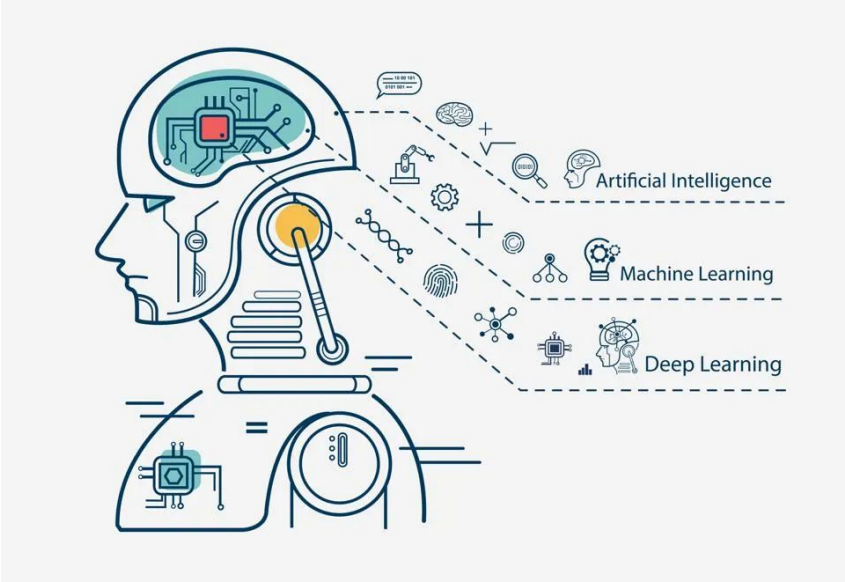
Robotics & AI
Practical aspects with ROS



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UNIVERSITY OF EASTERN FINLAND

Henki Robotics

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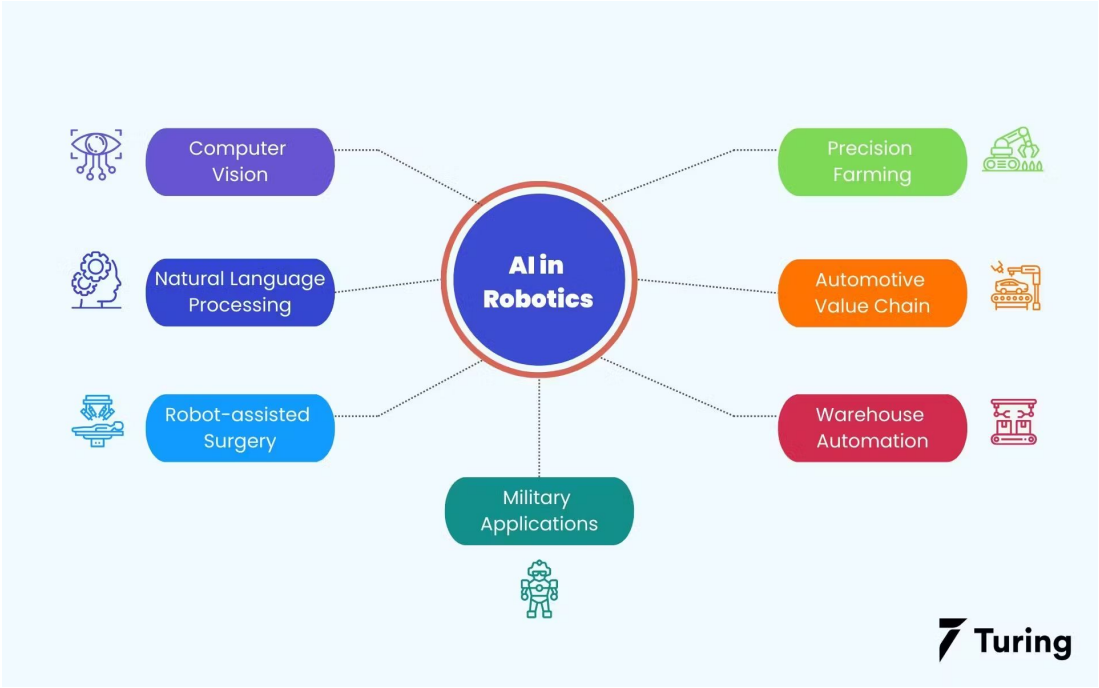
During this lecture…

1. AI applied in Robotics. Overview.
    a. AI & Robotics. A perfect match, or maybe not?
    b. AI methods applied in Robotics in 2024
    c. Benefits & challenges of applying AI in Robotics
    d. Domains where AI is applied in Robotics
2. How do we successfully integrate AI with our robot?
    a. Hardware. Computers & Sensors
    b. Choose the right method for your application
    c. Collect and prepare the data
    d. Test and iterate with your robot & AI model
    e. Deploy and monitor
3. Real-world examples of AI applied in robotics
4. How is AI integrated with ROS?
    a. The Nvidia ISAAC ROS ecosystem
    b. LLM integrations

