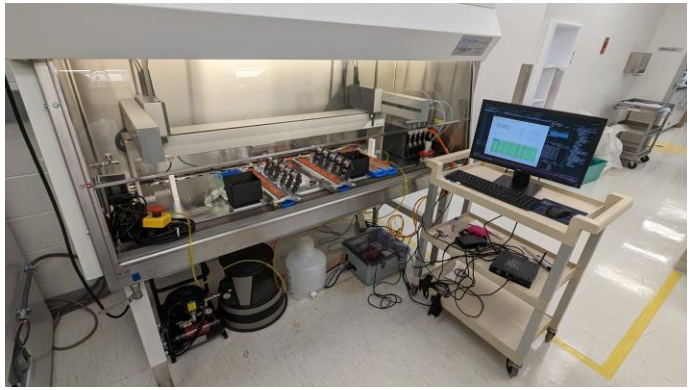
ROX 101

INTRODUCTION TO ADVANCED ROBOTICS

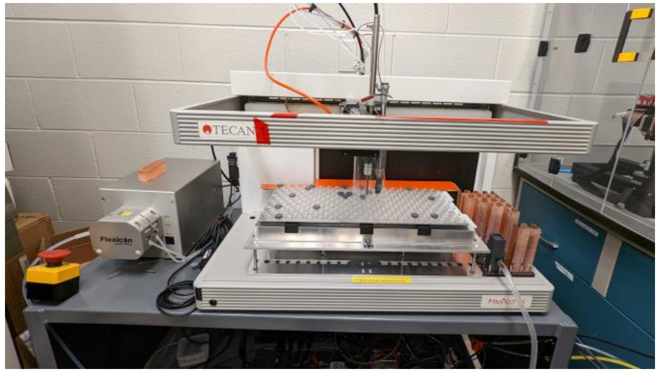
THE INTRO

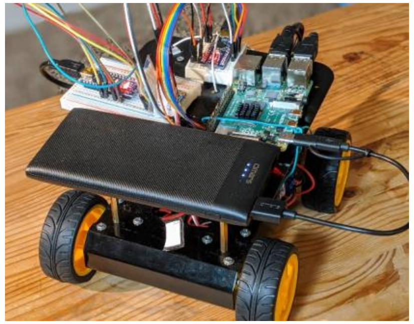
About me

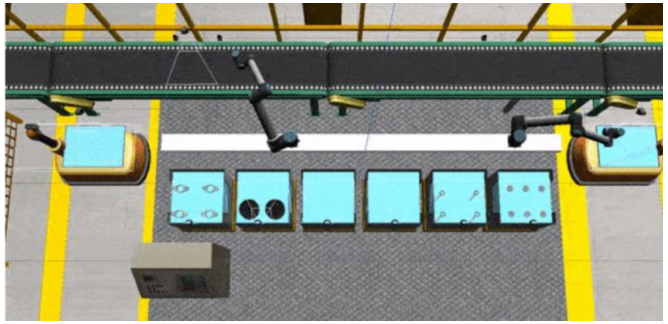
- I'm Srujan Panuganti
- Education
  - Bachelor of Technology in Electronics and Instrumentation Engineering from VNRVJIET, Hyderabad, India
  - Masters in Robotics from University of Maryland, College Park, Maryland, US
- Work
  - Founder and Robotics Engineer at Xairo Tech Private Limited
  - Worked as Instrument Scientist at AbbVie Inc. in Chicago, US
  - Worked as Robotics Engineer at ARIS Technology LLC in Chicago, US



• Few of the robot systems that I built







About Xairo

Xairo's Vision
Xairo envisions to make Human-Robot co-living Harmonious.

Xairo's Mission
At Xairo we are on a mission to pioneer innovations in Sustenance, Safety, Exploration and Universal Peace (S, S, E, U)

1.Sustenance - Healthcare, Agriculture
2.Safety - Disaster Management & Rescue, Security, Emergency Response
3.Exploration - Terrestrial, Aquatic, Aerial and Space Exploration and
4.Universal Peace - Peace keeping, Defense

About Xairo

- We are currently focused on Safety, especially within the area of Artificial Intelligence. We are currently studying the trustworthiness aspect of the currently available AI agents and tools. We are motivated towards building tools and workflows to make sure the AI agents are trustworthy
- We also conduct training sessions providing Advanced knowledge in Robotics to enthusiastic individuals active in Robotics and working professionals within the field.

About Xairo

- Our office is in P-406, VJ Hub at VNRVJIET, Hyderabad
- The founding team includes Srujan Panuganti and Pranavi Sura, alumnus of VNRVJIET (2012-2016) graduated with a B.Tech. degree in Electronics and Instrumentation Engineering.

Why should you study Robotics?

- To keep yourself updated with latest trends in robotics industry.
- To have a competitive edge within robotics, for the expected increase in robotics jobs around the world
- To innovate new robotic technologies to solve various problems.
- To become a Robotics Entrepreneur
- By Learning Robotics, you can make a career in Automotive industries(autonomous cars), Computer Vision, Artificial Intelligence and Machine Learning roles, Automation and Control Industry, Industrial Robotics and many more.
- You can find robotics roles in almost every engineering industry.

Course Outline

- Session 1 – 07/09/2024
    - Quiz #1
    - Part 1 – About Robotics and the current State of The Art
    - Part 2 – Key aspects in Robotics
    - Part 3 – Hardware tools in Robotics.
    - Activity – Lab tour
    - Lunch break
    - Part 4 – Software tools in Robotics
    - Part 5 – Usage of a Linux system
    - Hands on Activity – Hands on for Linux commands
    - Hands on T-Rex
    - Assignment #1

Course Outline

- Session 2 – 14/09/2024
  - Quiz #2
  - Part 1 – Before ROS2
  - Part 2 – Concepts in ROS2
  - Lunch break
  - Part 3 – Concepts in ROS2
  - Activity – Handson ROS2
  - Part 4 – Concepts in ROS2
  - Group Assignment #1

Course Outline

- Session 3 – 21/09/2024
  - Quiz #3
  - Part 1 –2D and 3D Geometry
  - Hands on Activity – Exercise on tf2
  - Part 2 – Obstacle Space, Workspace
  - Lunch break
  - Part 3 – Building URDF
  - Activity – URDF Visualization
  - Activity – turtlebot3 bringup
  - Part 5 – About Mapping, Localization in ROS2
  - Group Assignment #2

Quiz #1

- https://forms.gle/yk8ptDP5ih52LHxg7

Part 1

- What is a Robot?
- Why Robots?
- Kinds of Robots
- Areas where robots are used
- Robot Systems

What is a Robot?

What is a Robot?

https://www.xmachines.ai/agricultural-robots

What is a Robot?

Performance in a compact size

With a reach of 1300 mm and a payload of up to 30 kg, UR's next-generation cobot handles more tasks, fits more applications and helps in more environments than ever before.

Learn more about UR30

https://www.universal-robots.com/

What is a Robot?

