Certificate I: Understanding AI and Machine Learning in Africa

Course AIML01: Artificial Intelligence – Past, Present, and Future

Module 3: Example Applications

Lecture 2: AI Applications in Robotics

Carnegie Mellon University
Africa

Learning Objectives

1. Provide examples of contemporary robots and understand that their capabilities fall well short of the robots in science fiction movies

2. Highlight the main features of AI-enabled robotics, sometimes referred to as cognitive robots

3. Explain the concept of robot-enhanced therapy for children with autism spectrum disorder (ASD)

4. Identify one of the goals of cognitive robotics and explain the associated technical challenges

Lecture Contents

1. Science fiction robots vs. contemporary real robots
2. Types of robot and application domains
3. Robotics, AI, and cognition
4. Robot-enhanced therapy for children with autism spectrum disorder (ASD)
5. Cognitive robotics
6. Lecture summary
7. Recommended reading & references

Science Fiction Robots vs. Contemporary Real Robots

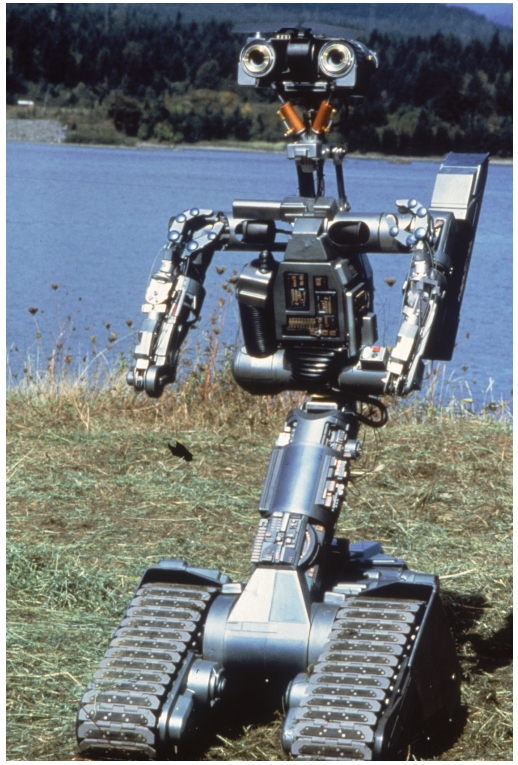
Robots feature prominently in the general public's perception of AI

This is due in part to the way they are portrayed in science fiction movies

https://www.imdb.com/title/tt0091949/

Science Fiction Robots vs. Contemporary Real Robots

From cute robots such as Johnny 5 in Short Circuit



Source: https://www.imdb.com/title/tt0091949/

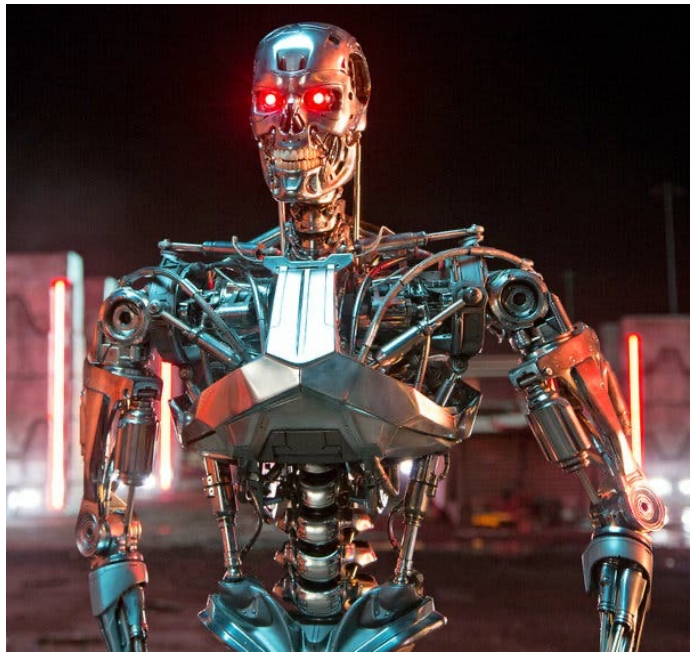
Science Fiction Robots vs. Contemporary Real Robots

... and WALL·E

Source: https://pixar.fandom.com/wiki/WALL%E2%80%A2E_(character)

Science Fiction Robots vs. Contemporary Real Robots

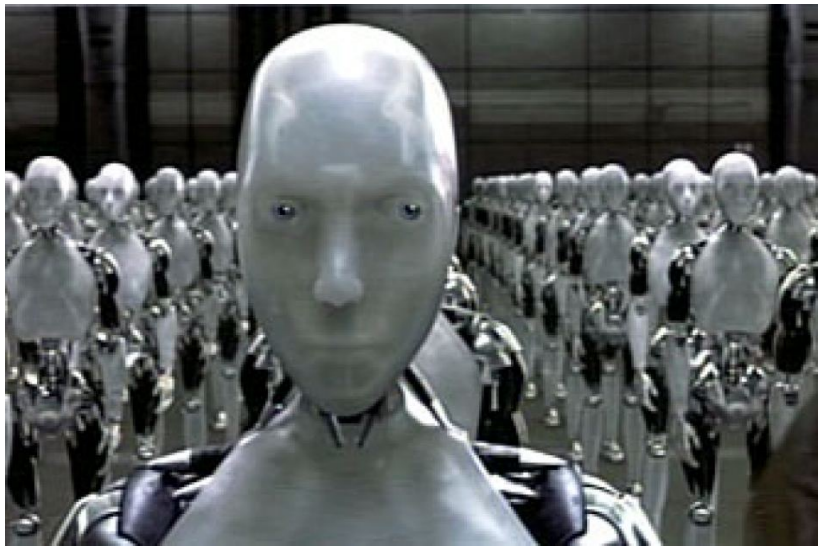
To more threatening robots such as the Skynet Terminator



Soource: https://www.nytimes.com/2015/05/26/science/darpa-robotics-challenge-terminator.html

Science Fiction Robots vs. Contemporary Real Robots

Sonny in I, Robot



Source: https://www.abc.net.au/news/2004-07-21/i-robot-modern-interpretations-foresee-the-three/2012544?nw=0

Science Fiction Robots vs. Contemporary Real Robots

... and Chappie

Source: https://www.abc.net.au/news/2004-07-21/i-robot-modern-interpretations-foresee-the-three/2012544?nw=0

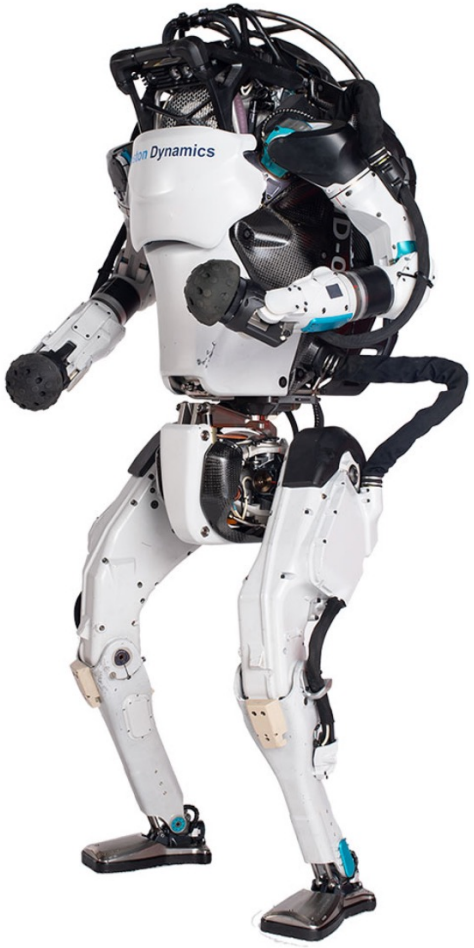
Science Fiction Robots vs. Contemporary Real Robots

There is a long way to go to match science fiction ...

But impressive progress in mechatronics and control over the past ten years

Science Fiction Robots vs. Contemporary Real Robots

For example, consider the mobility displayed by Atlas from Boston Dynamics



Atlas

Atlas is the most agile humanoid in existence. It uses whole-body skills to move quickly and balance dynamically. It can lift and carry objects like boxes and crates, but its favorite tricks are running, jumping, and doing backflips.

