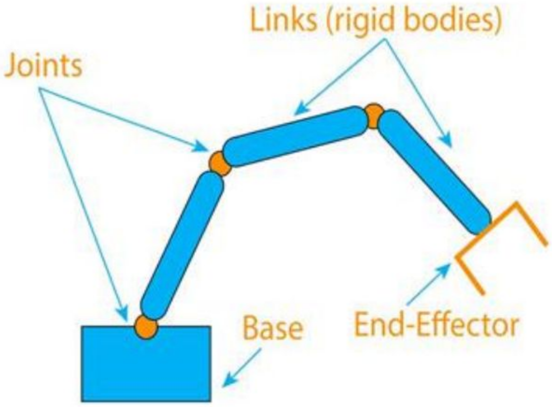
Robot Manipulators. Robot Arms
How do we control them in ROS?



Source: MathWorks

UNIVERSITY OF EASTERN FINLAND

Henki Robotics

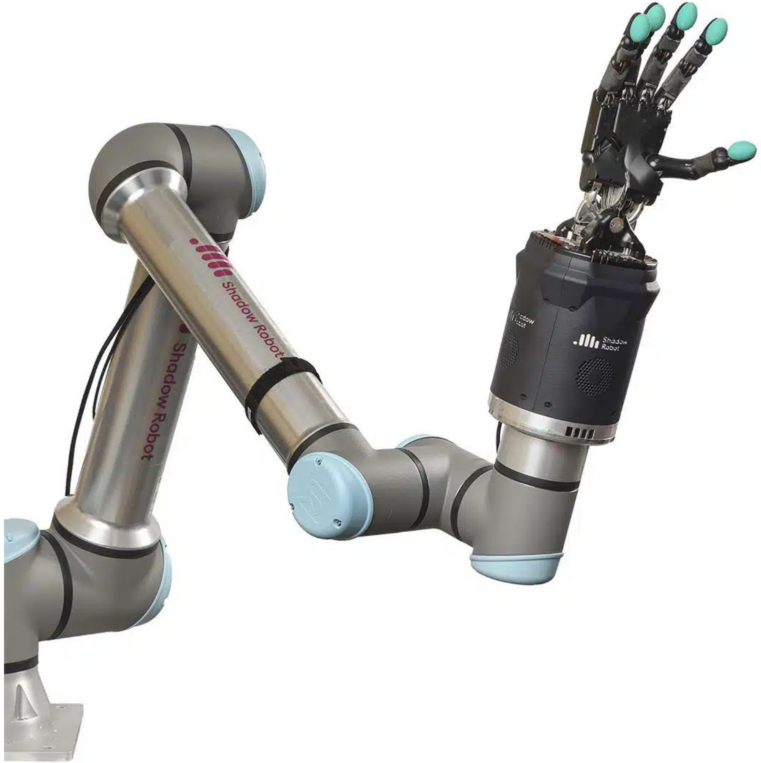
George-Cosmin Porusniuc
Co-Founder & Robotics Consultant @ Henki Robotics

What are Robot manipulators/arms? (I)

Definition:
A **robot manipulator** (or **robot arm**) is a mechanical structure made up of rigid links connected by joints, designed to position and orient an end-effector (e.g., gripper or tool) to interact with the environment in a controlled and repeatable way.

They are typically used in:

- factories
- warehouses
- medicine
- research
- home robots

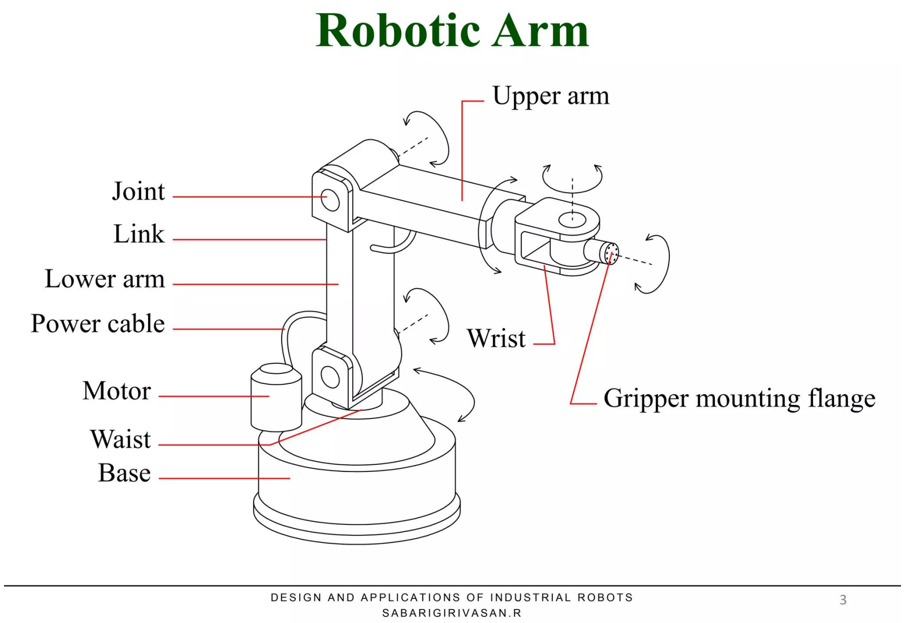


https://shadowrobot.com/news/how-does-a-robotic-manipulator-work/

What are Robot manipulators/arms? (II)

Key parts of a robot manipulator

1. **Links:**
   - Rigid segments (like bones)
2. **Joints**
   - Moving connections between links (like shoulders, elbows, wrists).
   - Joints add *degrees of freedom* (DoF) such as rotation and translation
3. **Actuators**
   - Motors that power the joints.
4. **End-effector**
   - The tool at the tip of the arm:
     - i. Gripper
     - ii. suction cup
     - iii. welding torch
     - iv. Screwdriver
     - v. camera
5. **Controller**
   - The computer that calculates joint movement and commands the actuators.



Robotic Arm

DESIGN AND APPLICATIONS OF INDUSTRIAL ROBOTS
SABARIGIRIVASAN.R

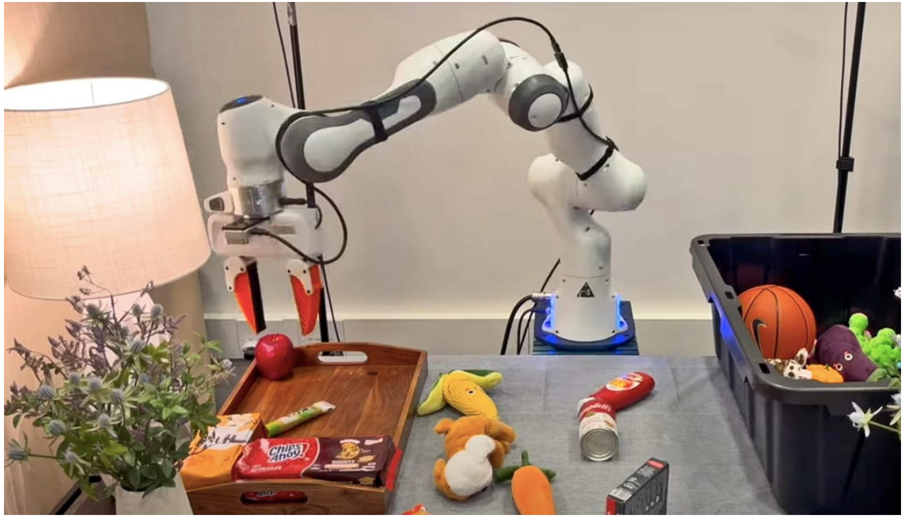
3

https://www.slideshare.net/slideshow/robot-manipulator-91903399/91903399

What are Robot manipulators/arms? (III)