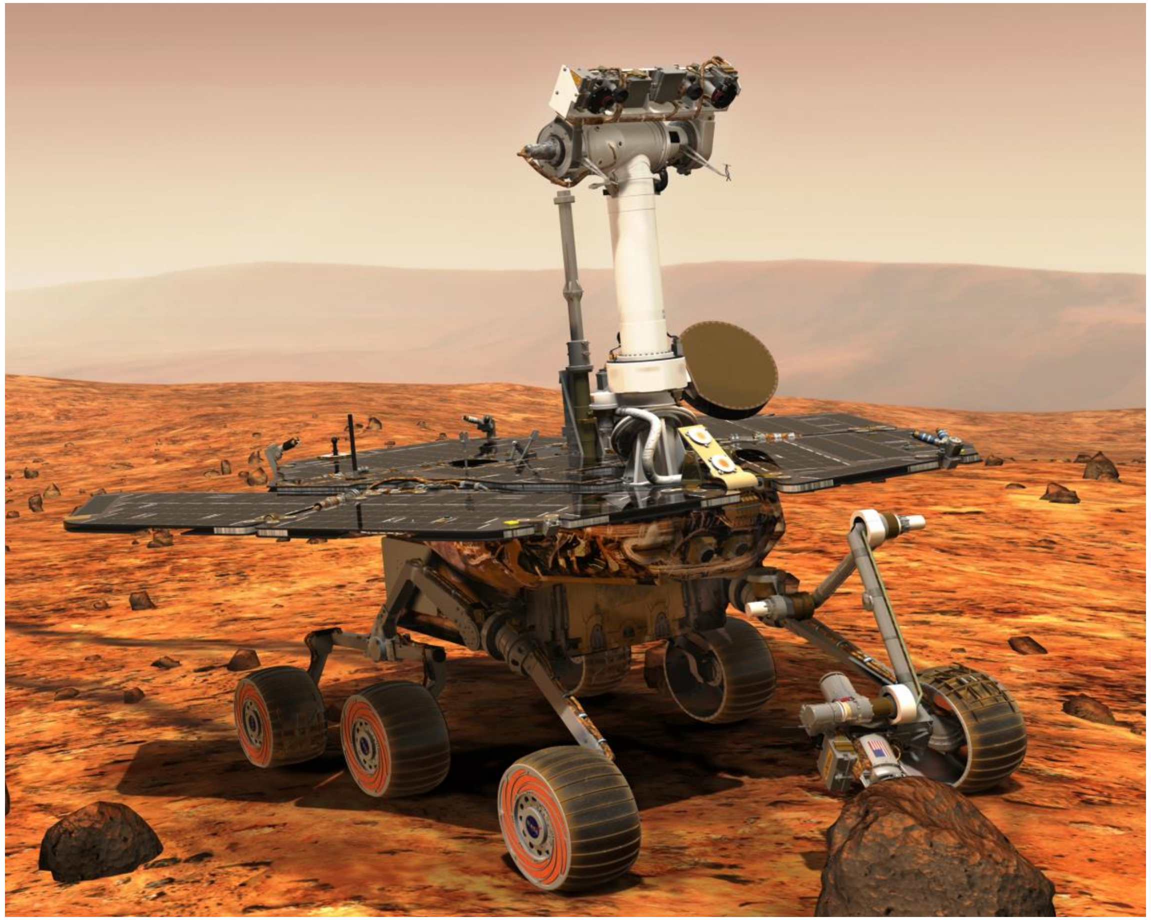
https://www.hp.com/

What is a Robot?

What is a Robot?

https://www.bosch-pt.co.in/

What is a Robot?

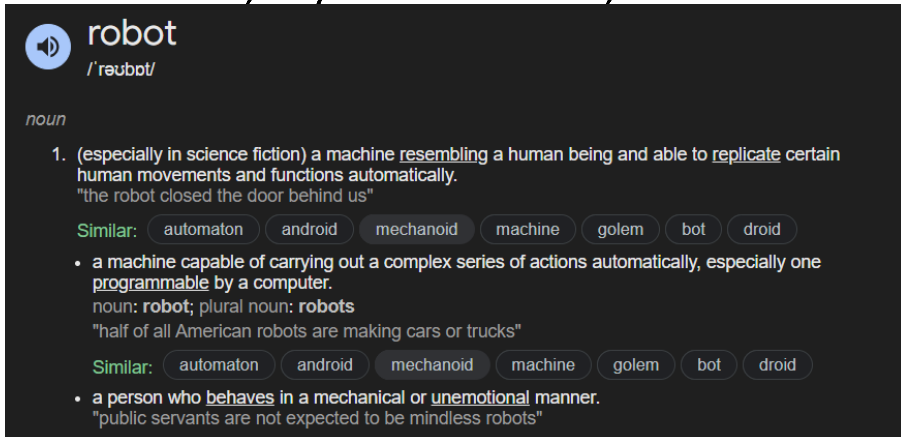


http://www.spaceflightinsider.com/

What is a Robot?

- “Any automatically operated machine that replaces human effort, though it may not look much like a human being or function in a humanlike manner. The term comes from the play *R.U.R.* by Karel Capek (1920).”(from Merriam-Webster online)
- “A robot is:
  1. An artificial device that can *sense* its environment and *purposefully act* on or in that environment;
  2. An *embodied* artificial intelligence; or
  3. A machine that can *autonomously* carry out useful work.”

Source: “Robotics: A Very Short Introduction,” by Alan Winfield, Oxford Univ. Press, 2012



Another Definition of a Robot

- Robots are machines that can replace humans in a task requiring both physical and mental activity.

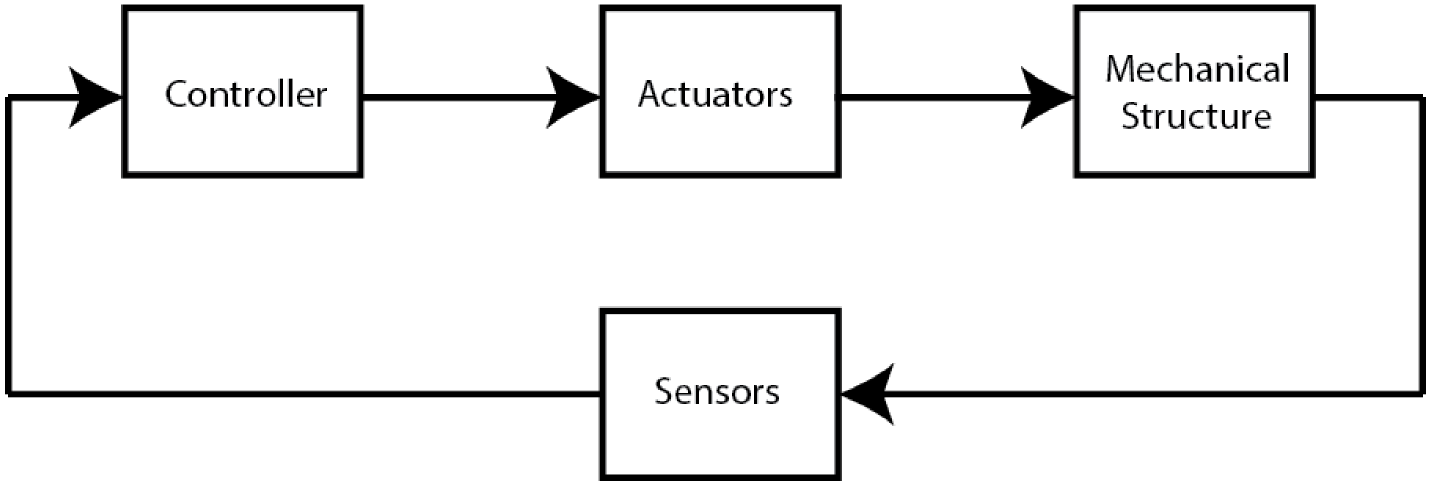


Figure1: Generic block diagram for a robot.

Why Robots?

Why Robots?