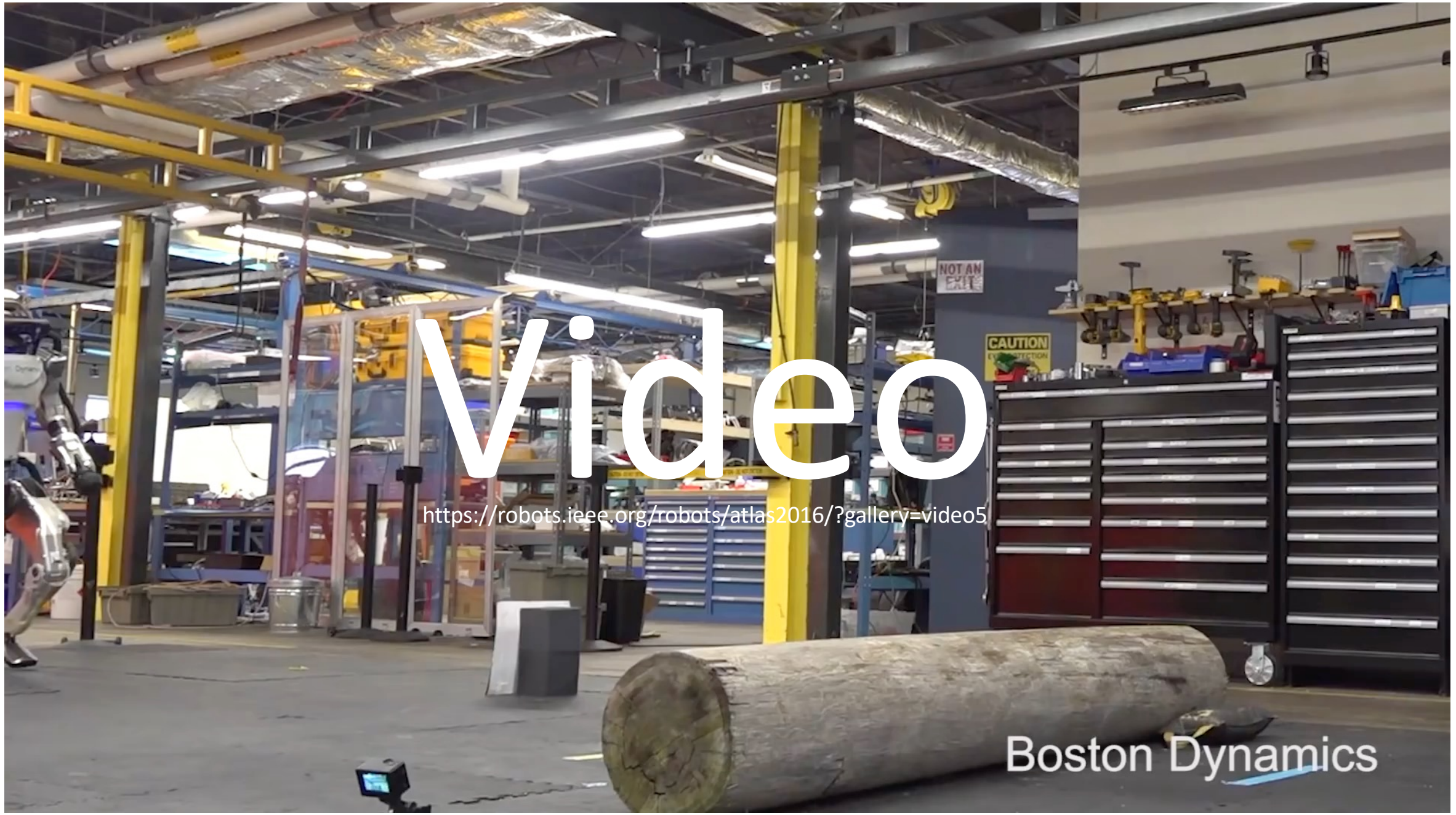
CREATOR
Boston Dynamics

COUNTRY
United States

YEAR
2016

TYPE
Humanoids, Industrial

Source: https://robots.ieee.org/robots/atlas2016/


Video
https://robots.ieee.org/robots/atlas2016/?gallery=video5
NOT AN EXIT
CAUTION
Boston Dynamics

Science Fiction Robots vs. Contemporary Real Robots

And Spot, also from Boston Dynamics

Spot

Spot is a compact, nimble four-legged robot that can trot around your office, home, or outdoors. It can map its environment, sense and avoid obstacles, climb stairs, and open doors. It can also fetch you a drink.

CREATOR
Boston Dynamics

COUNTRY
United States

YEAR
2016

TYPE
Industrial, Research

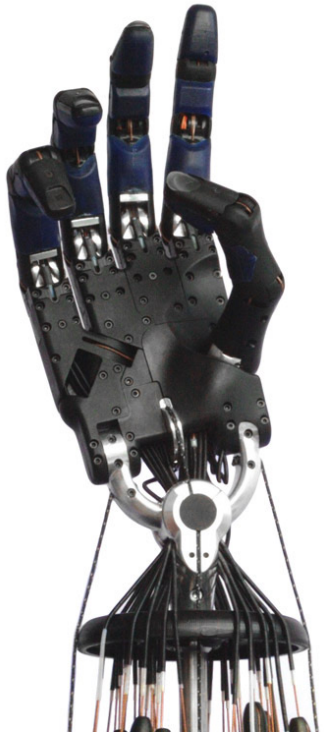
Source: https://robots.ieee.org/robots/spotmini/

Video

https://robots.ieee.org/robots/spotmini/?gallery=video1

Science Fiction Robots vs. Contemporary Real Robots

Or the dexterity of the
Shadow Hand



Shadow Hand

The Shadow Dexterous Hand is one of the most advanced robot hands in the world. It's designed to replicate as much of the functionality, dimensions, and range of motion of the human hand as possible.

CREATOR
Shadow Robot Company

COUNTRY
United Kingdom

YEAR
2004

TYPE
Industrial, Telepresence, Research

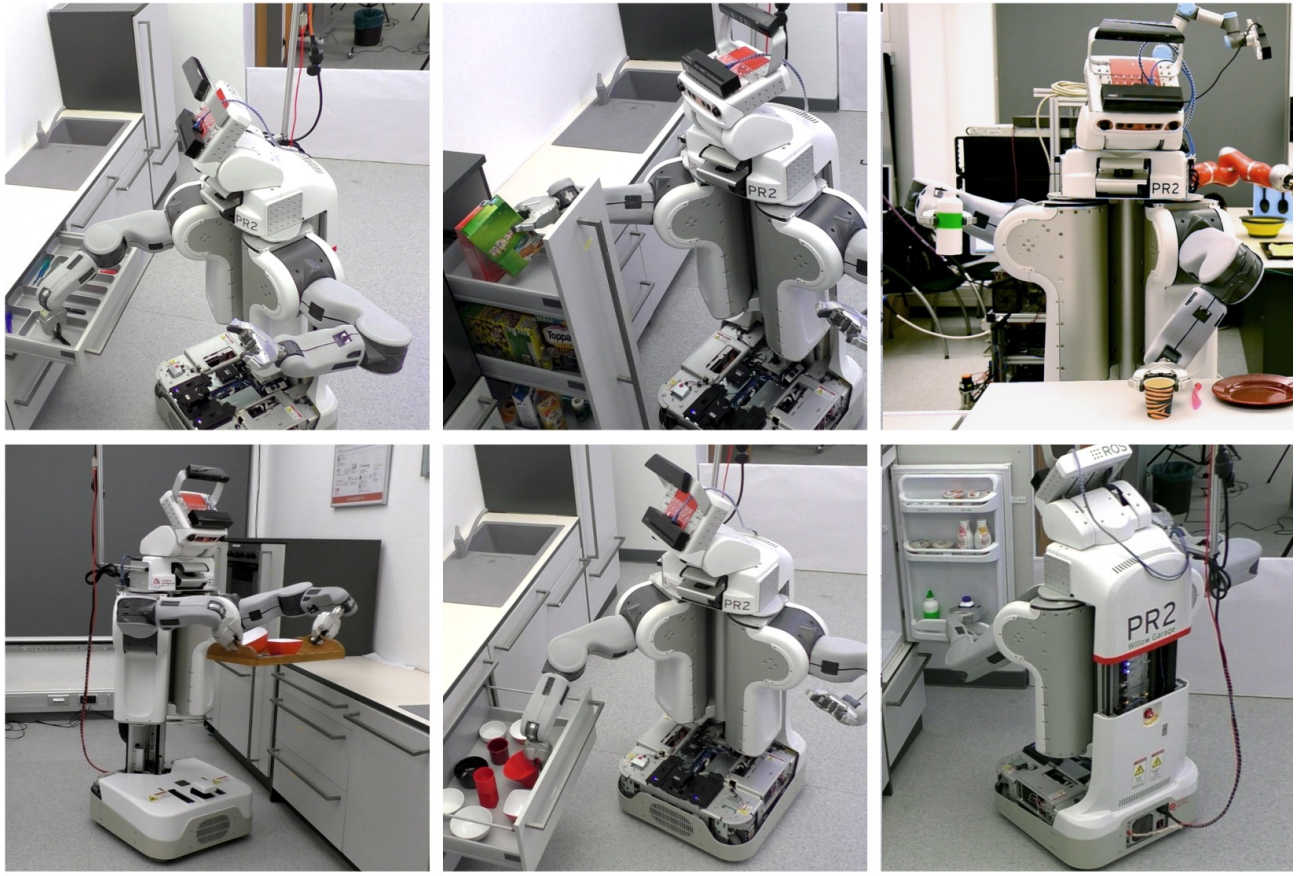
Source: https://robots.ieee.org/robots/shadow/