AI applied in robotics Overview



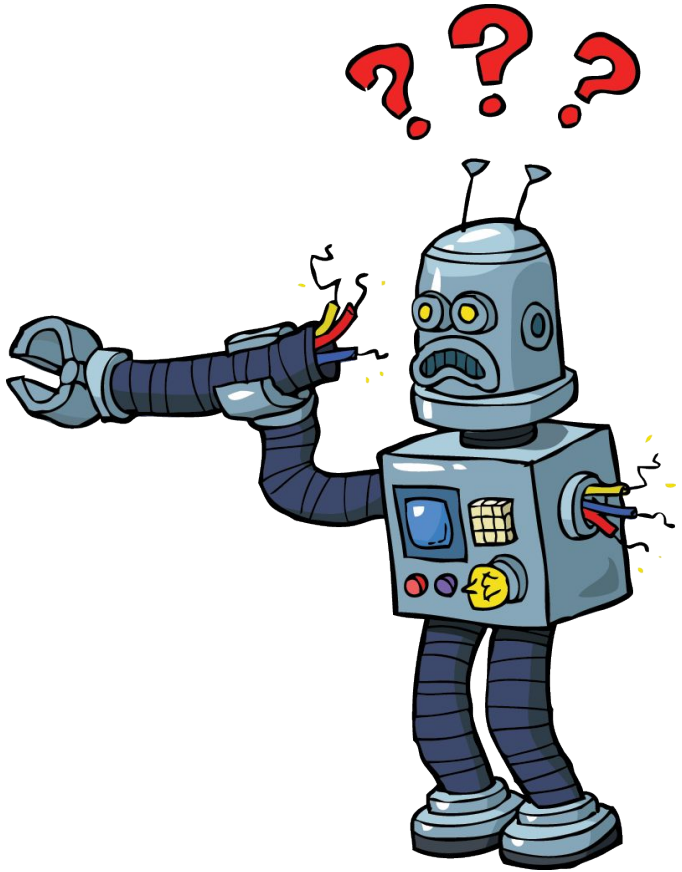
https://www.turing.com/kb/artificial-intelligence-in-robotic-technology

AI & Robotics. A perfect match?

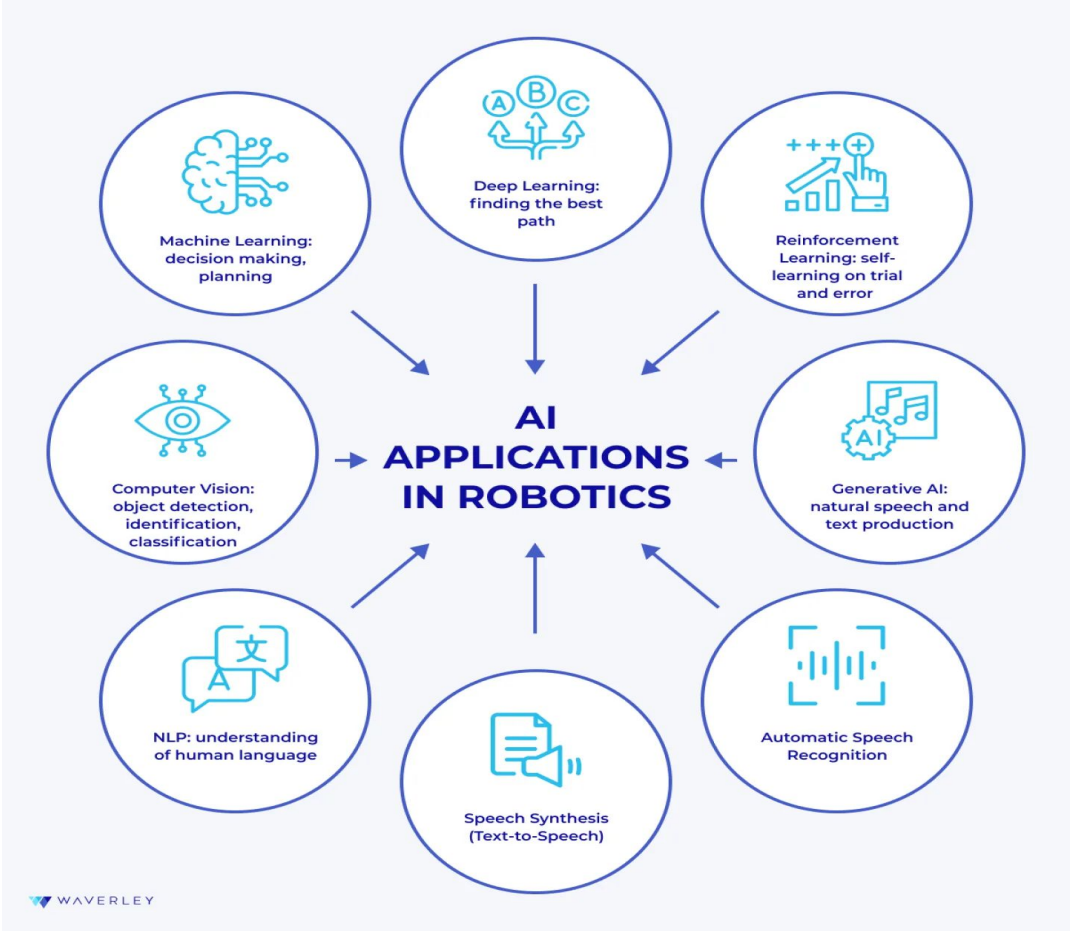
- Whenever someone thinks of AI, they usually think of humanoid robots as a physical representation.
- Before the 80s and the emergence of Machine Learning as a research field robotic tasks were executed using heuristic-based methods.
- With the evolution of both Robotics and AI, computers became cheaper 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 2024