- We need robots to make our lives easier and safer.
- They can perform tasks that are dangerous, repetitive, Dexterous, inaccessible or require precision beyond human capabilities.
- Robots help in various fields, from manufacturing and healthcare to space exploration and disaster response.
- By taking on these roles, robots enhance productivity, improve safety, and allow humans to focus on more complex and creative tasks.

Hazardous

LAPD Bomb Squad

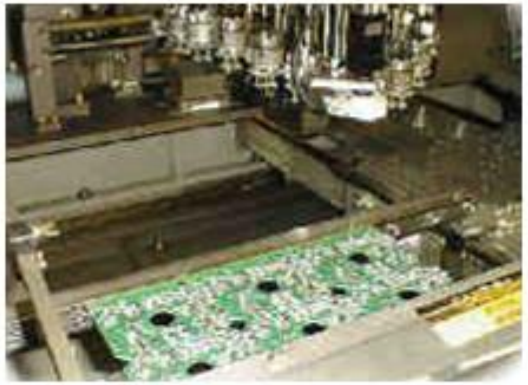
Repetitious

Automated car painting

Dexterous

Automotive welding

Precise



Circuit board manufacturing

da Vinci robot for cardiothoracic surgery

Inaccessible

Curiosity rover on Mars

Components of a Robot

- One can think of a robot as a device consisting of five kinds of components
    1. Sensors
    2. Actuators
    3. “Brain”—some sort of computing device to interpret sensor signals, make decisions, and perform control.
    4. A mechanical structure to hold all of the other components and enable them to do physical tasks.
    5. Power supplier

Kinds of Robots

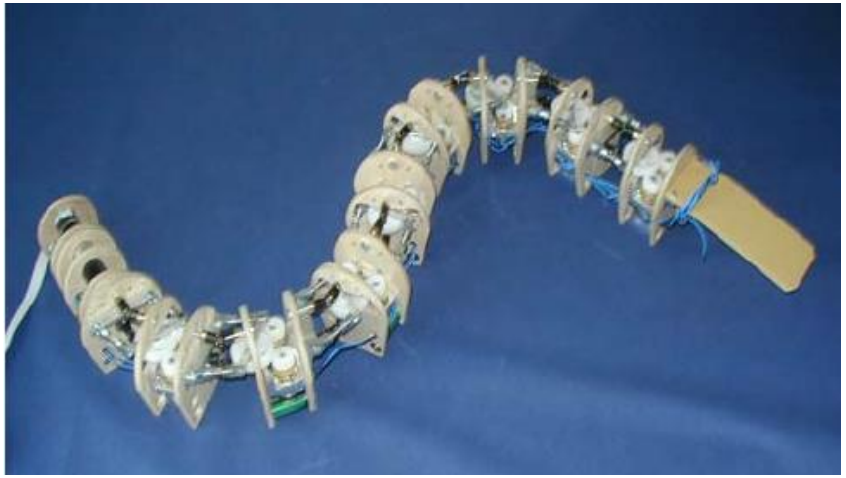
Articulated Robots

- Serial Link Manipulators
  - Joints in series
  - Location of one depends on those preceding it
  - Prismatic or revolute (rotary)
- Parallel Link Manipulators
  - Joints in parallel
  - Joints fixed to common base
  - Prismatic or revolute
  - [Acrome Stewart Platform - YouTube]

https://svayarobotics.com

Articulated Robots

- Hyper-redundant systems
  - Many more DoF than necessary to achieve arbitrary end effector pose
  - Links often shorter with more limited range
  - Number of joints allows obstacle avoidance
  - Examples
    - Elephant trunk
    - Snakes
    - Tentacles



https://www.researchgate.net/figure/The-hyper-redundant-robot-of-AASS-test-prototype_fig1_279970620

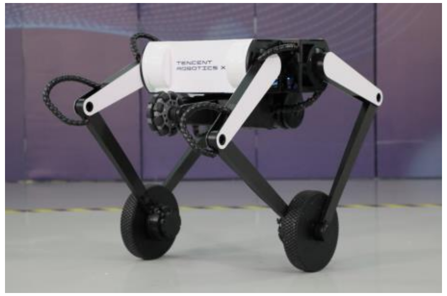
Mobile Robots

- Mobile robots
  - Base frame moves through the world
  - World contact can vary
  - Examples
    - Quadcopters
    - Wheeled robots
    - Walking robots
    - Underwater robots

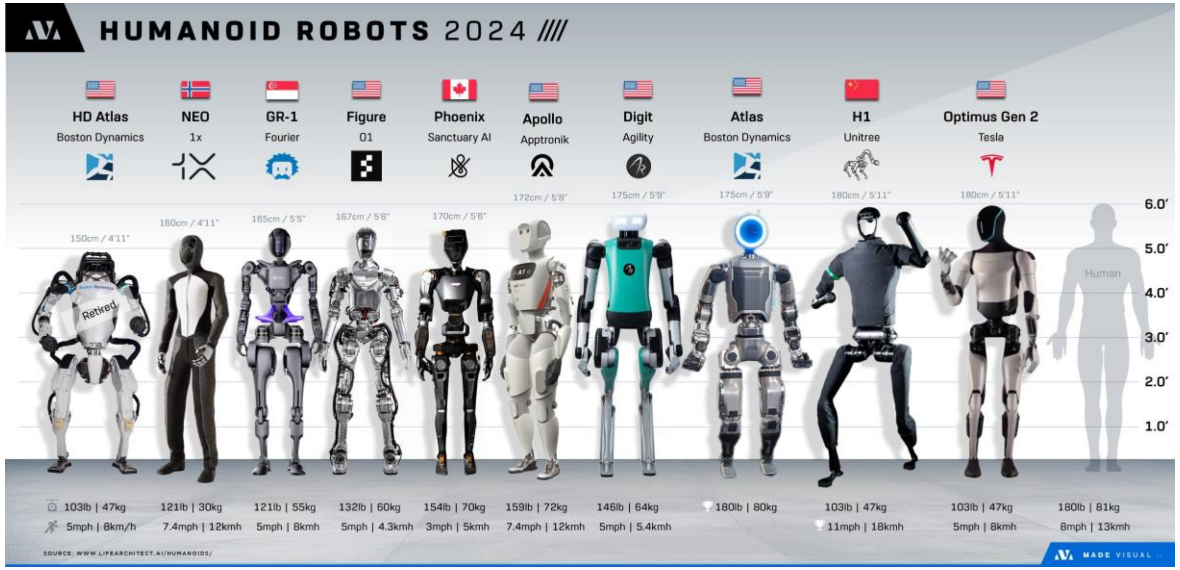
https://www.theengineer.co.uk/

Mobile Robots

- **Wheeled Robots**



- **Legged Robots**



Mobile Robots

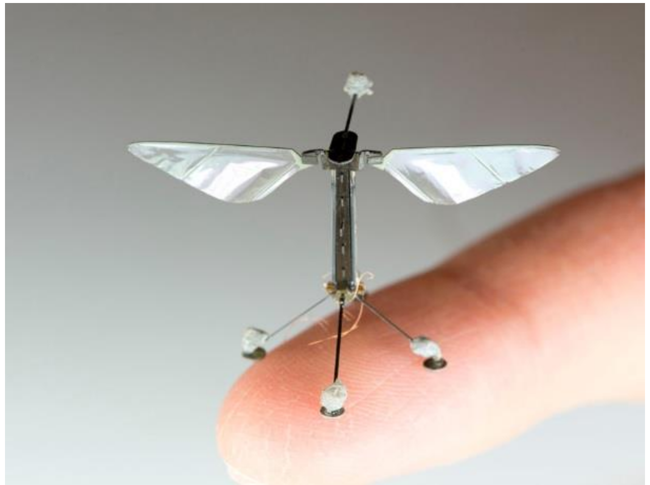
- **Unmanned Aerial Vehicles (UAVs)**, also commonly known as Drones, are the aircrafts without a human pilot