Video
https://robots.ieee.org/robots/shadow/?gallery=video4

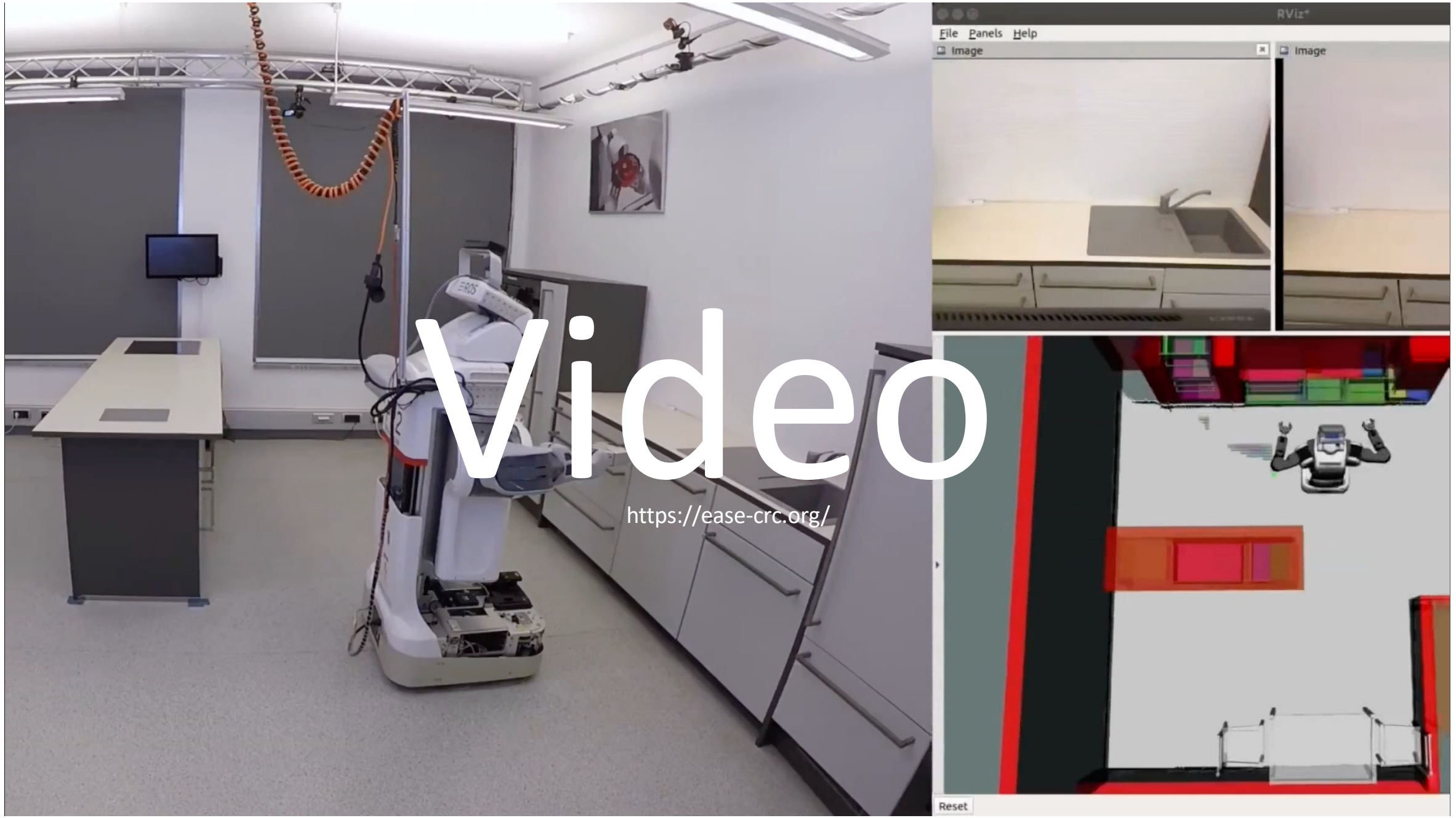
Science Fiction Robots vs. Contemporary Real Robots

There have also been recent advances in cognition-enabled robot manipulation in everyday activities

Such as setting a table, preparing a simple meal, and clearing up afterwards



Source: https://ease-crc.org/



Video

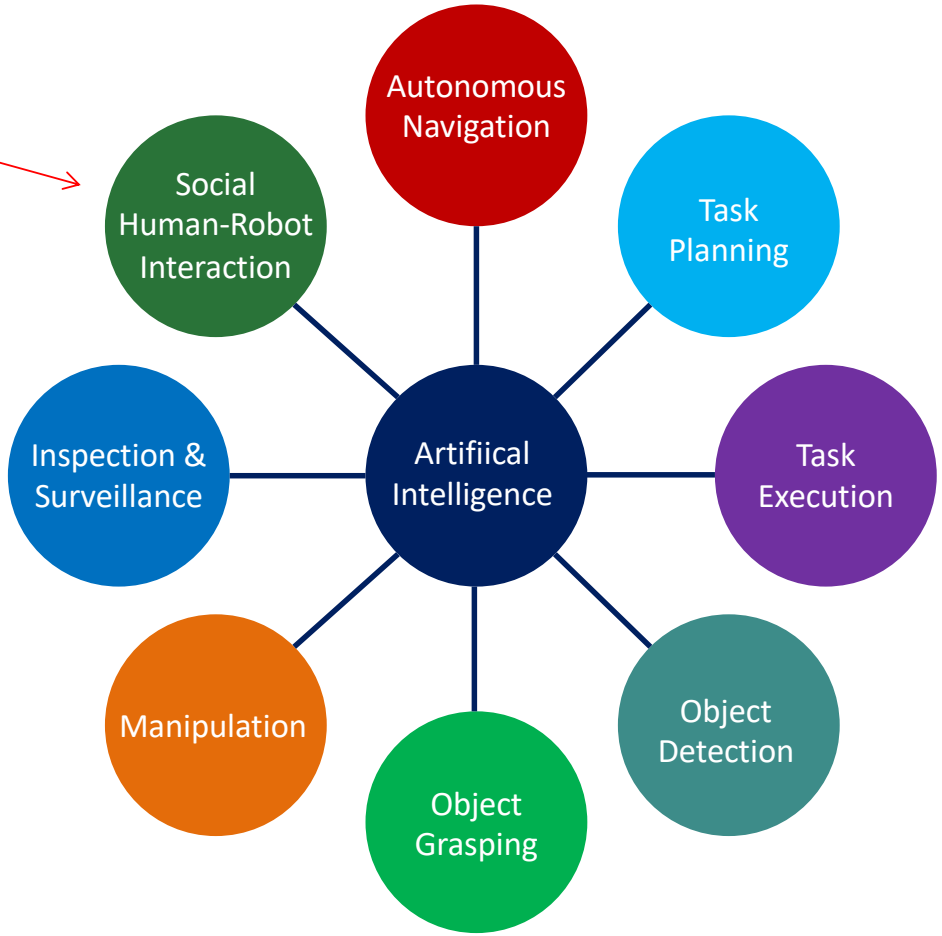
https://ease-crc.org/

Uses of AI in Robotics

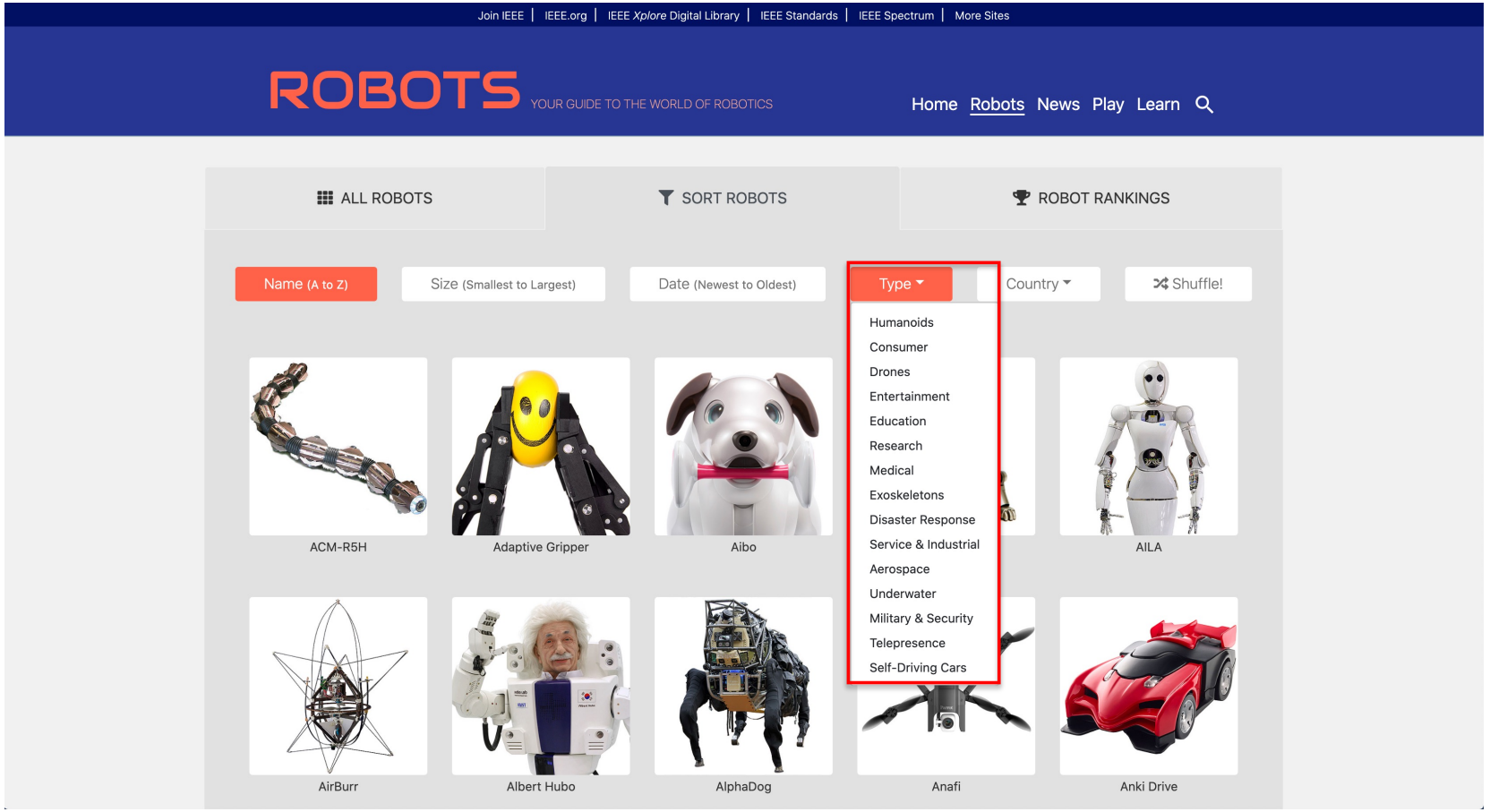
- Robotics is a key element of the domain of AI
- AI tools and techniques play a central role in achieving the robust performance that is required of robots
- Especially when they are operating in environments that are not engineered to facilitate their operation

