

State of the Art
and Research
Needs

ROBOTICS

• Fred Proctor
National Institute of
Standards and Technology, Retired

OUTLINE

Key Concepts

$$\begin{bmatrix} X_x & Y_x & Z_x & P_x \\ X_y & Y_y & Z_y & P_y \\ X_z & Y_z & Z_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



Dexterous Manipulation

Mobility

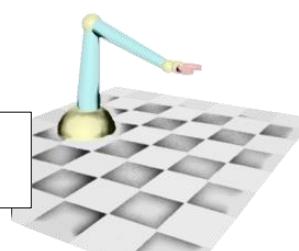


Sensing and Perception



Collaborative Robots

Simulation



Planning



Artificial Intelligence



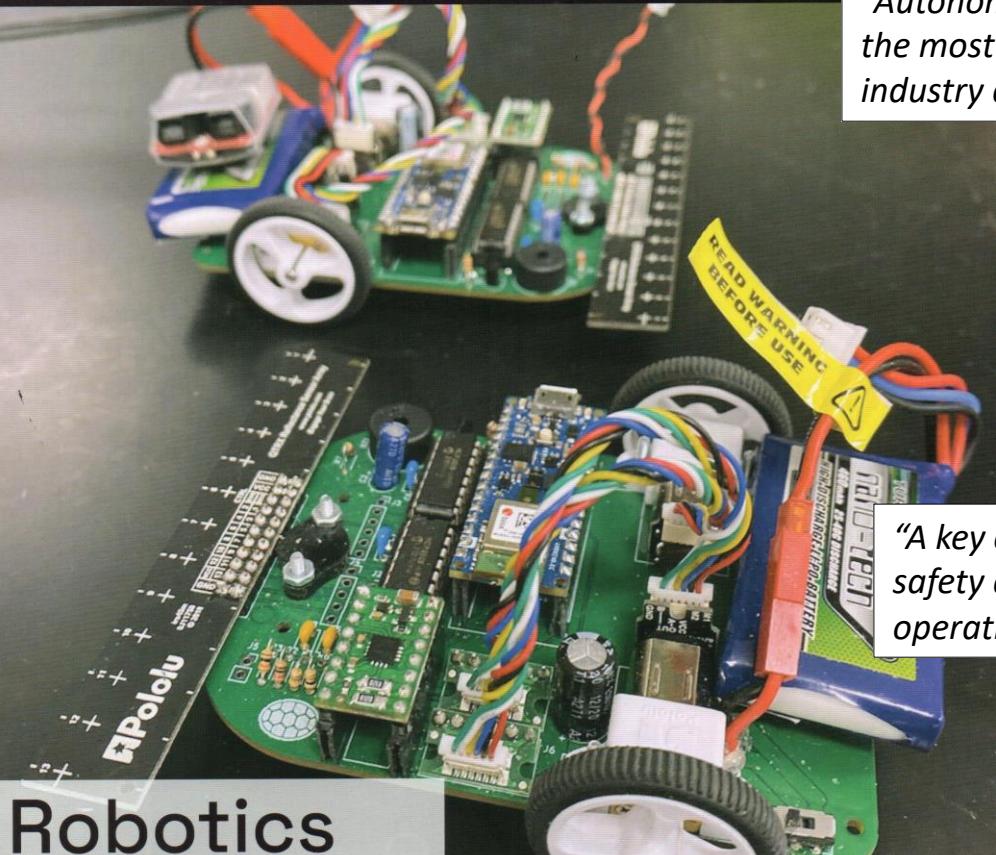


CONNECTIONS

DEPARTMENT of ELECTRICAL & COMPUTER ENGINEERING

A. JAMES CLARK SCHOOL of ENGINEERING

SPRING 2022



Robotics

The Road To Innovative Research Programs

PROGRAM HIGHLIGHT Major Updates to the Electrical Engineering Undergraduate Program | **RESEARCH UMD**

Wins \$5M Phase 2 NSF Convergence Accelerator Award | **ALUMNI** Four New Distinguished Alumni Named

FACULTY NEWS Khaligh Wins Nagamori Award | **PHILANTHROPY** Gary Connor Undergraduate Advising Fund

UNIVERSITY OF MARYLAND / FEARLESS IDEAS

feature STORY

Robotics: The Road to Innovative Research Programs

The Electrical and Computer Engineering Department has expanded widely in the areas of robotics and autonomous systems. Robots are transforming the future in many ways, from cloud-connected home robots to drone-use for public security, autonomous vehicles, robots for healthcare, and much more. The use of robotics will increase productivity, reduce human error, save time, and prove to be safer to use in many different environments and ways. Researchers in the Department are conducting research in several aspects of robotics, and are gaining funding from a variety of organizations for their work.

"Autonomous driving has become one of the most anticipated technologies in both industry and academic research groups"

navigation in challenging urban environments. They are collaborating with many industry partners and have also released datasets for the research community.

Robot Motion Planning and Navigation
Manocha's group has also been working on single- and multi-robot planning algorithms. Their earlier work focused on problem detection algorithms and systems

feature STORY

Safety and Resilience in Collaborative Operation of Human-Robot Teams

A key challenge for robotics is ensuring safety and resilience in collaborative operation of human-robot teams (e.g. on the manufacturing floor, warehouse settings, etc.). It is also important to understand how to safely interact with an environment, as well as in unstructured activity (e.g. humans at one's computer). Prof. George Kantor is working on understanding the needs of the operator, as well as in unstructured environments (e.g. humans at one's computer).

"Smellicopter" Drone uses Chemicals in the Air
Researchers from the University of Maryland, the University of Minnesota, and the Air Force Center of Excellence on Nature-Inspired Flight Technologies and Ideas (NIFTI) have developed "Smellicopter," an autonomous drone that uses a live antenna from a moth to detect odors and fly toward them to sniff them out. The results of the work were published in the journal *NPJ Bioinspiration &*

ce Office of Scientific Research is creating solutions to small, remotely located problems. The Clark School currently hosts Professor Pamela Pannier, who leads the ECE/ISR, Professor John Baras, and Associate Professor

Drones hold great potential for performing tasks in difficult, dangerous places, including search and rescue in unstable structures following a natural disaster or navigating a region with demolished devices. To assist in these tasks, researchers are developing sensors that can detect and even sense chemicals in the air. But most artificial sensors are not sensitive or fast enough to be able to find and process specific smells while flying through patchy odor plumes.

Many alumni of ISL are making their mark in projects of national importance. Dr. Philip Twiss is a Robotics System Engineer in the Aerial and Orbital Image Analysis Group at NASA's Jet Propulsion Laboratory. He is a member of the systems engineers for rover navigation on the Mars 2020 Perseverance Rover mission. The rover is designed to detect signs of ancient life and collect samples of rock and soil for return to Earth at a later date, possibly return to Earth in 2031. It was launched July 30, 2020, and will land February 18, 2021, on the Jezero Crater. Mars.

Twiss completed his B.S. in both electrical engineering and computer science at the University of Maryland in 2008, and his Ph.D. in electrical and computer engineering at Georgia Institute of Technology in 2012. Twiss worked in ISL from 2007-2008.

CONNECTIONS SPRING 2022

AI and Autonomy for Multi-Agent Systems

An interdisciplinary research team led by the University of Maryland, College Park (UMD) and in partnership with the University of Maryland, Baltimore County (UMBC) has entered into a cooperative agreement with the U.S. Army Research Laboratory (ARL) worth up to \$68M.

The agreement brings together a large, diverse collaborative of researchers—leveraging the University System of Maryland's national leadership in engineering, robotics, computer science, operations research, modeling and simulation, and autonomy systems—becoming more central to the STEM industries in which engineering and computer science graduates work. Robotics has become a "must-know" field. Robotics courses generate long wait lists and a demand for more classes and sections.

The robust effort encompasses three areas of research thrusts, each supported by a team of faculty, staff, and students. The new collaboration builds on a more than 25-year history of research and development in AI, autonomy, and modeling and simulation to spur the development of technologies that reduce human workload and risk in complex environments such as the

New Undergraduate Minor in Robotics and Autonomous Systems

During Fall 2021, the University of Maryland began offering a new undergraduate minor in Robotics and Autonomous Systems (RAS). With automation systems becoming more central to the STEM industries in which engineering and computer science graduates work, robotics has become a "must-know" field. Robotics courses generate long wait lists and a demand for more classes and sections.

The new minor is administered by the Maryland Robotics Center (MRC), part of the Institute for Systems Research within the Clark School of Engineering. MRC currently provides technical direction to the Maryland Applied Graduate Engineering (MAGE) Master of Engineering program in Robotics and will expand its educational mission to include the new cross-disciplinary engineering, mechanical

well as with real robots in the lab or in research & supported by best standards. Prof. Barnes directs the Systems Integration Laboratory (SEL), and the Robotics and Cognition (ARC) Laboratory, a program of collaboration with industry labs and associated student internships. He also collaborates with researchers at the University of Munich in Germany, and the Royal Institute of Technology (KTH) in Sweden. ■

"Foundational aspects of robotics research include trusted autonomy (autonomous systems that can self-monitor execution of tasks, self-correct execution, and self-learn)"

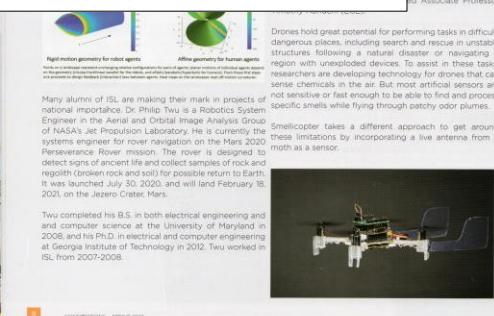


NEWLY-OPENED SMART BUILDING TO SPUR AUTONOMY RESEARCH

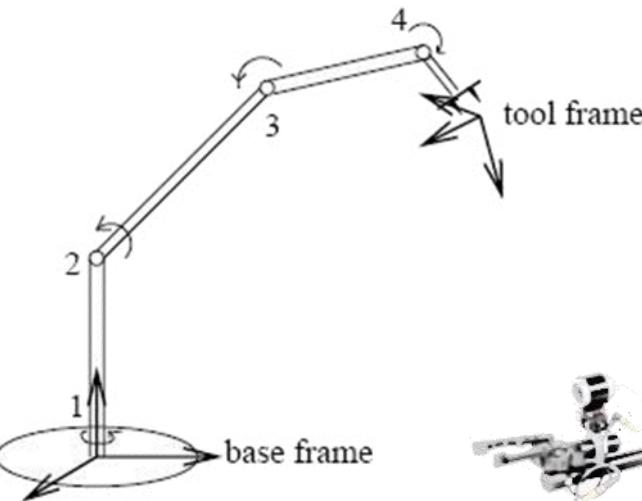
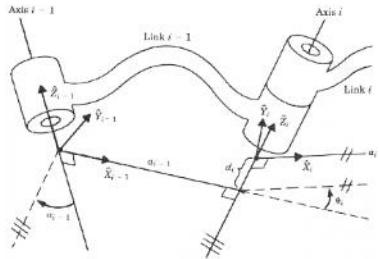
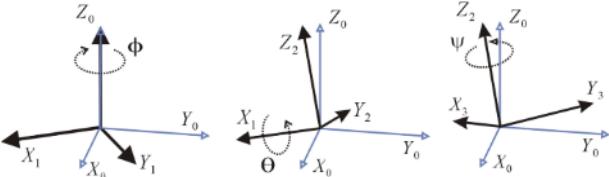
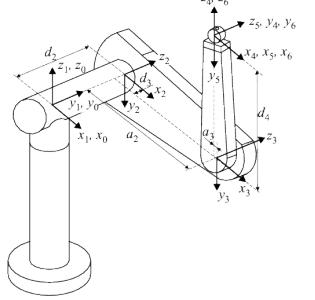
The University of Maryland, already a leader in autonomy and unmanned systems research, is poised for further innovation with the launch of a state-of-the-art facility at the University of Maryland at Southern Maryland (USM).

The new Southern Maryland Autonomous Research and Technology (SMART) Building, located in St. Mary's County, includes underwater, air, and land testing facilities that are expected to be utilized widely by researchers at UMD's James Clark School of Engineering, the Department of Computer Science, the Institute for Systems Research, the Maryland Robotics Center (MRC), and other departments, centers, and units at UMD.

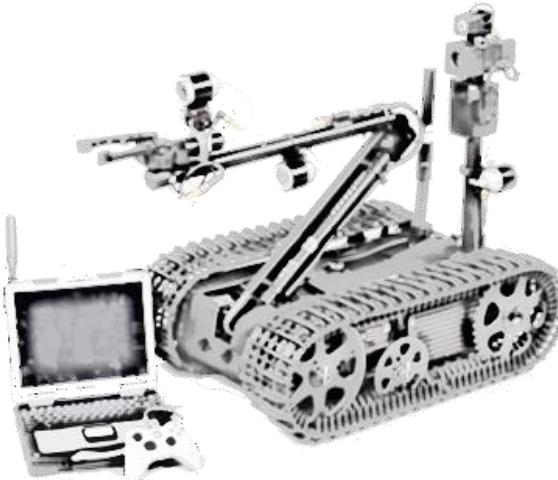
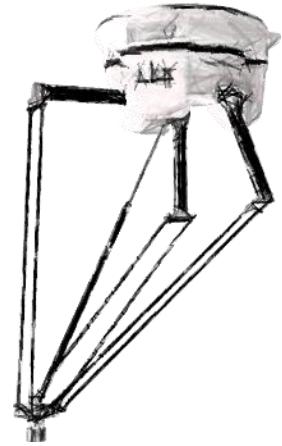
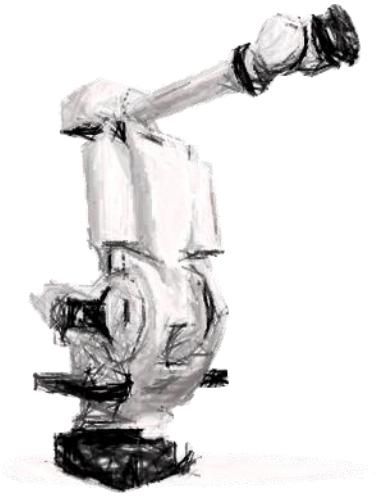
The \$86M, 84,000-square-foot building is home to among other labs and facilities, the Maryland Autonomous Research and Innovation Xploration (MATRIX) Lab, which features an 80' by 60' open-air land lab with an amphibious pool, a hydrology lab, a wind tunnel, a water tunnel, a wave tank 50' by 150 cm cross-section, an AR/VR capable research space, roof-top antenna farm, and outdoor ground and air vehicle testing. ■



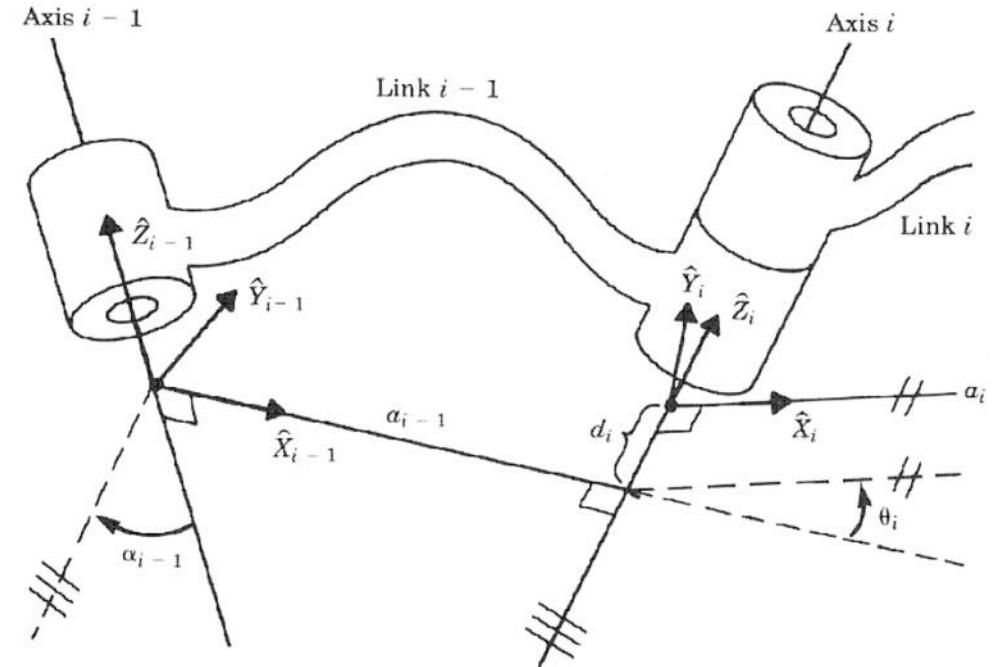
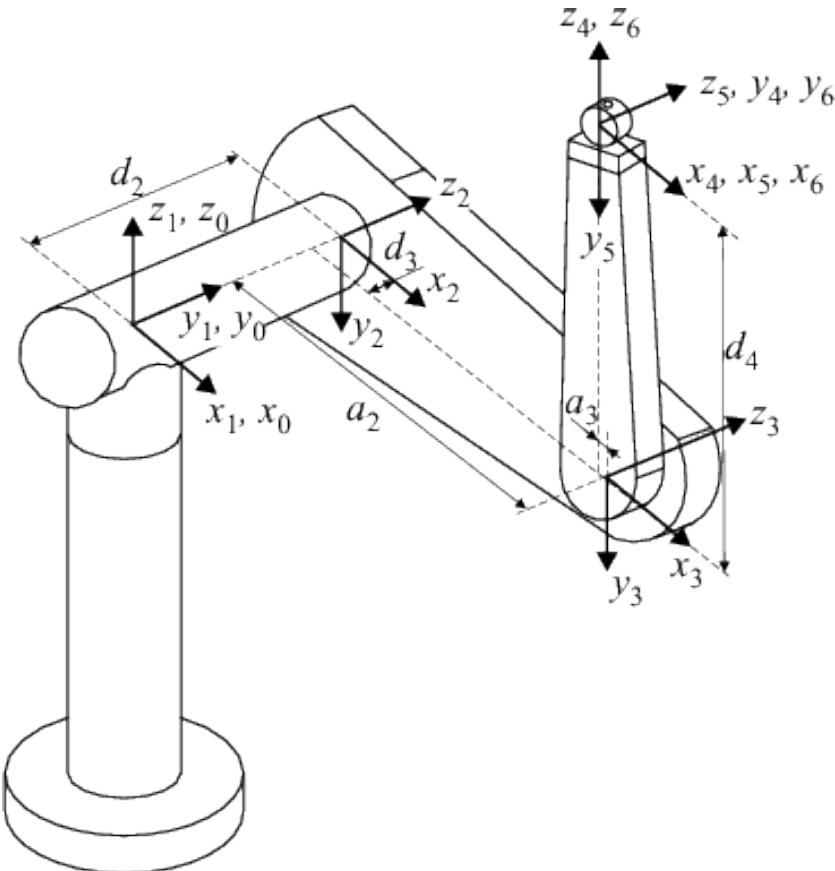
KEY CONCEPTS



$$\begin{bmatrix} X_x & Y_x & Z_x & P_x \\ X_y & Y_y & Z_y & P_y \\ X_z & Y_z & Z_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

