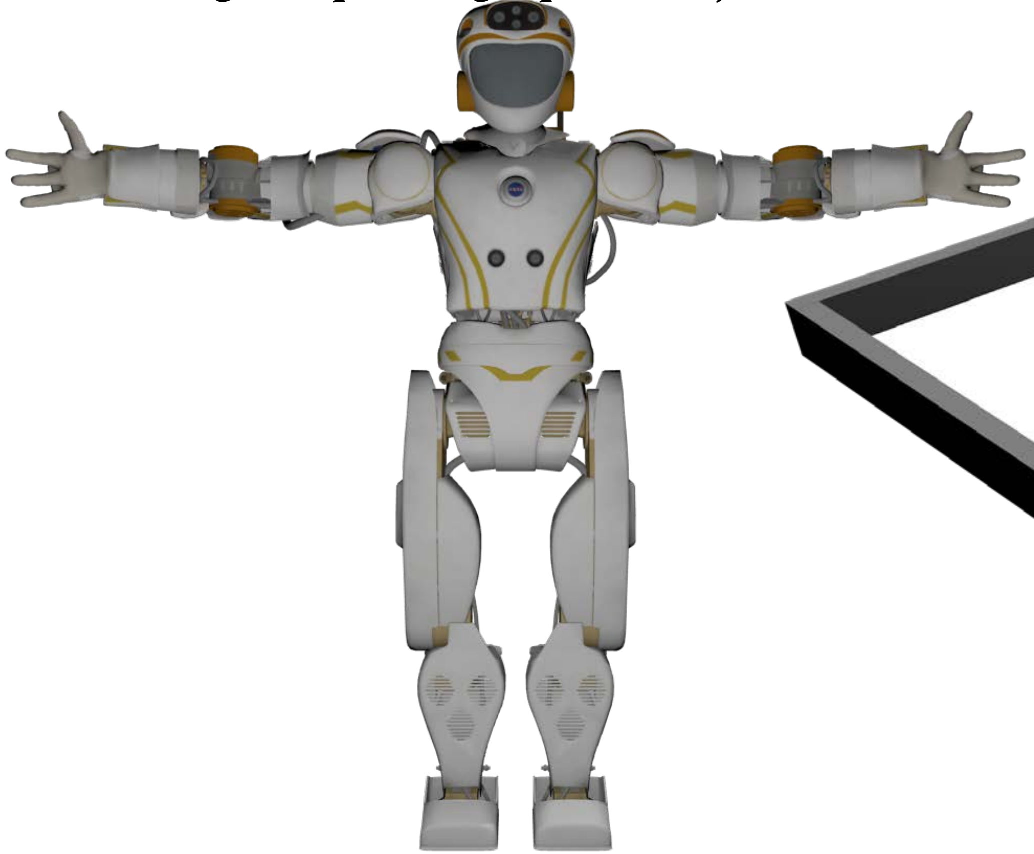
Control action =
Gain x Error signal

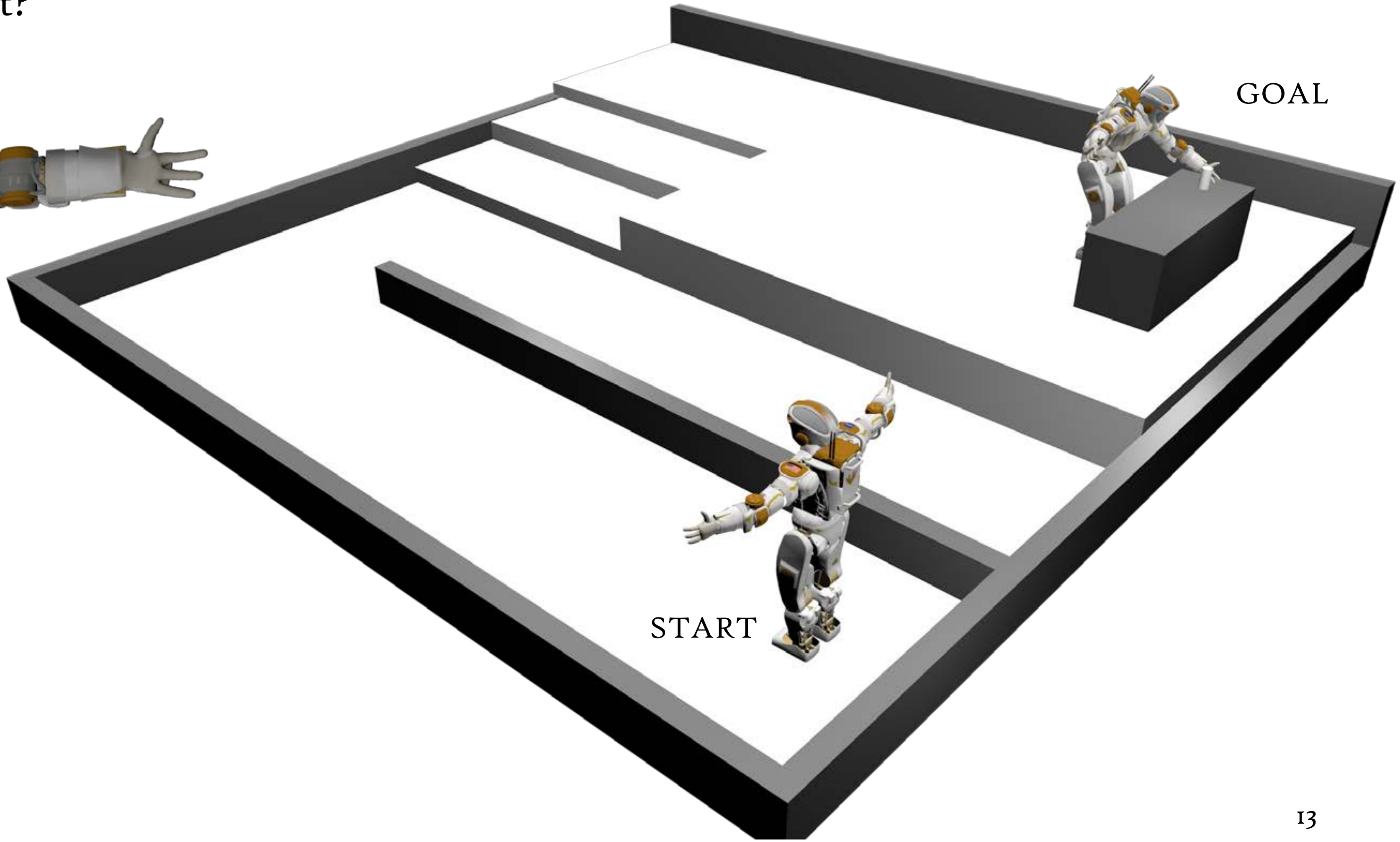




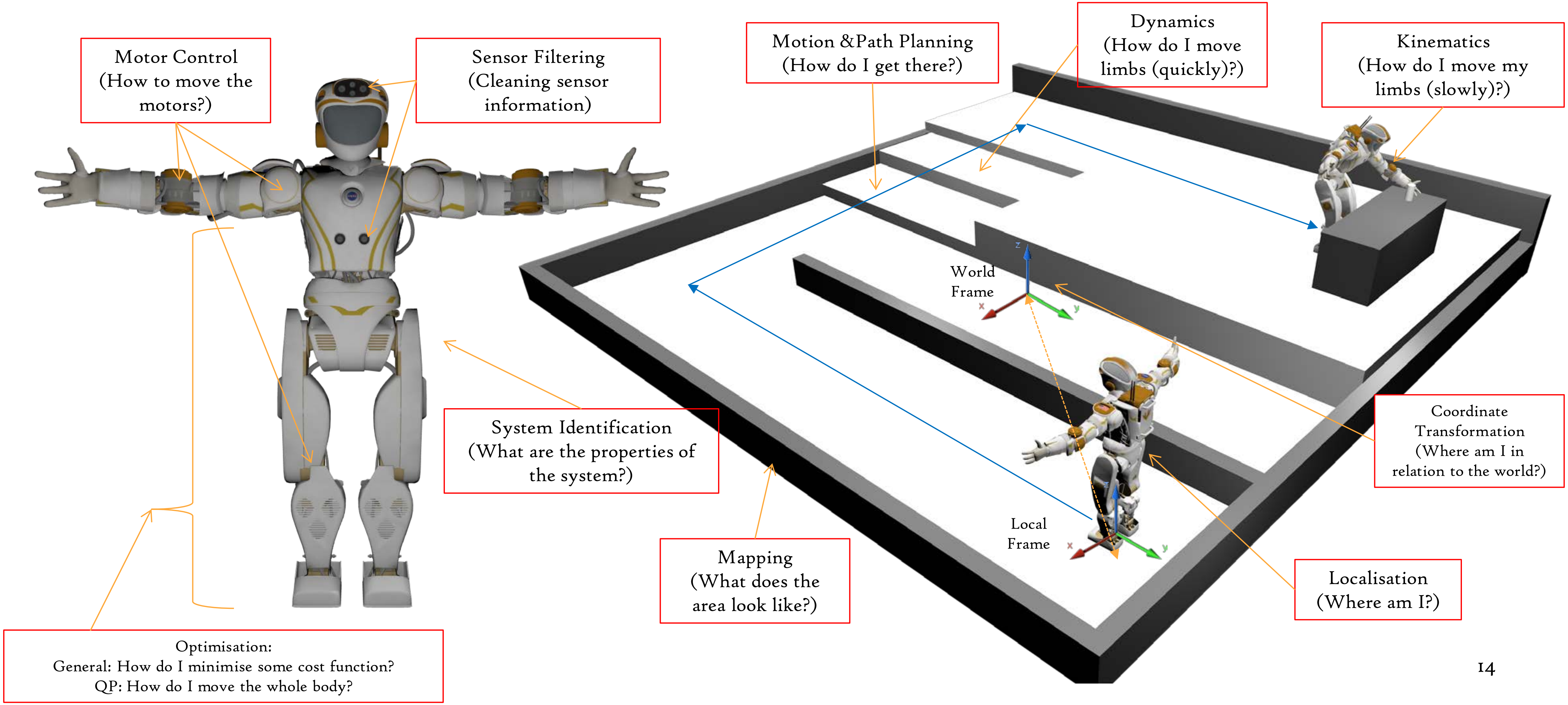