Uses of AI in Robotics

Natural language processing
Face recognition
Sentiment analysis
Gesture understanding
Intention recognition



Types of Robot and Application Domains



Source: https://robots.ieee.org/robots/

Types of Robot and Application Domains

Type: Humanoid

Domain: Consumer & Entertainment

Social HRI

Human-Robot Interaction

Pepper

Pepper is a friendly humanoid designed to be a companion in the home and help customers at retail stores. It talks, gesticulates, and seems determined to make everyone smile.

CREATOR
SoftBank Robotics
(originally created by Aldebaran Robotics, acquired by SoftBank in 2015)

COUNTRY
Japan

YEAR
2014

TYPE
Humanoids, Consumer, Entertainment

Source: https://robots.ieee.org/robots/pepper/

Types of Robot and Application Domains

Type: Humanoid

Domain: Education, Research, Healthcare

Social HRI

Nao

Nao is a small humanoid robot designed to interact with people. It's packed with sensors (and character) and it can walk, dance, speak, and recognize faces and objects. Now in its sixth generation, it is used in research, education, and healthcare all over the world.

CREATOR
SoftBank Robotics
(originally created by Aldebaran Robotics, acquired by SoftBank in 2015)

COUNTRY
France

YEAR
2008

TYPE
Humanoids, Research, Education

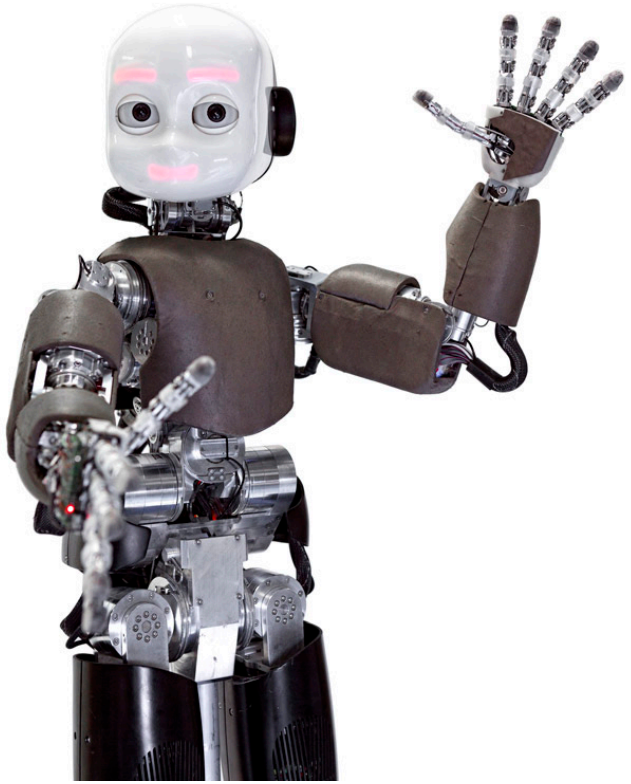
Source: https://robots.ieee.org/robots/nao/

Types of Robot and Application Domains

Type: Humanoid

Domain: Research

Manipulation, Cognition



iCub

iCub is a child-size humanoid robot capable of crawling, grasping objects, and interacting with people. It's designed as an open source platform for research in robotics, AI, and cognitive science.

CREATOR
RoboCub Consortium and IIT

COUNTRY
Italy

YEAR
2004

TYPE
Humanoids, Research

Source: https://robots.ieee.org/robots/icub/

Types of Robot and Application Domains

Type: Humanoid

Domain: Research

Mobile Manipulation

Armar

Armar is a robot created to be a helper in industrial environments. Its humanoid form lets it use human tools like power drills and hammers. Earlier versions were home helpers that could clean tables and load the dishwasher.

CREATOR
Karlsruhe Institute of Technology

COUNTRY
Germany

YEAR
2017

TYPE
Humanoids, Research

Source: https://robots.ieee.org/robots/armar/

Types of Robot and Application Domains

Type: Humanoid

Domain: Research

Social HRI

HRP-4

HRP-4 is one of the world's most advanced humanoids, the culmination of a decade of R&D. It's designed to collaborate with humans and can perform remarkably natural, human-like movements.

CREATOR
Kawada Industries and AIST

COUNTRY
Japan

YEAR
2010

TYPE
Humanoids, Research

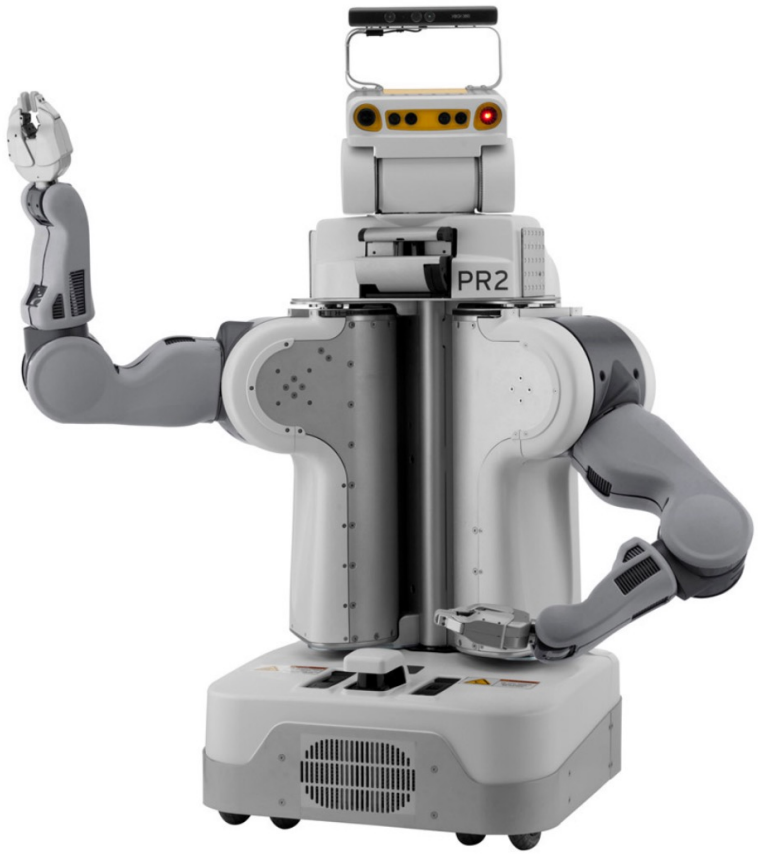
Source: https://robots.ieee.org/robots/hrp4/

Types of Robot and Application Domains

Type: Humanoid

Domain: Research

Mobile Manipulation



PR2

The PR2 is one of the most advanced research robots ever built. Its powerful hardware and software systems let it do things like clean up tables, fold towels, and fetch you drinks from the fridge.

CREATOR
Willow Garage

COUNTRY
United States

YEAR
2010

TYPE
Research, Humanoids

Source: https://robots.ieee.org/robots/pr2/

Types of Robot and Application Domains

Type: Humanoid

Domain: Industrial

Manipulation

Sawyer

Sawyer is an industrial collaborative robot designed to help out with manufacturing tasks and work alongside humans. You can teach it new tasks by demonstrating what to do using the robot's own arm.