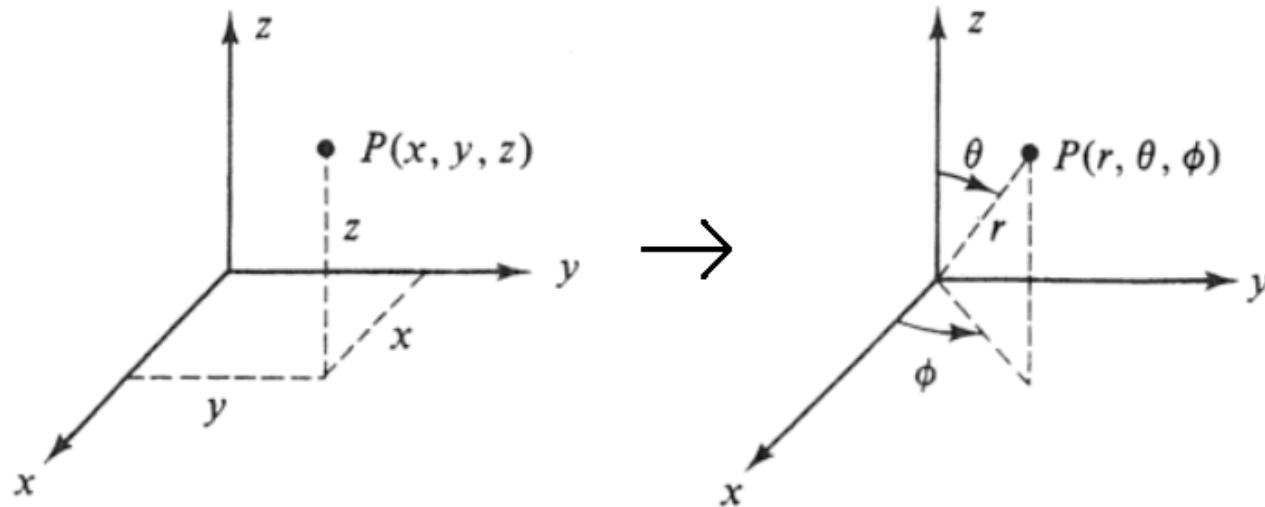


Kinematics define the geometric relationship between robot *links* and the *joints* that connect them



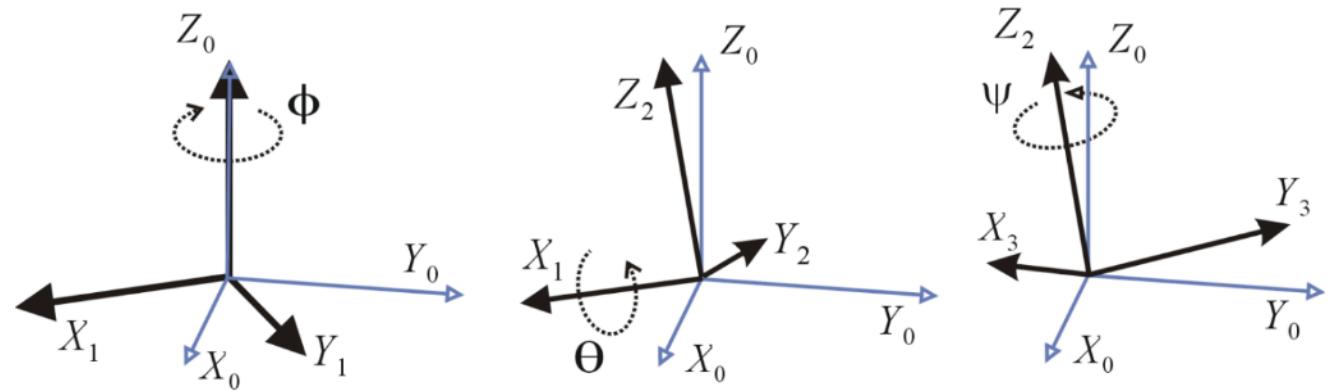
The Denavit-Hartenberg standard form is widely used to represent kinematics, with 4 parameters for each joint-link pair

The position and orientation of an object in our 3D space takes 3 numbers for position and 3 for orientation



There are several equivalent ways to represent position, e.g., X-Y-Z or spherical coordinates

Likewise for orientation, e.g., roll-pitch-yaw or Euler angles



Rotation matrices let you chain together rotations using matrix multiplication

$$R_x(\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \theta & -\sin \theta \\ 0 & \sin \theta & \cos \theta \end{bmatrix}$$

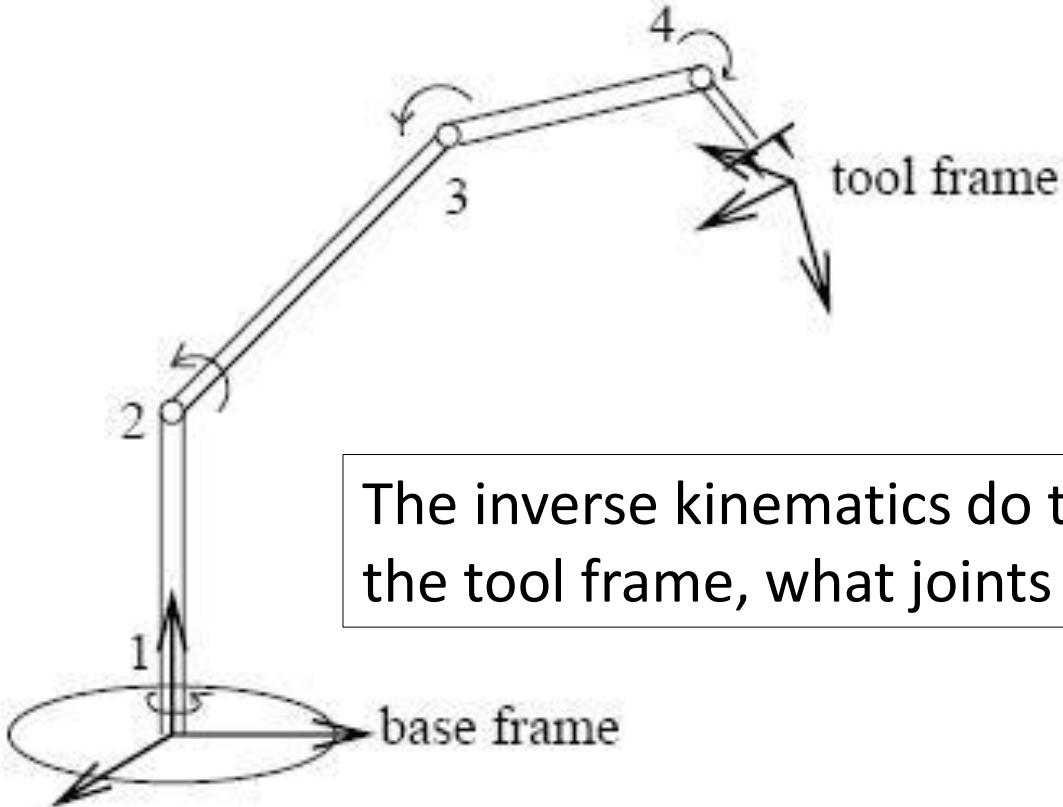
$$R_y(\theta) = \begin{bmatrix} \cos \theta & 0 & \sin \theta \\ 0 & 1 & 0 \\ -\sin \theta & 0 & \cos \theta \end{bmatrix}$$

$$R_z(\theta) = \begin{bmatrix} \cos \theta & -\sin \theta & 0 \\ \sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

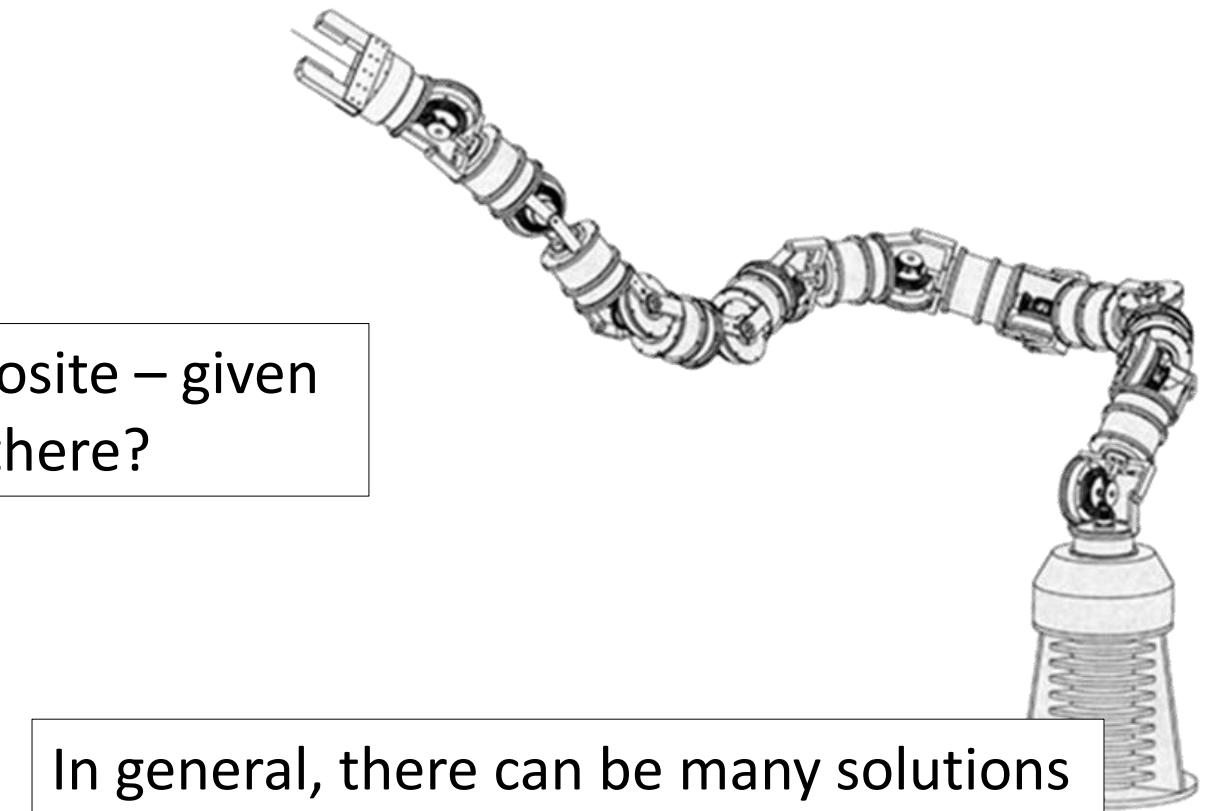
$$\begin{bmatrix} X_x & Y_x & Z_x & P_x \\ X_y & Y_y & Z_y & P_y \\ X_z & Y_z & Z_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Homogeneous transforms are the full position and orientation version, padded with some extra fluff to make square matrices amenable to multiplication and inversion

The *forward kinematics* relate the pose at the end of the robot (its *tool frame*) with respect to the *base frame*, for a given set of joint values



The inverse kinematics do the opposite – given the tool frame, what joints get us there?



In general, there can be many solutions

Dynamics is the aspect of robot structures that handle speeds, forces and torques

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \\ \omega_x \\ \omega_y \\ \omega_z \end{bmatrix} = \left[\frac{dh(q)}{dq} \right]_{6 \times n} \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \vdots \\ \dot{q}_n \end{bmatrix}_{n \times 1}$$

$$J = \left(\frac{dh(q)}{dq} \right)_{6 \times n} = \begin{bmatrix} \frac{\partial h_1}{\partial q_1} & \frac{\partial h_1}{\partial q_2} & \dots & \frac{\partial h_1}{\partial q_n} \\ \frac{\partial h_2}{\partial q_1} & \frac{\partial h_2}{\partial q_2} & \dots & \frac{\partial h_2}{\partial q_n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{\partial h_6}{\partial q_1} & \frac{\partial h_6}{\partial q_2} & \dots & \frac{\partial h_6}{\partial q_n} \end{bmatrix}_{6 \times n}$$

The *Jacobian matrix* relates changes in joint values (e.g., joint speeds) to changes in the Cartesian position (e.g., linear- and angular speed of the wrist)

In general, it is not a square matrix; its *pseudo-inverse* can be used to pick from many configurations (over-actuated) or find a best fit (under-actuated)

It is also used to relate joint torques to wrist forces and vice-versa

Types of Robot Kinematics

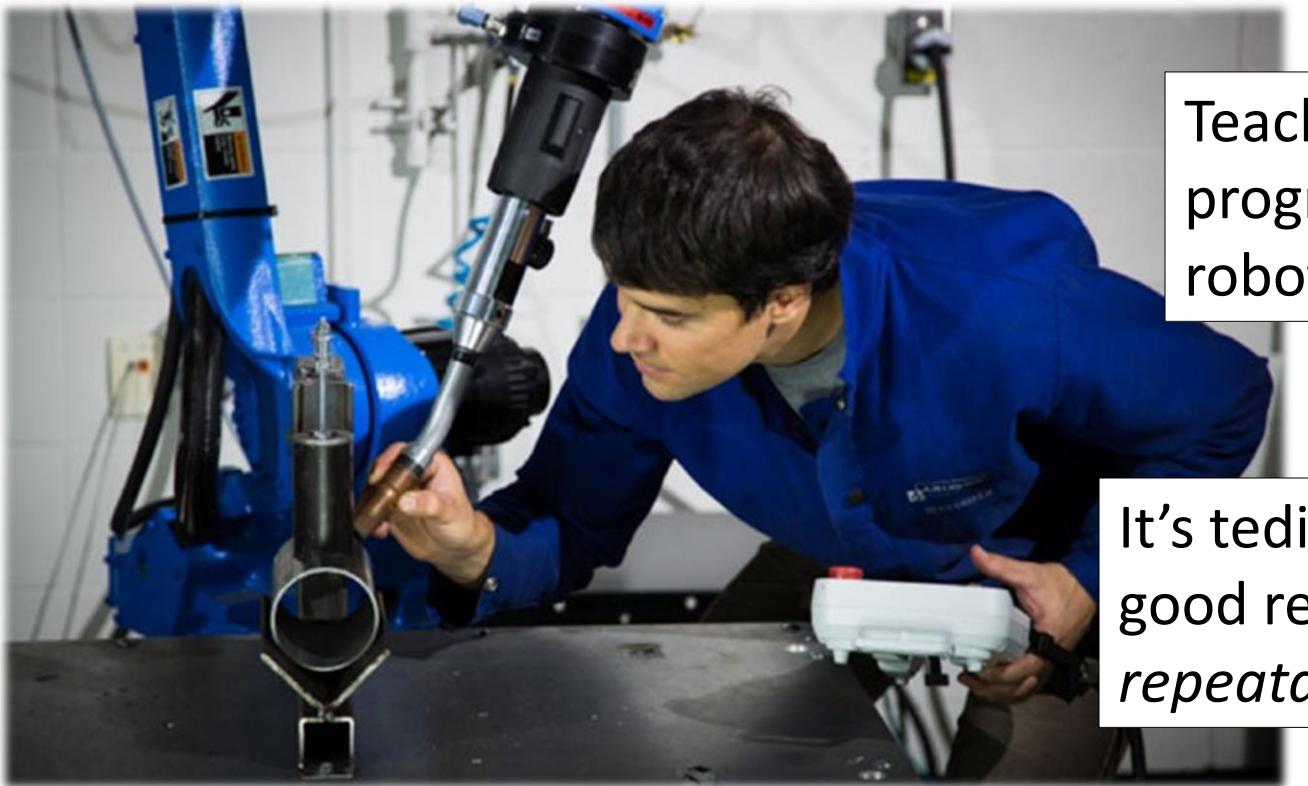
Parallel links



Serial links



Credits: ABB; Fanuc; Unimation



Teach programming is the dominant programming method – manually guiding the robot, recording poses, playing them back

It's tedious and time consuming, but gives good results since it relies on the robot's *repeatability*, typically below 1 mm