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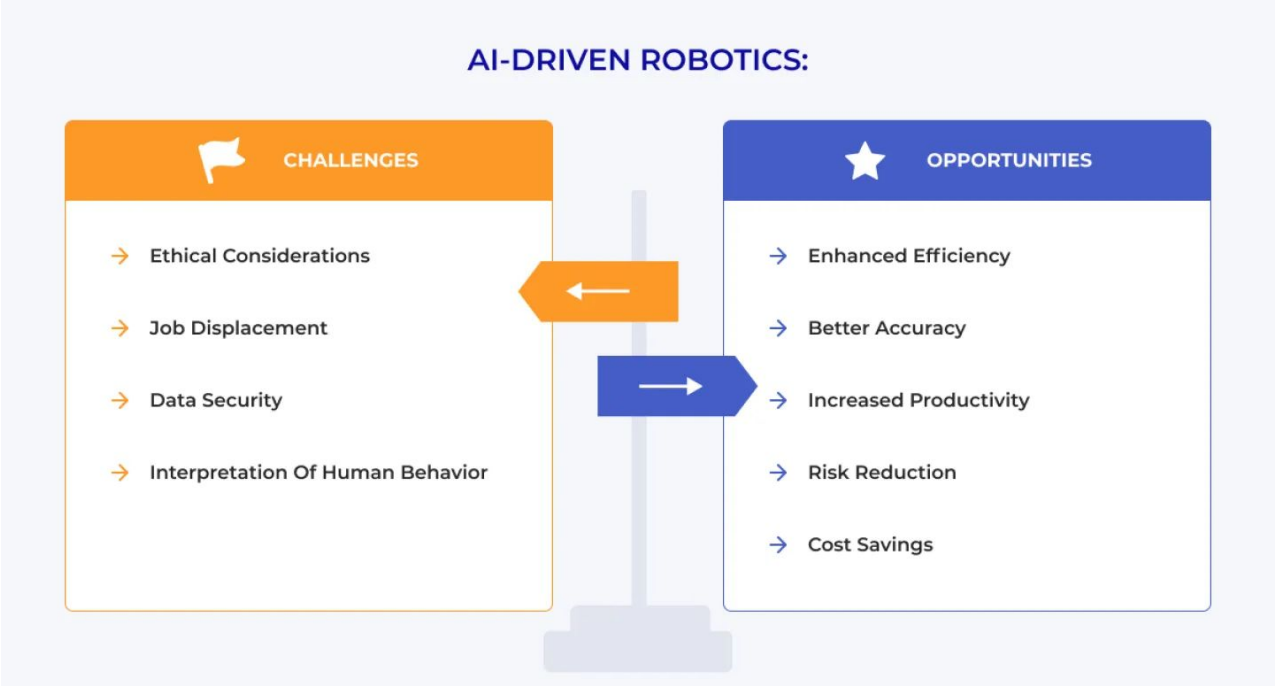
Benefits & challenges of applying AI in robotics



Additional challenges:

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

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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