A robot manipulator performs tasks such as:

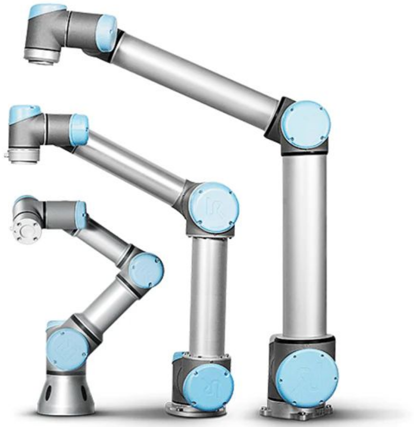
- pick-and-place
- assembly
- painting
- welding
- packaging
- sorting
- surgical assistance
- lab automation

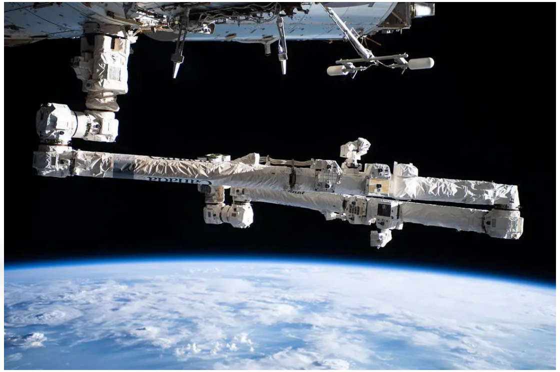


https://www.futurity.org/manipgen-robots-manipulating-objects-3259572-2/

Examples of manipulators used in the industry

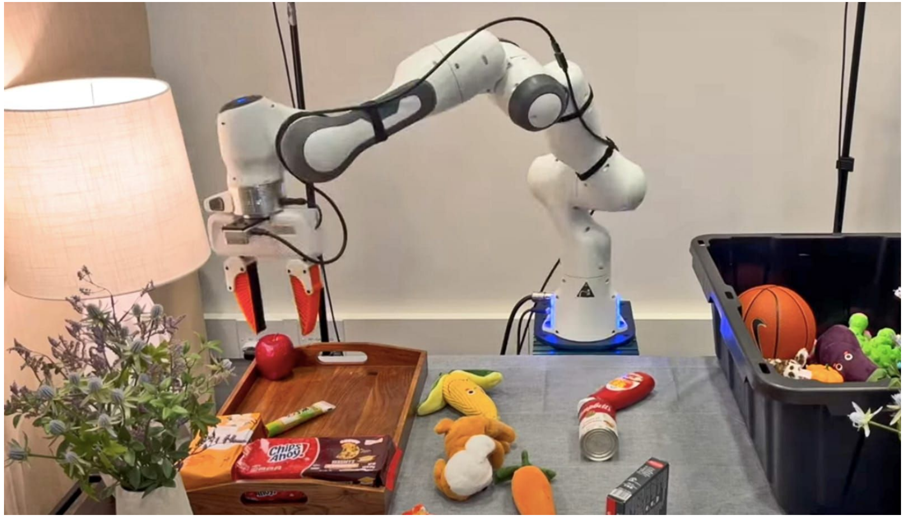
- **KUKA KR6** industrial arm
- **UR10** collaborative robot
- **Franka Emika Panda** research robot
- **NASA Canadarm2** space station manipulator
- **Dobot** small educational arms
- **Trossen Robotics** PincherX 100





What matters when working with robot manipulators?

- **Degrees of Freedom (DOF)**
- **Tool Center Point (TCP)**
- **Rotations**
- **Translations**
- **Kinematics - forward and inverse**
- **Frames**
- **Links**
- **Constraints**



https://www.futurity.org/manipgen-robots-manipulating-objects-3259572-2/

Common Kinematics Libraries

For ROS: MoveIt, KDL (Kinematics & Dynamics Library) - We'll be mostly using MoveIt2 with ROS2

Industrial robots: vendor-built solvers inside controllers.

ROS

MoveIt

MoveIt2

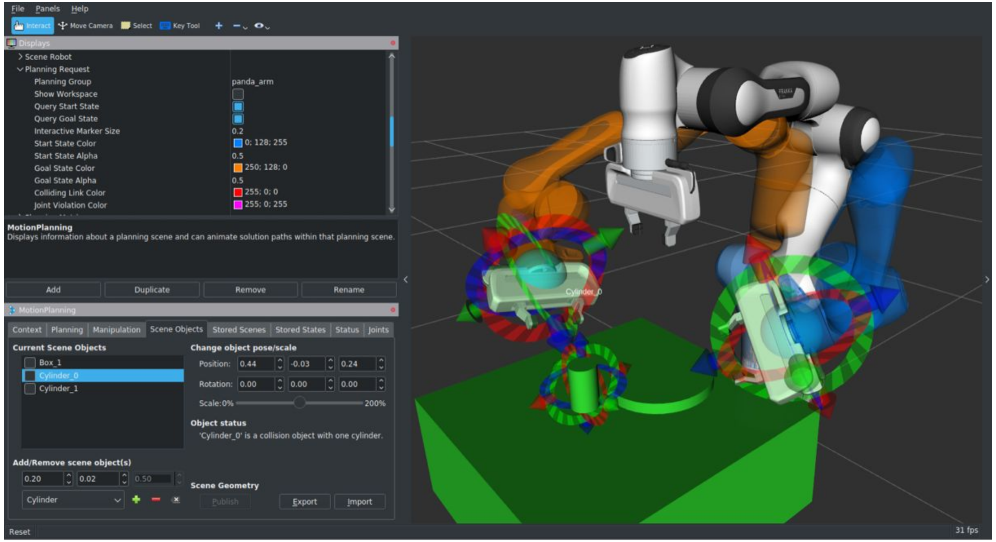
FANUC

KUKA

ABB

The MoveIt stack

- **MoveIt** is the most popular library/stack for working with robot manipulators in ROS 2
- It comes already packed with everything you need:
  - Motion planning
  - Manipulation
  - Inverse Kinematics
  - Control
  - 3D perception
  - Collision checking
  - A 3D interactive visualizer
  - Gazebo simulations
- It supports all the major ROS 2 releases and is constantly updated
- https://moveit.ai/
- https://github.com/moveit/moveit2



Scene Robot
Planning Request

Planning Group	panda_arm
Show Workspace	□
Query Start State	☑
Query Goal State	☑
Interactive Marker Size	0.2
Start State Color	0; 128; 255
Start State Alpha	0.5
Goal State Color	250; 128; 0
Goal State Alpha	0.5
Colliding Link Color	255; 0; 0
Joint Violation Color	255; 0; 255

MotionPlanning
Displays information about a planning scene and can animate solution paths within that planning scene.