CREATOR
Rethink Robotics

COUNTRY
United States

YEAR
2015

TYPE
Industrial

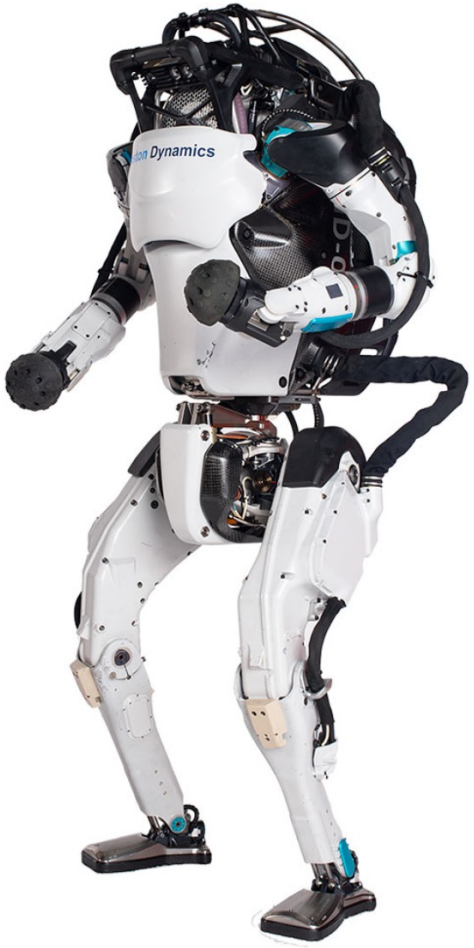
Source: https://robots.ieee.org/robots/sawyer/

Types of Robot and Application Domains

Type: Humanoid

Domain: Industrial

Navigation,
Inspection & Surveillance



Atlas

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CREATOR
Boston Dynamics

COUNTRY
United States

YEAR
2016

TYPE
Humanoids, Industrial

Source: https://robots.ieee.org/robots/atlas2016/

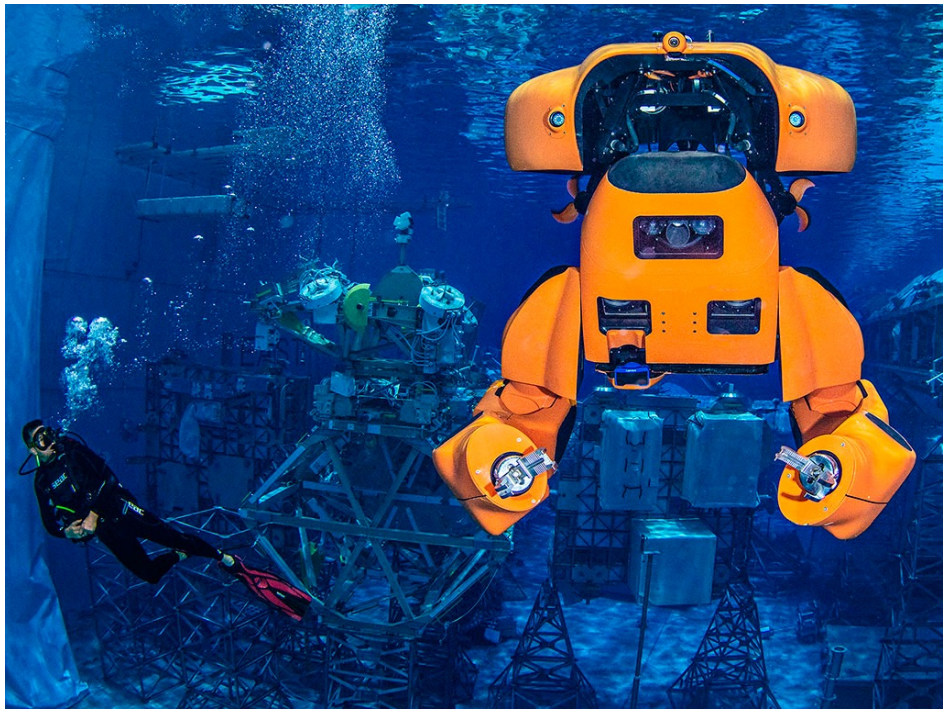
Types of Robot and Application Domains

Type: Humanoid

Domain: Industrial

Surveillance

Exploration



Aquanaut

Aquanaut is an unmanned underwater vehicle that can transform itself from a nimble submarine designed for long-distance cruising into a half-humanoid robot capable of carrying out complex manipulation tasks. It can inspect subsea oil and gas infrastructure, operate valves, and use tools.

CREATOR
Houston Mechatronics Inc.

COUNTRY
United States

YEAR
2019

TYPE
Underwater, Industrial

Source: https://robots.ieee.org/robots/aquanaut/

Types of Robot and Application Domains

Type: Organismoid

Domain: Research

Disaster response

ANYmal

ANYmal is a rugged, autonomous four-legged robot designed for inspection and manipulation tasks. It uses sensors to scan the terrain and avoid obstacles, and can operate in rain, snow, wind, waterlogged rooms, and dusty environments.

CREATOR
ETH Zurich and ANYbotics

COUNTRY
Switzerland

YEAR
2016

TYPE
Industrial, Research, Disaster Response

Source: https://robots.ieee.org/robots/anymal/

Types of Robot and Application Domains

Type: Organismoid

Domain: Military

Surveillance

AlphaDog

AlphaDog is a quadruped robot the size of a mule (a big, mean mule). It's powered by a hydraulic actuation system and is designed to assist soldiers in carrying heavy gear over rough terrain.

CREATOR
Boston Dynamics

COUNTRY
United States

YEAR
2011

TYPE
Military & Security, Research

Source: https://robots.ieee.org/robots/alphadog/

Types of Robot and Application Domains

Type: Organismoid

Domain: Industrial

Surveillance

Spot

Spot is a compact, nimble four-legged robot that can trot around your office, home, or outdoors. It can map its environment, sense and avoid obstacles, climb stairs, and open doors. It can also fetch you a drink.

CREATOR
Boston Dynamics

COUNTRY
United States

YEAR
2016

TYPE
Industrial, Research

Source: https://robots.ieee.org/robots/spotmini/

Types of Robot and Application Domains

Type: Organismoid

Domain: Consumer

Entertainment

Aibo

Aibo is a friendly robotic dog whose personality and behavior evolves over time. It can recognize its owner's face, detect smiles and words of praise, and learn new tricks. And of course, it loves to be petted.

CREATOR
Sony

COUNTRY
Japan

YEAR
2018

TYPE
Consumer, Entertainment

Source: https://robots.ieee.org/robots/aibo2018/

Social Robots

Type: Organismoid

Domain: Consumer

Entertainment

Keepon

Keepon is a social robot that interacts with people and dances when music is playing. It's used to engage with children in autism research. A toy version, My Keepon, is designed for general audiences.

CREATOR
BeatBots

COUNTRY
United States

YEAR
2003

TYPE
Consumer

Source: https://robots.ieee.org/robots/keepon/

Social Robots

Type: Organismoid

Domain: Medical

Therapy

Requires almost no technical skill to operate: has been used by psychologists, anthropologists, health researchers to study psychological and physiological effects on people

Paro

Paro is a robotic baby harp seal designed as a therapeutic tool for use in hospitals and nursing homes. The robot is programmed to cry for attention and respond to its name. It includes an off switch.

CREATOR
AIST

COUNTRY
Japan

YEAR
2004

TYPE
Medical

Source: https://robots.ieee.org/robots/keepon/

Types of Robot and Application Domains

Type: Organismoid

Domain: Research

Locomotion

Salamandra robotica II

Salamandra robotica II is an amphibious robot inspired by the salamander's anatomy and nervous system. It's used to study robot locomotion and test neurobiological models in real environments.

CREATOR
Biorobotics Laboratory at EPFL

COUNTRY
Switzerland

YEAR
2012

TYPE
Research

Source: https://robots.ieee.org/robots/salamandra/

Types of Robot and Application Domains

Type: Manipulator

Domain: Industrial

Product assembly

Meca500

Meca500 is the world's smallest, most compact six-axis industrial robot arm. It's also one of the most precise. And with an embedded controller it can easily be transported and set up in confined spaces.

CREATOR
Mecademic

COUNTRY
Canada

YEAR
2015

TYPE
Industrial

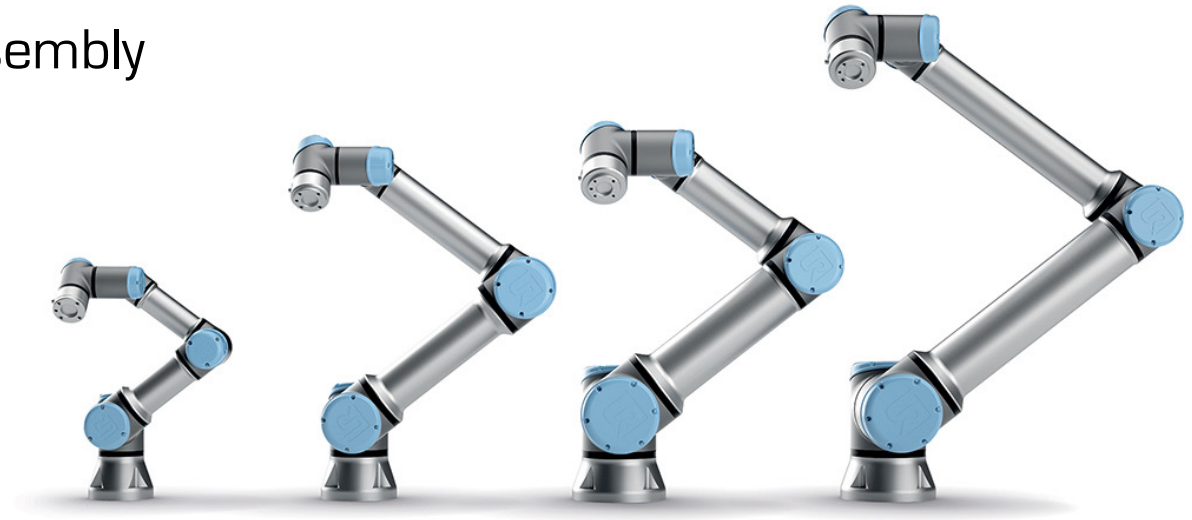
Source: https://robots.ieee.org/robots/meca/

Types of Robot and Application Domains

Type: Manipulator

Domain: Industrial

Product assembly



UR

Universal Robots cobots are versatile, lightweight collaborative robotic arms designed to work safely alongside humans. Users program it through an intuitive touch-screen interface and by positioning the robot with their hands.