How do we control a Robot?

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

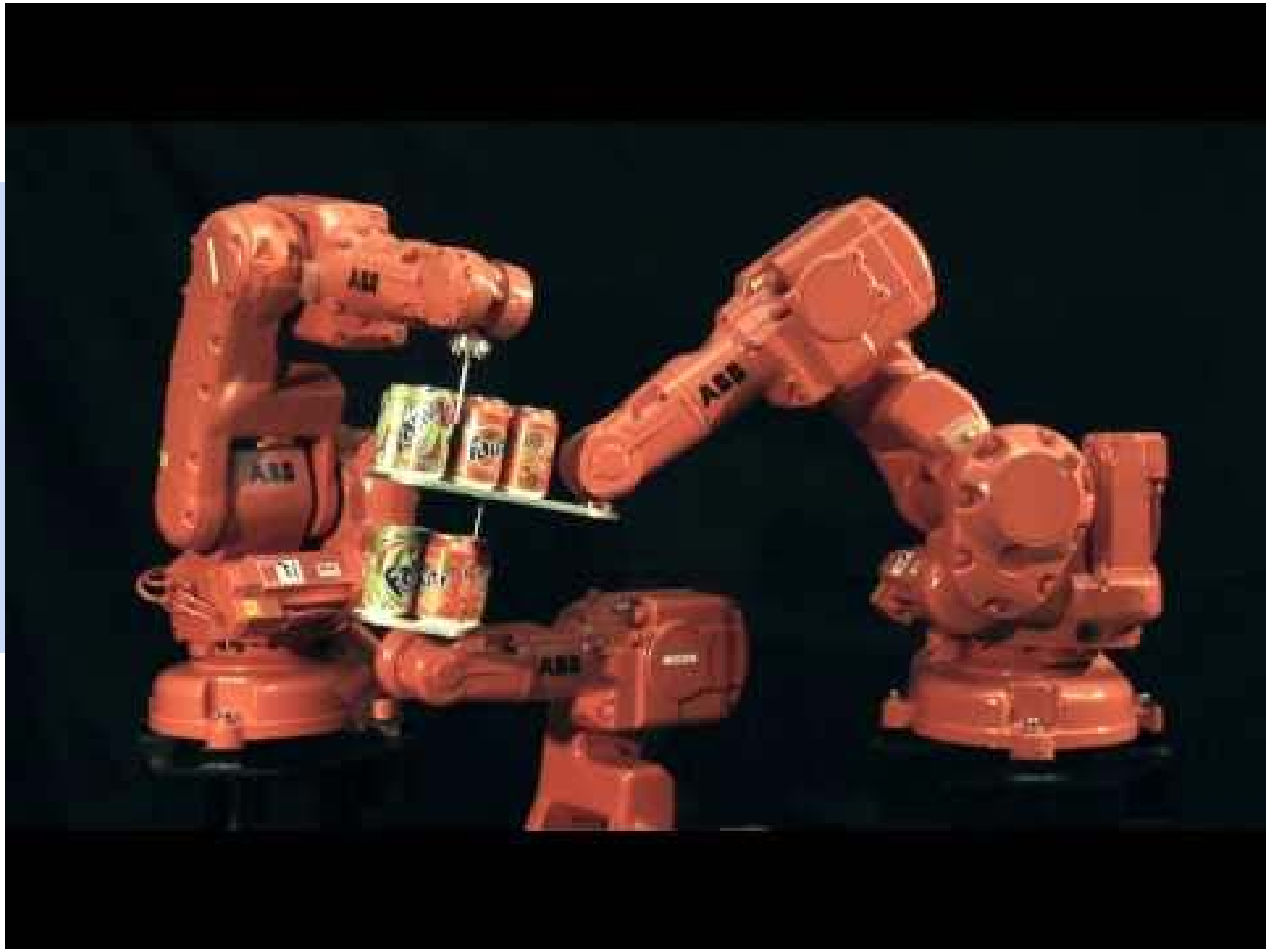
Robot *intelligence* – Levels of Autonomy