Current Scene Objects
□ Box_1
□ Cylinder_0
□ Cylinder_1

Change object pose/scale
Position: 0.44 -0.03 0.24
Rotation: 0.00 0.00 0.00
Scale:0% 200%

Object status
'Cylinder_0' is a collision object with one cylinder.

Add/Remove scene object(s)
0.20 0.02 0.50
Cylinder

Scene Geometry

Robotics & AI
Practical aspects with ROS

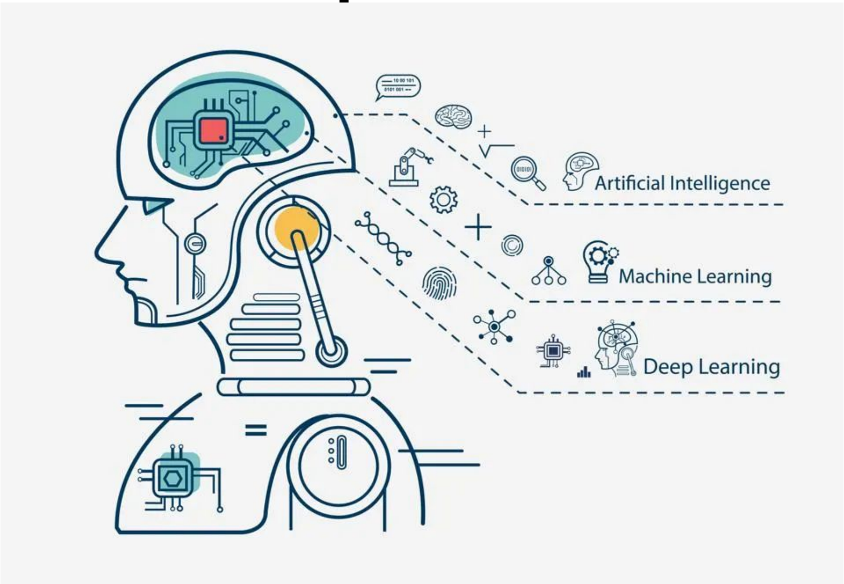


Image source

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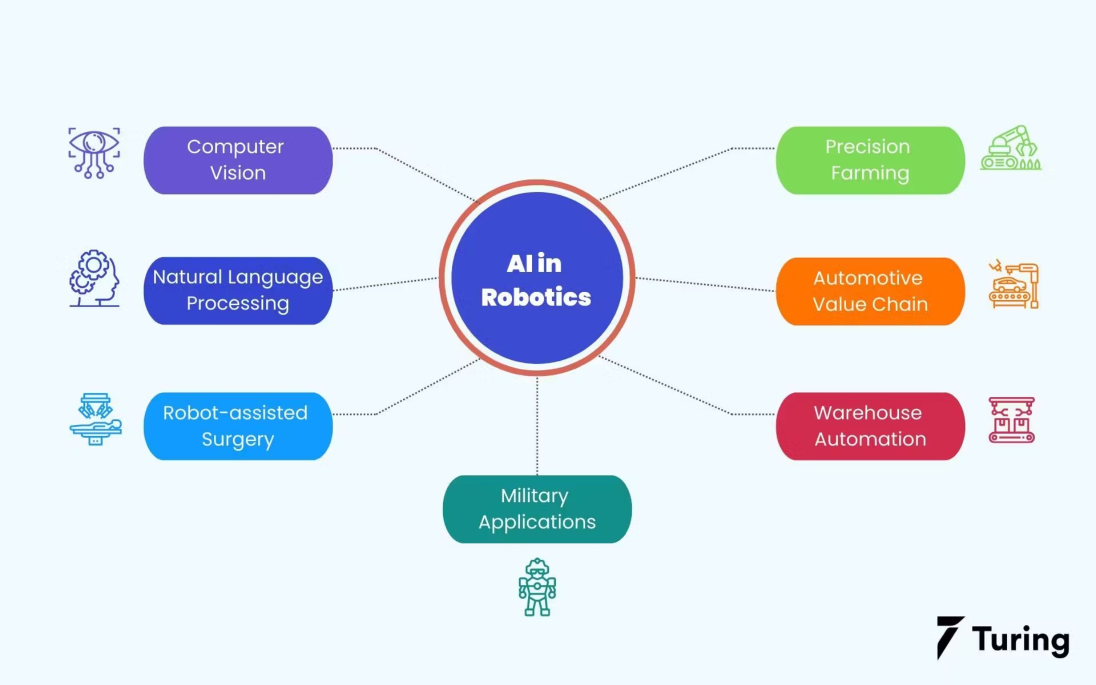
AI applied in robotics Overview



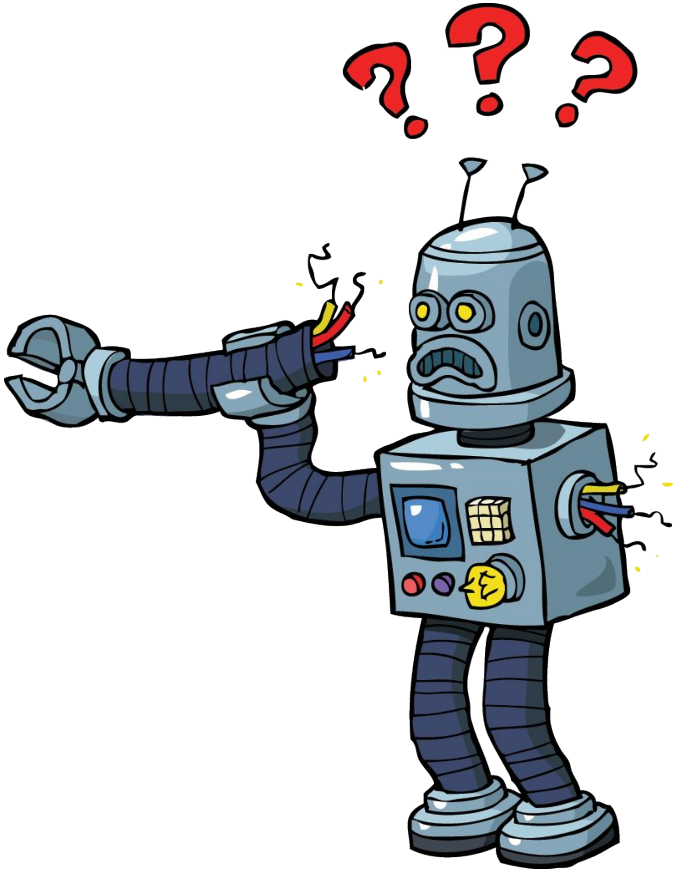
https://www.turing.com/kb/artificial-intelligence-in-robotic-technology

AI & Robotics. A perfect match?