Low accuracy
High repeatability



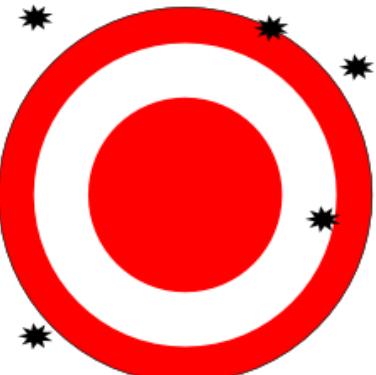
High accuracy
High repeatability

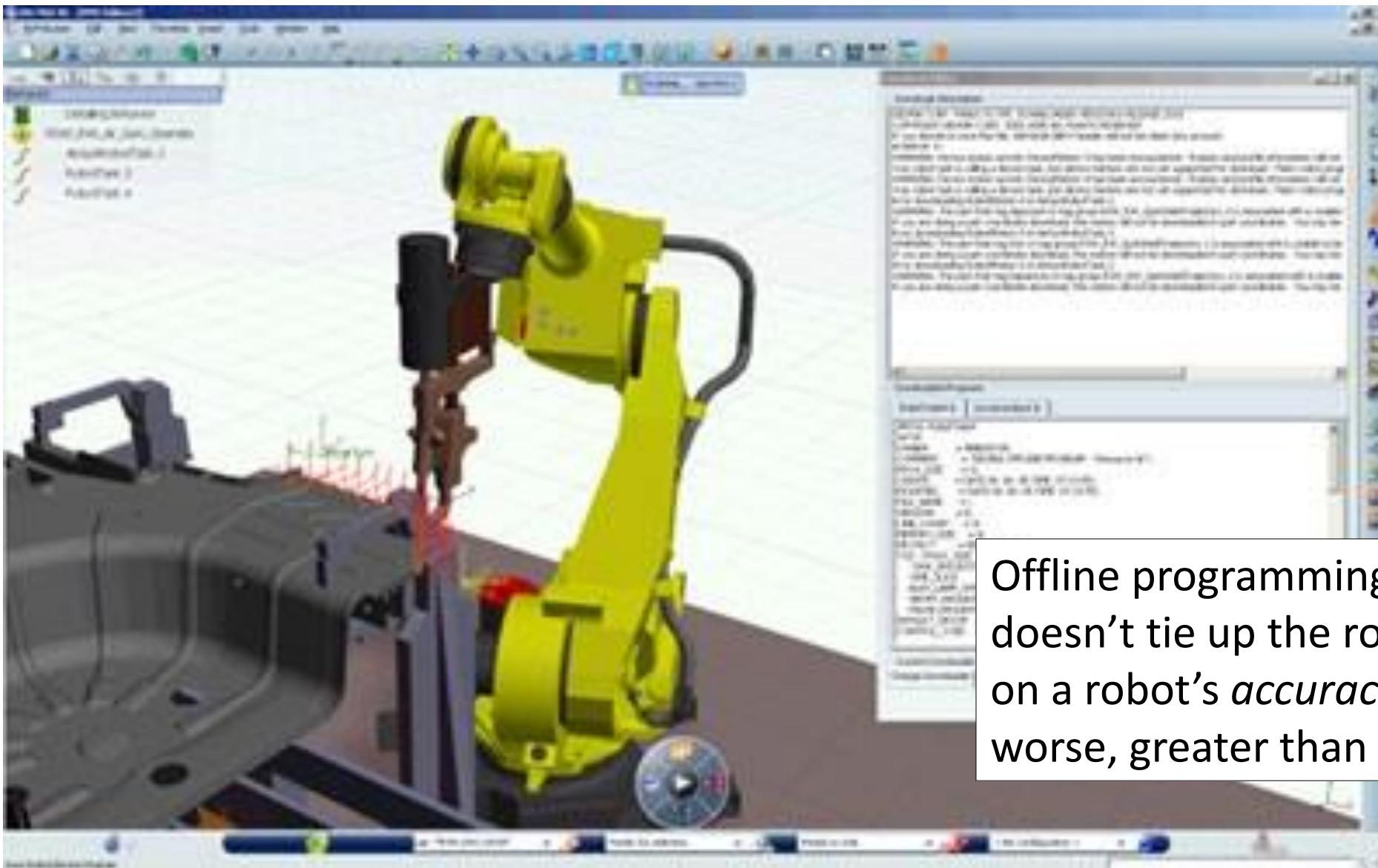


High accuracy
Low repeatability



Low accuracy
Low repeatability



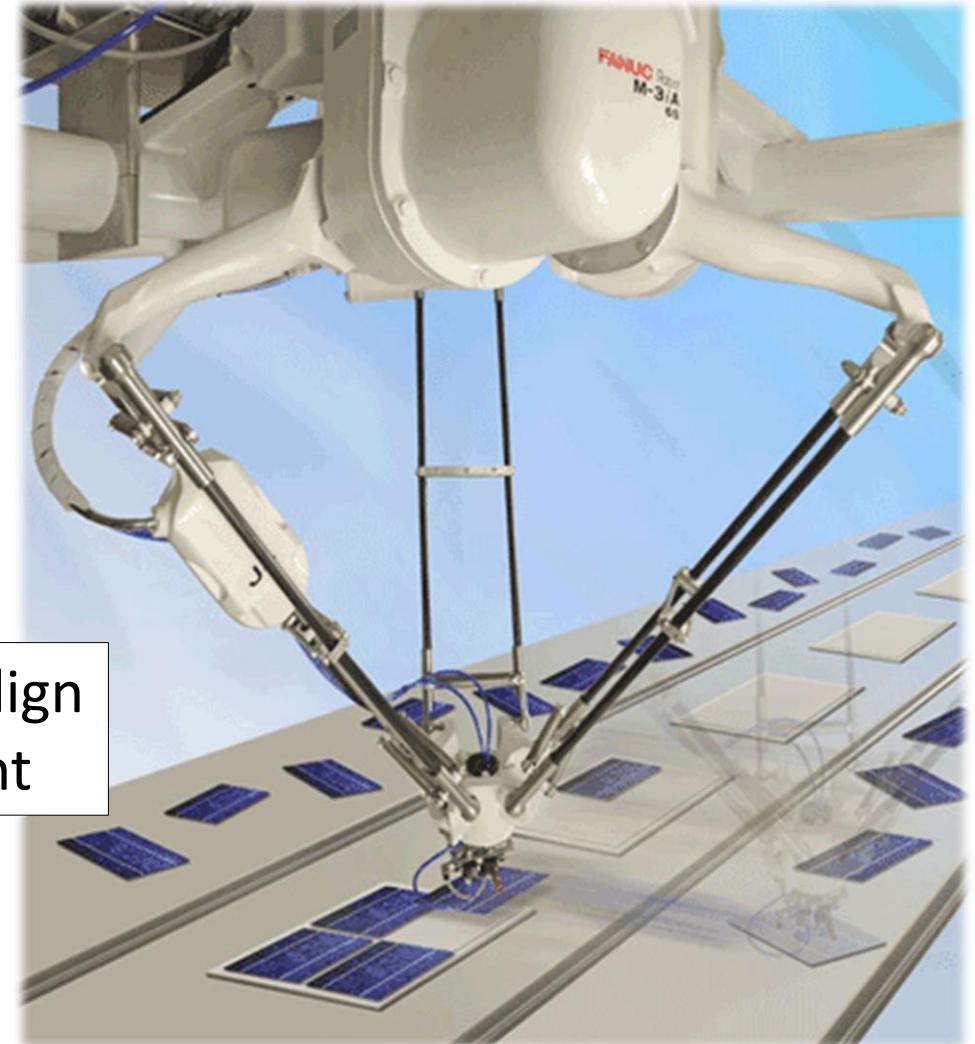


Offline programming is faster, and doesn't tie up the robot, but it relies on a robot's *accuracy*, typically much worse, greater than 1 mm

Sensors can improve the accuracy of robots in demanding applications



Force and torque sensors can detect contact and guide insertion tasks



Vision sensing can precisely align semiconductor chip placement

Credits: Fanuc; Robotiq



Haptic devices “push back” on operators, conveying forces felt by the robot



3D vision microscopes and haptic feedback are used during microsurgery

Credits: Kuka; Intuitive Surgical

Mobile robots are usually *teleoperated* by a person



Some robots are *autonomous*, and can plan actions and take corrective actions themselves by sensing the environment

Credits: iRobot; John Deere; Qinetiq

Useful robots are connected to other things



Robot *controllers* provide many options for input/output and networking



The nice thing about standards is there are so many to choose from



Internet connectivity and standards are becoming more common for industrial devices



Credits: Adept

INTERNET OF THINGS RELATED STANDARDS

Below is a partial listing of IEEE standards related to the Internet of Things.

[IEEE 754™-2008](#) - IEEE Standard for Floating-Point Arithmetic

[IEEE 802.1AS™-2011](#) - IEEE Standard for Local and Metropolitan Area Networks - Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks

[IEEE 802.1Q™-2011](#) - IEEE Standard for Local and metropolitan area networks--Media Access Control (MAC) Bridges and Virtual Bridged Local Area Networks

[IEEE 802.3™-2012](#) - IEEE Standard for Ethernet

[IEEE 802.3.1™-2011](#) - IEEE Standard for Management Information Base (MIB) Definitions for Ethernet

[IEEE 802.11™-2012](#) - IEEE Standard for Information Technology--Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 10: Mesh Networking

[IEEE 802.11ad™-2012](#) - IEEE Standard for Local and Metropolitan Area Networks - Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications - Amendment 3: Enhancements for Very High Throughput in the 60 GHz Band

[IEEE 802.15.1™-2005](#) - IEEE Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements. - Part 15.1: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANs)

[IEEE 802.15.2™-2003](#) - IEEE Recommended Practice for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements Part 15.2: Coexistence of Wireless Personal Area Networks With Other Wireless Devices Operating in Unlicensed Frequency Bands



The Robot Operating System (ROS) is a popular open-source framework for developing robot applications



ROS 1 is the original Linux-based system



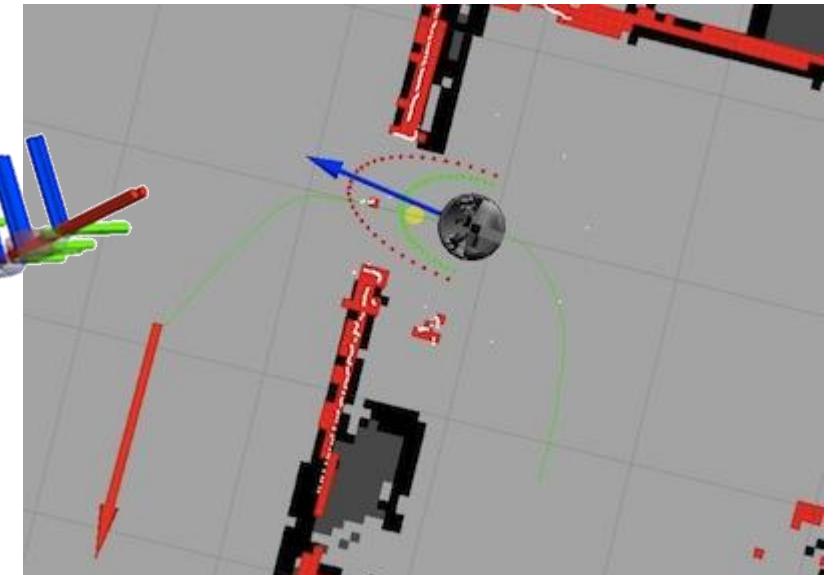
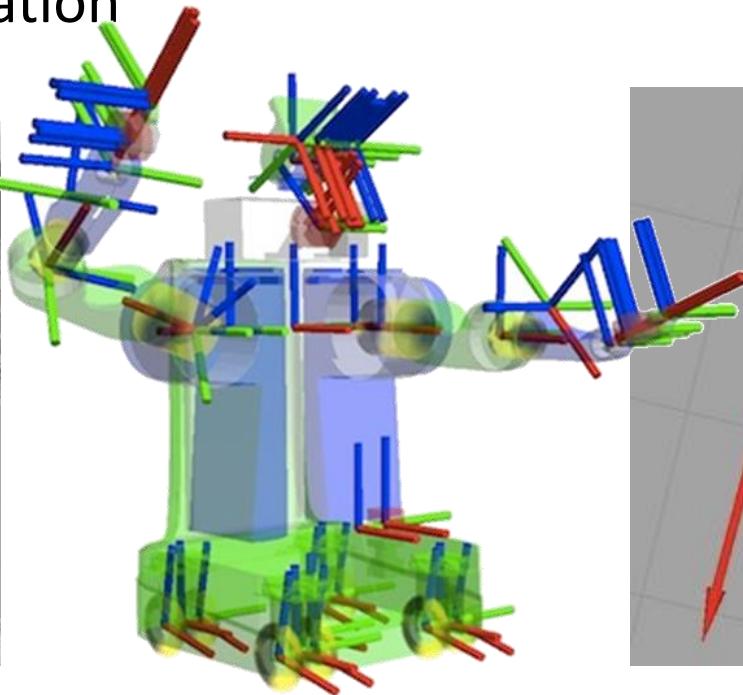
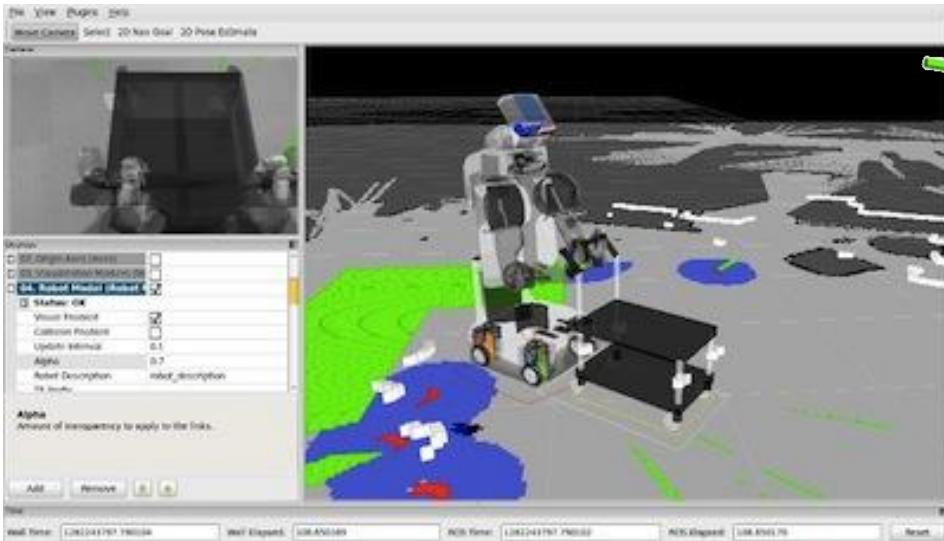
ROS 2 works on Linux, Windows, MacOS



Micro-ROS works on embedded systems like Arduino and Raspberry Pi

ROS

- Standard Message Definitions for Robots
- Robot Geometry Library
- Robot Description Language
- Visualization and Diagnostics
- Pose Estimation
- Localization, Mapping, and Navigation





Bin
picking



Box
loading

Package
delivery



Surgery



Robots Everywhere!



Mining



Farming

Room delivery



Credits: Amazon; Autonomous Solutions; Boston Dynamics; Fanuc; UC Berkeley; Savioke

Software Development

- *Source Code Management (SCM)*: version control, issue tracking, concurrent development
 - Version control supports file versioning, branching parallel versions for later merging, tagged releases
 - Examples: Concurrent Versioning System (CVS), Git, Mercurial
 - Host sites enable web-based collaboration
 - Examples: SourceForge, GitHub (ROS), BitBucket
- *Continuous Integration (CI)*: source code merged and built continually, possibly several times daily
 - You define build rules and tests to run; code is built and tested automatically; results are posted
 - Often offered as a feature in hosted sites
 - Examples: Jenkins, Travis (ROS *Build Farm*)



Bitbucket



Jenkins



Travis CI

Software Development

- *Virtualization*: virtual machines give you a complete computer system, emulated on a (much faster) computer
 - *Virtual Machines* are the full computer: hardware, operating system, and system software
 - *Containers* share the same hardware and operating system, but give you your own copy of resources such as system libraries and the root file system
 - Examples: Unix chroot, VMWare, VirtualBox, Docker
- *Cloud Computing*: your software (VM, Container, ...) runs on a server somewhere externally (e.g., a data center on the Internet)
 - *Edge Computing* runs some of the computation close to the source, such as on servers in your facility
 - *Fog Computing* is similar, for Internet of things (IoT)
 - Examples: Amazon Web Services, Microsoft Azure



Pair Programming

- *Pair programming*: assistants within integrated development environments (IDEs) that help programmers by autocompleting source code
- Artificial intelligence (AI) programs trained on huge bodies of source code form the foundation; IDEs determine the intent of a sequence of source code and suggest the rest
- GitHub's Copilot is a prominent example, using OpenAI's Codex model
- Microsoft's Intellisense and Intelllicode are similar
- Somewhat controversial: trained on open source that has a variety of licenses; does an auto-complete require the license of what was used to (mostly) train it * ?



* spectrum.ieee.org/ai-code-generation-ownership

sentiments.ts

write_sql.go

parse_expenses.py

addresses.rb

```
1 #!/usr/bin/env ts-node
2
3 import { fetch } from "fetch-h2";
4
5 // Determine whether the sentiment of text is positive
6 // Use a web service
7 async function isPositive(text: string): Promise<boolean> {
8     const response = await fetch(`http://text-processing.com/api/sentiment/`, {
9         method: "POST",
10        body: `text=${text}`,
11        headers: {
12            "Content-Type": "application/x-www-form-urlencoded",
13        },
14    });
15    const json = await response.json();
16    return json.label === "pos";
17}
```

Copilot

You enter your intent using a comment;
Copilot fills out the body

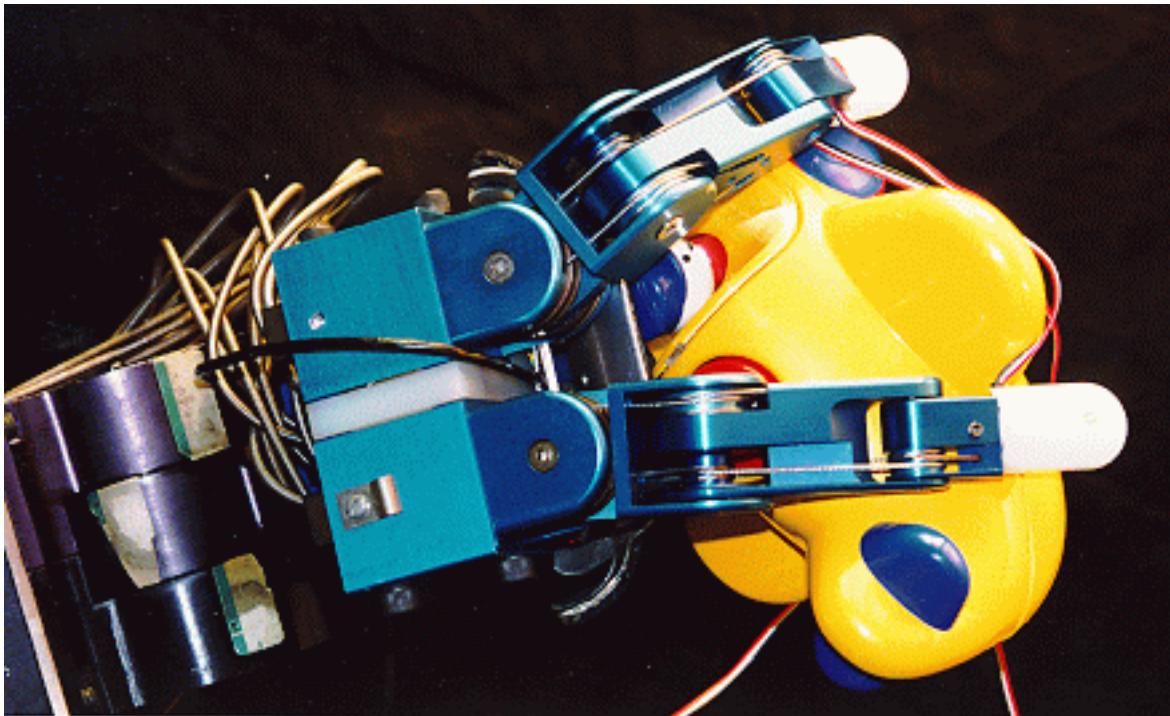
DEXTEROUS MANIPULATION



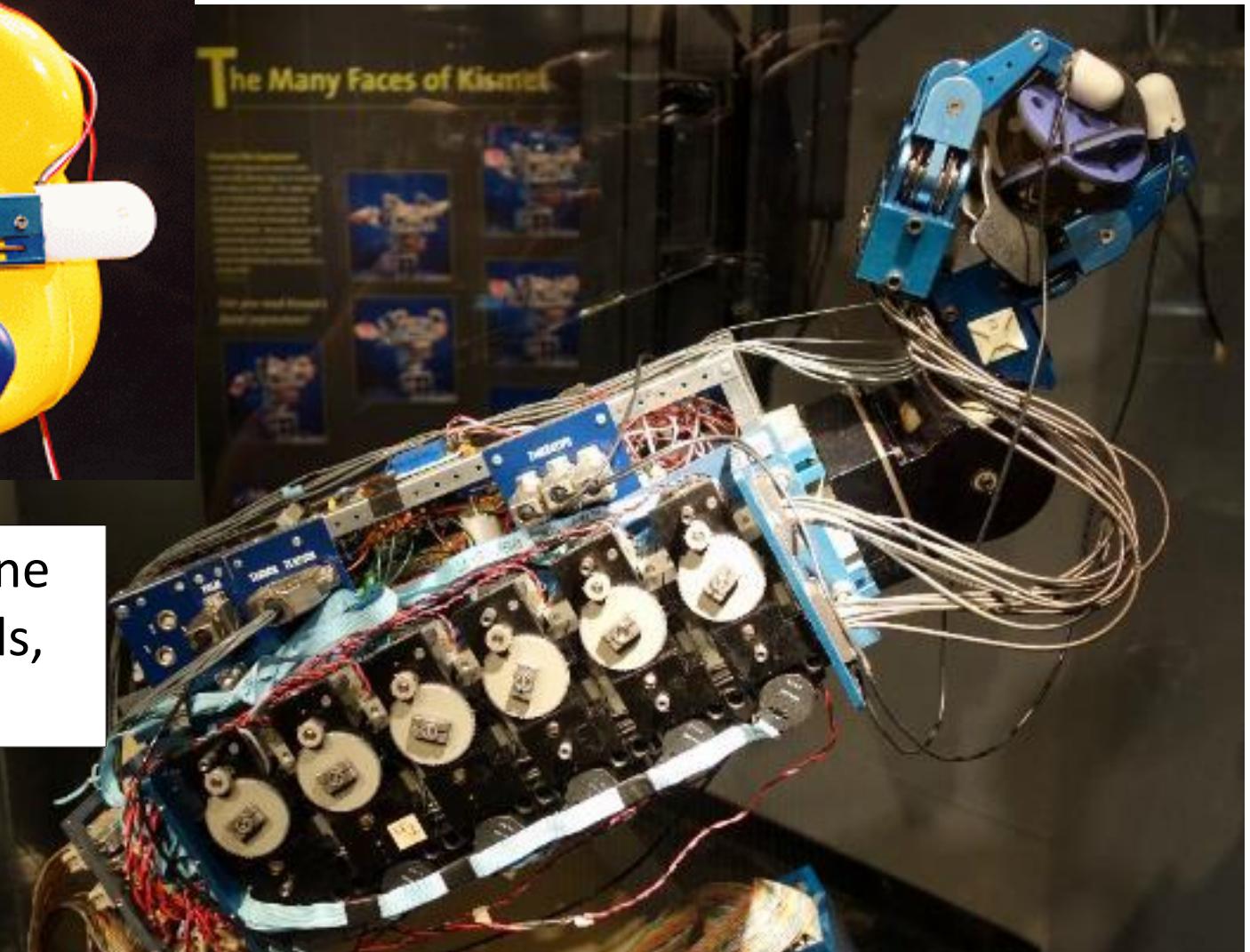
Traditional jaw- and vacuum-type grippers are common today, with continued innovation