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

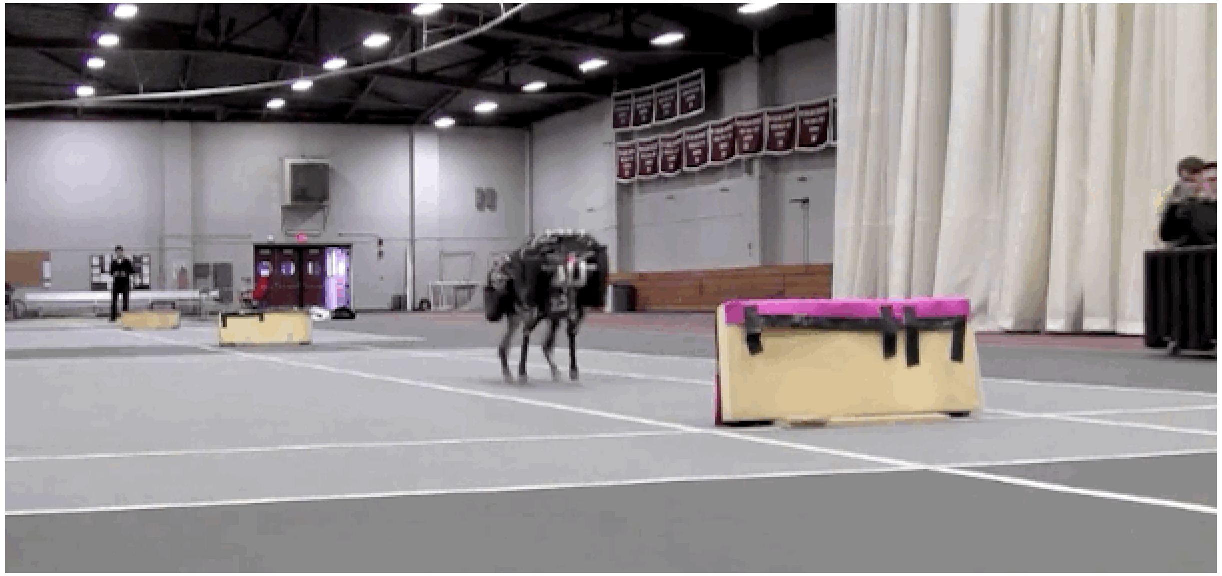


© ABB Robotics

Robots: Mapping Behaviours to Concepts Needed

Tasks and performance that can only be achieved by dynamic motions

Source: Boston Dynamics (Atlas)



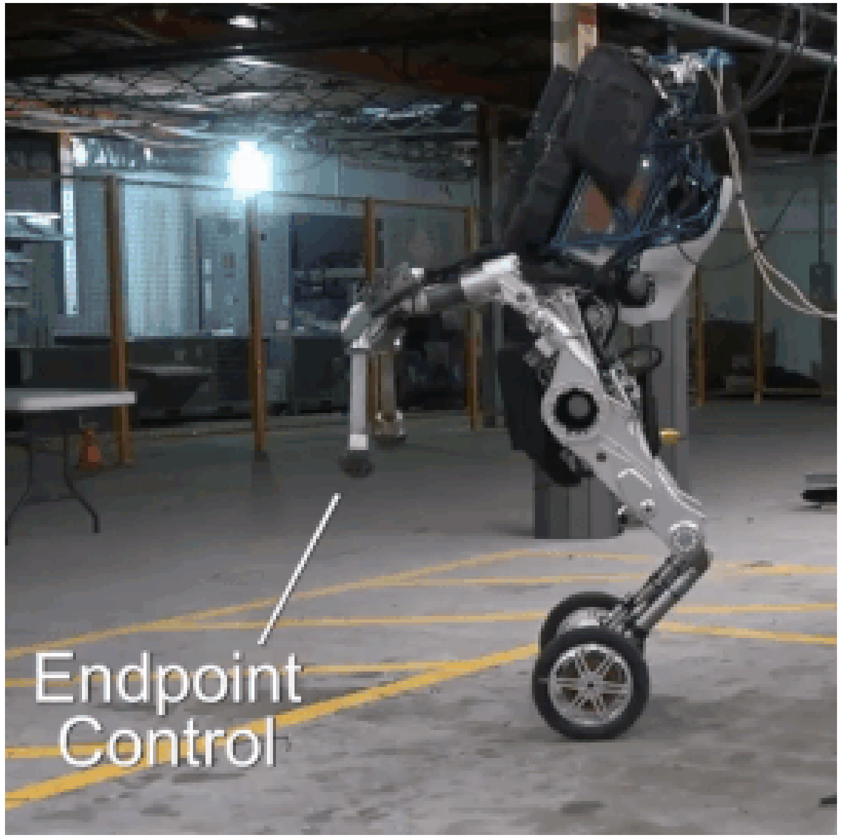
Source: MIT (Cheetah)

Robots: Mapping Behaviours to Concepts Needed

Sorting parcels in warehouse application

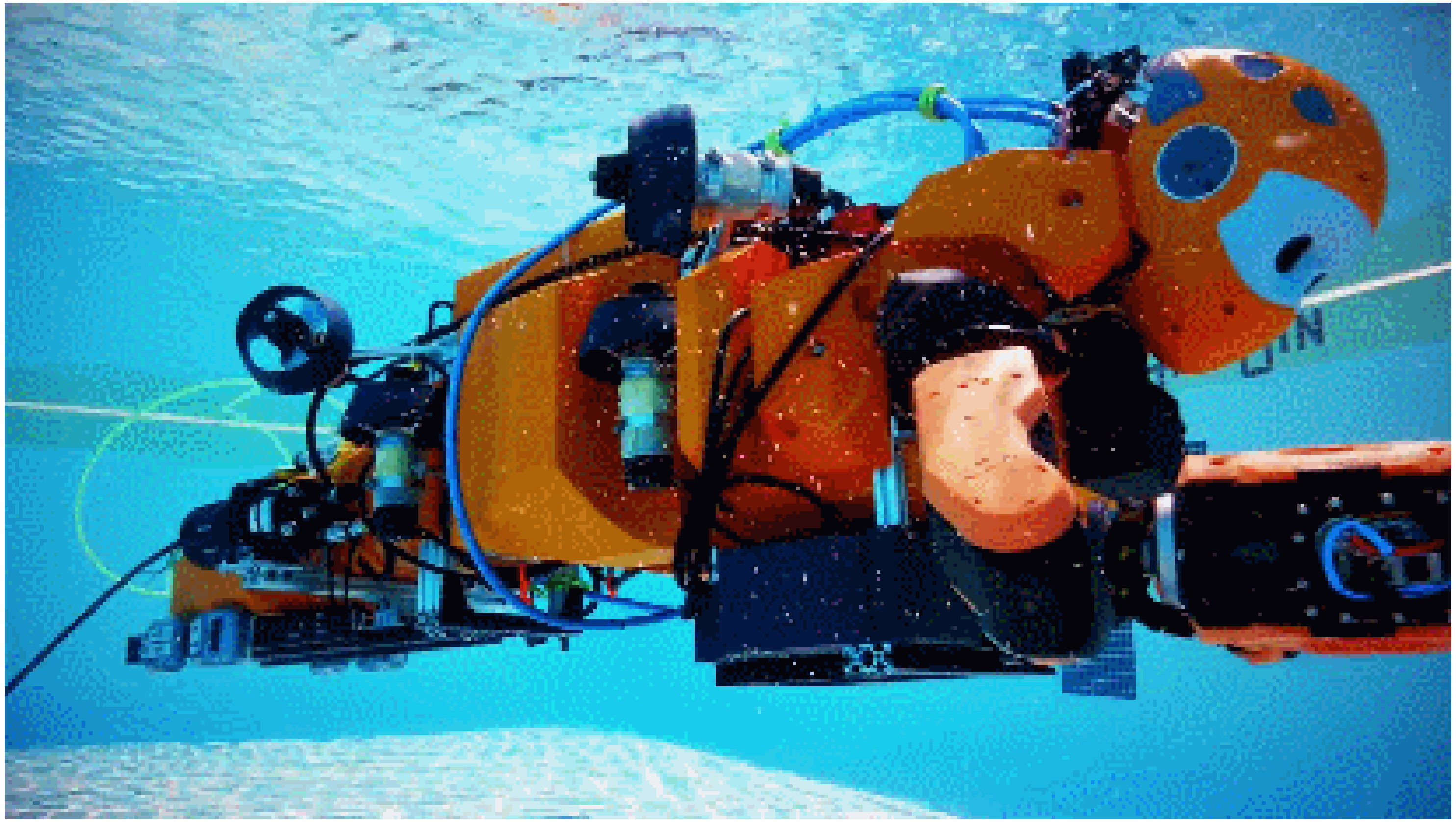
Digital System & control
Localization and Mapping
Path & Motion Planning