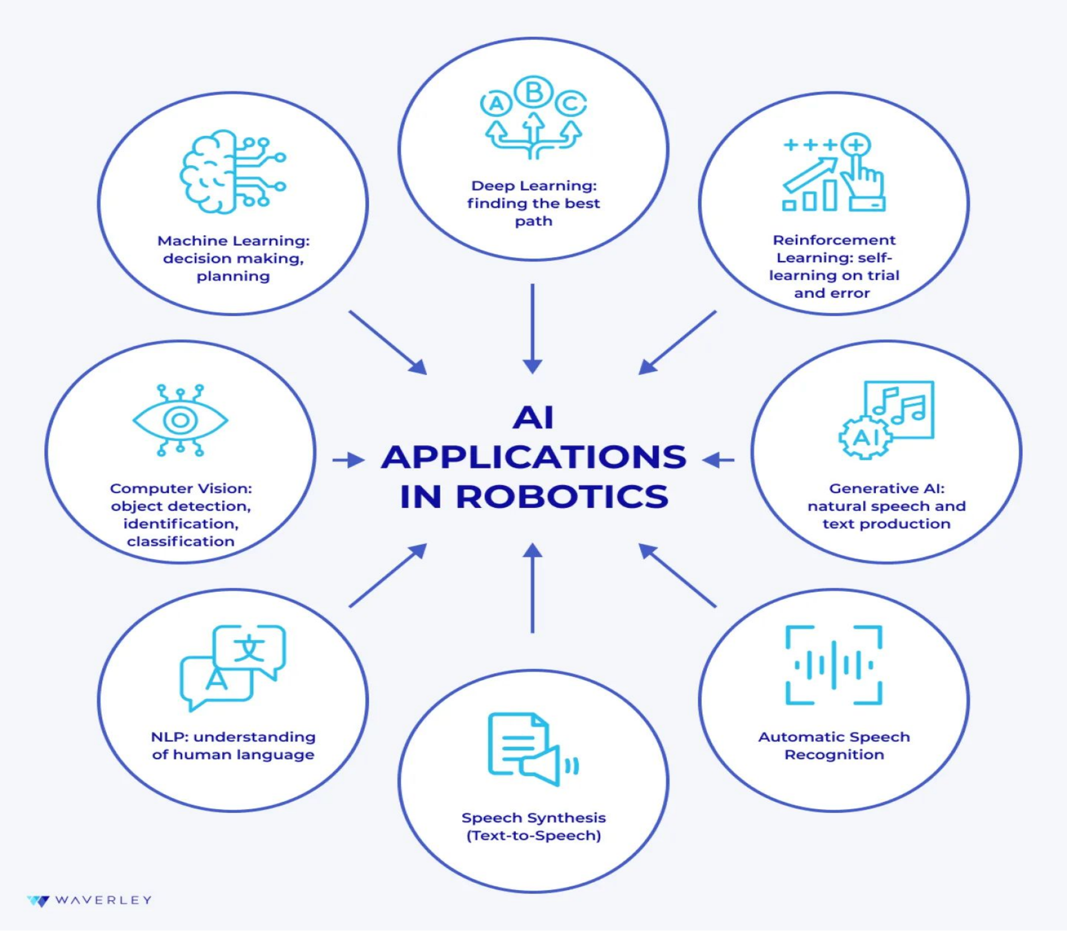
- Whenever someone thinks of AI, they usually think of humanoid robots as a physical representation.
- Before the 80s and the emergence of Machine Learning as a research field robotic tasks were executed using heuristic-based methods.
- With the evolution of both Robotics and AI, computers became cheaper and more efficient, and thus AI methods have gradually been integrated into robot systems
- Every robot is equipped with various data sources (sensors) which provide the data that AI models require for fine-tuning

…or maybe not?

- It is true that the CPU architectures, GPUs, and the computers installed on robots are more powerful and cheaper than ever, but often most AI models are too large and computationally heavy to be deployed “at the edge”
- Training general models that can accomplish multiple types of tasks is very difficult (if not impossible). In production robots, each task requires a separate AI model/method, and immense amounts of training data
- Robot tasks are heavily dependent on context. A model might perform better in some environments, and poorly in others.



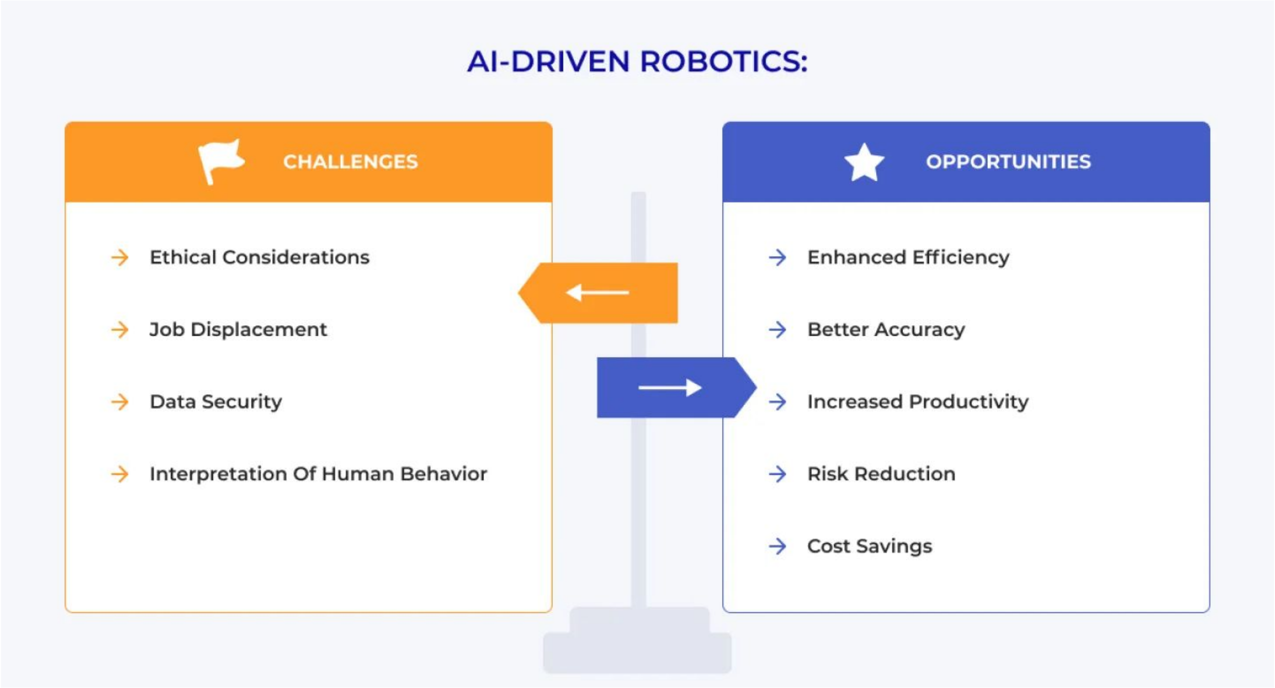
AI methods applied in Robotics in 2025


Deep Learning: finding the best path
Machine Learning: decision making, planning
Reinforcement Learning: self-learning on trial and error
AI
APPLICATIONS
IN ROBOTICS
Computer Vision: object detection, identification, classification
Generative AI: natural speech and text production
NLP: understanding of human language
Automatic Speech Recognition
Speech Synthesis (Text-to-Speech)
WAVERLEY