CREATOR
Universal Robots

COUNTRY
Denmark

YEAR
2008

TYPE
Industrial

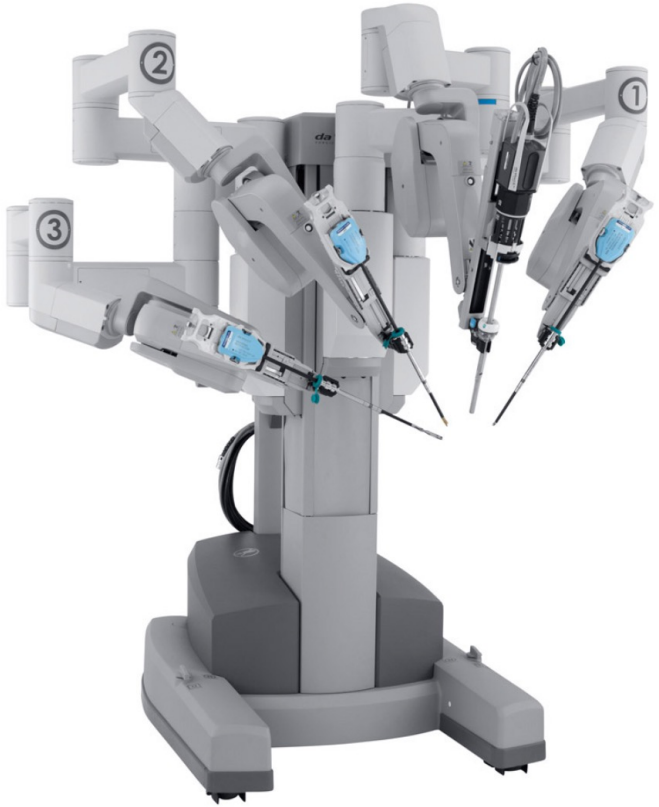
Source: https://robots.ieee.org/robots/ur/

Types of Robot and Application Domains

Type: Manipulator

Domain: Medical

Surgery & Inspection



Da Vinci

The da Vinci is a surgical robot designed for minimally invasive procedures. It has four arms equipped with surgical instruments and cameras that a physician controls remotely from a console.

CREATOR
Intuitive Surgical

COUNTRY
United States

YEAR
1999

TYPE
Medical

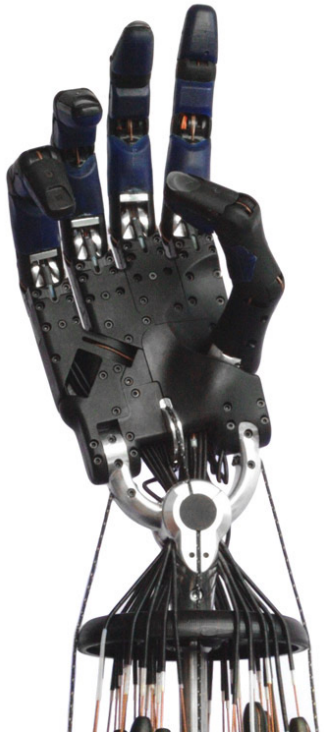
Source: https://robots.ieee.org/robots/davinci/

Types of Robot and Application Domains

Type: Manipulator

Domain: Industrial

Dexterous grasping



Shadow Hand

The Shadow Dexterous Hand is one of the most advanced robot hands in the world. It's designed to replicate as much of the functionality, dimensions, and range of motion of the human hand as possible.

CREATOR
Shadow Robot Company

COUNTRY
United Kingdom

YEAR
2004

TYPE
Industrial, Telepresence, Research

Source: https://robots.ieee.org/robots/shadow/

Types of Robot and Application Domains

Type: Mobile

Domain: Consumer

Cleaning

Roomba

Roomba is an autonomous vacuum and one of the most popular consumer robots in existence. It navigates around clutter and under furniture cleaning your floors, and returns to its charging dock when finished.

CREATOR
iRobot

COUNTRY
United States

YEAR
2002

TYPE
Consumer

Source: https://robots.ieee.org/robots/roomba/

Types of Robot and Application Domains

Type: Mobile

Domain: Education

Navigation

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CREATOR
iRobot

COUNTRY
United States

YEAR
2002

TYPE
Consumer

Source: https://robots.ieee.org/robots/roomba/

Types of Robot and Application Domains

Type: Mobile

Domain: Industrial

Product transport

Picker Robots

Picker Robots are mobile machines designed to autonomously retrieve and carry products in a warehouse. The robots are directed through AI-powered software that identifies the most efficient paths for them to pick, replenish, return, and count goods.

CREATOR
inVia Robotics

COUNTRY
United States

YEAR
2015

TYPE
Industrial

Source: https://robots.ieee.org/robots/invia/

Types of Robot and Application Domains

Type: Mobile

Domain: Industrial

Product transport

Freight

Freight is an autonomous mobile base for use in warehouses to transport materials from point A to point B. The robot platforms come in three zippy flavors – 100, 500 and 1500, all of which represent the payload it can handle in kilograms.

CREATOR
Fetch Robotics

COUNTRY
United States

YEAR
2014

TYPE
Industrial

Source: https://robots.ieee.org/robots/freight/

Types of Robot and Application Domains

Type: Mobile

Domain: Research

Navigation

Boss

Boss is the world's smartest Chevy Tahoe. In 2007, it won the DARPA Urban Challenge for autonomous vehicles, taking home a $2 million prize for not breaking any traffic laws or running anyone over.

CREATOR
Carnegie Mellon University

COUNTRY
United States

YEAR
2007

TYPE
Autonomous Vehicle, Research

Source: https://robots.ieee.org/robots/boss/

Types of Robot and Application Domains

Type: Mobile

Domain: Research

Navigation

Google Self-Driving Car

Google's self-driving car is a modified Toyota Prius that can autonomously drive in city traffic and on highways. The goal is developing technology to reduce traffic accidents and increase road efficiency.

CREATOR
Google

COUNTRY
United States

YEAR
2010

TYPE
Autonomous Vehicle, Research

Source: https://robots.ieee.org/robots/beam/

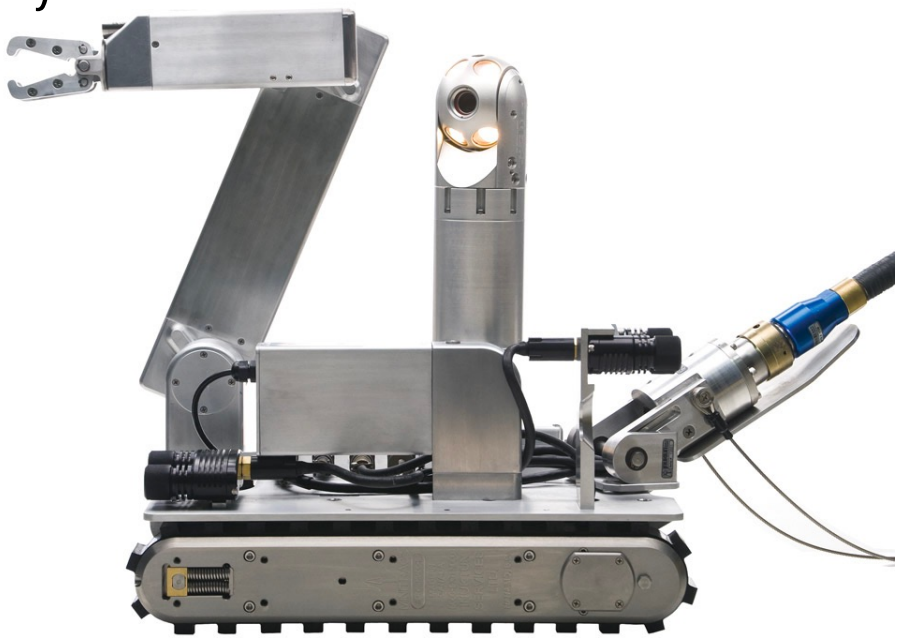
Types of Robot and Application Domains

Type: Mobile

Domain: Military & Security

Surveillance

Disaster Response



Versatrax

Versatrax 450 TTC is a mobile robot designed for hazardous environments. It allows users to locate, inspect, and safely remove dangerous materials from any site faster than by conventional means.

CREATOR
Inuktun Services

COUNTRY
Canada

YEAR
2012

TYPE
Industrial, Military & Security, Disaster Response

Source: https://robots.ieee.org/robots/inuktun/

Types of Robot and Application Domains

Type: Mobile

Domain: Military, Security

Surveillance

Disaster Response

Kobra

Kobra is a rugged, remote control robot designed to search for explosives and carry out reconnaissance missions. It rolls on tank-like treads, and its manipulator arm can lift heavy payloads.