Northrop Grumman Bat carrying EO/IR and SAR sensors, laser rangefinders, laser designators, infrared cameras

Underwater Robots

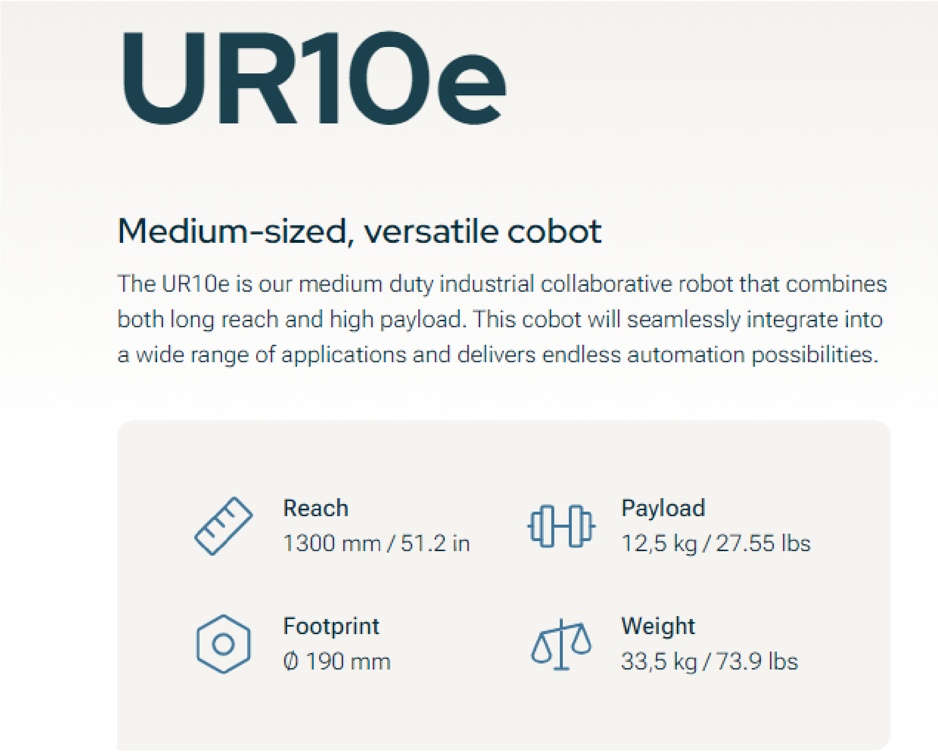
Mobile Robots

- Bio Inspired Robots
  - Bio inspired robots take inspiration from different lifeforms in our world. They became extremely popular in the 90s to explore new kinds of robots

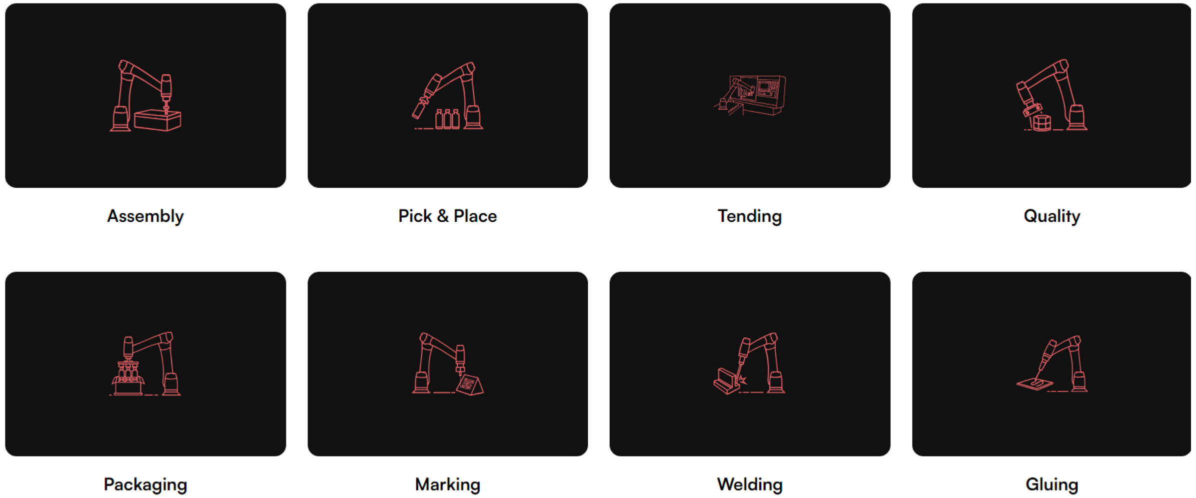


Areas where robots are used

Industrial Applications



https://www.machinemetrics.com/



- **Robotic-assisted surgery** is a minimally invasive surgery technique that allows doctors to perform many types of complex procedures with more precision, flexibility and control than is possible with conventional techniques
- Robotic surgery may be used for a number of different procedures, including coronary artery bypass, cutting away cancer tissue, gallbladder removal, hip replacement, hysterectomy, total or partial kidney removal, kidney transplant, and mitral valve repair

- **Rehabilitation robots** are used in helping people with reduced motor control or impaired physical functioning to gain the motor control back by stimulating motor functions of brain.

- **Farming robots** include weed removal robots, harvesting robots, fruit picking robots, crop inspection robots and more. Robots are heavily used in Agriculture.
- Drones are being used in India for fertilizer spraying

- **Educational robotics** teaches the design, analysis, application and operation of robots.
- Reconfigurable robots, designed as easy to assemble and easy to program

- **Sanitation** is an area actively being looked at by the robotics community.
- Robotics is helping in replacing unpleasant and dangerous jobs within sanitation

Bandicoot by Genrobotic Innovations

Domestic robots

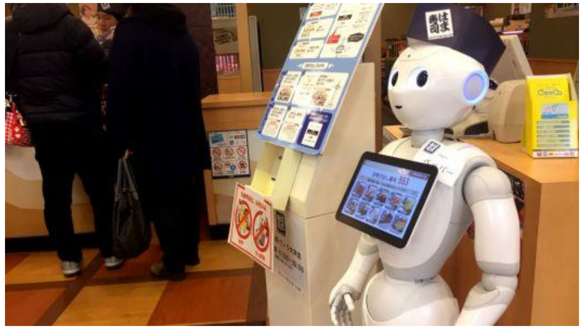
- There is an increasing interest in building humanoid robots specifically catered towards domestic needs

Companion robots are

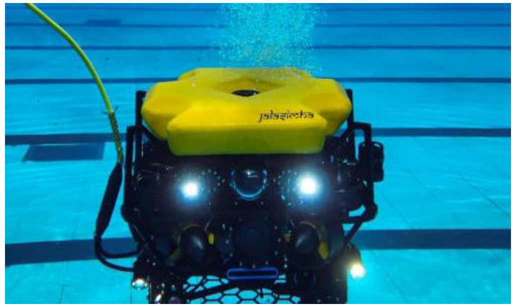
- designed to play, have fun and make conversations.
- They are generally designed to expression emotions too.