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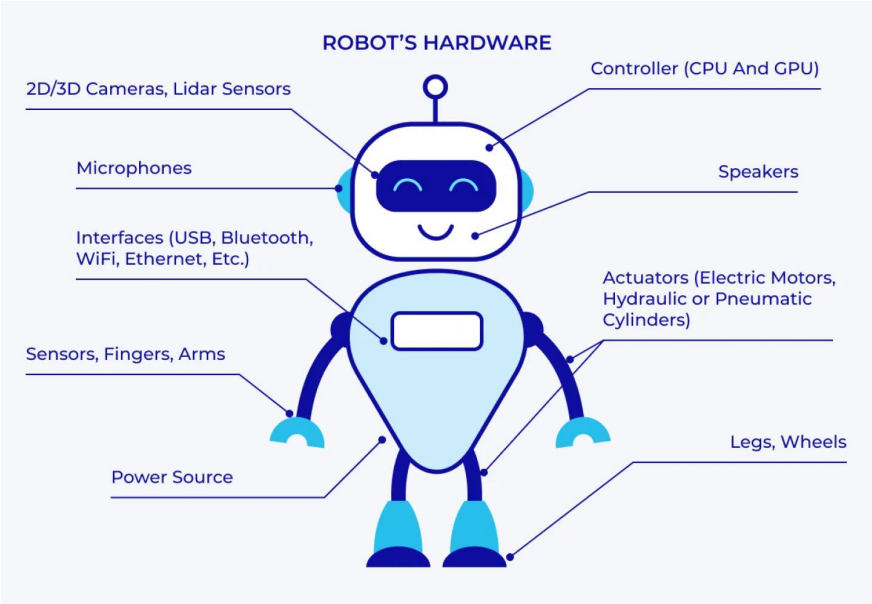
How do we successfully integrate AI with our robot?

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



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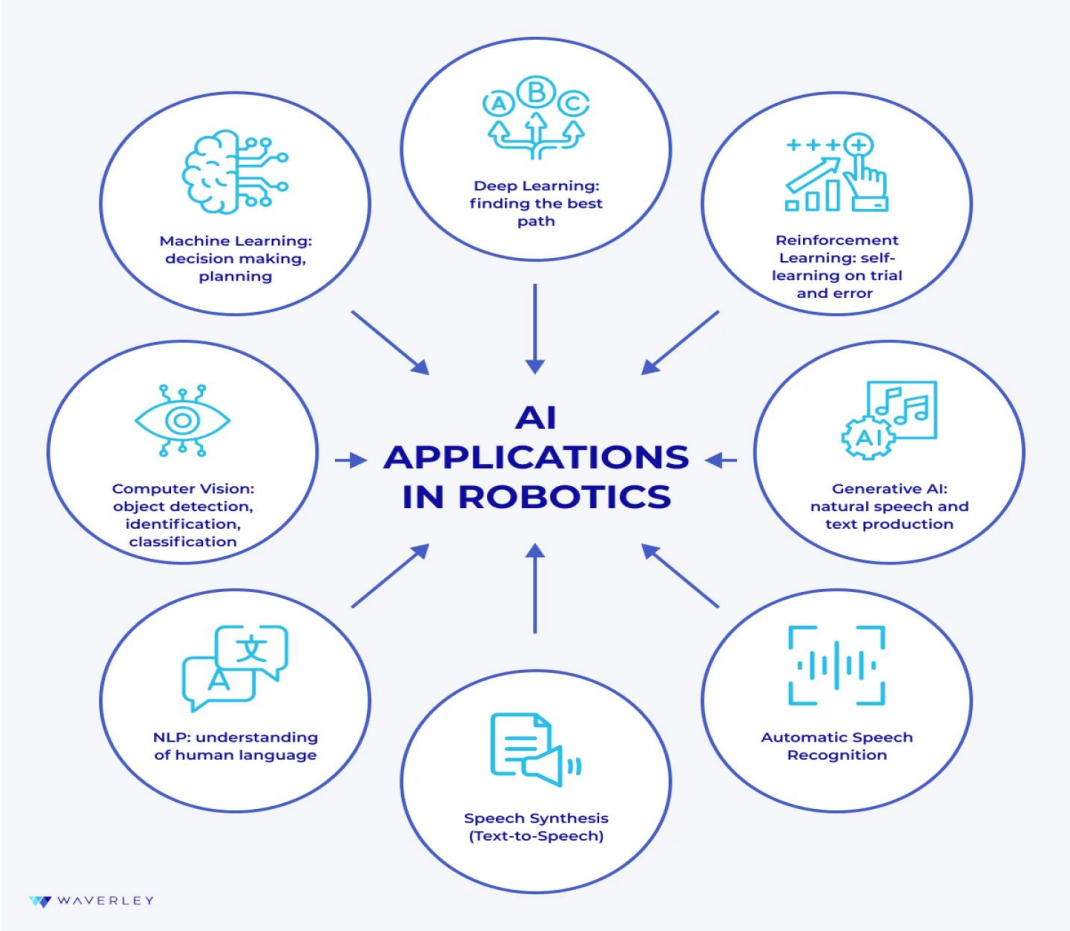
Choose the right method for your application