Credits: ABT Robotic; Empire; HTE Technologies; Materilise; Schunk



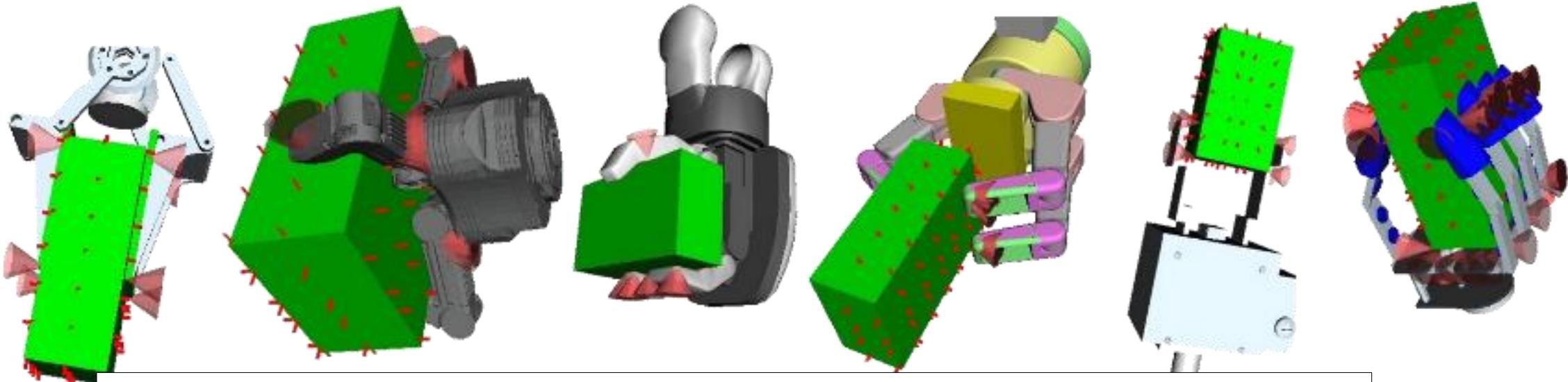
The Stanford/JPL Hand, c. 1985, one of the first anthropomorphic hands, actuated by cables



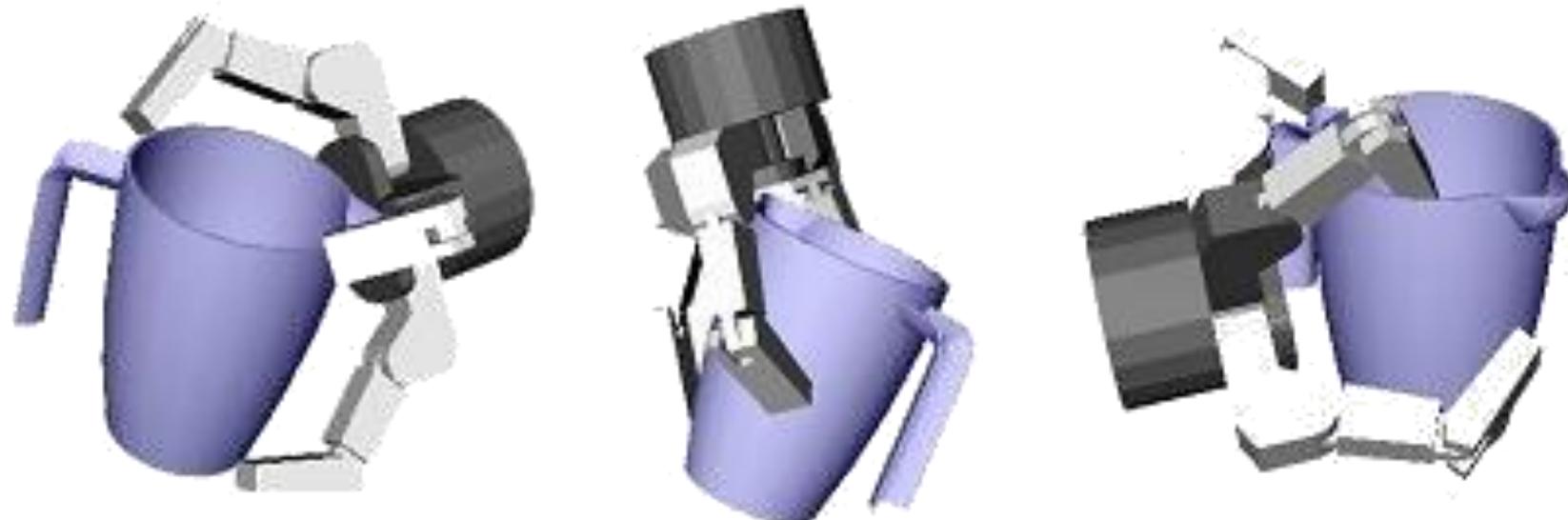


Dexterous hands today:
active research, some
commercially available,
including tactile sensing

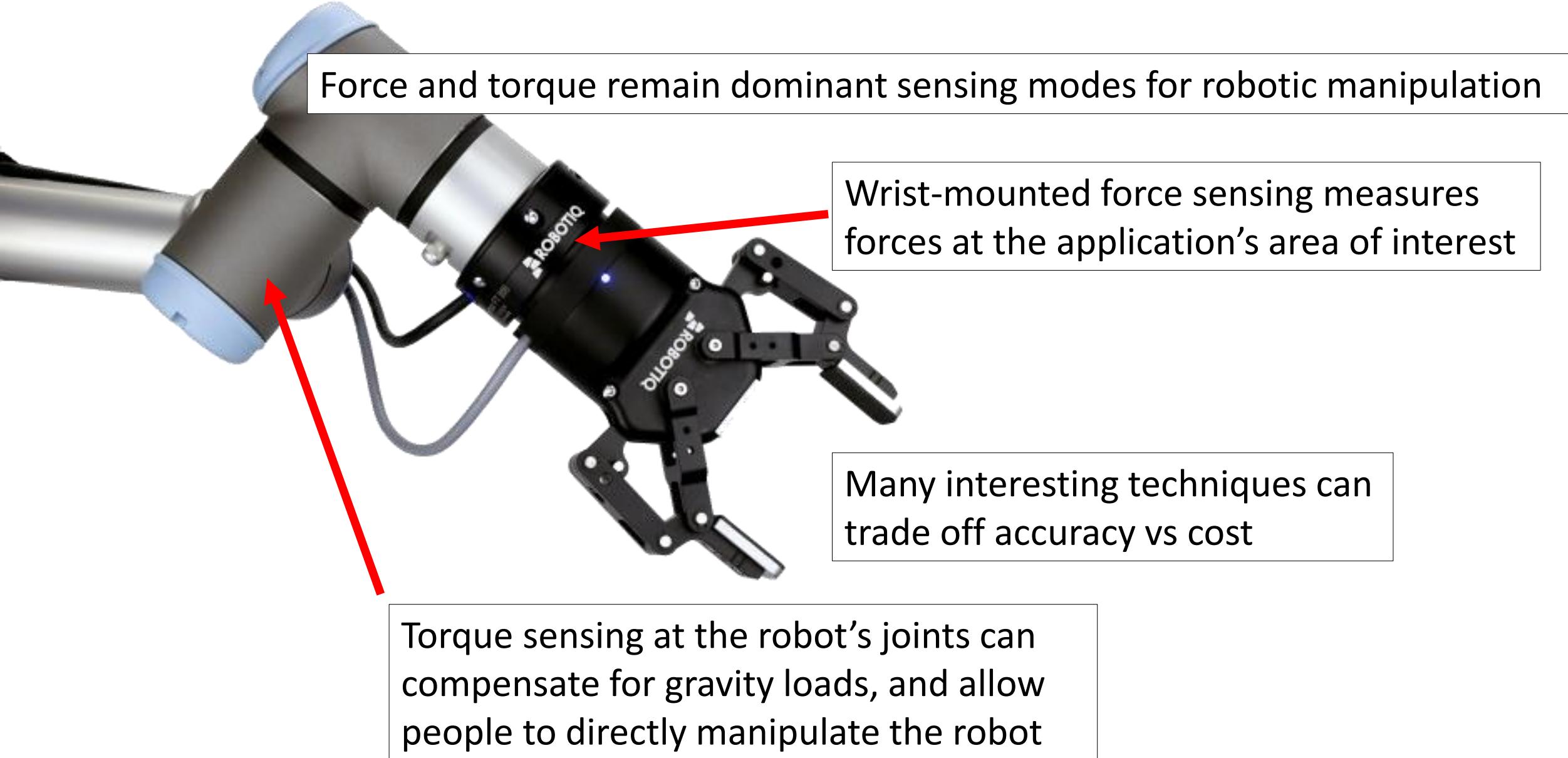
Credits: Barrett; Empire; Robotiq; Schunk; Shadow; SynTouch; U of Washington



Where to put the fingers? Grasp planning is an active research area



Credits: OpenRAVE; Rosen Diankov



Credits: Robotiq; Universal

Kitting Demo

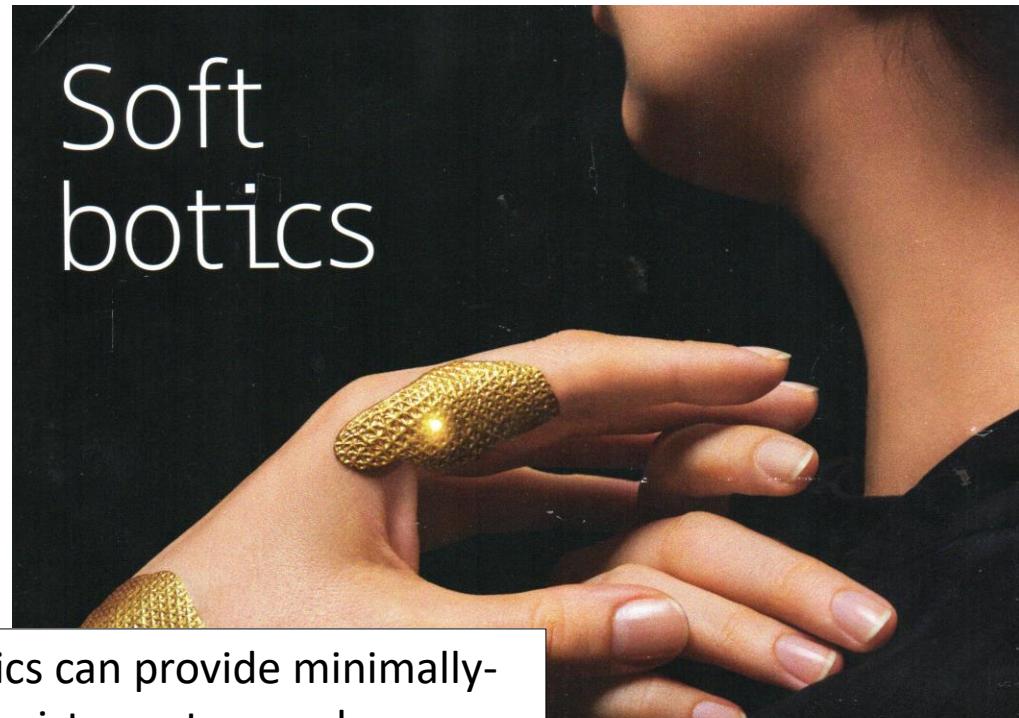
Yaskawa Motoman SDA10 & Robotiq Adaptive Gripper



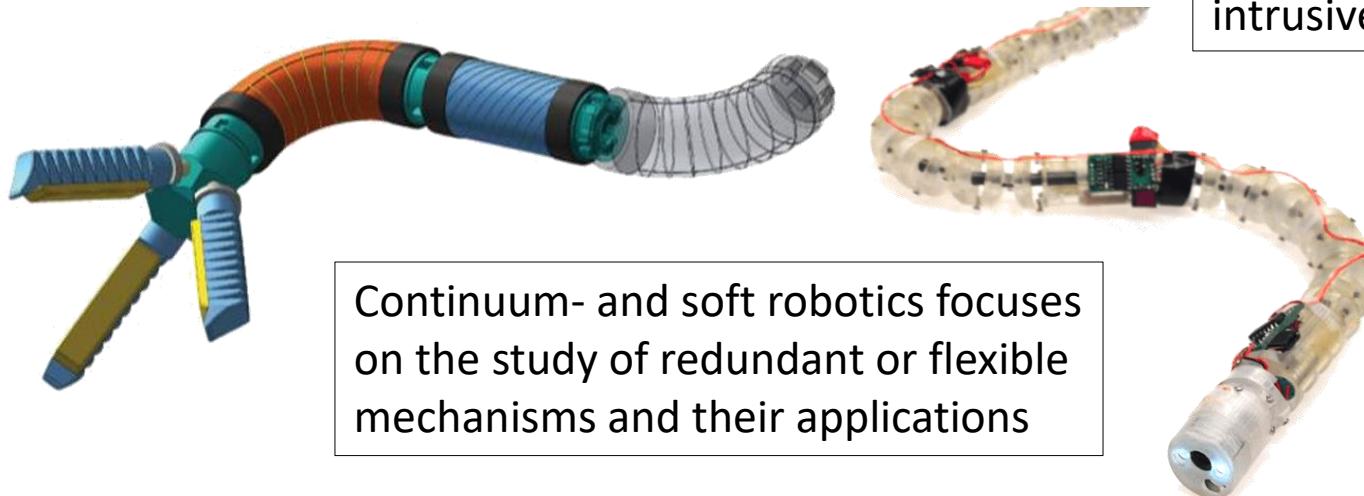
Soft robotics is an emerging technology



“Soft robot tentacle is
scarily effective”



Soft robotics can provide minimally-intrusive assistance to people



Continuum- and soft robotics focuses
on the study of redundant or flexible
mechanisms and their applications

Credits: Electronics Weekly, Carnegie-Mellon,
Georgia Tech, MIT, Shenyang University of Technology

BRINGING ROBOTICS INTO EVERYDAY LIFE.

An engineering revolution is underway in soft machines and robots to assist people in new ways through next-generation systems.

In Softbotics, our vision is to create a step change in moving robotics from large industrial scale to smaller human scale and thereby entering households, workplaces, hospitals and aspects of the environment to provide new solutions.

One day people around the globe will be touched by the enhanced performance these technologies will offer.

Learn more about partnering with us: softbotics.org.

Carnegie Mellon University
College of Engineering

MOBILITY

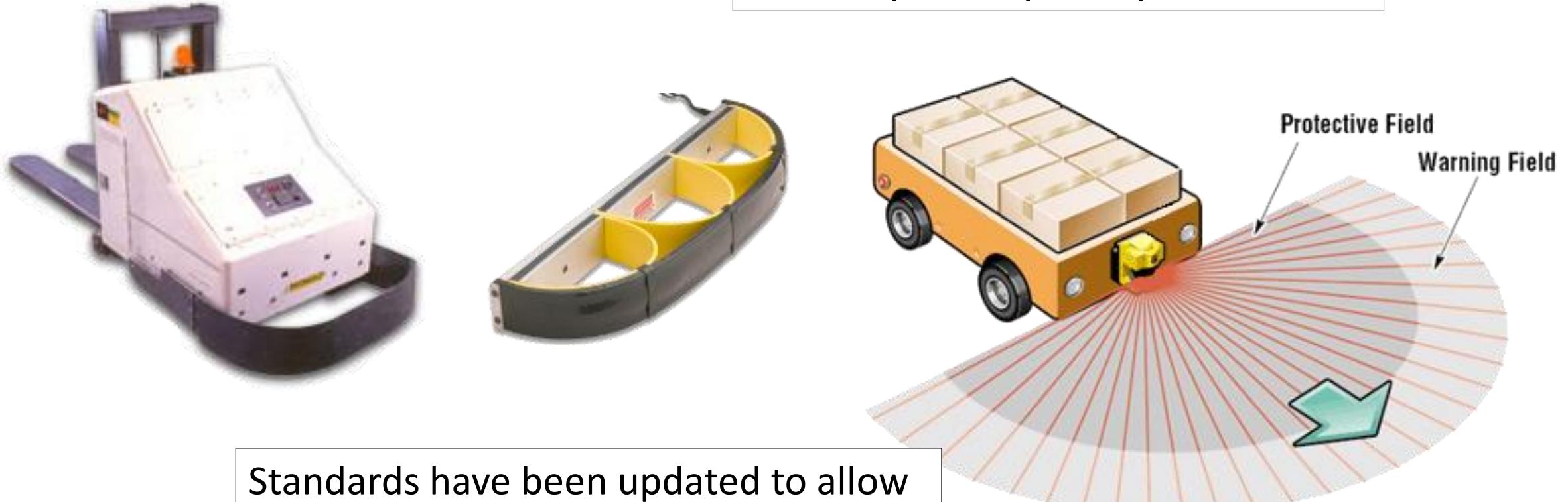
Traditional automated guided vehicles (AGVs) perform well in structured environments, with many varieties



Infrastructure modifications may be needed: embedded guide wires, magnetic paint, reflective beacons, QR tags, elevator controller integration

Safety is always a concern

Contact bumpers are common, and were required by safety standards



Standards have been updated to allow non-contact scanning sensors

Credits: AGV International; CoreCon; Tapeswitch

autonomous vehicles (self-driving cars)



2007



2018

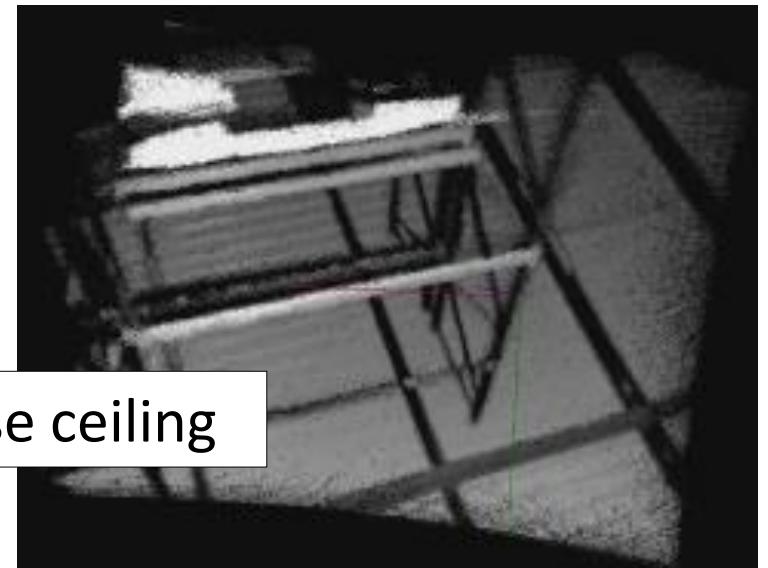


2022

cameras + lidar + GPS + maps

Infrastructure-free installations are the goal: wireless communication, on-board localization and mapping