Service robots

- Food serving robot in restaurants
- Robot Hospitality
- Helping humans navigating areas



- AUVs are used to study lakes, the ocean, and the ocean floor. A variety of sensors can be affixed to AUVs to measure the concentration of various elements or compounds, the absorption or reflection of light, and the presence of microscopic life
- Exploration and Extraction Programs, Long-term data collection in oceanography and coastal management



ROV jalasimha by Coratia Technologies

A serviceman of Separate 14th Regiment of Armed Forces of Ukraine, call-sign Spokiy, tests and prepares to operate FPV strike drone in his base on the front line in the Zaporizhia region | Oleg Petrasyuk/EPA

OSAM-1, a Satellite Repair Robot

ClearSpace-1, an Outer Space Trash Collector

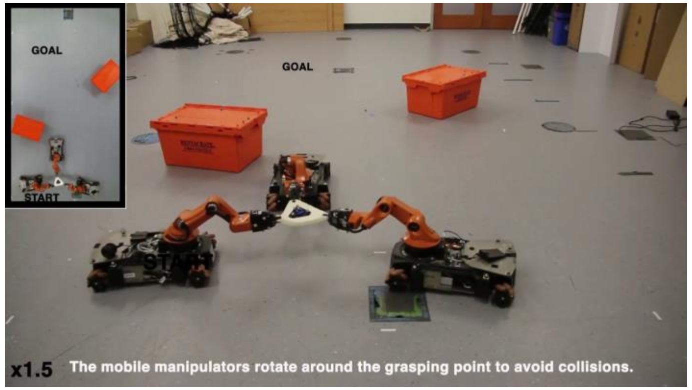
Julius, the robot above, can track people, robots, and machines, as well as monitor environmental conditions, in mines like this one, the research and teaching mine Reiche Zeche in Germany. Credit: Eckardt Mildner

Robot Systems

Robot Systems

- Autonomous Mobile Robots (AMRs)
  - AMRs are being extensively used in warehouse automation

- Multi robot systems are used to accomplish some of the complex tasks easily



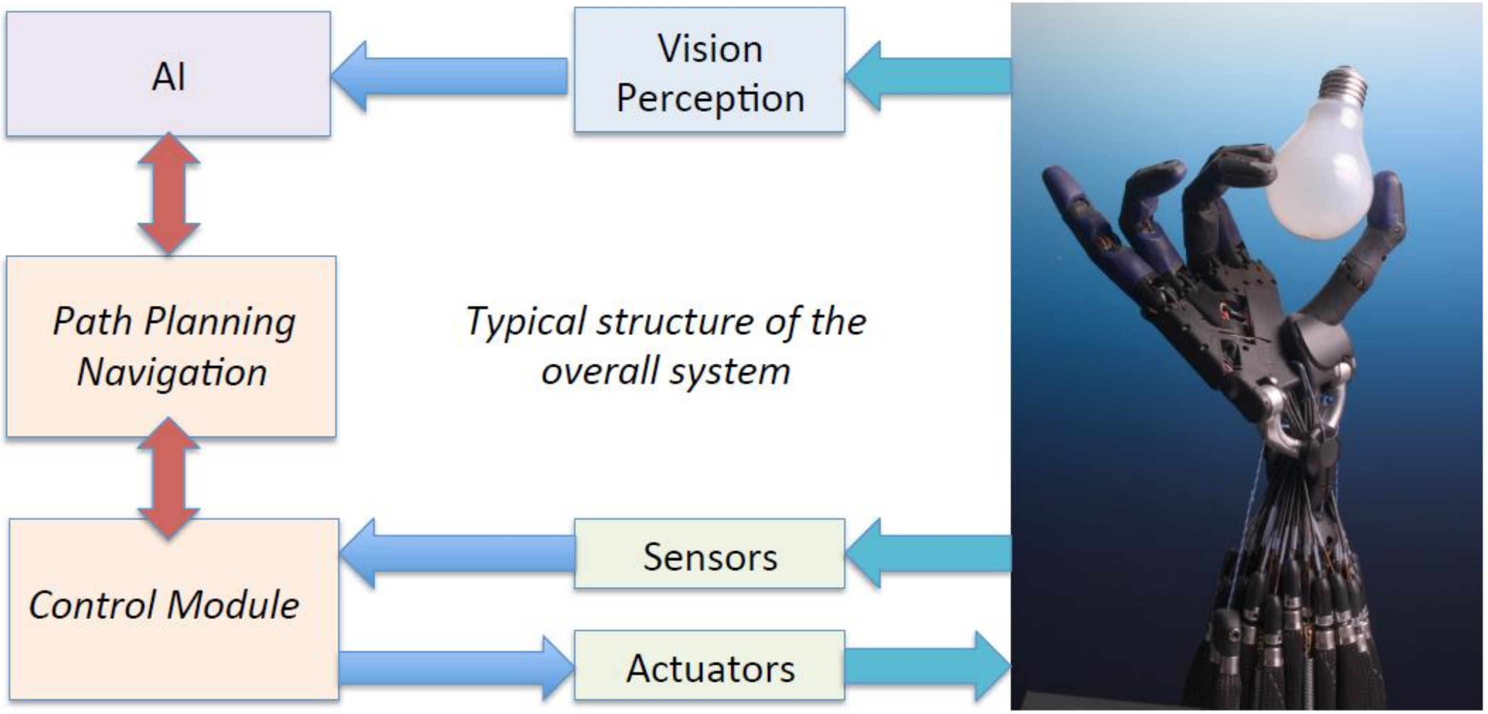
- Collaborative robots enables robot-robot interactions and safe human-robot interactions