AND LLMs, ofc :)

Source

Benefits & challenges of applying AI in robotics



AI-DRIVEN ROBOTICS:

CHALLENGES

- Ethical Considerations
- Job Displacement
- Data Security
- Interpretation Of Human Behavior

OPPORTUNITIES

- Enhanced Efficiency
- Better Accuracy
- Increased Productivity
- Risk Reduction
- Cost Savings

Additional challenges:

- Computationally heavy
- Task-specific data scarcity
- High success threshold
- Task-specific complexity

Source

Domains where AI is successfully applied in robotics

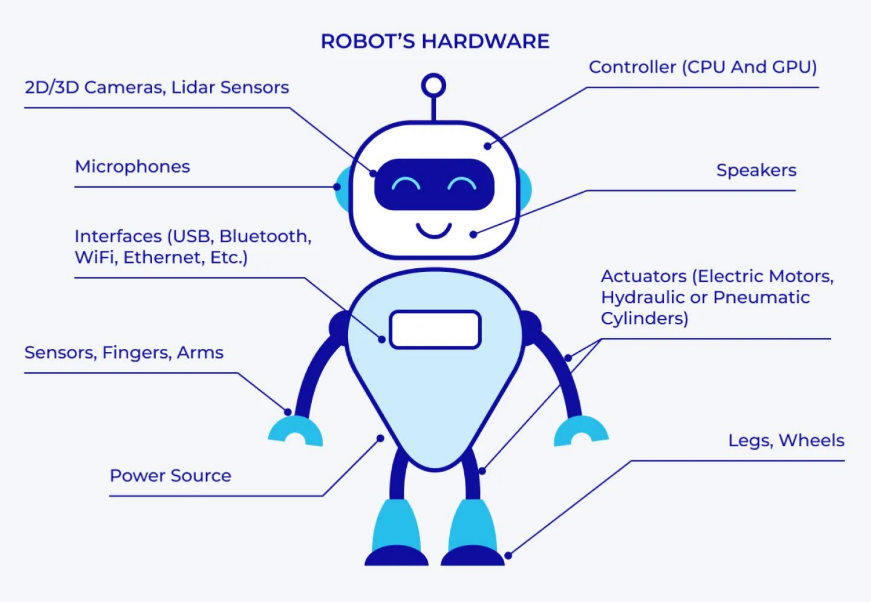
- **Manufacturing**
  - **Quality control** - improved product quality, reduced human intervention
  - **Collaborative Robots** - improved safety, boosted productivity
  - **Autonomous Robots** - increased human safety, improved precision
  - **Assembly Robots** - accident prevention, workflow optimization
- **Aerospace**
  - **Autonomous Rovers** - efficient Mars surface research, improved object identification
  - **Robot companions** - improved work experience and efficiency for astronauts
- **Disaster response**
  - **Drones** - more successful and safer rescue missions
- **Logistics**
  - **Drones** - improved navigation and route planning, increased delivery speed
  - **Autonomous Rovers** - improved workflow, less accidents, less costs, more profit
- **Agriculture** - reduced waste and labour costs, optimal workflow, improved crop yield
  - **Drones**
  - **Autonomous Rovers**
  - **Robot Arms**
- **Healthcare**
  - **Robotic Assistants** - performance increase for medical staff
  - **Robotic Surgery** - greater precision, less risk for the patient
  - **Service Robots** - personalized experience, improved emotional state for the patient
- **Customer service**
  - **Social Robots** - increased customer engagement
  - **Service Robots** - increased product and service delivery speed
- **MilTech**
  - **UAVs -** safer reconnaissance and surveillance
  - **UGVs** - safer operations
- **Smart Homes**
  - **Service robots and robot assistants** - better support for people with disabilities, efficient house chores, learning companion for kids

Source

How do we successfully integrate AI with our robot?