SLAM using images of the warehouse ceiling

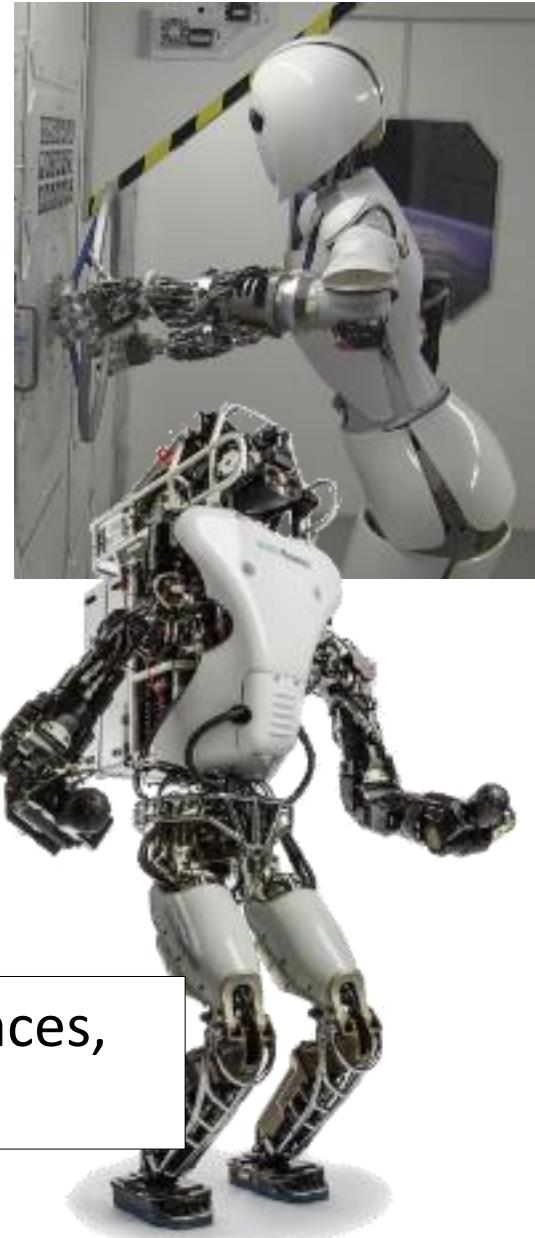


Credits: Stanford U/MDV-Mohr; Waymo; Tesla

Mobile manipulation is an active R&D topic



The 2015 Amazon
Picking Challenge posed
a practical problem



Full human-like abilities for walking on uneven surfaces,
climbing steps, and opening doors is on the horizon

Credits: Boston Dynamics; Kuka; TU Berlin/RBO; U of Bremen/DFKI

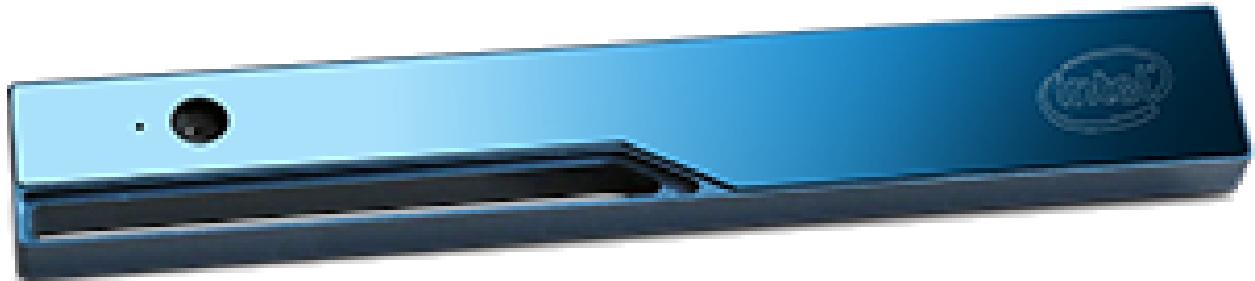


Boston Dynamics



<https://www.youtube.com/watch?v=tF4DML7FIWk>

SENSING AND PERCEPTION



Consumer-grade sensors are being used in serious research, and in industrial applications



Credits: ASUS; Intel; Microsoft; Occipital

Lidar provides hi-resolution 2D and 3D range images directly

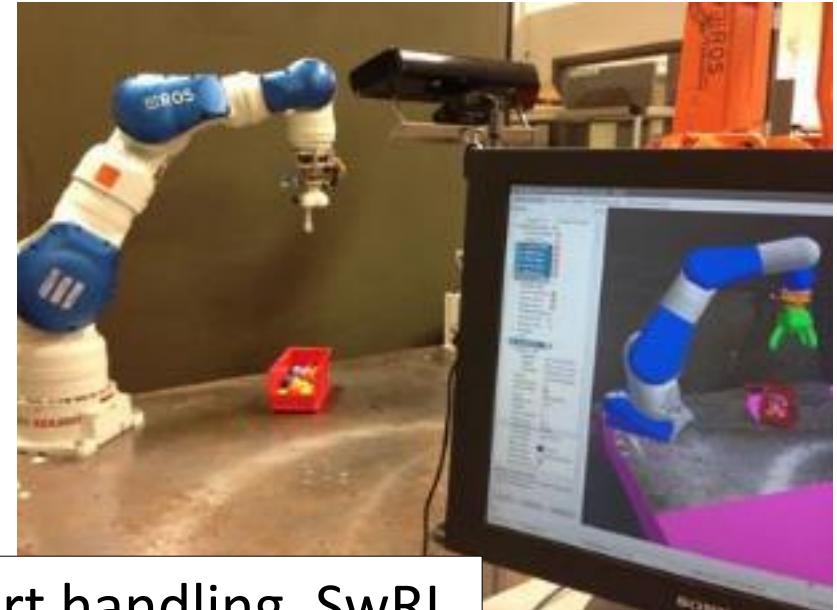


3D pose measurement is common, driven by the motion capture market

Credits: Cognex; Hokuyo; Optitrack; SICK; Velodyne; Vicon



Robot teaching, U of Tarapacá



Robot part handling, SwRI



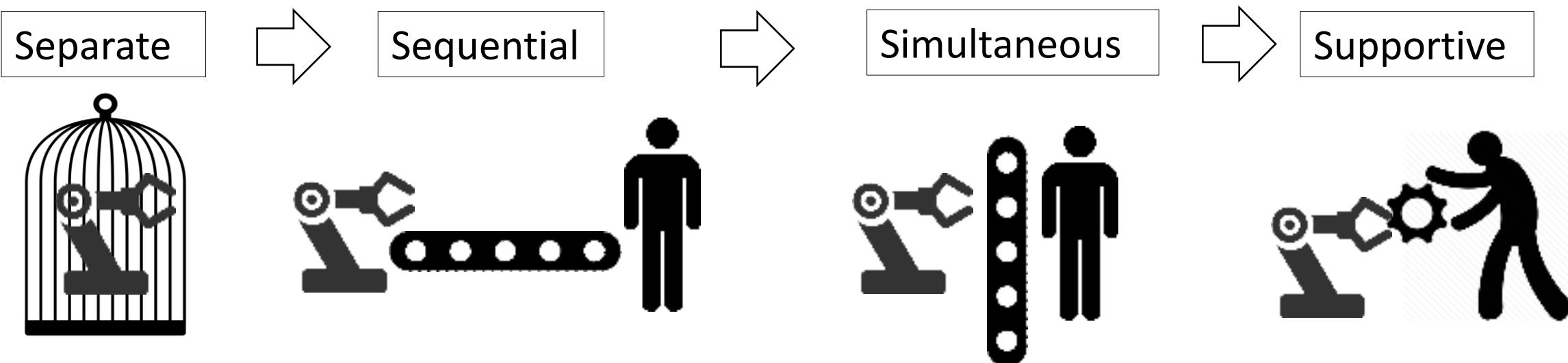
Box depalletizing, Motoman

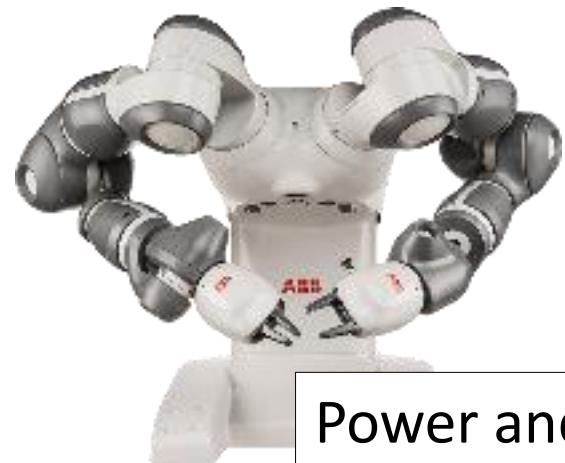
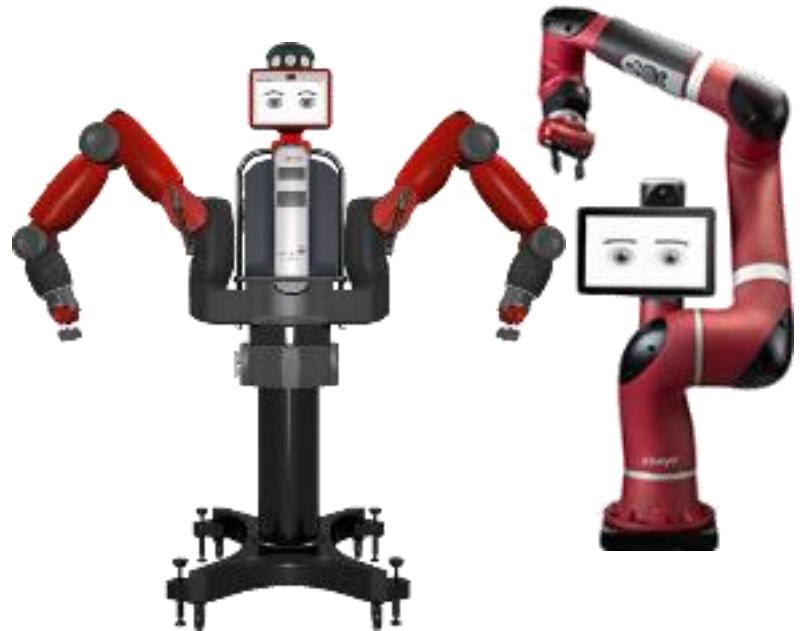


Chicken fileting, SINTEF

COLLABORATIVE ROBOTICS

- Interactive activity involving the robot and a person
- Independent motion of the robot and person
- The robot and person share a workspace at the same time
- Physical contact between the robot and a person, directly or indirectly



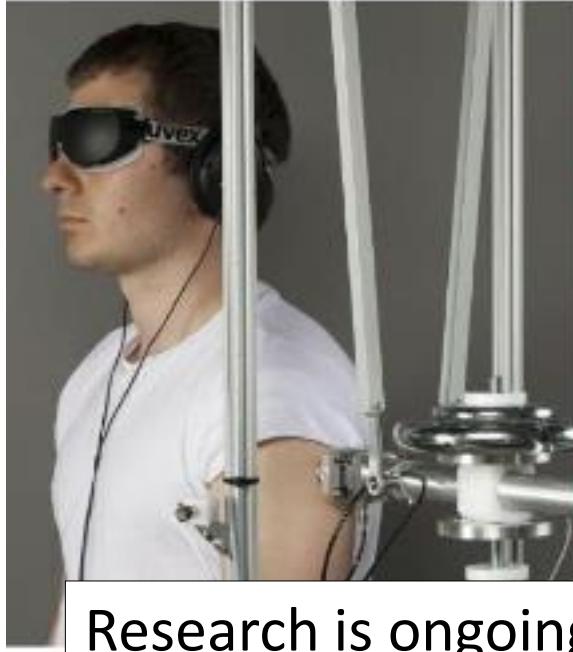


Speed and separation monitoring systems reduce the robot speed when people are close

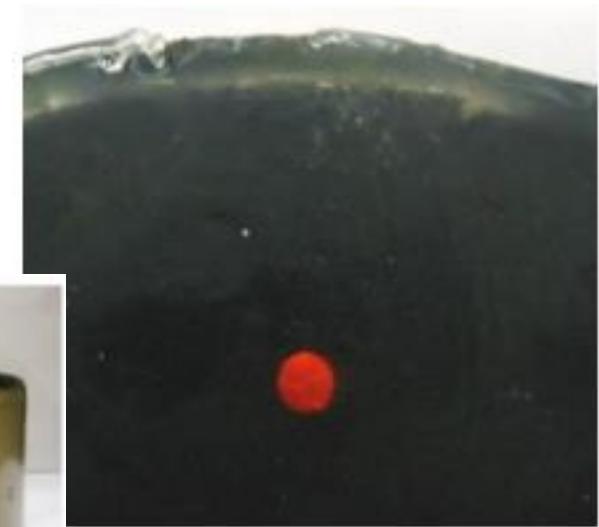
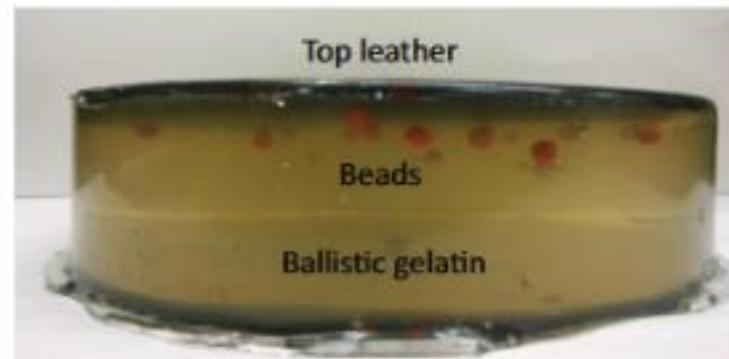
Credits: ABB; F&P; Fanuc; Kuka; Rethink; Universal



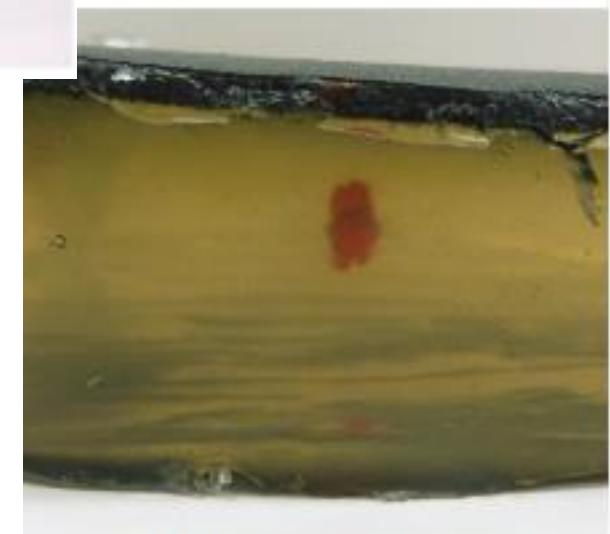
How badly can robots hurt people?



- Initial pre-phase of collision tests
- Five subjects
 - 2 female, 3 male
- Five body locations
 - Thorax
 - Shoulder
 - Upper arm
 - Lower arm
 - Hand
- Different impactor geometries
- Different impact masses



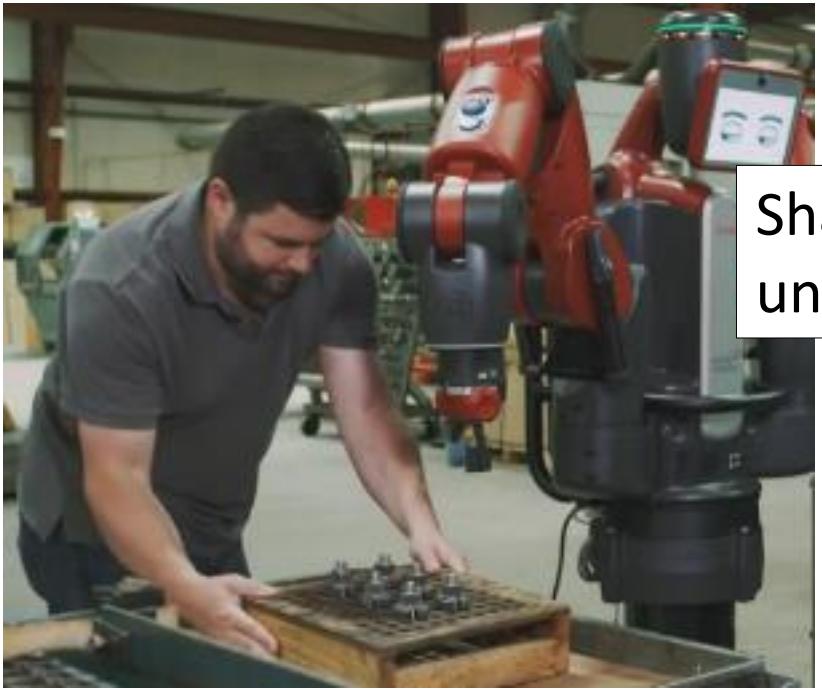
(a) Before impact testing



(b) After impact testing

Credits: Fraunhofer IFF/Magdeburg; NIST

Research is ongoing to quantify the “Biomechanical Limit Criteria” using human subjects



Sharing a kit
unloading task



An interactive CNC
grinding application

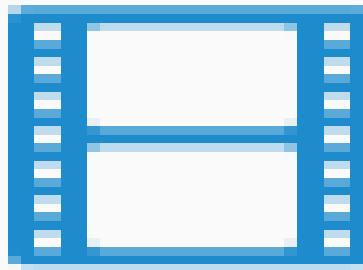


Working together to
prepare samples

Hand guiding lets people
move the robot directly

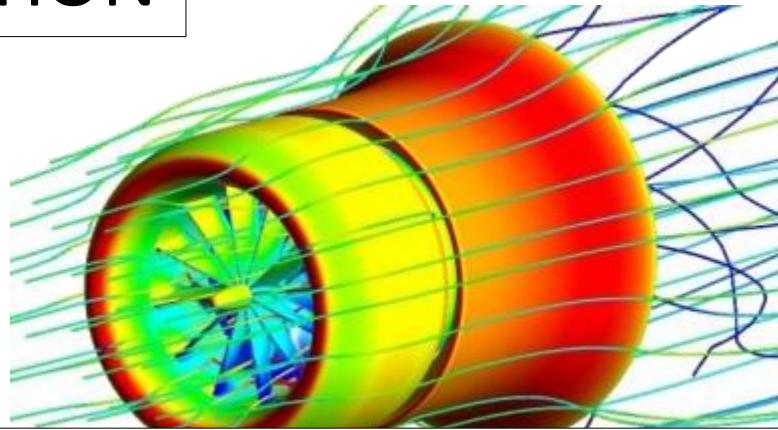
Credits: ABB; Kuka; Rethink; Universal





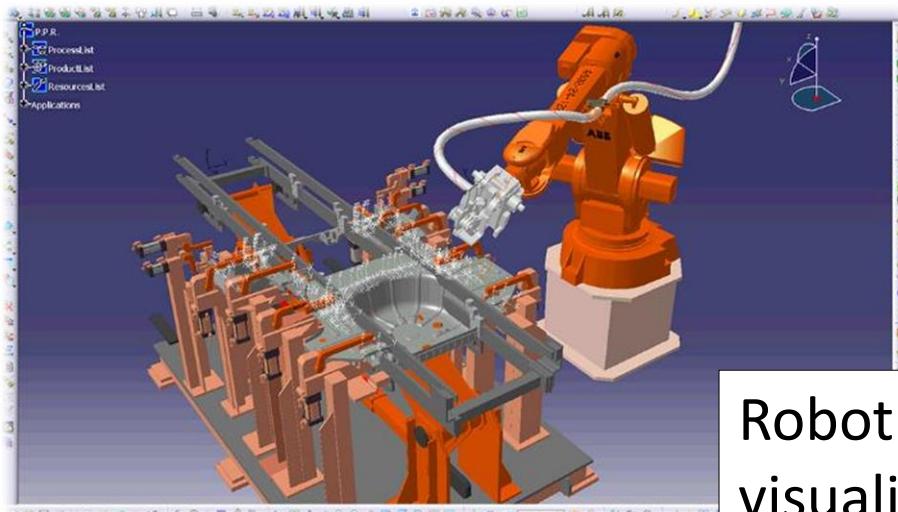
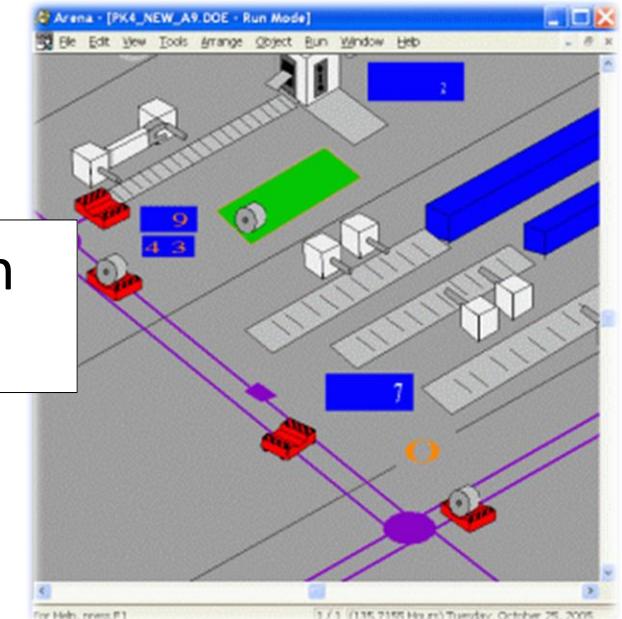
Robots with joint torque sensing can be hand guided