Part 2

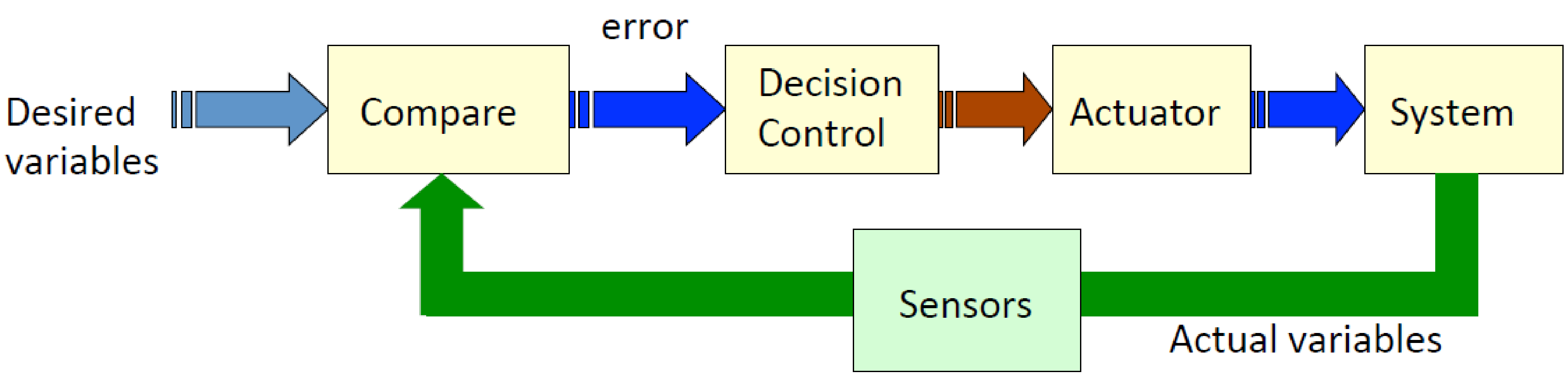
- Key aspects in Robotics

Software in Robotics

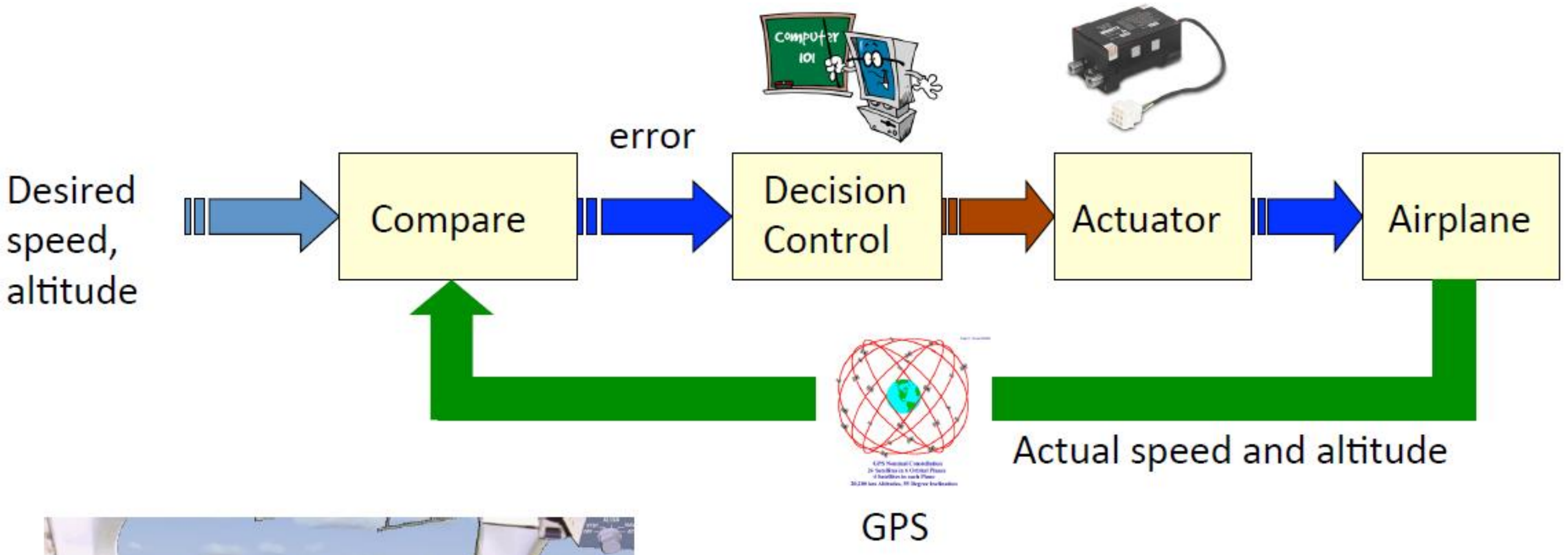
- Typical Robotic System



Robot Control

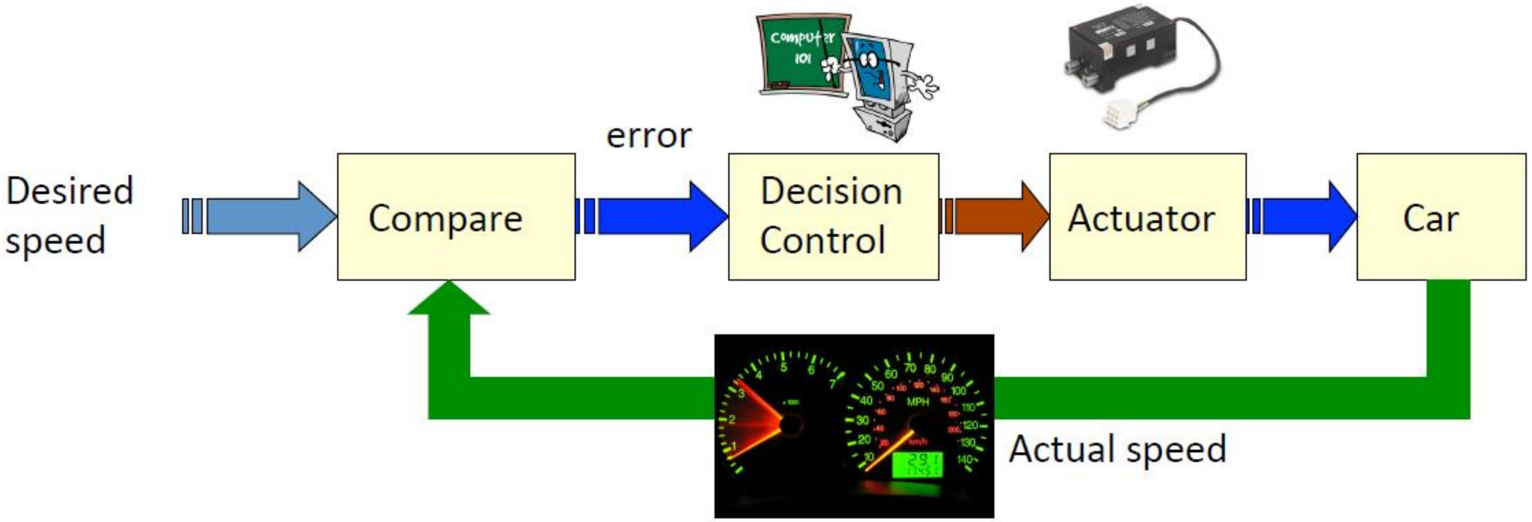


Robot Control



Autopilot

Robot Control



Cruise control

Robot Control

- Motivation
  - Convenience and consistency
  - Environmental protection
  - Precision for better performance
  - Medicine: anesthesia control and remote--surgery
  - Space exploration and commercial use

Some popular techniques

- Proportional-Integral-Derivative Control (PID)
- Linear–quadratic regulator Control (LQR)
- Linear–quadratic–Gaussian Control (LQG)
- Model Predictive Control (MPC)

Robot Modelling

- Robot modelling deals with
  - Rigid body transformations
  - Kinematics
    - Forward Kinematics
    - Inverse Kinematics
    - Velocity Kinematics
  - Dynamics
  - Contact Modelling
  - Grasping
  - Locomotion
  - Contrains

Robot Modelling

- Kinematics
  - Motion of bodies and mechanisms without inquiring into the causes (e.g. forces)
- Forward Kinematics
  - Given a complete set of configuration parameters (joint angles), determine the mapping from the robot's base frame to the robot's tool frame (end effector)
  - Sequence of coordinate transformations
  - Denavit-Hartenberg convention is a compact way to solve/represent this mapping for serial chains

Robot Modelling

- Inverse Kinematics
  - Given a (desired) mapping between the robot's base frame and its tool frame (end effector), determine a set of configuration parameters (joint angles) that will satisfy the mapping
  - Often not unique (elbow up vs. elbow down)
  - Less formulaic than solving forward kinematics (some "art" to it)
  - Spherical wrists significantly simplify the problem for serial chain manipulators

Robot Modelling

- Velocity Kinematics
  - Relationship between tool velocity and joint velocities, represented by the Jacobian
  - Important in trajectory following
  - Differentiation of forward kinematic equations