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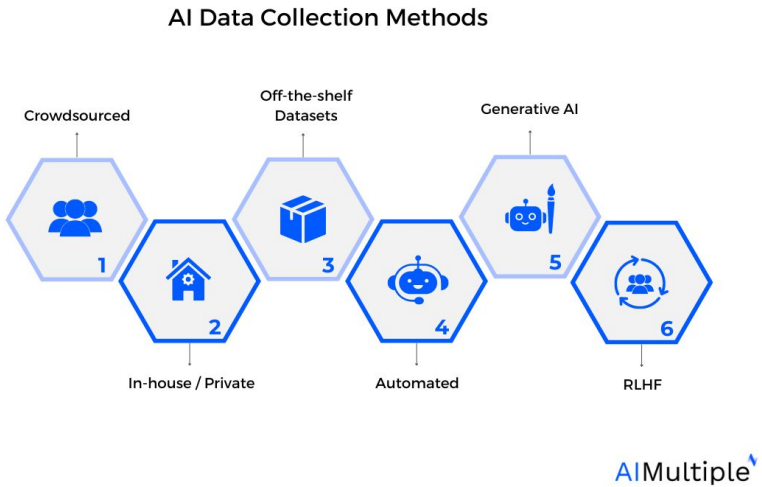
Collect and prepare your data

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!



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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.

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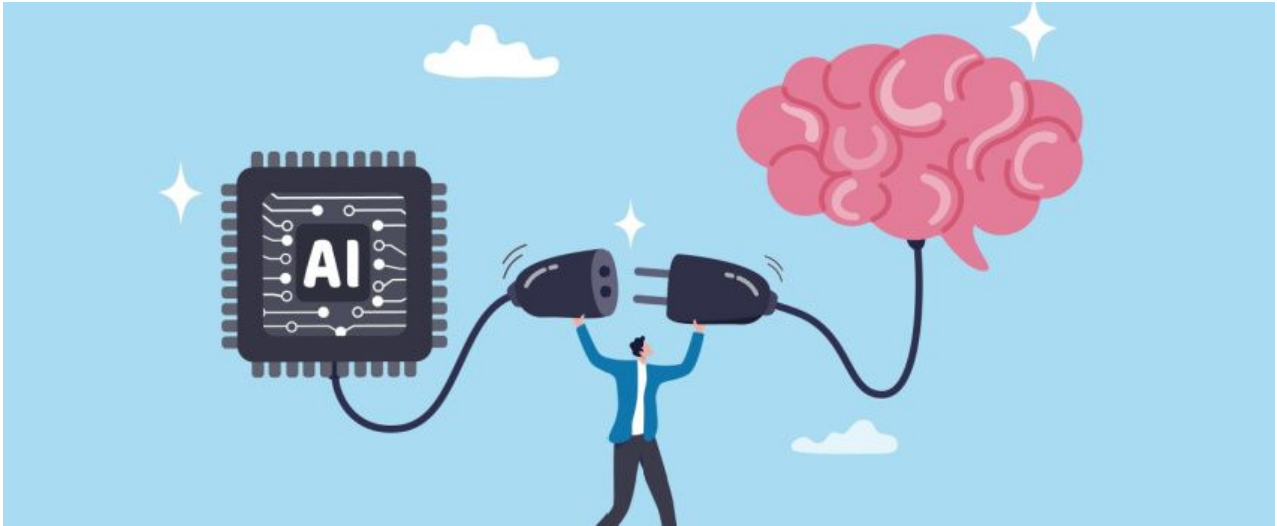
Deploy & monitor

- 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.



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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

Bottobo AMR

- A collaborative robot for supply chain and logistics, which means that in addition to autonomous work and navigation around the facilities, it adapts to human behavior.
- Bottobo's proprietary Warehouse Intelligence System integrates with other client's business applications to provide them with business intelligence features.