SIMULATION



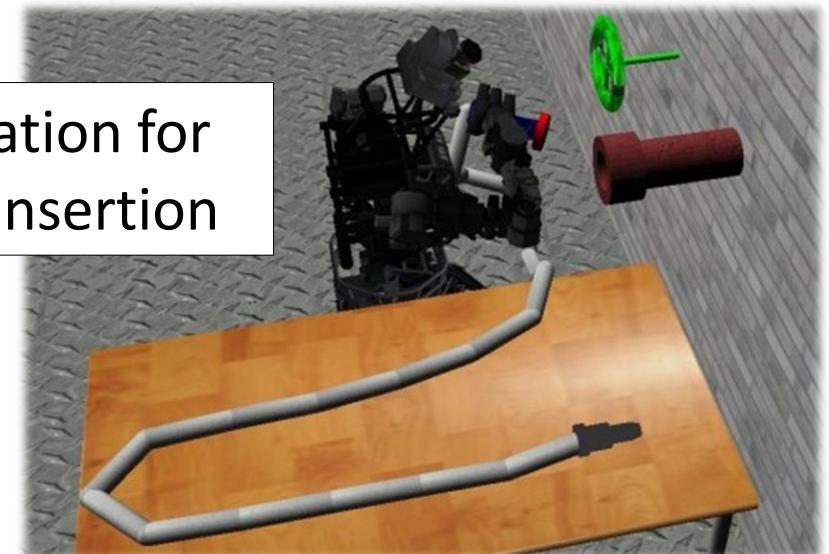
Computational fluid dynamics + heat transfer

Discrete event simulation
for estimating cycle time



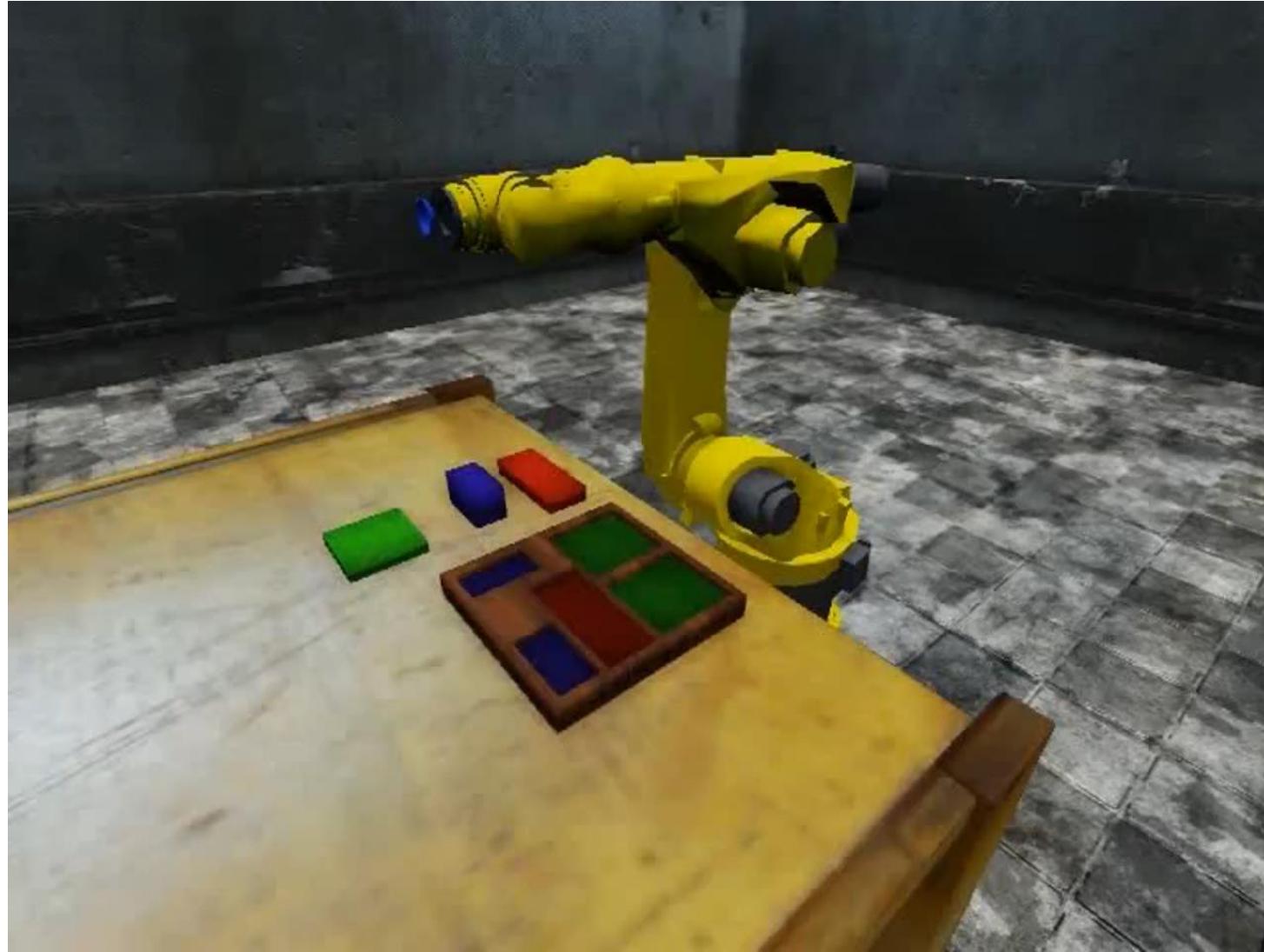
Robot workcell
visualization

Physics simulation for
robotic hose insertion



Credits: ANSYS; Arena; DARPA; Delmia

You can “cheat” in simulation to work around unmodeled effects



Objects can be made to snap to the robot, or magically appear

Physics simulations use today's high-performance graphical processing units (GPUs)



GPU arrays can provide scalable simulation power

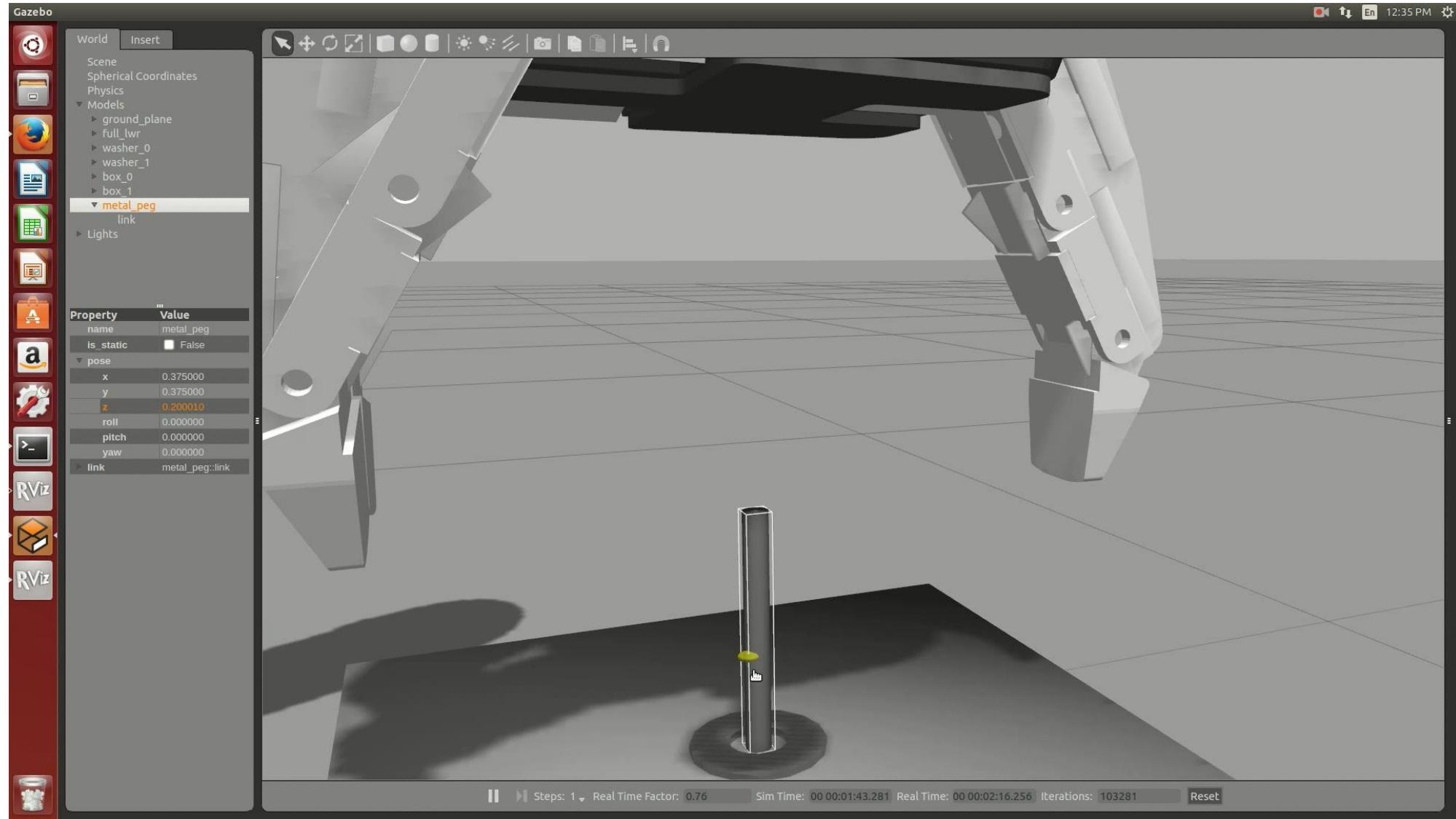


Software tools like CUDA simplify tedious programming

and fill rooms



Credits: Elsa; HPC Paris; nVIDIA

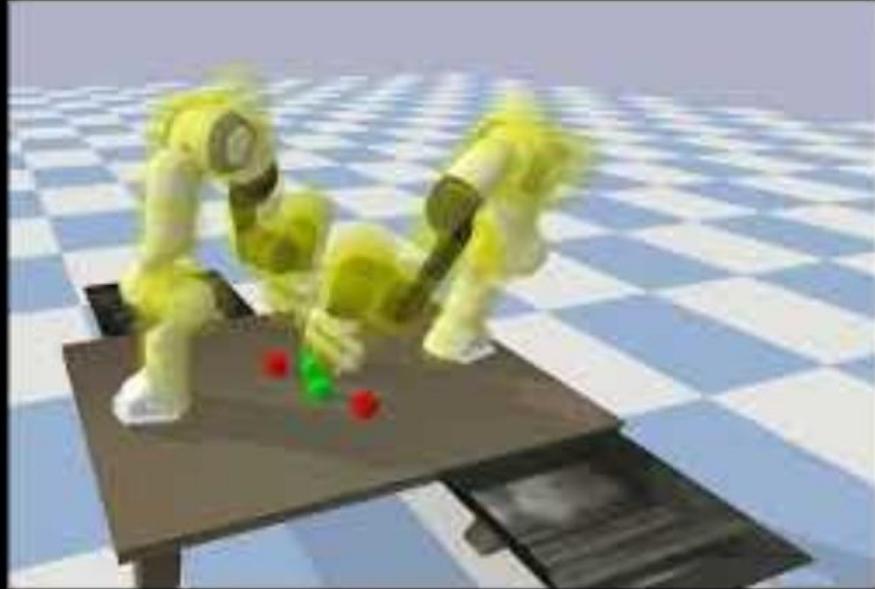


Physics simulation in ROS and Gazebo showing robot and object interactions

PLANNING

Planning robot motion in changing environments
is becoming more prevalent

Two-Robot Pick and Place Scenario – RF-CV (ours)

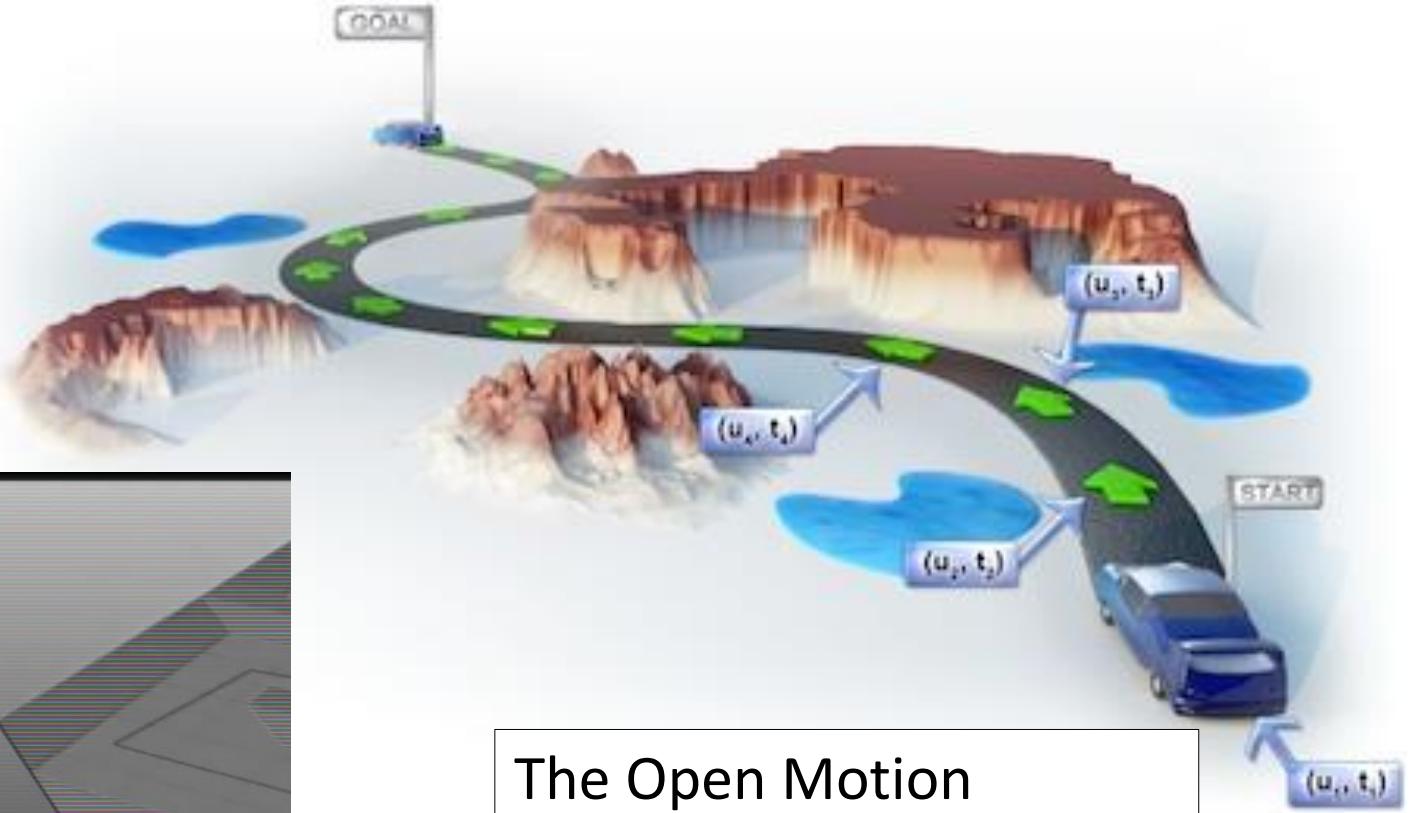
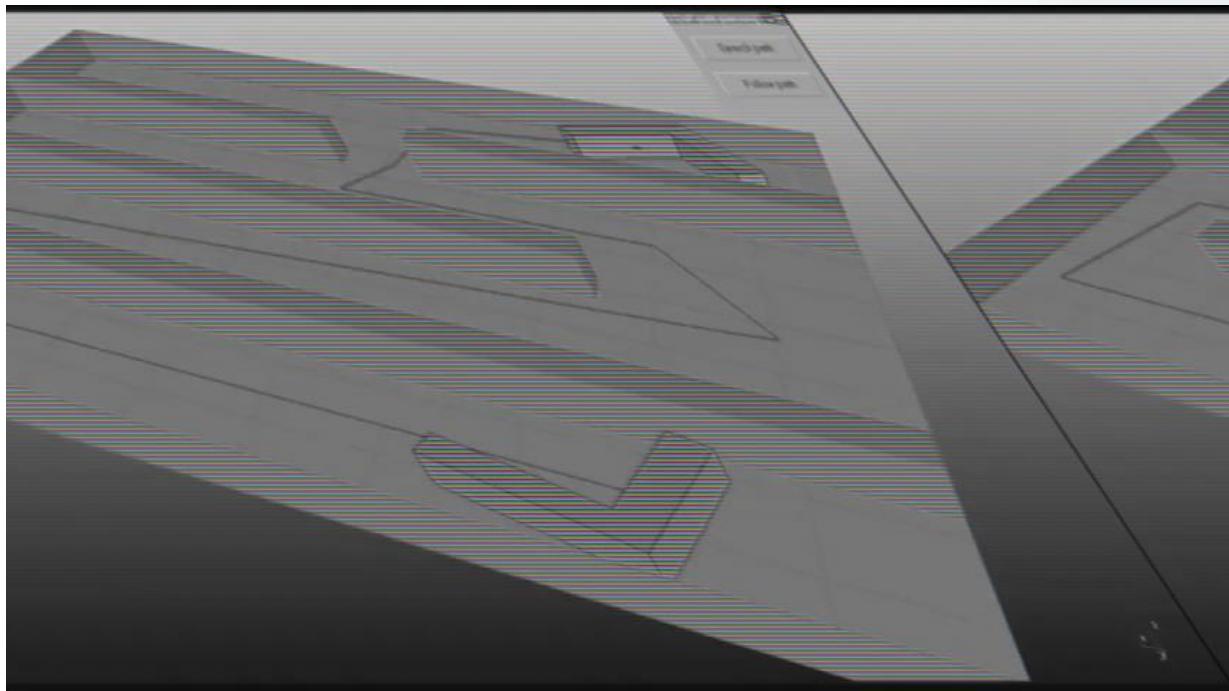


Extra degrees of freedom allow the selection of configurations that avoid collisions

<https://youtu.be/jaJBrSecDcM>

Rollout Fabrics + Goal Estimation + Deadlock Resolution does not require communication of the current goal.