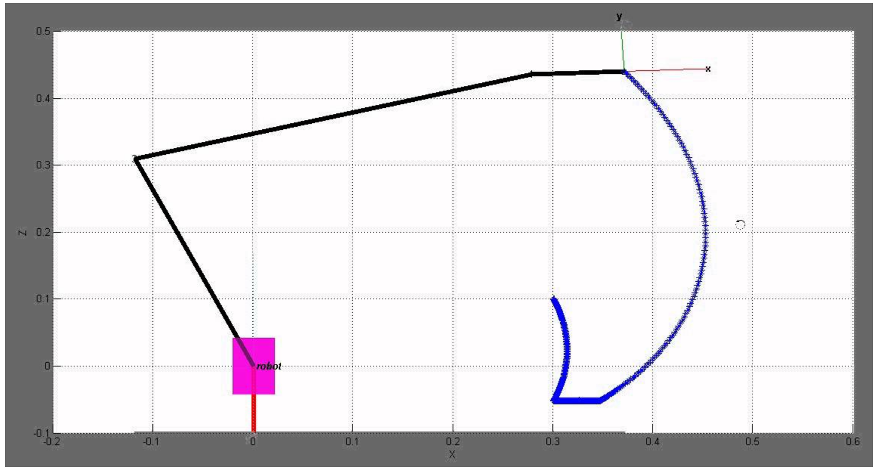


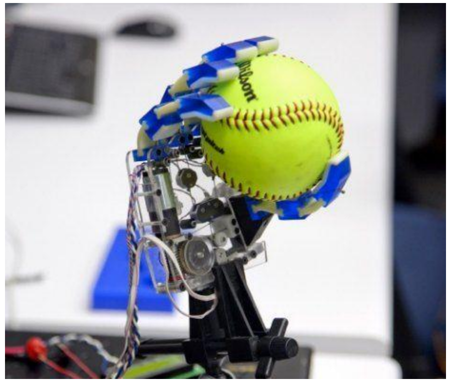
Image from: https://www.youtube.com/watch?v=imy9_7DA1ao

Robot Modelling

- Dynamics
  - Relationship between forces/torques applied and the resulting accelerations
  - Required to control robots through time
- Two techniques
  - Lagrangian
  - Recursive Newton-Euler

Robot Modelling

- Contact Modeling
  - Mathematical expression of the range of forces and moments able to be exerted from a given region or point on the robot that is touching the world
  - Typically limited to pushing
  - Often represented as a point
  - Important for mobility and manipulation (work)
- Grasping
  - Establishing a set of contacts on the surface of an object for the purpose of constraining potential movements



Robot Modelling

- Locomotion
  - Movement about the world
- Constraints
  - Holonomic vs. Non-holonomic
    - Number of controllable degrees of freedom compared with the total degrees of freedom

Motion Planning

Two Key Problems

1. **Motion Planning:** Given a mechanism, a *known* environment, and a known start and goal, compute a set of inputs (e.g. a joint trajectory) that moves the robot from start to goal without collision.

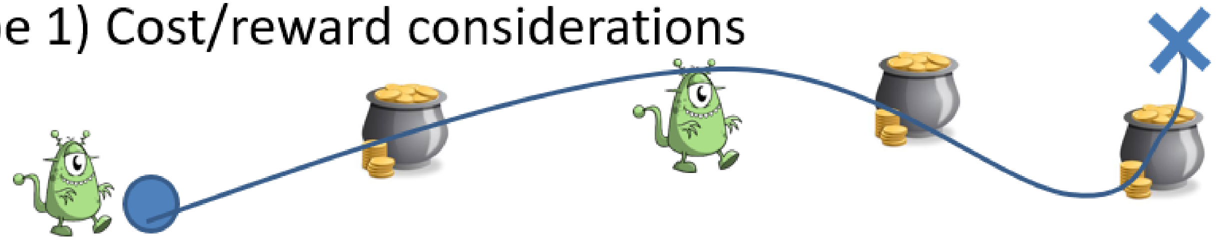
2. **Localization and Mapping:** Given no *a priori* knowledge, use information from sensing and motion to *simultaneously* compute a model of the environment (a map) and robot location within the environment.

Johns Hopkins Whiting School of Engineering 600.436/600.636 G.D. Hager S. Leonard

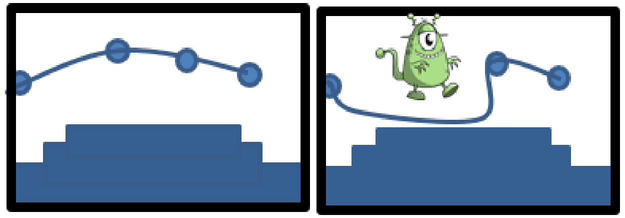
Motion Planning

- Finding action sequence to achieve a goal

Type 1) Cost/reward considerations

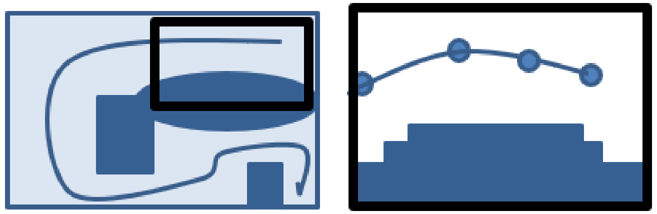


Type 2) Contingency



Type 3) Hierarchical

1. Find door
2. Open door
3. Exit



Dr. Michael Otte

Path Planning

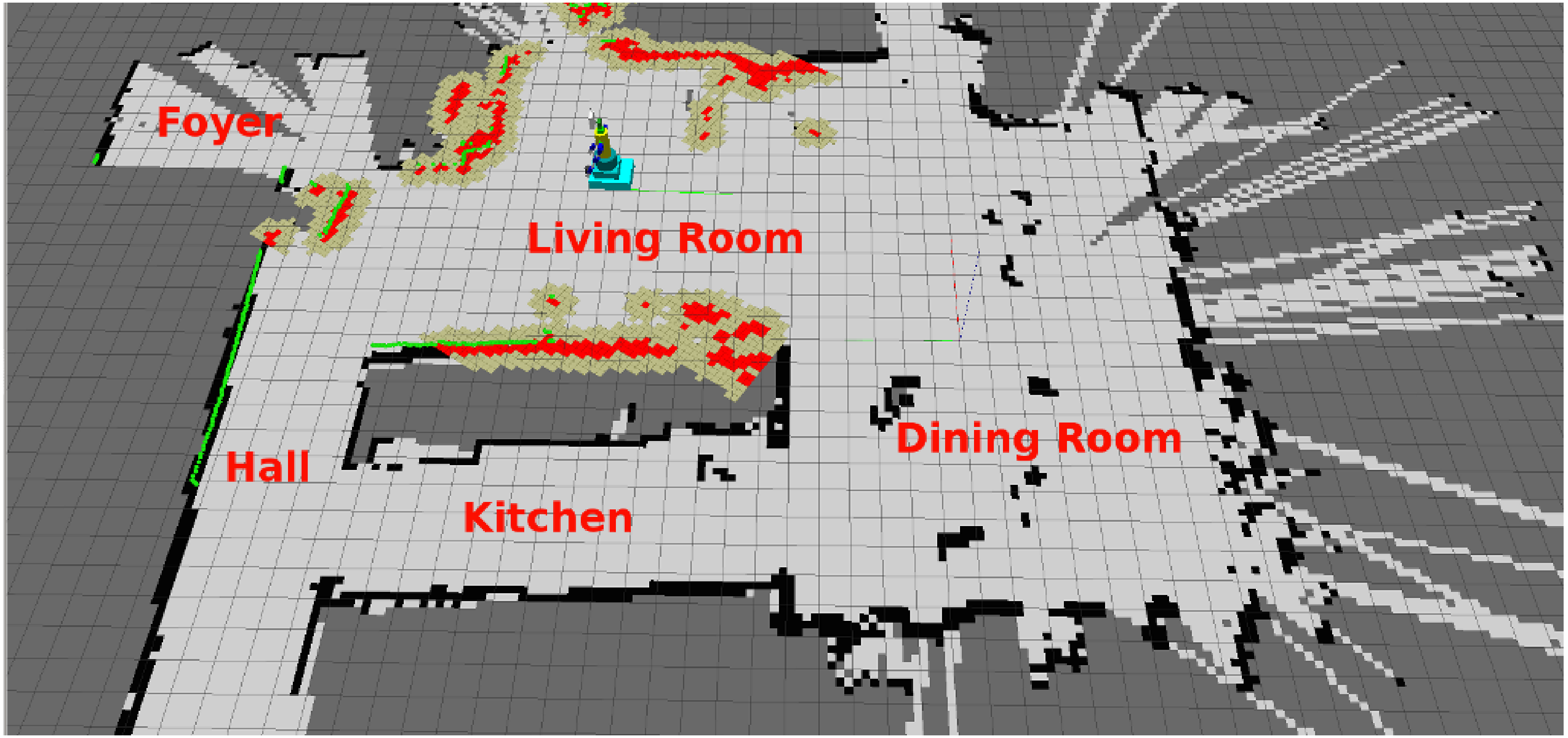
- Some popular path planning algorithms including offline and online planners
  - Dijkstra’s
  - A*,
  - Rapidly exploring Random Trees (RRT)
  - RRT*,
  - Point to Point