CREATOR
Endeavor Robotics
(Originally created by iRobot)

COUNTRY
United States

YEAR
2011

TYPE
Military & Security, Disaster Response

Source: https://robots.ieee.org/robots/kobra/

Types of Robot and Application Domains

Type: Mobile

Domain: Consumer

Telepresence

Beam

Beam is a telepresence robotic system that can "teleport" you to a remote location, allowing you to move around and interact with people. It is easy to drive and has a large display to improve face-to-face, or screen-to-face, communication.

CREATOR
Suitable Technologies

COUNTRY
United States

YEAR
2011

TYPE
Telepresence, Consumer

Source: https://robots.ieee.org/robots/beam/

Types of Robot and Application Domains

Type: Drone

Domain: Military

Surveillance

Global Hawk

The Global Hawk is an unmanned aerial vehicle that's used for high-altitude, long-duration surveillance. You tell it what to do, and it can take off, fly, spy, and return without any human input.

CREATOR
Northrop Grumman

COUNTRY
United States

YEAR
2001

TYPE
Aerospace, Military & Security, Drones

Source: https://robots.ieee.org/robots/globalhawk/

Types of Robot and Application Domains

Type: Drone

Domain: Medical

Delivery

Zipline

Zipline is an autonomous fixed-wing aircraft drone used to carry blood and medicine from a distribution center to wherever it's needed. It can launch within minutes, and travel in any weather.

CREATOR
Zipline

COUNTRY
United States

YEAR
2016

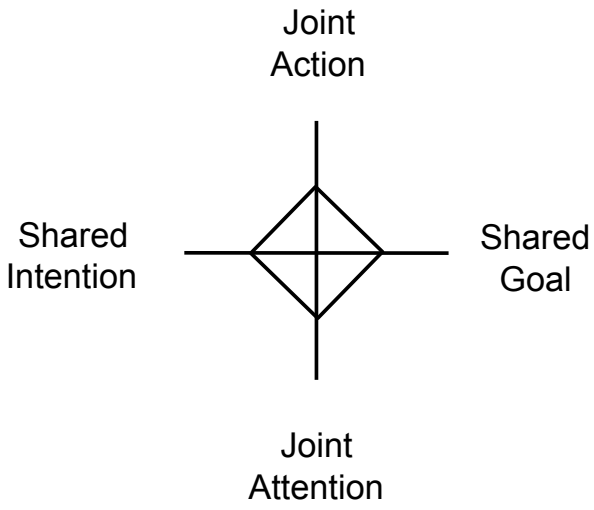
TYPE
Drones, Medical

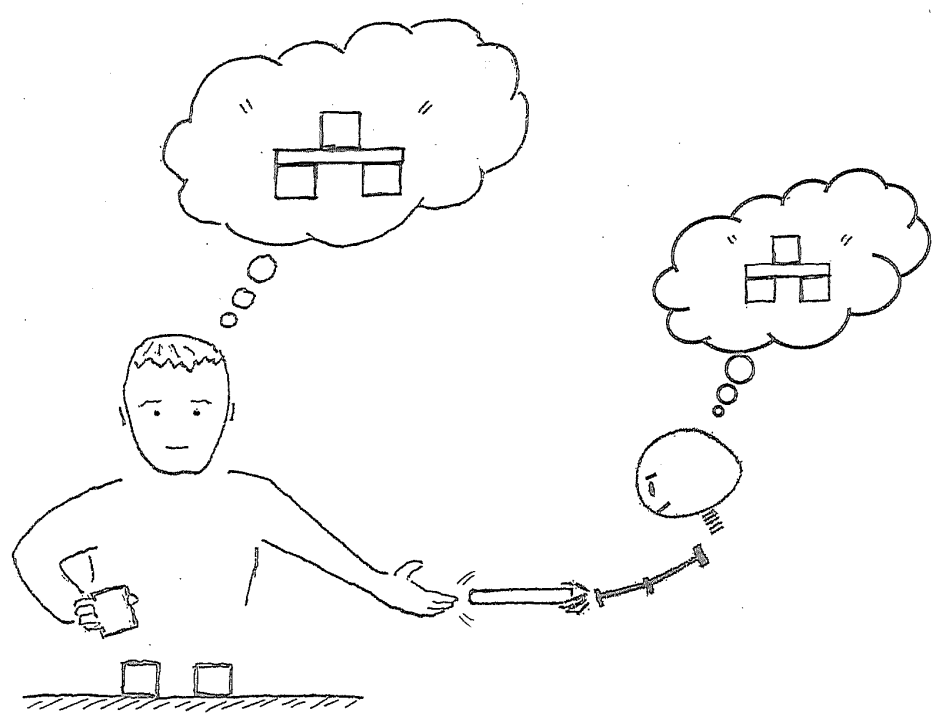
Source: https://robots.ieee.org/robots/zipline/

Video

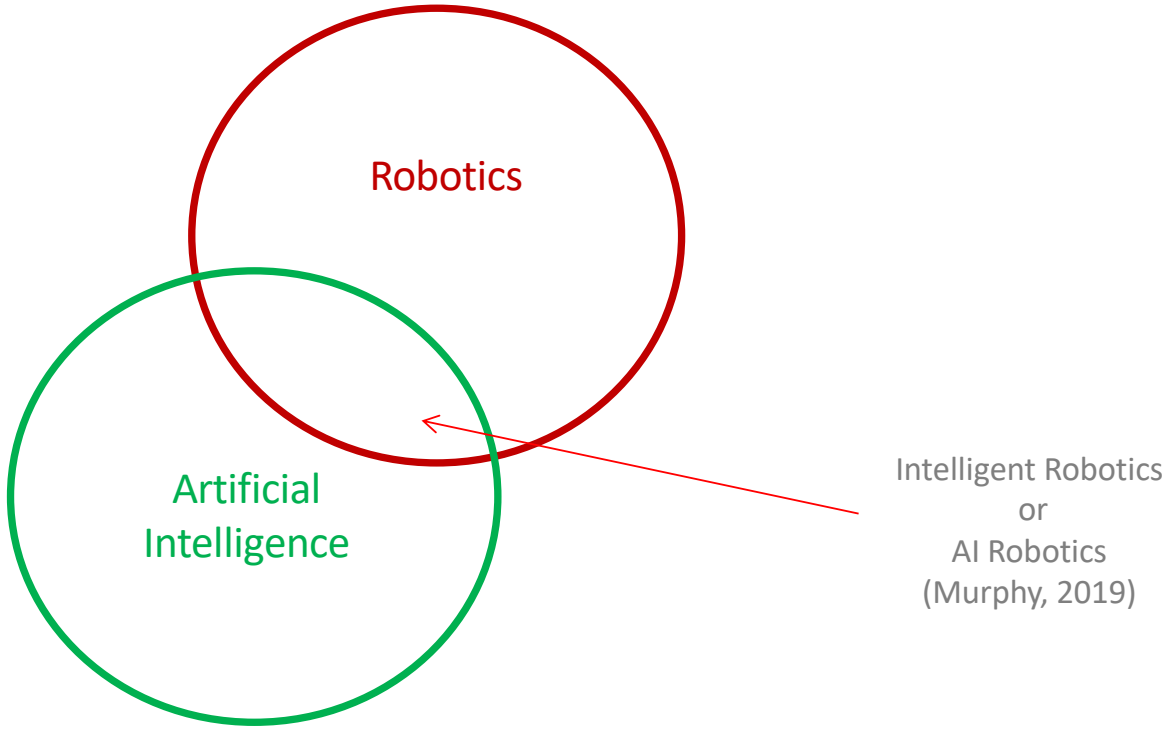
http://www.vernon.eu/videos/Zipline_drop.mp4

Robotics, AI, and Cognition

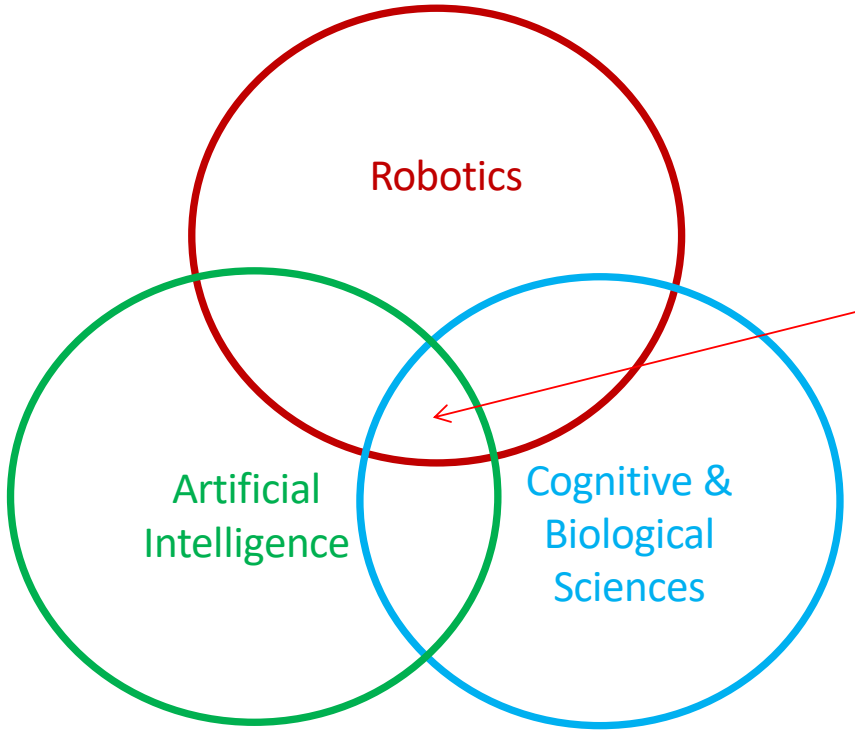




Robotics, AI, and Cognition



Robotics, AI, and Cognition



Cognitive Robotics:

Perception
Attention
Action selection
Memory,
Learning
Reasoning
Metacognition
Prospection

(Vernon, 2022)

Robot-enhanced Therapy for Children with ASD

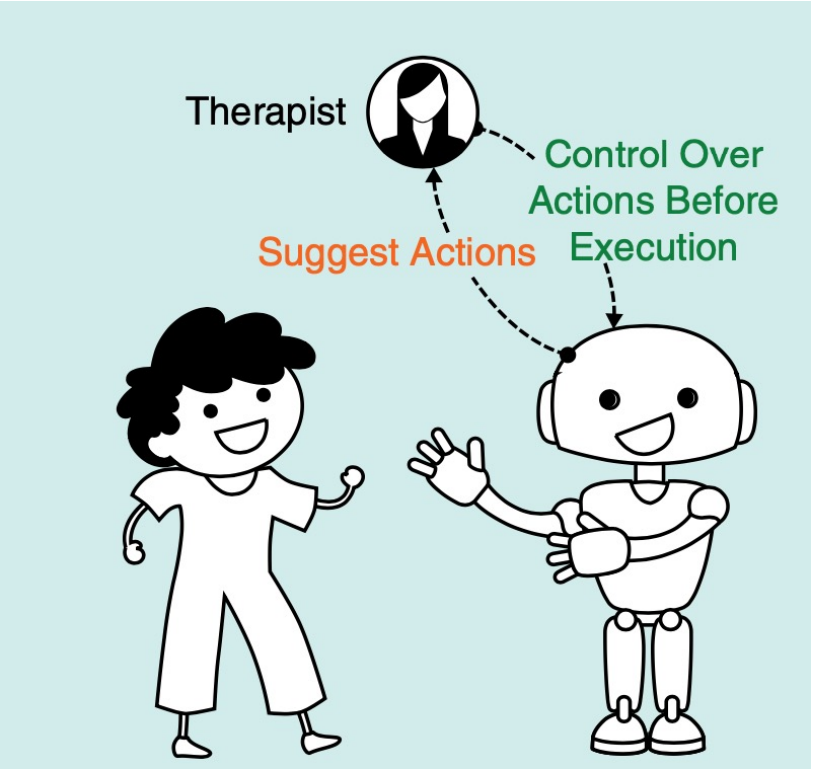
Robots assist a psychotherapist working with children with autism spectrum disorder ASD

(Cao et al., 2019)

Robot-enhanced Therapy for Children with ASD

Under the guidance of clinical practitioner, this project developed

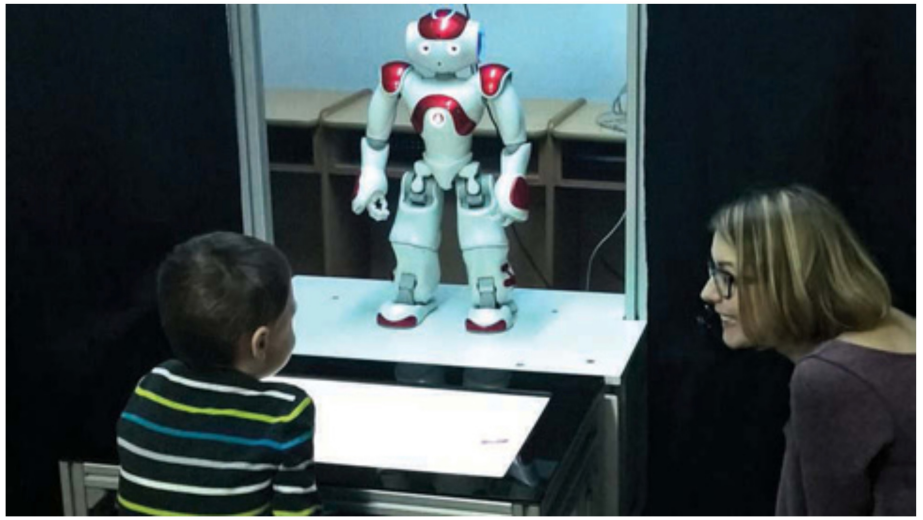
- Interactive capabilities for social robots
- That allowed them to engage a child in clinically-derived exercises



(Cao et al., 2019)

Robot-enhanced Therapy for Children with ASD

The robot can operate autonomously for limited periods under the supervision of a psychotherapist



(Cao et al., 2019)

Robot-enhanced Therapy for Children with ASD

AI provides the cognitive ability to interpret

- Body movement
- Appearance-based cues of emotion

The robot assesses the child's actions

- Maps them to therapist-specific classes of behavior
- Identifies appropriate robot responses
- As specified by the therapists

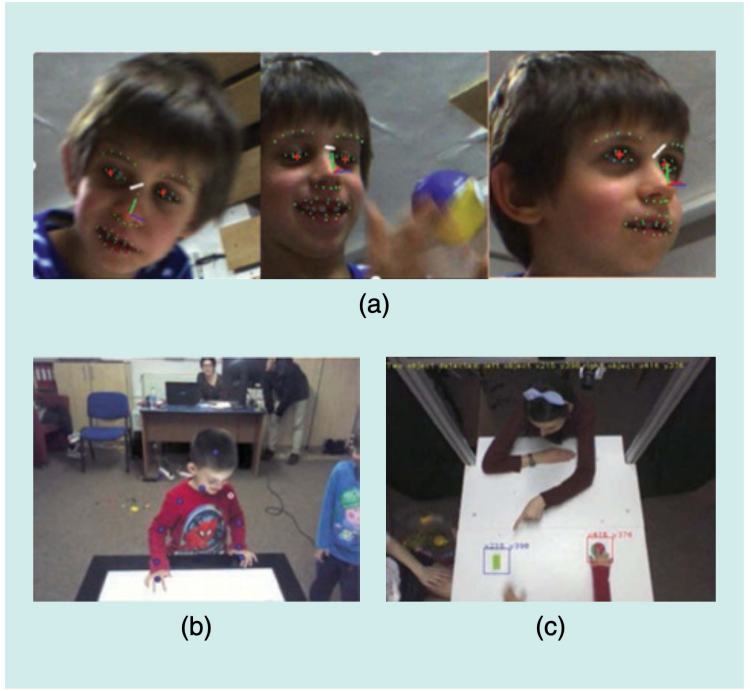


Figure 4. The advanced sensing system performances: (a) gaze estimation, (b) action recognition, and (c) object tracking.

(Cao et al., 2019)

Cognitive Robotics

One goal of cognitive robotics

- Allow humans to give a robot some task
- By stating that task in the same terms they would use if they were talking to another human being
- That is, without having to specify how the task is the be carried out
- This capability is provided by the CRAM cognitive architecture (Beetz et al., 2020)

A PR2 robot pours popcorn from a saucepan during a demonstration of cognition-enabled robot manipulation using the CRAM cognitive architecture

(Sandini et al., 2021)

Lecture Summary

1. Real robots don't yet have the abilities of the robots that we see in science fiction movies

2. Great progress is being achieved through the use of advanced control and artificial intelligence

3. There are many different types of robot, designed for a wide variety of application domains

4. At the intersection of the fields of robotics, artificial intelligence, and cognitive science is the field of cognitive robotics, which aims to develop robots that can

   – Interact naturally with people
   – Carry out tasks without having to be told exactly how to perform each step in the task

Recommended Reading

Cao, H.-L., Gomez Esteban, P., Baxter, P., Belpaeme, T., Billing, E., Cai, H., Coeckelbergh, M., Costescu, C., David, D., De Beir, A., Hernandez Garcia, D., Kennedy, J., Liu, H., Matu, S., Mazel, A., Kumar Pandey, A., Richardson, K., Senft, E., Thill, S.,Van de Perre, G., Vanderborght, B., Vernon, D., Wakanuma, K., Yu, H., Zhou, X., Ziemke, T. (2019). Robot-Enhanced Therapy: Development and Validation of a Supervised Autonomous Robotic System for Autism Spectrum Disorders Therapy, IEEE Robotics and Automation Magazine, Vol. 26, No. 2, pp. 49-58.

http://vernon.eu/publications/19_Cao_et_al_IROS.pdf

Sandini, G., Sciutti, A. and Vernon, D. (2021). Cognitive Robotics. In M. Ang, O. Khatib, and B. Siciliano (Eds.), Encyclopedia of Robotics. Springer.

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https://mitpress.mit.edu/books/introduction-ai-robotics-second-edition

Vernon, D. (2022), Cognitive Architectures, in Cognitive Robotics, Cangelosi, A. and Asada, M. (Eds.). Cambridge, MA: MIT press, 2022.
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