ROS planning “plug-ins” can be used for various applications



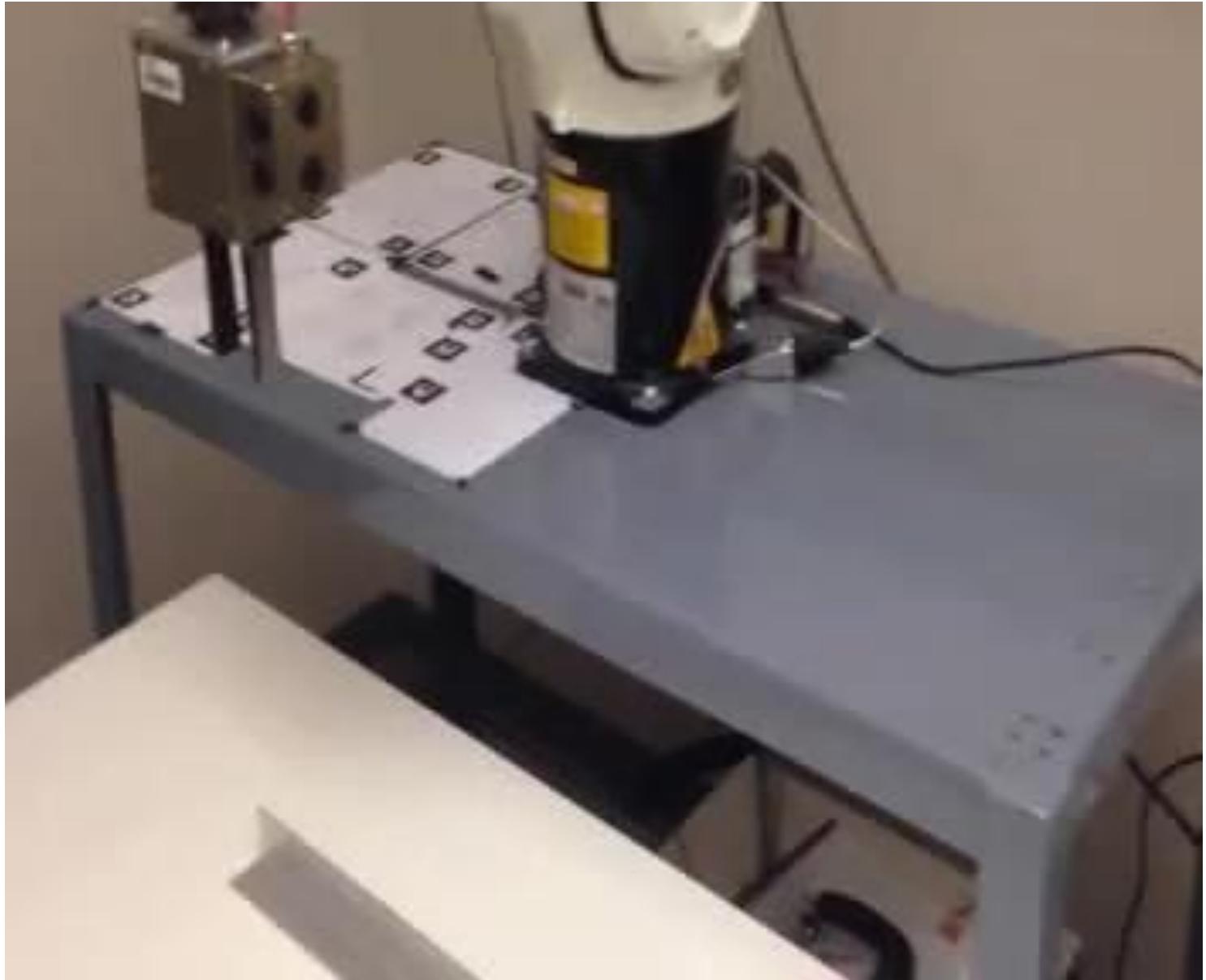
The Open Motion
Planning Library (OMPL)

Path planning visualized in Gazebo

Credits: Timotei Robotics; Rice University

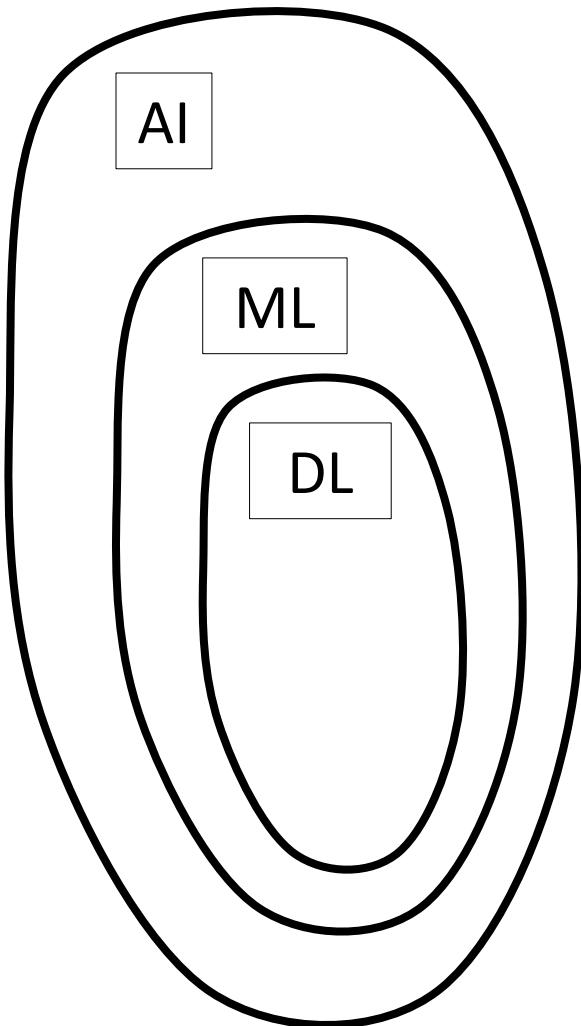
Knowledge-based planning uses information about actions and consequences to find unexpected solutions to problems

The search spaces can be extremely large; heuristics can be used to prune out probable dead ends, focus on promising leads



Credits: Georgia Tech

ARTIFICIAL INTELLIGENCE



Artificial Intelligence: the science and engineering of making intelligent machines

- Rules engines, expert systems, symbolic computing

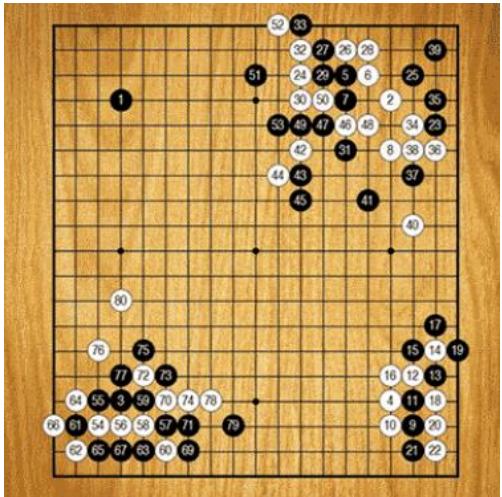
Machine Learning: the field of study that gives computers the ability to learn without being explicitly programmed

- Neural networks, objective function optimization

Deep Learning: neural networks with many layers

- Unsupervised learning: That thing is like this other thing.
- Supervised learning: That thing is a “double bacon cheese burger”. Labeling can be laborious, often manual.
- Reinforcement learning: Eat that thing because it tastes good and will keep you alive longer.

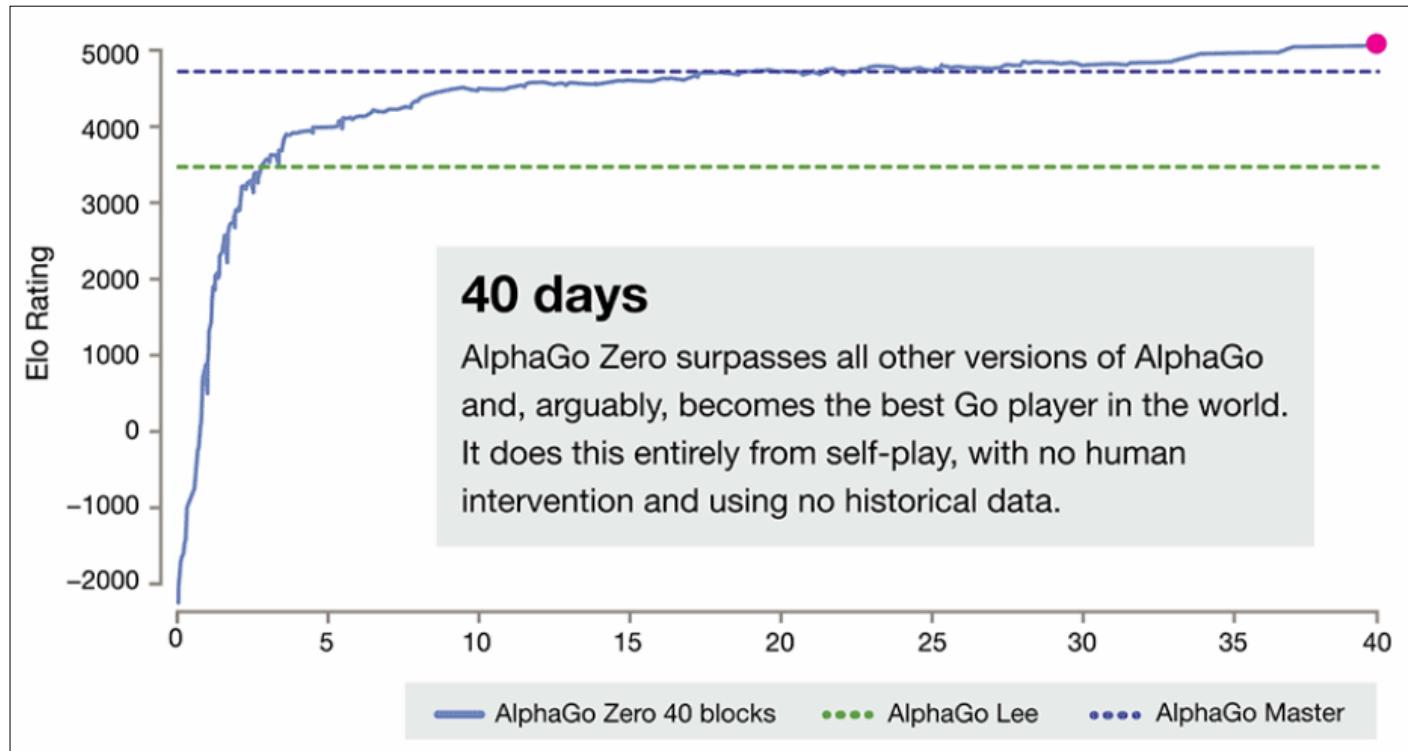
AlphaGo Zero: Deep reinforcement learning from scratch



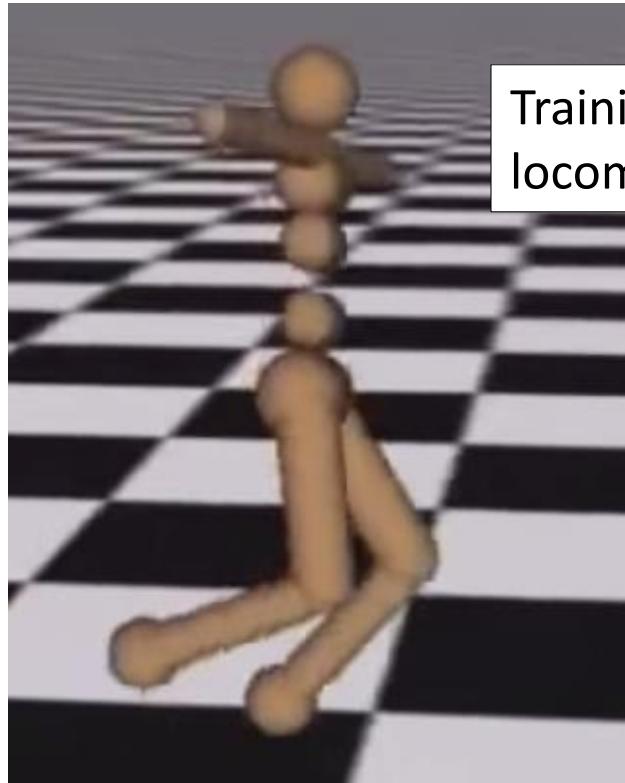
Game of Go: place stones on a 19x19 grid to surround more of your opponent's stones

Much more complex than chess; at least 10^{170} board positions

- AlphaGo was the first computer program to beat the world champion, in March 2016
- AlphaGo trained on thousands of professional games
- AlphaGo **Zero** learns to play by playing games against itself, starting from completely random play



AI and DRL for Robotics



Training in simulation:
locomotion; robo-sumo

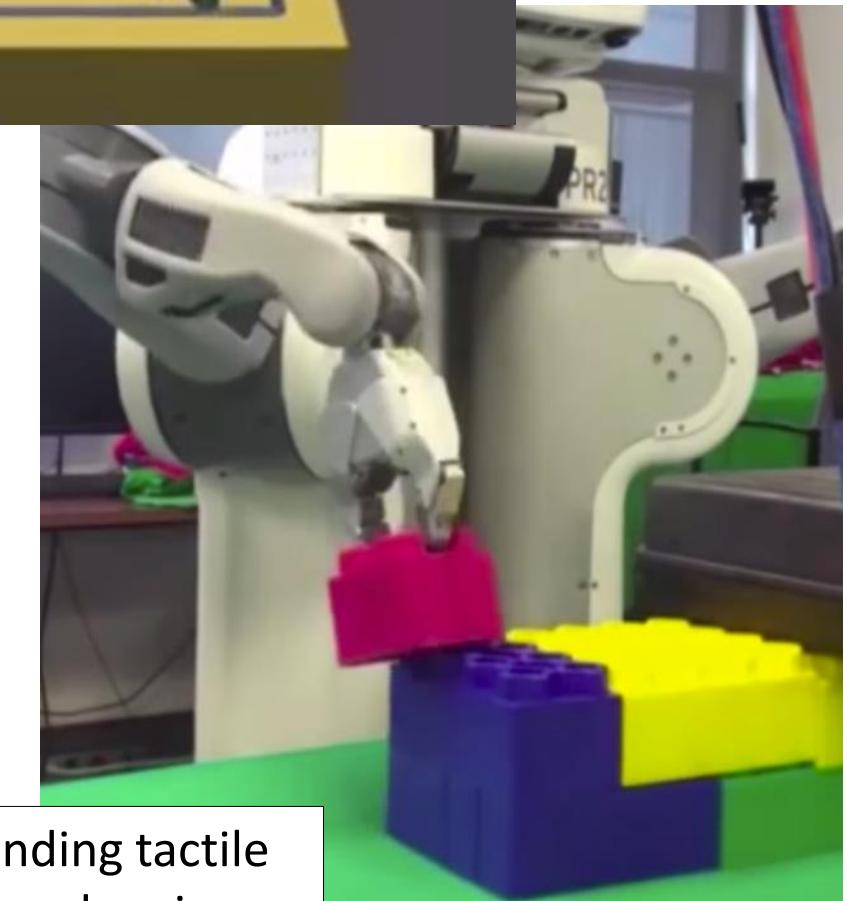


Control of difficult-to-model
systems: NASA's Super Ball Bot



Credits: Prof. Pieter Abbeel et al.

Understanding tactile
sensing for planning



ChatGPT – an AI Chatbot

- A *chatbot* is a computer program that uses natural language to converse with people
- ChatGPT uses the GPT-3 large-language model as the foundation, and has been applied to many non-chat uses:
 - writing and debugging computer programs
 - composing artwork, music, poetry, and student essays
 - answering test questions



2023-2-20

ChatGPT for Robotics: Design Principles and Model Abilities

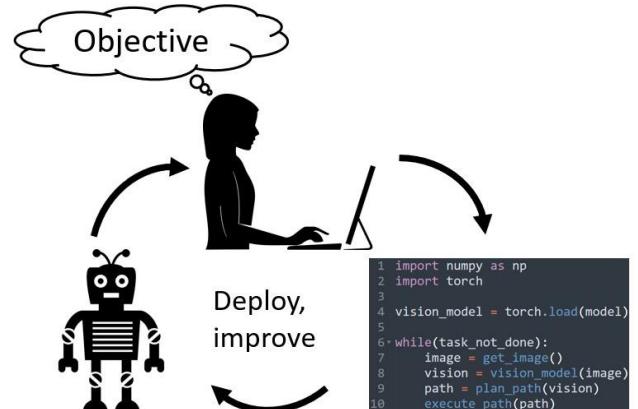
Sai Vemprala*, Rogerio Bonatti*, Arthur Bucker, and Ashish Kapoor
Microsoft Autonomous Systems and Robotics Research

This paper presents an experimental study regarding the use of OpenAI's ChatGPT [1] for robotics applications. We outline a strategy that combines design principles for prompt engineering and the creation of a high-level function library which allows ChatGPT to adapt to different robotics tasks, simulators, and form factors. We focus our evaluations on the effectiveness of different prompt engineering techniques and dialog strategies towards the execution of various types of robotics tasks. We explore ChatGPT's ability to use free-form dialog, parse XML tags, and to synthesize code, in addition to the use of task-specific prompting functions and closed-loop reasoning through dialogues. Our study encompasses a range of tasks within the robotics domain, from basic logical, geometrical, and mathematical reasoning all the way to complex domains such as aerial navigation, manipulation, and embodied agents. We show that ChatGPT can be effective at solving several of such tasks, while allowing users to interact with it primarily via natural language instructions. In addition to these studies, we introduce an open-sourced research tool called *PromptCraft*, which contains a platform where researchers can collaboratively upload and vote on examples of good prompting schemes for robotics applications, as well as a sample robotics simulator with ChatGPT integration, making it easier for users to get started with using ChatGPT for robotics.