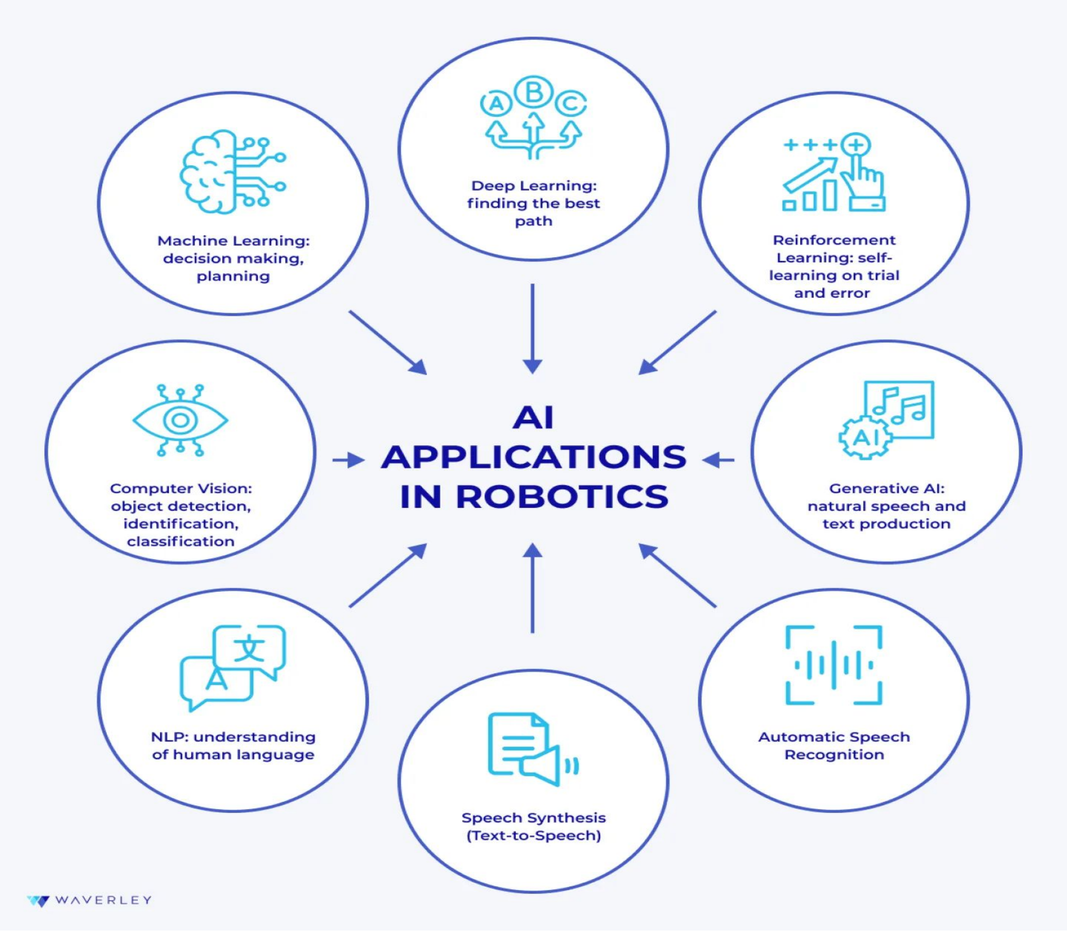
Hardware. Computers & Sensors

- Choosing a powerful enough computer is the most crucial aspect for your AI robotics application to succeed. The computer must be powerful enough to handle processing all the sensor data (cameras, lidars) and the real-time inference from the AI model.
  - The Nvidia Jetson computer family has onboard GPUs that can leverage CUDA acceleration straight on your robot
- Sensors are equally important!
  - Some cameras come already packed with AI models deployed on them, so that the main robot compute does not have to process anything extra.
    - https://www.luxonis.com/
    - https://www.stereolabs.com/en-fi/products/zed-2
  - Lidars


ROBOT'S HARDWARE
2D/3D Cameras, Lidar Sensors
Controller (CPU And GPU)
Microphones
Speakers
Interfaces (USB, Bluetooth, WiFi, Ethernet, Etc.)
Actuators (Electric Motors, Hydraulic or Pneumatic Cylinders)
Sensors, Fingers, Arms
Legs, Wheels
Power Source

Source

Choose the right method for your application

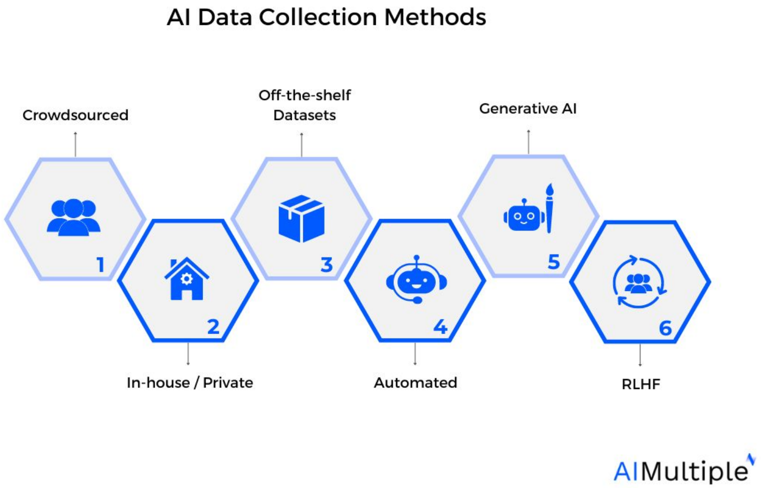

AI APPLICATIONS IN ROBOTICS
Machine Learning: decision making, planning
Deep Learning: finding the best path
A
B
C
Reinforcement Learning: self-learning on trial and error
Computer Vision: object detection, identification, classification
Generative AI: natural speech and text production
AI
NLP: understanding of human language
A
文
Speech Synthesis (Text-to-Speech)
Automatic Speech Recognition
WAVERLEY

Source

Collect and prepare your data

Key aspects to consider:

- **The purpose**, application area, and functionality of your robot will define the data scope it needs to train on.
- **Data annotation and labeling** will be needed for “raw” datasets. There are online resources that offer annotated CV datasets, such as ImageNet or CIFAR-10, but if your application field is too niche or existing datasets are not comprehensive enough, you will most probably have to label your training data yourself
- **Data augmentation**
- **Dataset balancing**
- **Consider ethical issues.** The data you collect and the way you label it will directly impact how your robot might interact with humans!



Source

Test & iterate with your robot and AI model

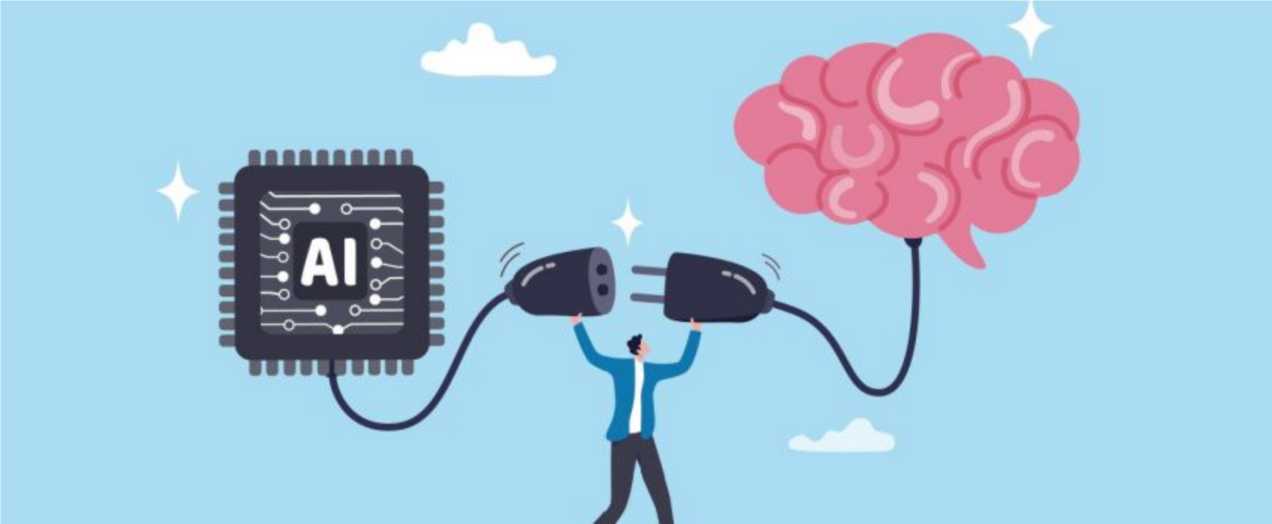
Robotics systems go through classic test levels as **component, integration, system, and acceptance testing**.

- **Simulation and laboratory testing** are must-do when developing a robot
- **Sensor calibration and disturbance testing** to make sure all sensors function normally
- **Tests for navigation and path planning** will verify the robot's ability to avoid obstacles, create accurate maps, and localize itself.
- **Autonomy testing** ensures the robot's decision-making algorithm is robust enough
- **Human-robot interaction tests** evaluate the adequacy and safety of a robot's perception and response to human behavior.