Robots: Mapping Behaviours to Concepts Needed



Spot-mini and Handle robots from Boston Dynamics

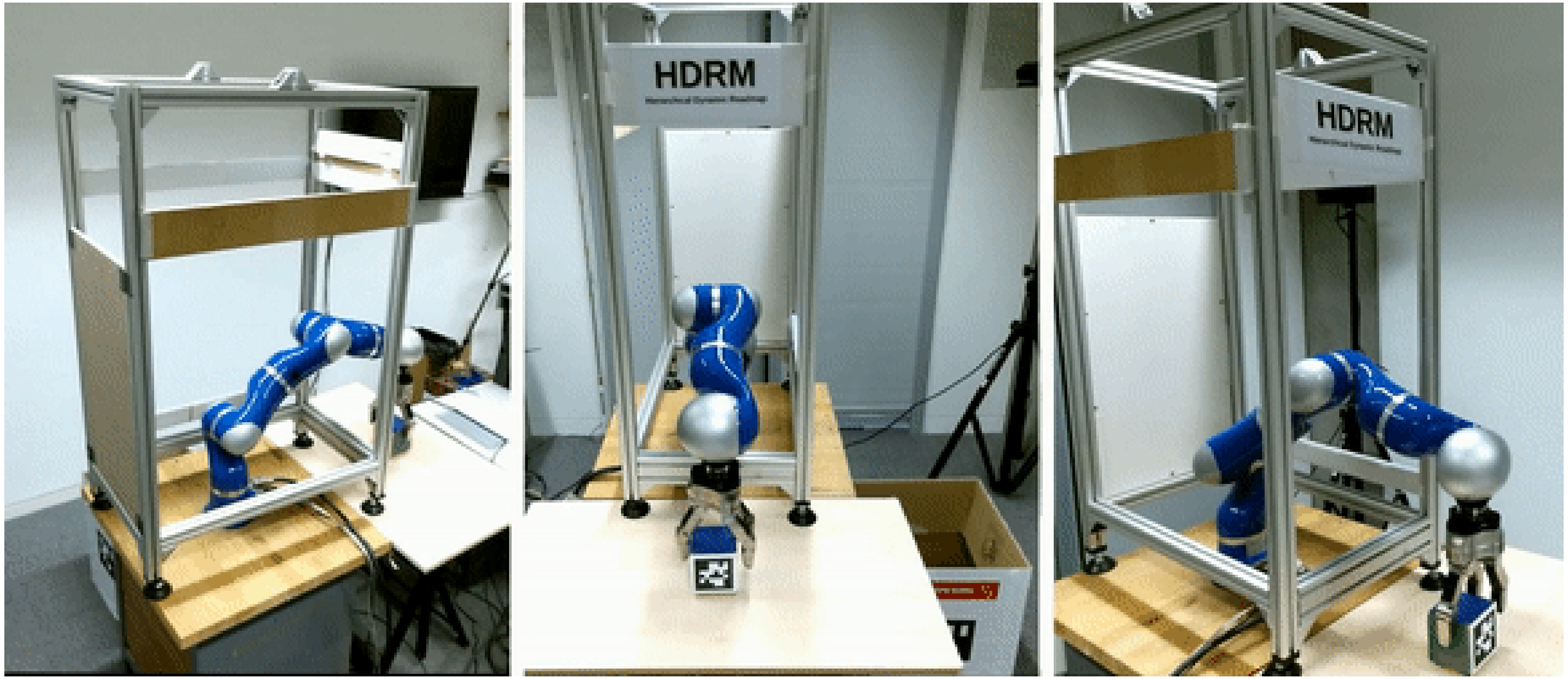
Robots: Mapping Behaviours to Concepts Needed



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)

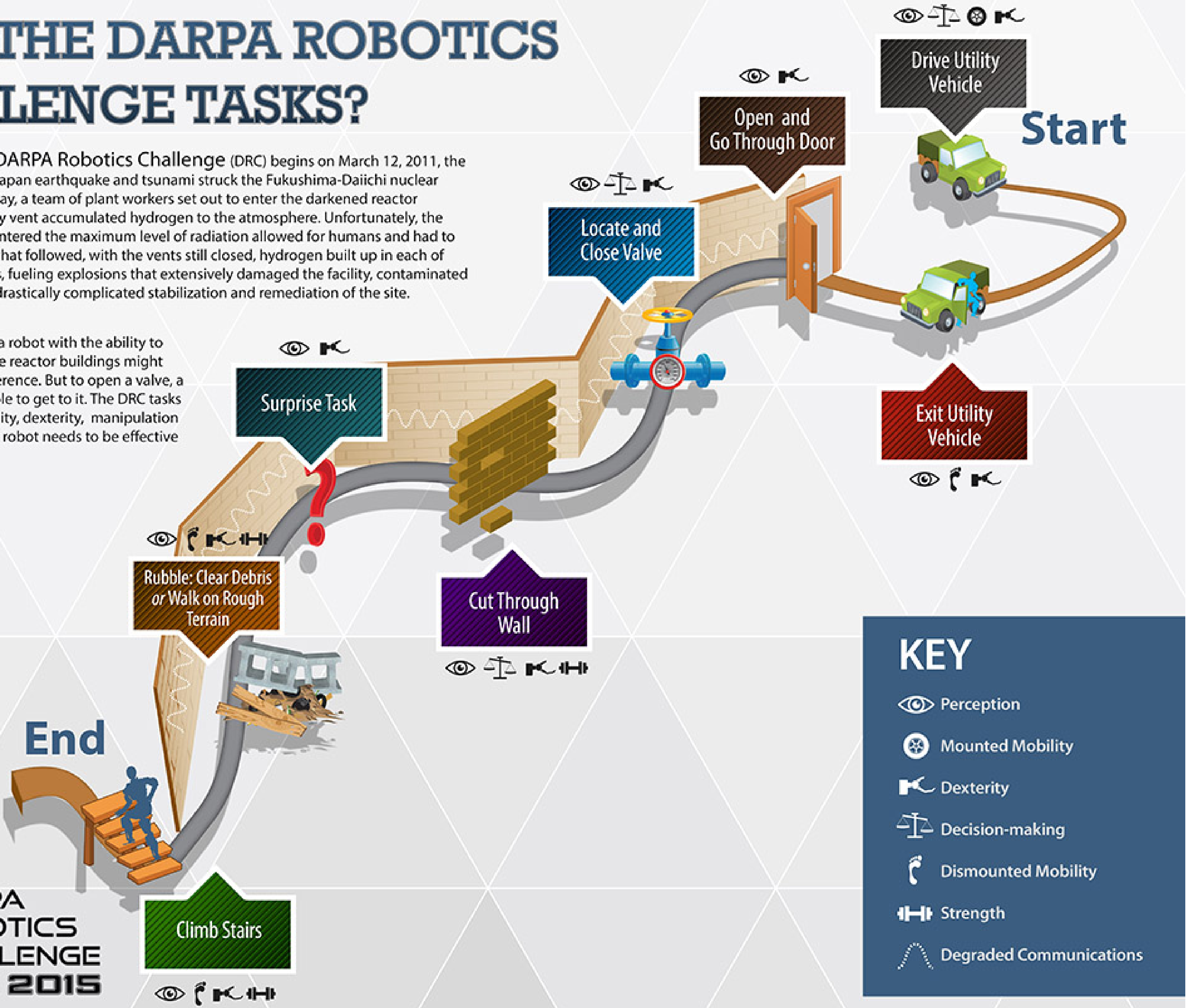
The Stanford Racing Team's Stanley won the 2005 DARPA Grand Challenge. The race helped jump-start interest in self-driving cars. Credit: Division of Work and Industry/National Museum of American History/Smithsonian Institution

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.