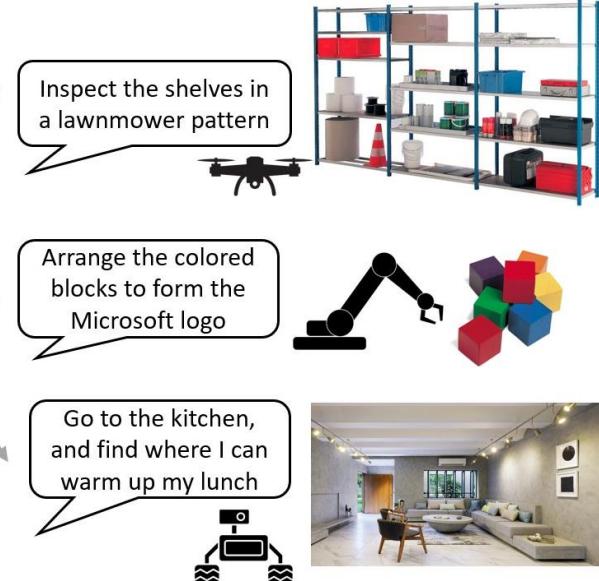
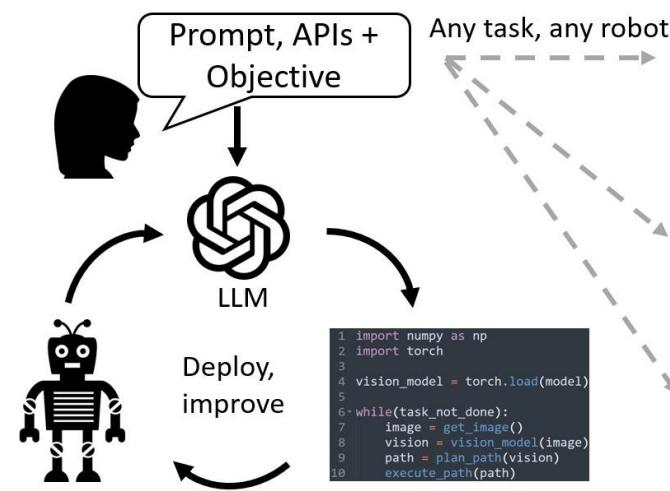
Videos and blog: aka.ms/ChatGPT-Robotics

PromptCraft, AirSim-ChatGPT code: <https://github.com/microsoft/PromptCraft-Robotics>

Robotics today: engineer *in the loop*

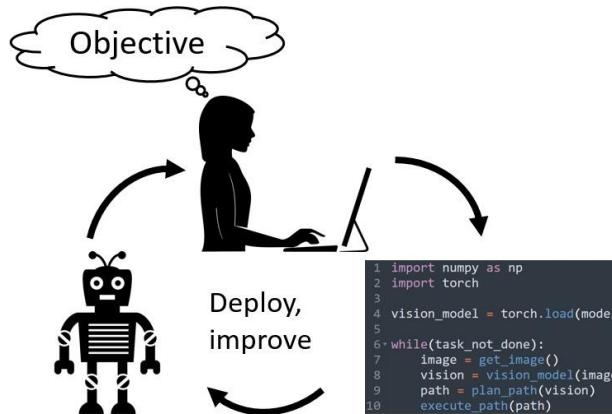


Goal with ChatGPT: user *on the loop*

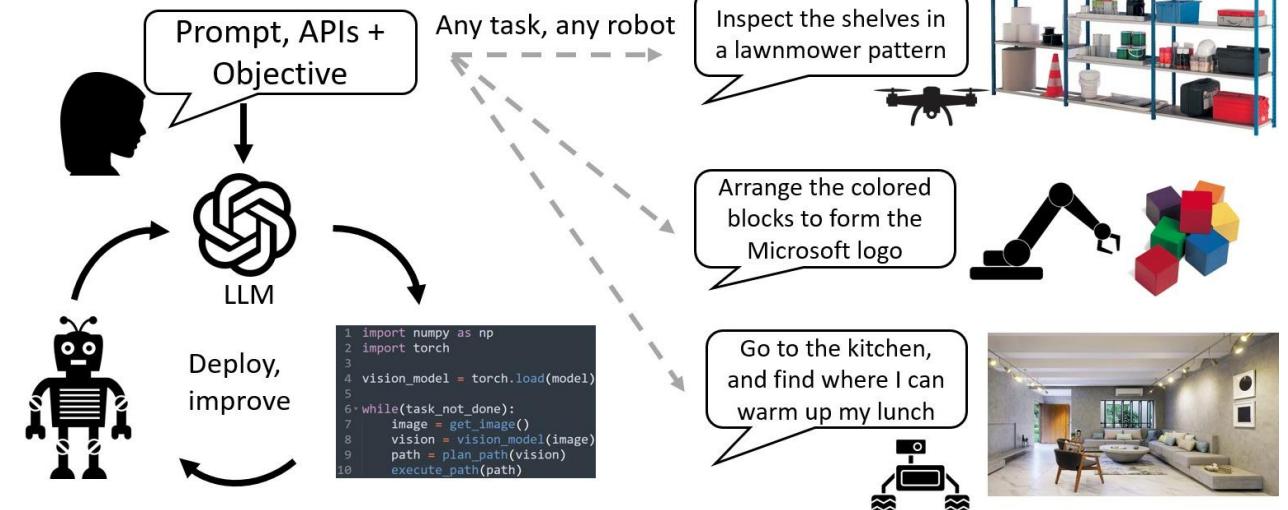


ChatGPT for Robotics

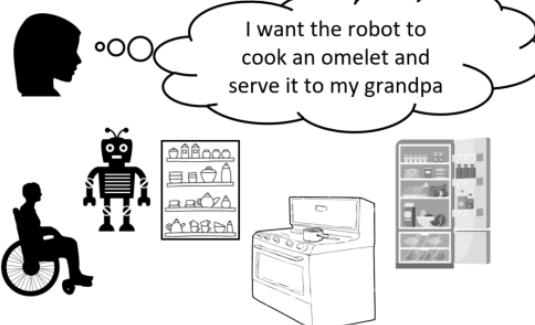
Robotics today: engineer *in the loop*



Goal with ChatGPT: user *on the loop*



① Define a task-relevant robot API library*

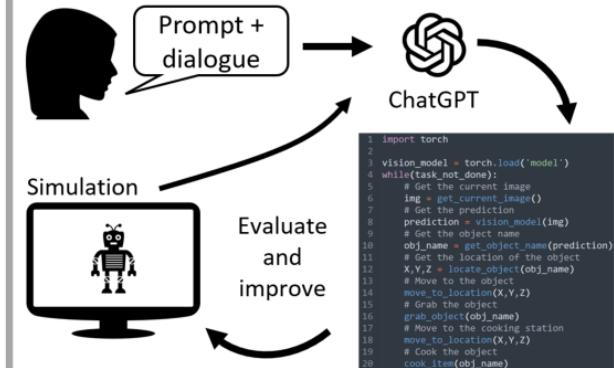


*APIs should be easily implementable on the robot and have descriptive text names for the LLM. They can be chained together to form more complex functions.

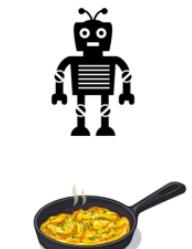
② Build prompt following engineering principles

Consider you are a home assistant robot. Your goal is to prepare an omelet for an elderly person. You are equipped with functions:
`locate_object(obj_name)`: returns a X,Y,Z tuple representing the location of the desired object defined by string "obj_name";
`move_to_location(X,Y,Z)`: moves the robot's hands to a specific X,Y,Z location in space. Returns nothing;
`cook_item(obj_name)`: cooks a particular item defined by "obj_name". Returns nothing;
`grab_object(obj_name)`: picks a particular object defined by "obj_name". Returns nothing;
Output python code with the sequence of steps that achieves your objective.

③ User *on the loop*: iterate on solution quality and safety



④ Execute!

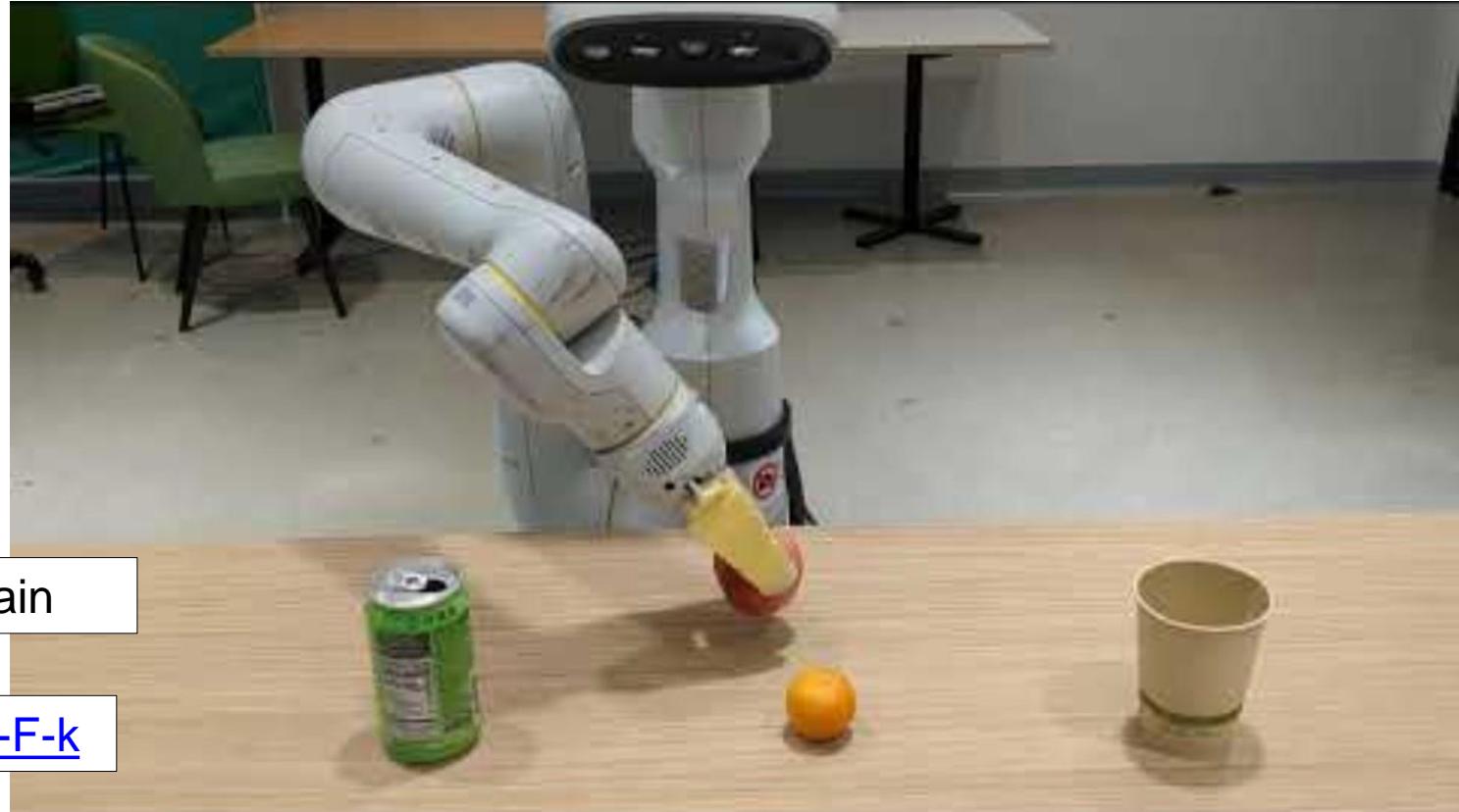


Addressing the Big Data training set problem for robotics

Unfortunately, the highly successful generative AI formula doesn't easily carry over into robotics because the Internet is not full of robotic-interaction data in the same way that it's full of text and images

In 2023, 32 robotics laboratories in North America, Europe, and Asia started the RT-X Project to assemble data, resources, and code to make general-purpose robots a reality

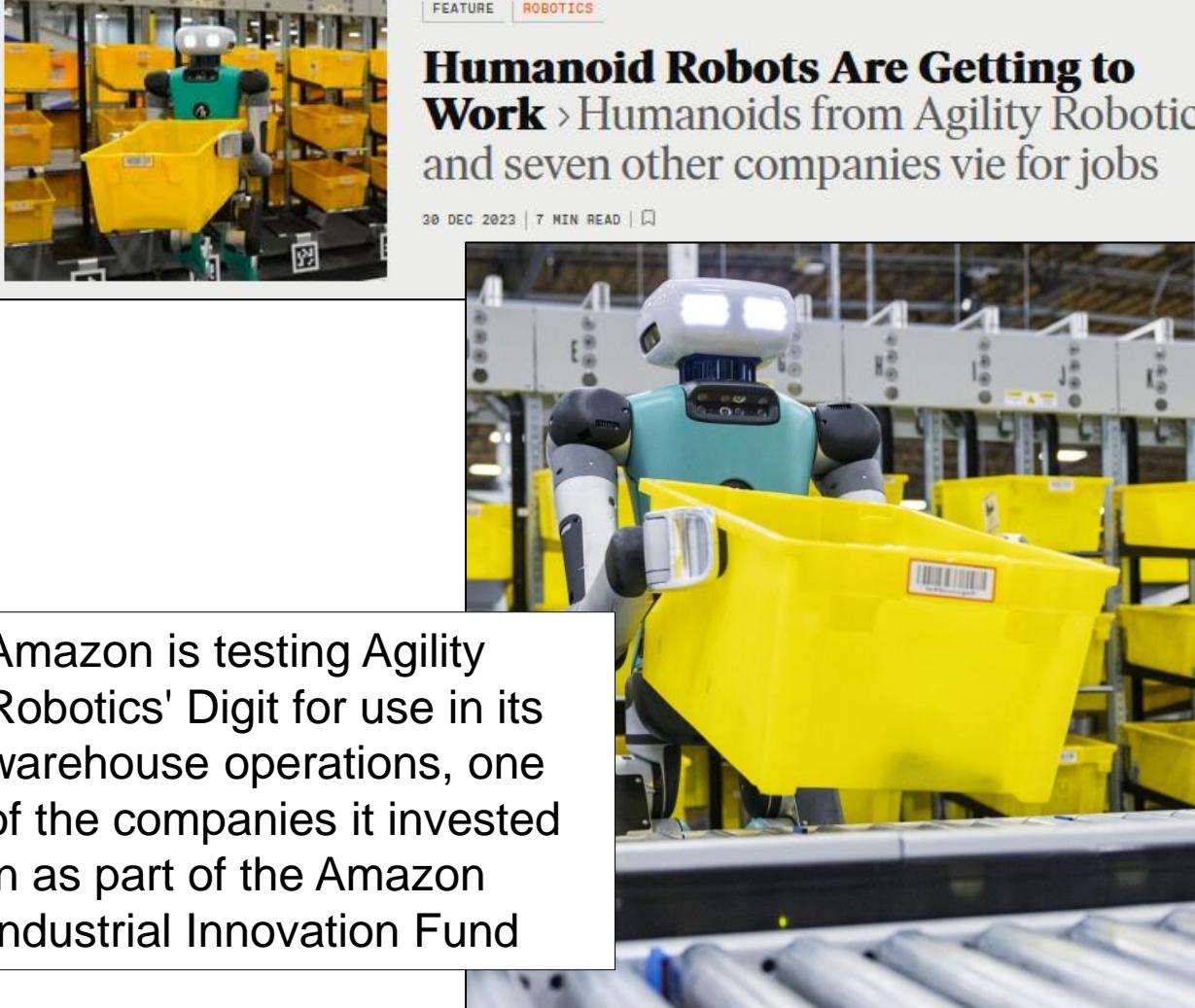
The RT-X dataset contains nearly a million robotic trials for 22 types of robots and behaviors including picking and placing objects, assembly, and specialized tasks like cable routing, with about 500 skills and interactions with thousands of different objects – the largest open-source dataset of real robotic actions in existence



<https://spectrum.ieee.org/global-robotic-brain>

<https://youtu.be/qSARoad-F-k>

After the DARPA Robotics Challenge ended in 2015 with several of the robots successfully completing the entire final scenario, the obvious question was: When would humanoid robots make the transition from research project to a commercial product?



FEATURE | ROBOTICS

Humanoid Robots Are Getting to Work

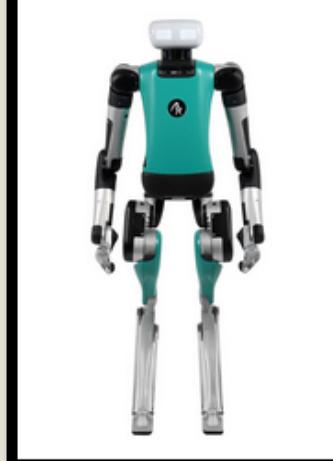
> Humanoids from Agility Robotics and seven other companies vie for jobs

30 DEC 2023 | 7 MIN READ |

Amazon is testing Agility Robotics' Digit for use in its warehouse operations, one of the companies it invested in as part of the Amazon Industrial Innovation Fund

Robots to Look for in 2024

Digit
Agility Robotics



Apollo
Apptronik



Neo
1X Technologies



Digit is most accurately described as "bipedal" rather than "humanoid." It has two legs, but its legs look more like those of an ostrich rather than a human's. This is a side effect of Agility's design process, the goal of which was to maximize the efficiency and robustness of legged locomotion.

Apptronik has worked on more than half a dozen humanoid robots over the past eight years, including NASA's Valkyrie. **Apollo** is the culmination of all this experience and is designed for manufacturability. Apptronik plans to field its robots in 10 pilot projects in 2024, with a full commercial release of Apollo in 2025.

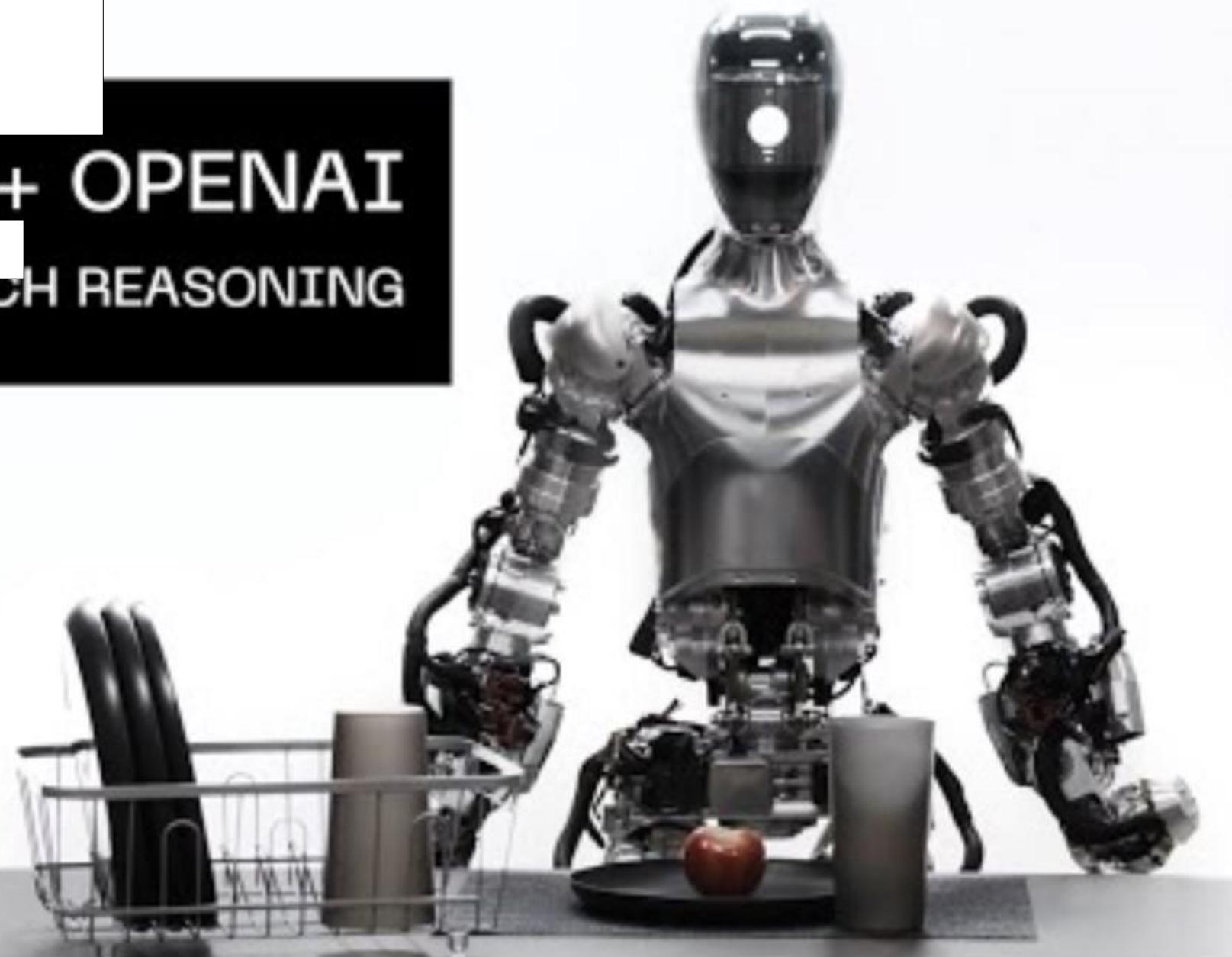
1X's soft, tendon-based robot is designed to have very low inertia with the goal of building a robot that's safe for humans to be around. The robot will weigh just 30 kilograms, with a carrying capacity of up to 20 kg. 1X, backed by OpenAI, hopes that Neo will become "an all-purpose android assistant to your daily life."

The Big Data training set
model has recently shown
some impressive results

FIGURE 01 + OPENAI

<https://youtu.be/Sq1QZB5baNw>

SPEECH-TO-SPEECH REASONING





Questions?