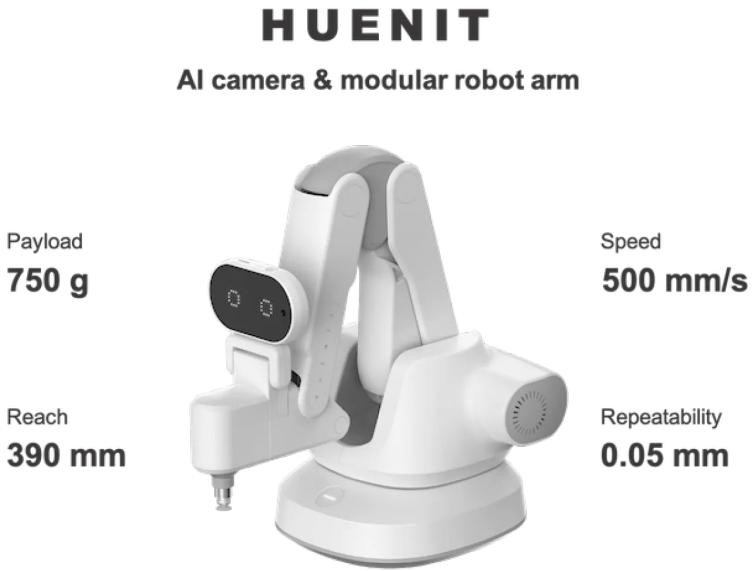
Ideasparq cleaning AMR

- Autonomous Floor Scrubber for cleaning large surface areas
- adaptable to the environment and, in addition to autonomous navigation, path planning, and obstacle avoidance due to their Lidar sensors and cameras, can analyze and optimize its movement patterns and performance using data analytics and ML.

Solomon robot arm

- Powered with proprietary AI vision software, Solomon’s vision-guided robots can efficiently do object picking and placing, material handling and positioning, and defect inspection and repair.
- https://www.solomon-3d.com/accupick-3d/

Huenit robot arm

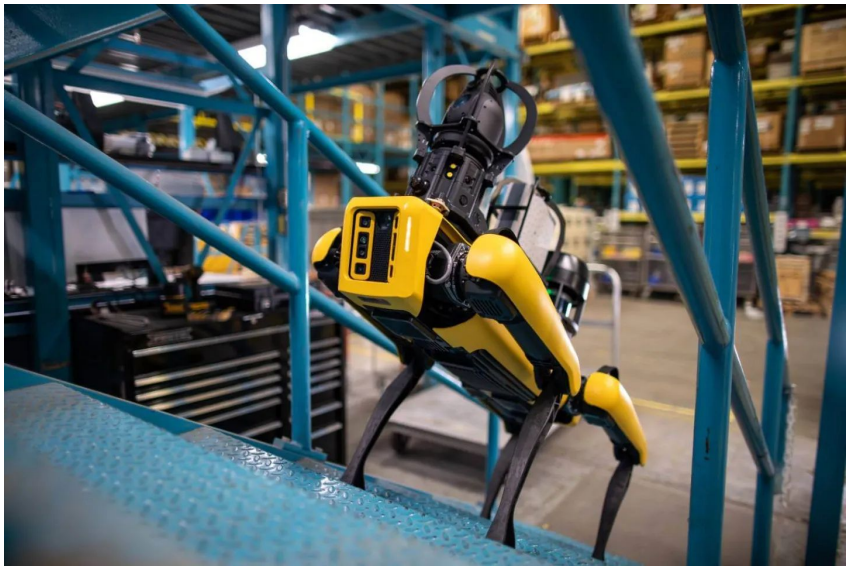


- This is a Kickstarter project for an AI-powered high-precision articulated robot for a household or a small business.
- It is equipped with a camera and microphones with computer vision and voice recognition capabilities. Its robotic arm is modular, so it can serve as a 3D printer, laser cutter and engraver, vacuum gripper, pen holder for writing and drawing, and more, depending on the model in use.

Techman AI Cobot

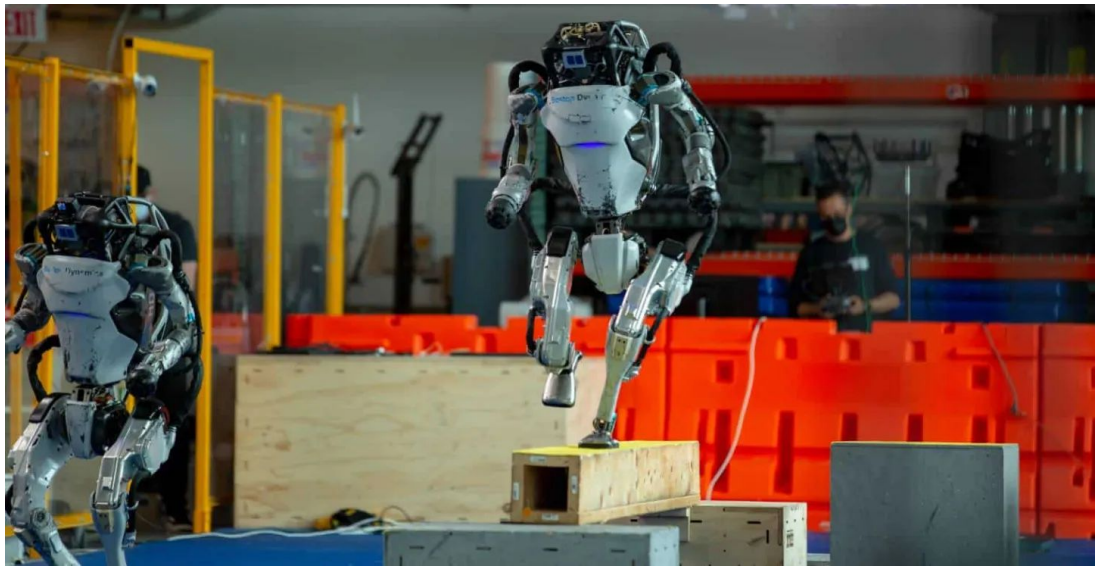
- This is a series of armed robots for the manufacturing industry, enhanced with AI vision technology to better feel the environment they operate in.
- The company has developed tailored TM AI+ Training Server, TM AI+ AOI Edge, and TM Image Manager software to enable clients to train AI models for their cobots, increase their accuracy, and deal with factory deployment.