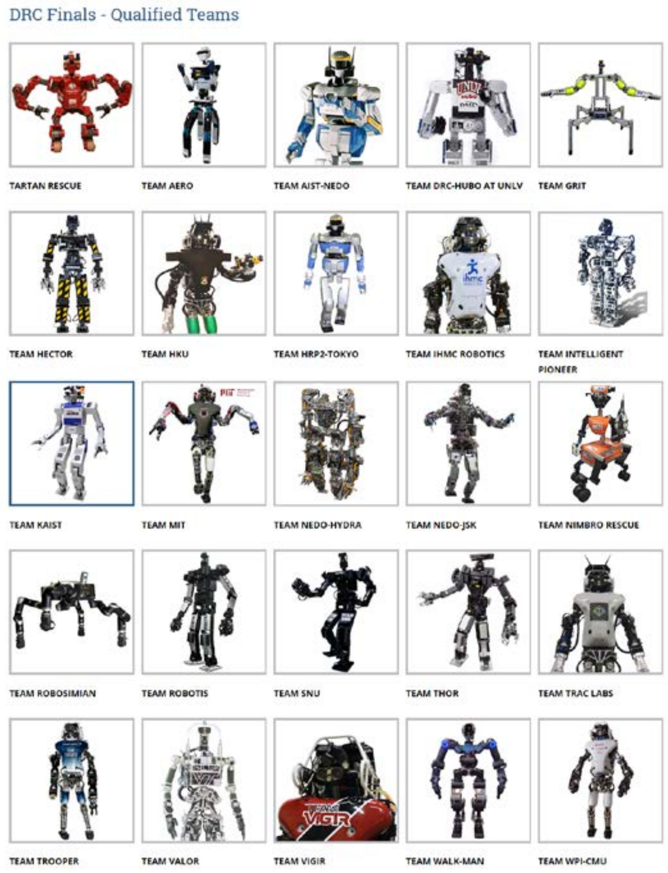
At Fukushima, having a robot with the ability to open valves to vent the reactor buildings might have made all the difference. But to open a valve, a robot first has to be able to get to it. The DRC tasks test some of the mobility, dexterity, manipulation and perception skills a robot needs to be effective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