Source

Deploy & monitor

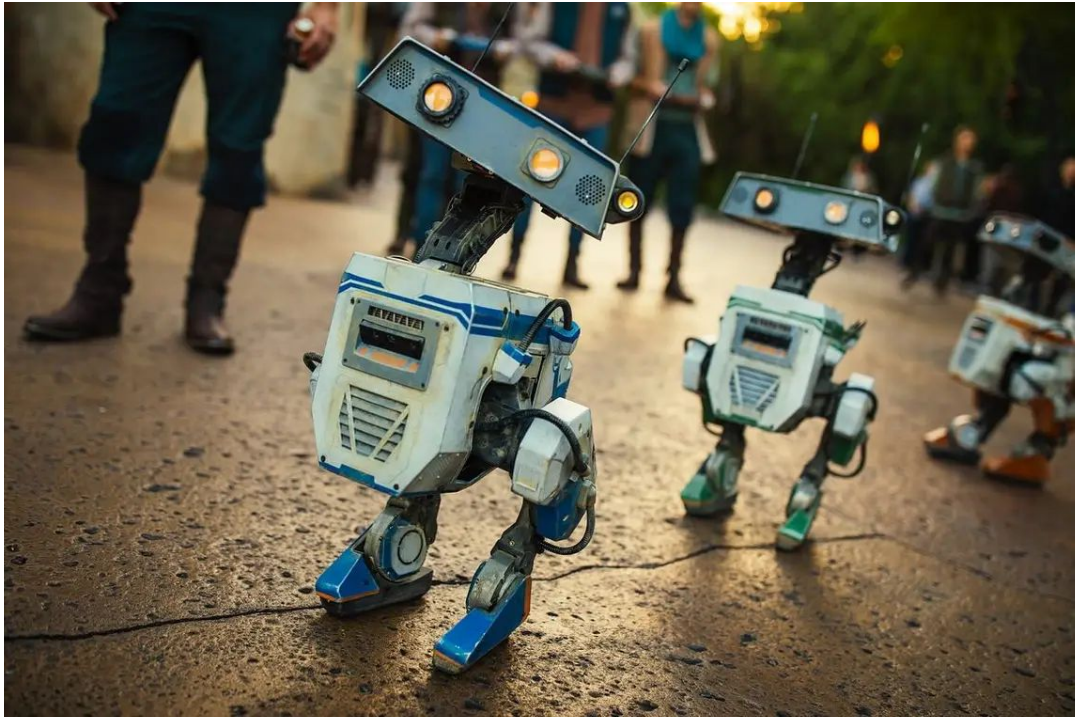
- Ensure **smooth integration of AI models with the Robotic System**, paying attention to communication protocols, compatibility with existing hardware, and real-time constraints.
- **Validate the real-world performance** of the AI models, confirming that they generalize well beyond the training data and simulations.
- **Implement safety protocols and mechanisms** to handle unexpected situations or errors.
- **Implement measures to protect sensitive data** collected or processed by the robotic system.
- **Ensure your robotic system is compliant** with relevant regulations and standards
- **Implement continuous improvement mechanisms** allowing for updates to AI models based on new data and experiences in the field.



Source

Real-world examples of AI applied in robotics

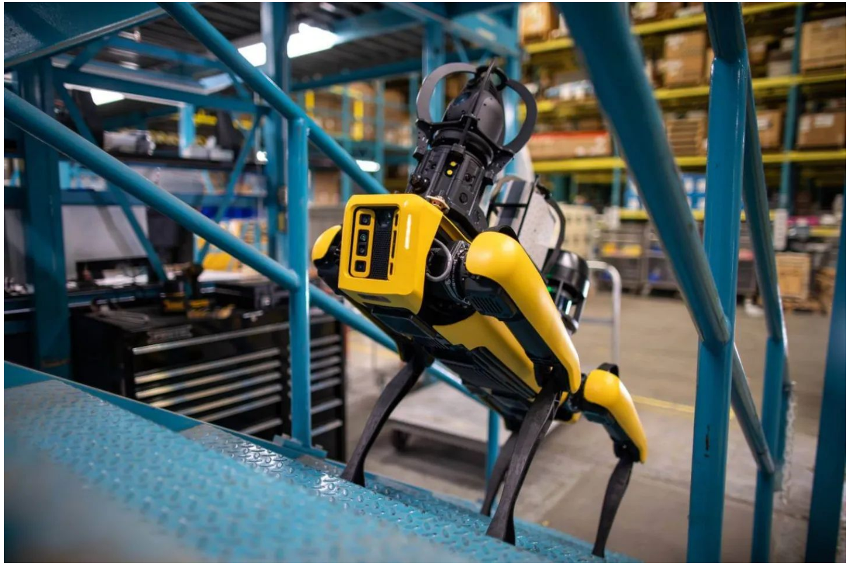
Disney Robots



https://www.wdwmagic.com/attractions/star-wars-land/news/19mar2024-disney-gives-us-another-look-at-the-ground-breaking-star-wars-ai-powered-bd-robots.htm

https://www.youtube.com/watch?v=qNfRgZMWyCI&t=8s

Spot

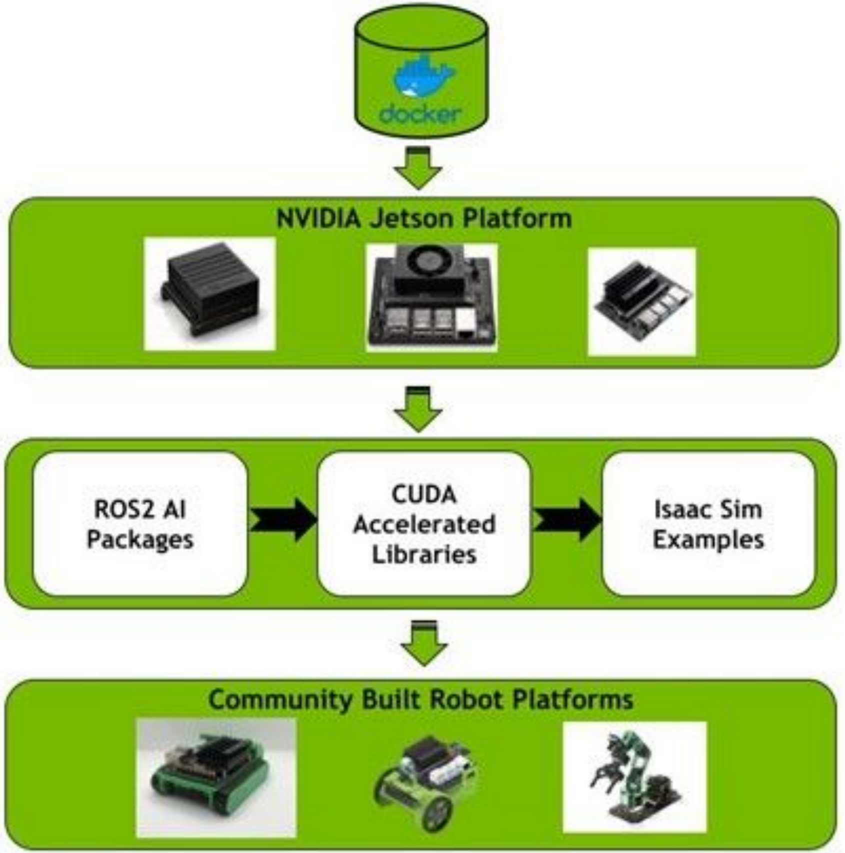


- One of the most famous developments of Boston Dynamics, this robo-dog can walk and navigate around many types of environments, especially outdoors, climb stairs, open doors, and, when equipped with an additional robotic arm, pick and put down objects.
- It already has applications for delivering visibility in hazardous environments, providing remote inspection, and construction site monitoring.