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

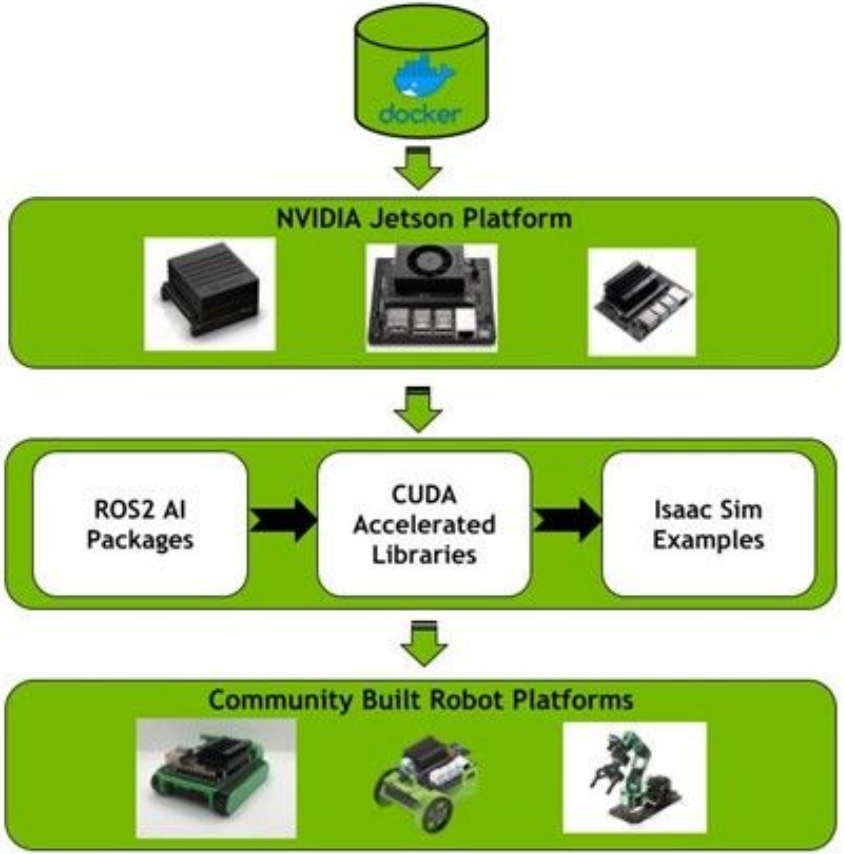


- Another, and the most advanced Boston Dynamics creation to date
- Having incredible abilities to run, jump, skip, and even flip quite smoothly due to advanced hardware and an AI-powered control system
- So far, it has been used for purely research purposes, helping robotic engineers study and push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

Other robots and methods shown during the lecture

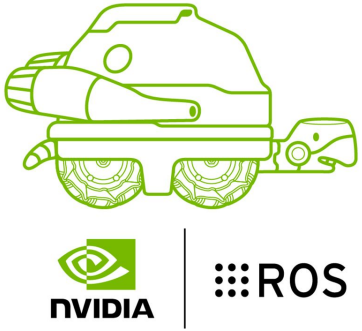
- ALOHA - Learning Fine-Grained Bimanual Manipulation with Low-Cost Hardware
- LQ Q9 robot

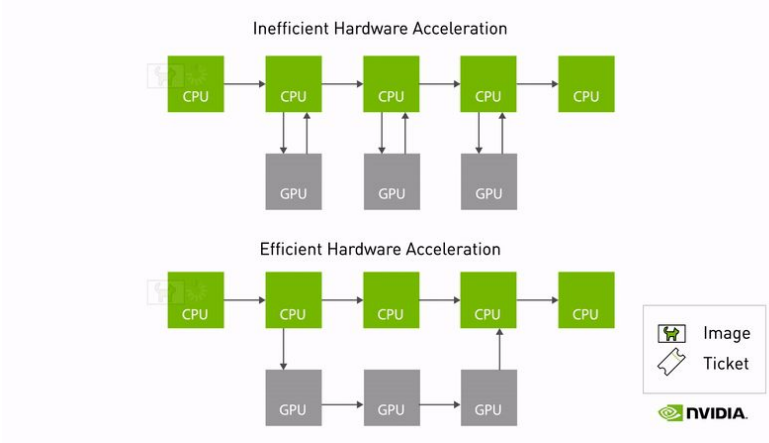
How is AI integrated with ROS?