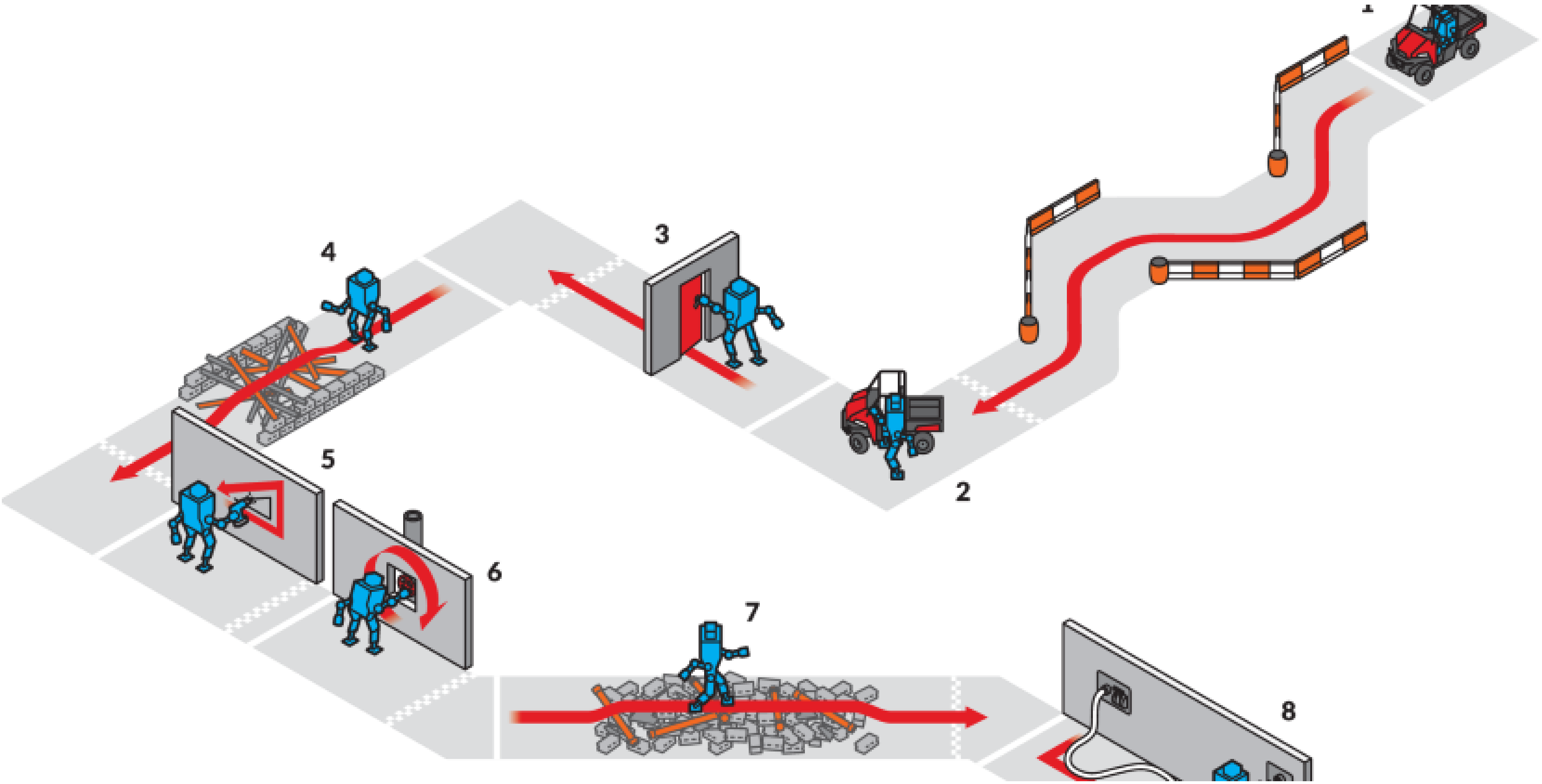


DARPA

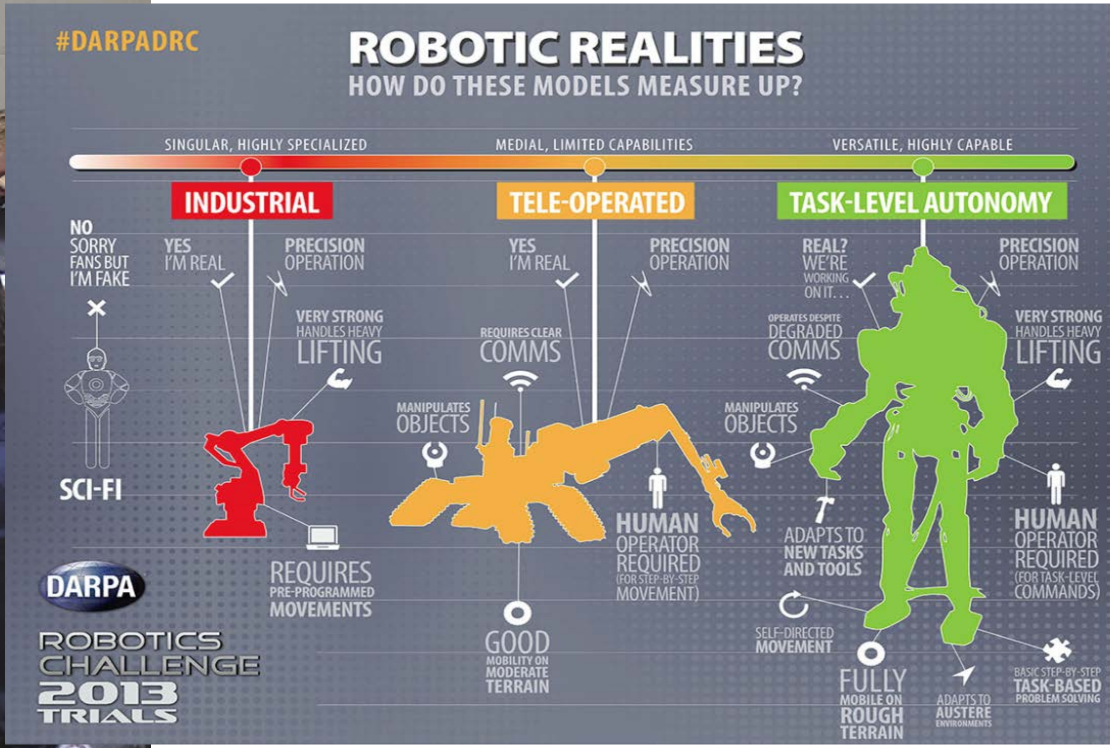
DARPA ROBOTICS CHALLENGE FINALS 2015

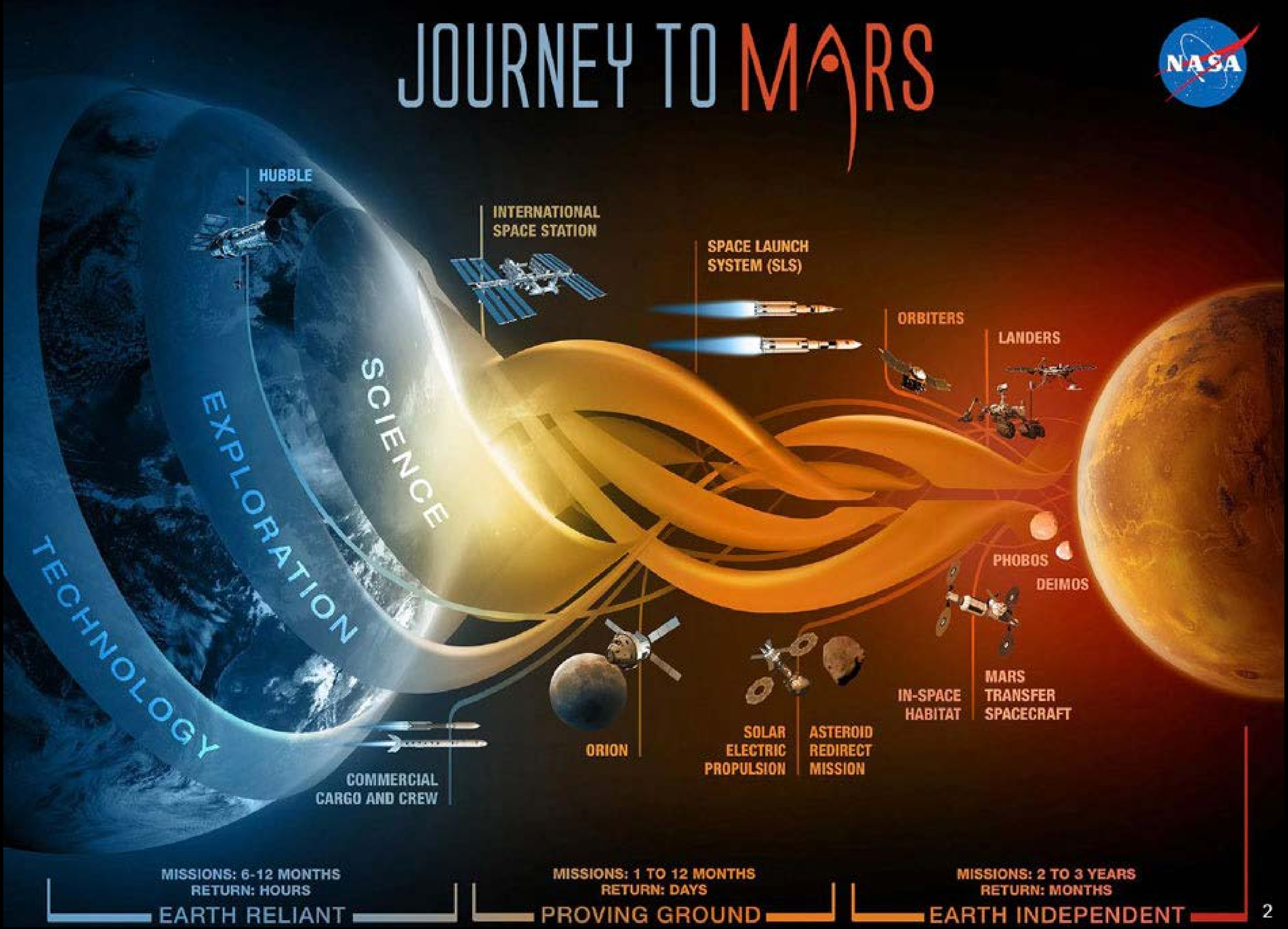
Towards Autonomy in General Environments