Atlas

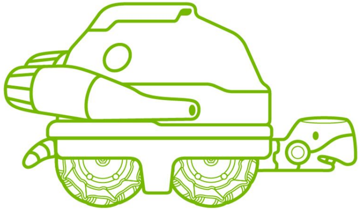
- Another, and the most advanced Boston Dynamics creation to date
- Having incredible abilities to run, jump, skip, and even flip quite smoothly due to advanced hardware and an AI-powered control system
- So far, it has been used for purely research purposes, helping robotic engineers study and push the limits of robotic mobility.

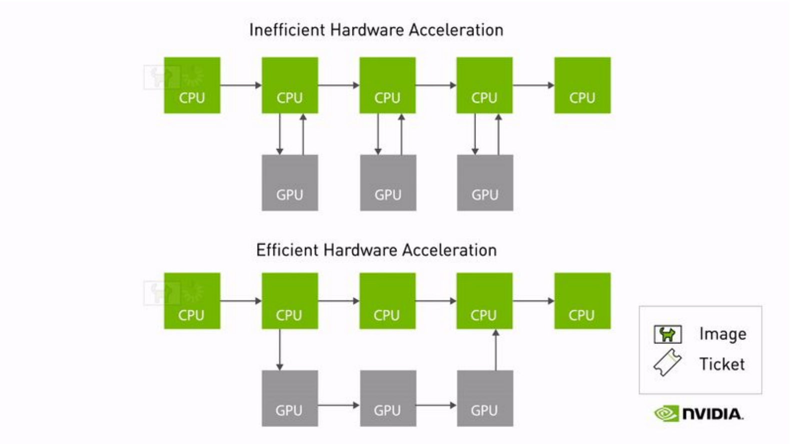
How is AI integrated with ROS?



Nvidia Isaac ROS (I)

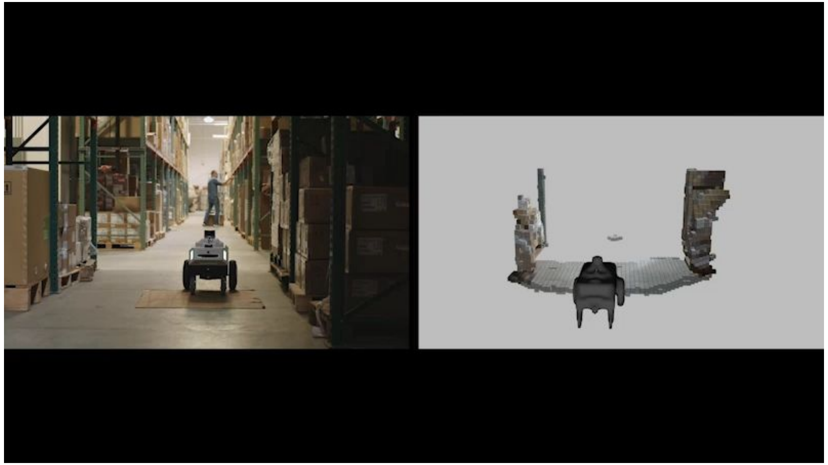
- The Nvidia Isaac ROS ecosystem is a collection of accelerated computing packages and AI models designed to streamline the development of advanced AI robotics applications
- NVIDIA Isaac ROS is built on the open-source ROS 2 software framework
- Isaac ROS delivers a rich collection of individual ROS packages (GEMs) and complete pipelines (NITROS) optimized for NVIDIA GPUs and NVIDIA Jetson™ platforms
- Plug and play with a selection of packages—for computer vision, image processing, robust object detection, collision detection, and trajectory optimization
- Isaac ROS is compatible with all ROS 2 nodes, making it easier to integrate into existing applications





Nvidia Isaac ROS (II)

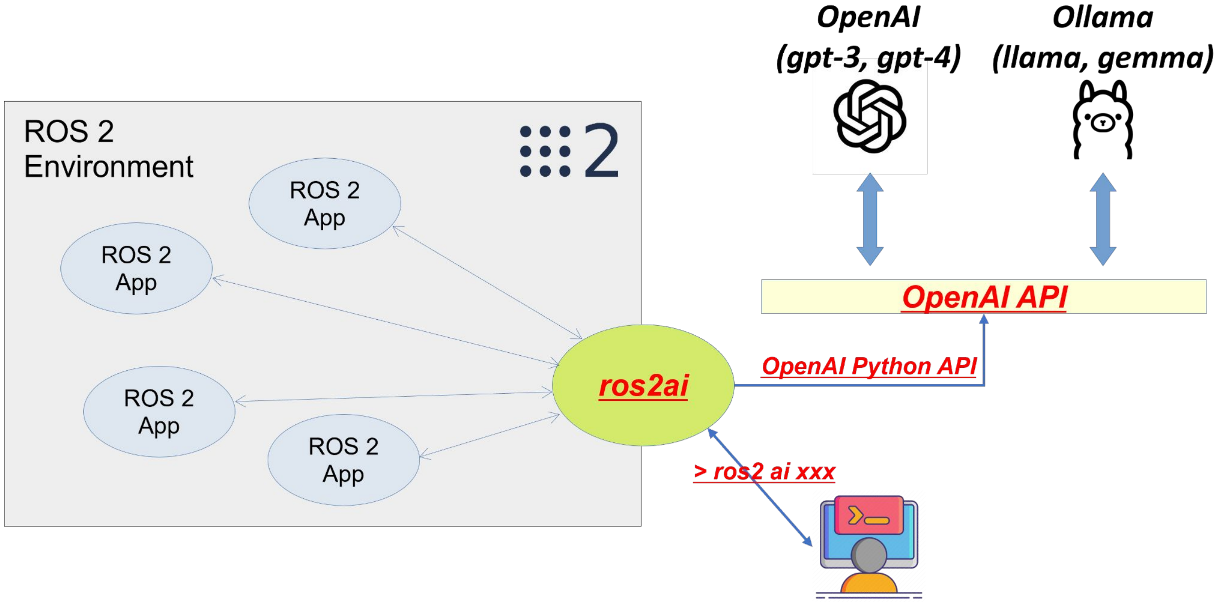
- The Nvidia Isaac ROS packages leverage CUDA hardware acceleration for native deployment of AI models on Nvidia GPU-powered machines
- Included packages:
  - Localization and Mapping
  - 3D scene reconstruction
  - Pose estimation and tracking
  - Motion planning
  - Many more
- https://www.nvidia.com/en-us/autonomous-machines/embedded-systems/
- https://nvidia-isaac-ros.github.io/nova/getting_started/platforms/nova_carter.html
- https://leopardimaging.com/nvidia-nova-devkit/



LLM ROS integration - ros2ai command line interface extension

- https://github.com/fujitatomoya/ros2ai

Let's see a demo of leveraging the GPT-4o-mini model straight in our ROS 2 ecosystem to better understand how to use ROS!



Thank you! 👋