Nvidia Isaac ROS (I)

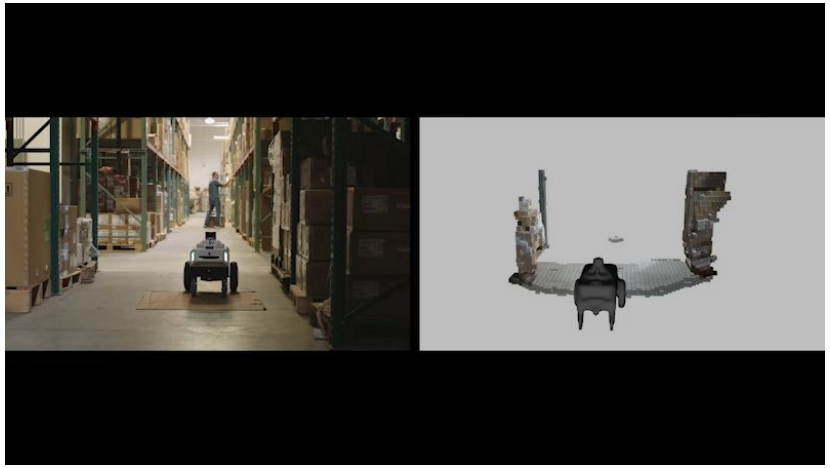
- The Nvidia Isaac ROS ecosystem is a collection of accelerated computing packages and AI models designed to streamline the development of advanced AI robotics applications
- NVIDIA Isaac ROS is built on the open-source ROS 2 software framework
- Isaac ROS delivers a rich collection of individual ROS 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)

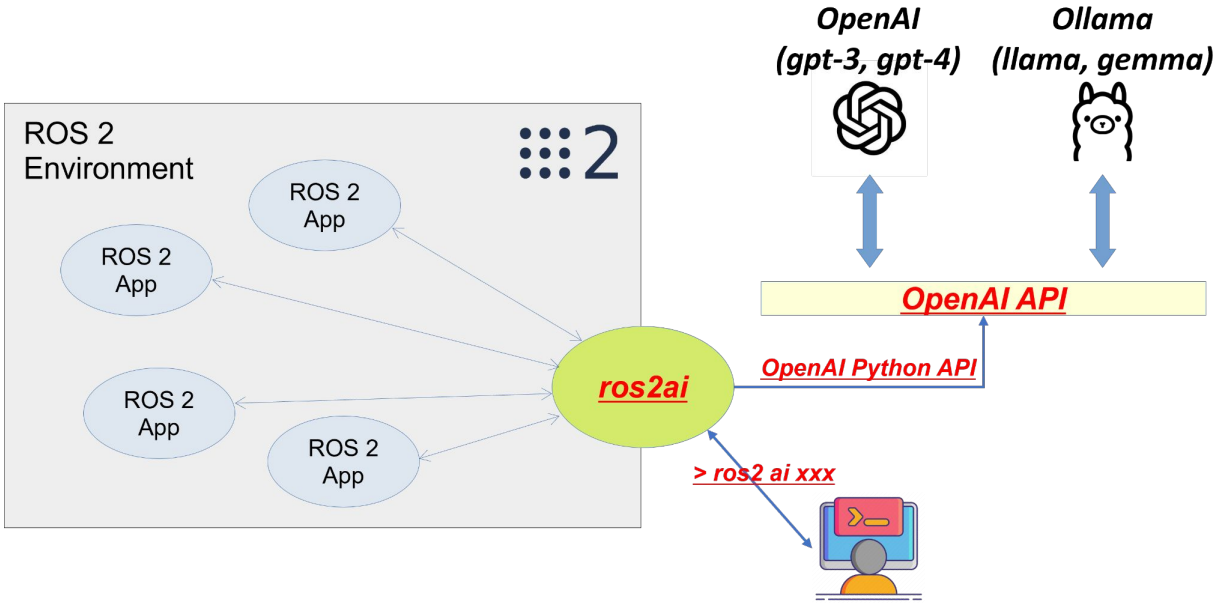
- The Nvidia Isaac ROS packages leverage CUDA hardware acceleration for native deployment of AI models on Nvidia GPU-powered machines
- Included packages:
  - Localization and Mapping
  - 3D scene reconstruction
  - Pose estimation and tracking
  - Motion planning
  - Many more
- https://www.nvidia.com/en-us/autonomous-machines/embedded-systems/
- 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!