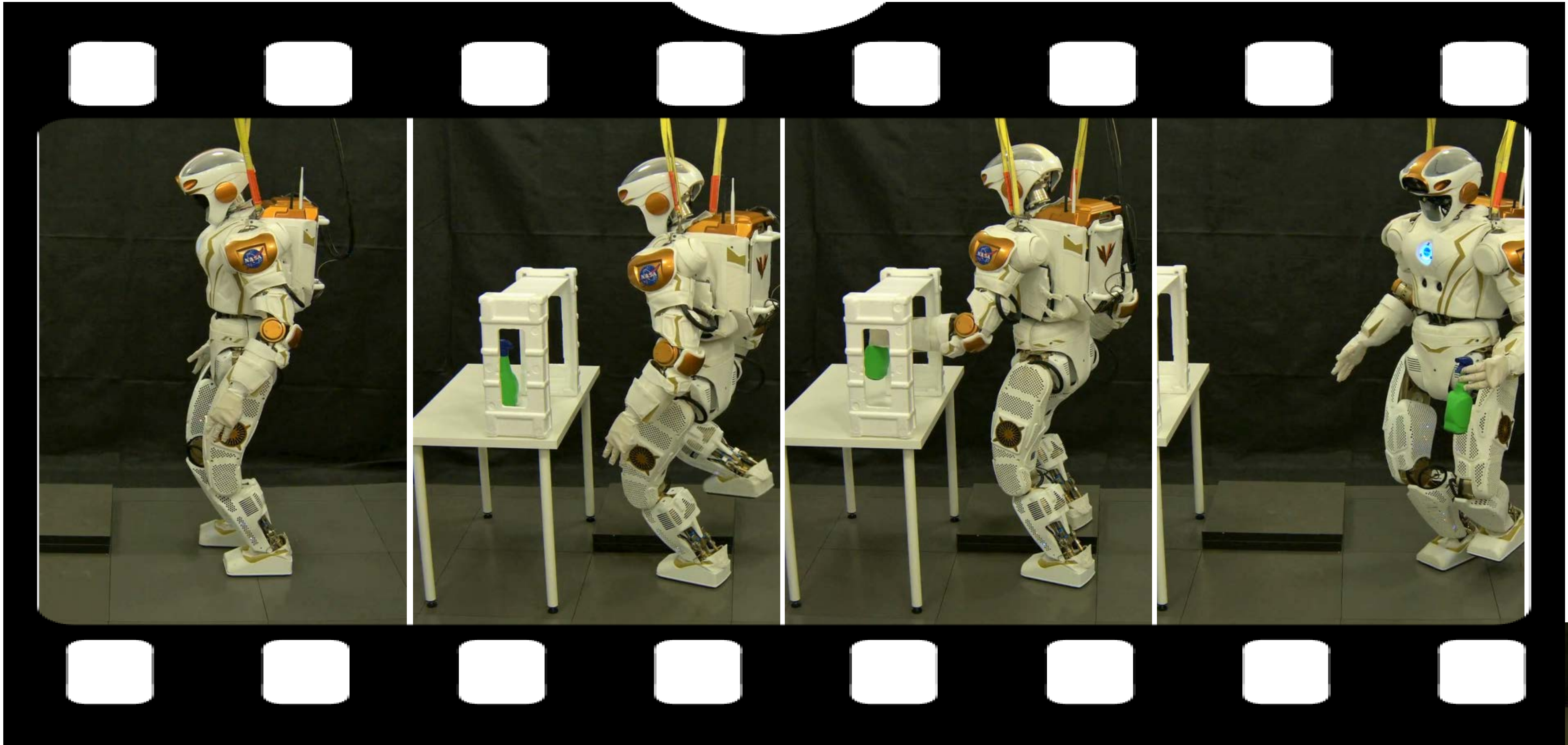


Human Intervention & Supervision in DRC 2015




JOURNEY TO MARS
NASA
HUBBLE
INTERNATIONAL SPACE STATION
SPACE LAUNCH SYSTEM (SLS)
ORBITERS
LANDERS
SCIENCE
EXPLORATION
TECHNOLOGY
PHOBOS
DEIMOS
ORION
SOLAR ELECTRIC PROPULSION
ASTEROID REDIRECT MISSION
IN-SPACE HABITAT
MARS TRANSFER SPACECRAFT
COMMERCIAL CARGO AND CREW
MISSIONS: 6-12 MONTHS
RETURN: HOURS
EARTH RELIANT
MISSIONS: 1 TO 12 MONTHS
RETURN: DAYS
PROVING GROUND
MISSIONS: 2 TO 3 YEARS
RETURN: MONTHS
EARTH INDEPENDENT

NASA Valkyrie Humanoid Robot @U. Edinburgh



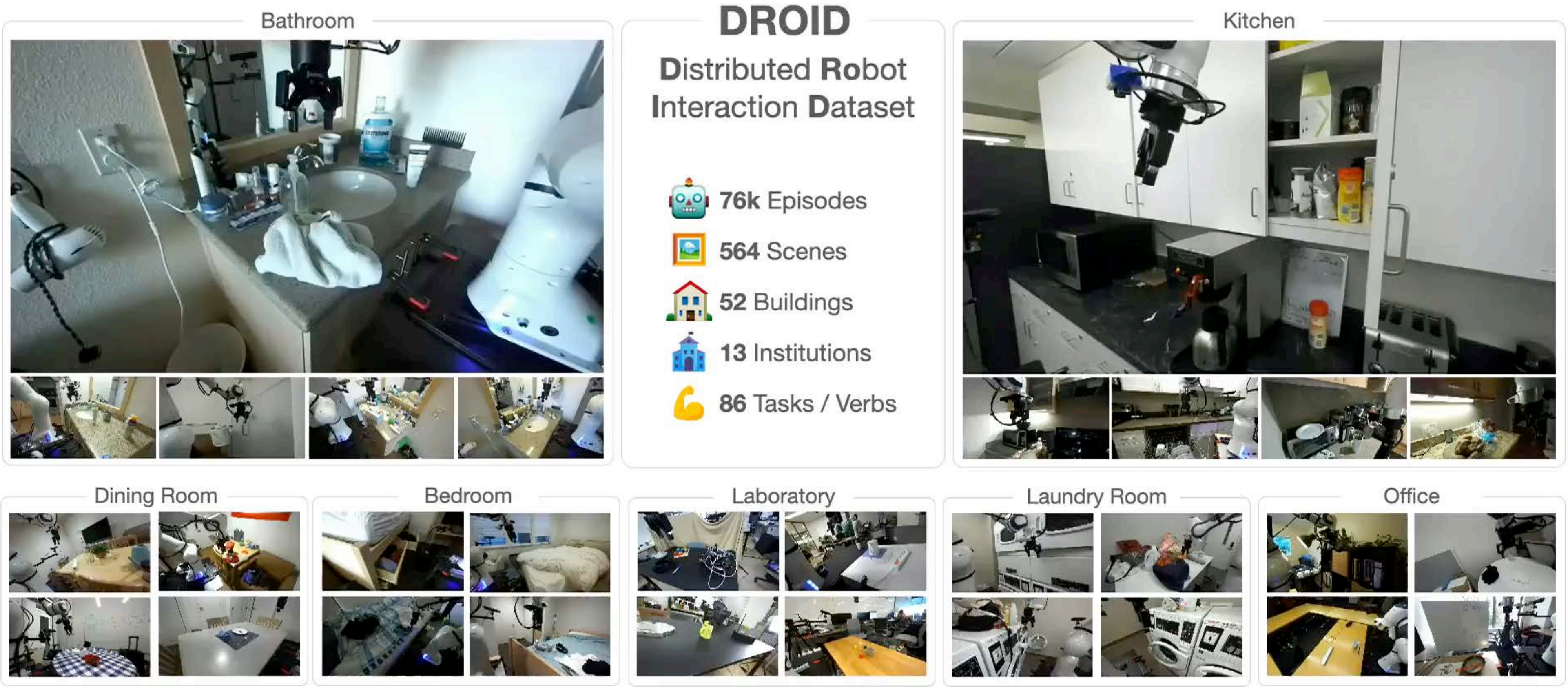
Towards task level autonomy, today...

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



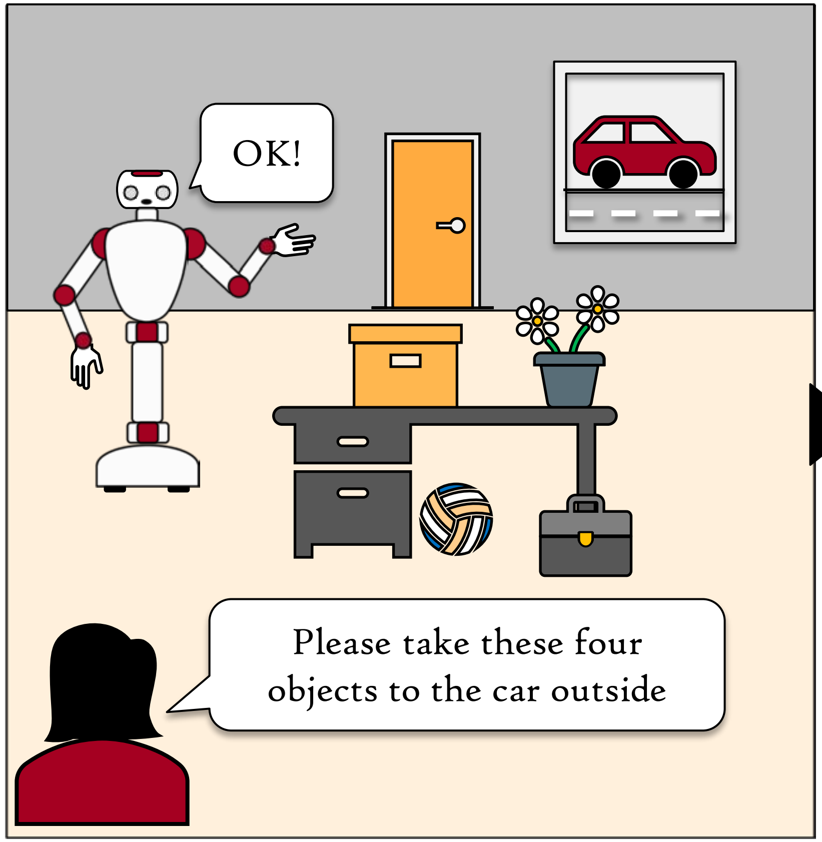
Bathroom
DROID
Distributed Robot Interaction Dataset
76k Episodes
564 Scenes
52 Buildings
13 Institutions
86 Tasks / Verbs
Kitchen
Dining Room
Bedroom
Laboratory
Laundry Room
Office

Are we there yet?

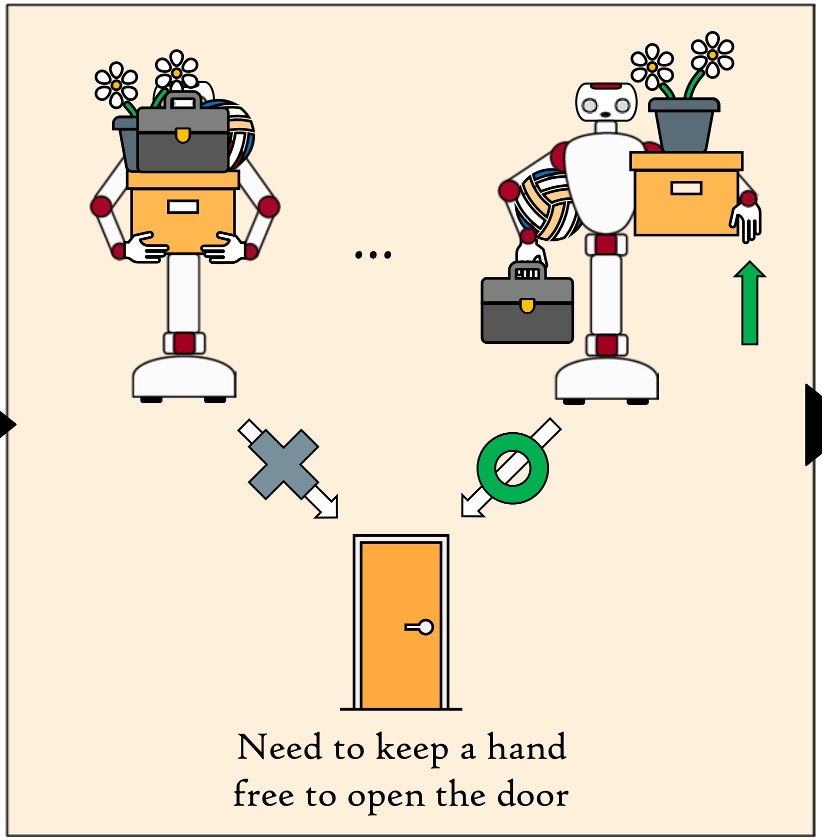
https://earlyarts.co.uk/blog/using-clay-to-nurture-young-childrens-development

Next Challenge: Whole-body Manipulation

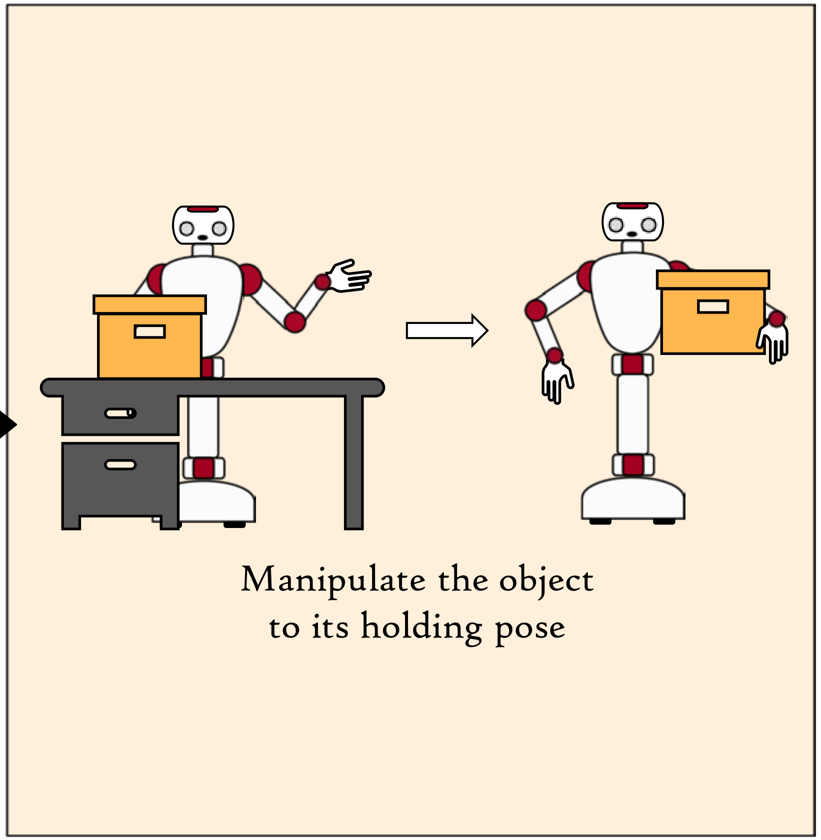
Overall task setting



Long-Horizon planning



WBM Planning & Control



V. Levé, J. Moura, N. Saito, S. Tonneau, and S. Vijayakumar, **Explicit contact optimization in whole-body contact-rich manipulation**, Humanoids, 2024
V. Levé, J. Moura, S. Tonneau, S. Fujita, T.Miyake and S. Vijayakumar, **Scaling Whole-Body Multi-contact Manipulation with Contact Optimization**, Humanoids 2025.

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 H. Choset, K.M. Lynch, S. Hutchinson, G. Kantor, Principles of Robot Motion: Theory, Algorithms, and Implementations.
Design of Advanced Controllers	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.