Some interesting research areas

- Planning for Hyper-Redundant Manipulators
- Human-Intention Aware Planning
- Foot Placement Planning for Legged Robots
- Coverage Planning
- Planning for Moving Target Search
- Planning for Surgical Robot Manipulation
- Planning for Radiation Therapy
- Manipulation and Grasping Planning
- Planning with Aggressive Maneuvers
- Integration of Task and Motion Planning
- Planning for Mobile Manipulation

- Assembly Planning
- Planning for Time Dependent State Transitions
- Planning for Magnetic Manipulation
- Planning for Optical Manipulation
- Planning for Robot Operations in Highly Dynamic Environments
- Planning for Ground Robot Operations over Rugged Terrains
- Anytime Planning Algorithms for Operations with Strict Time Constraints
- Planning Algorithms for Environments with Dynamic Obstacles
- Multi-agent Planning Algorithms
- Techniques for Smoothing Trajectories Computed using Sampling-based Planners

Mapping, Localization and Navigation

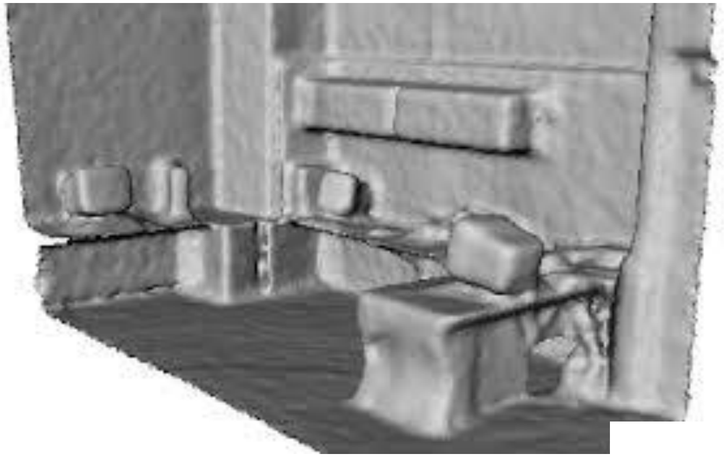


Perception

- Perception for Robots deals with 3 major problems
  - Reconstruction
  - Reorganization
  - Recognition

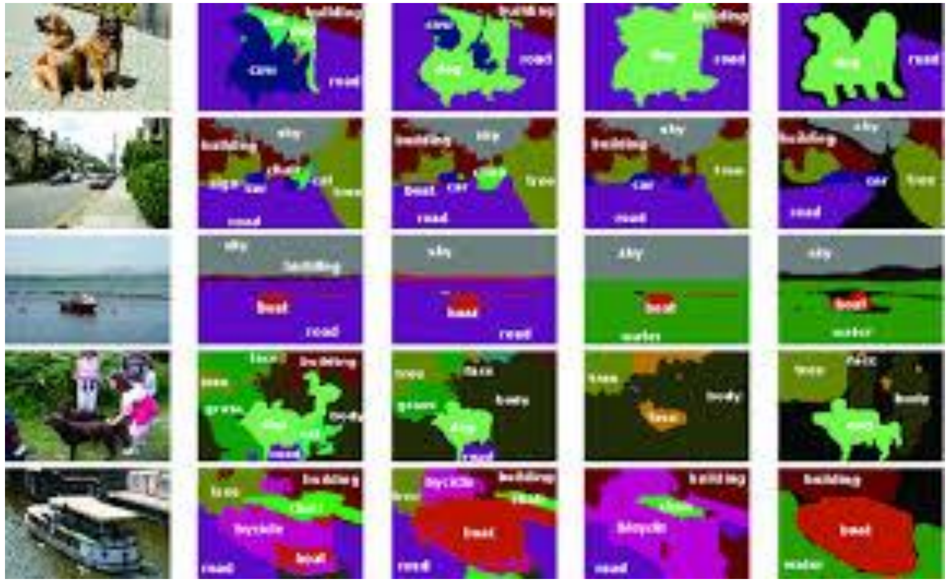
Perception

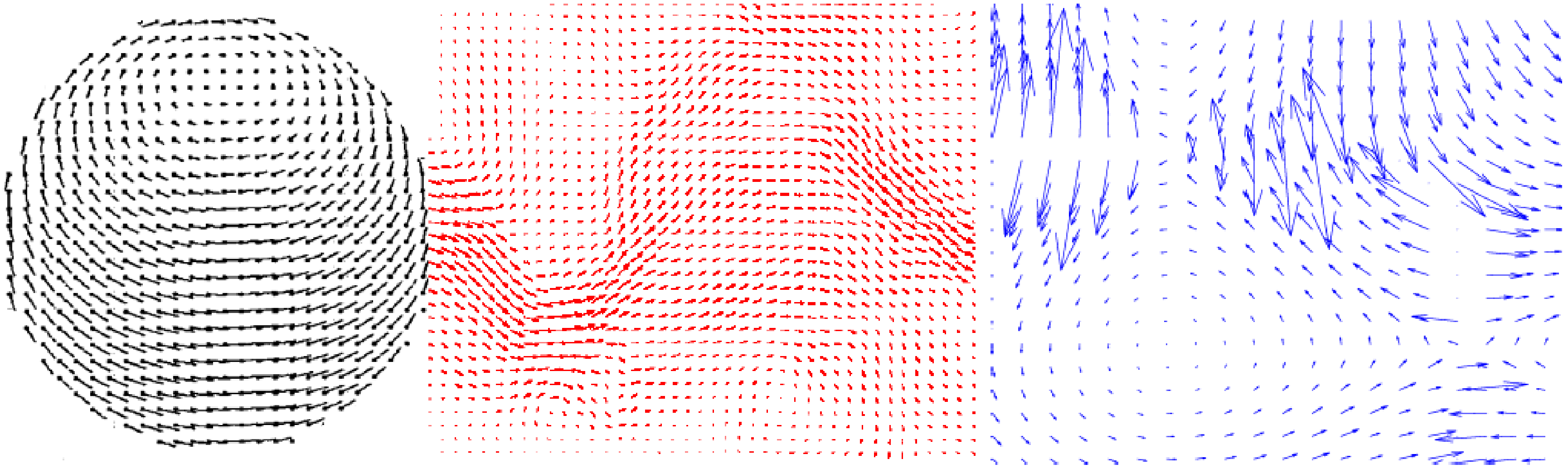
- Reconstruction



Perception

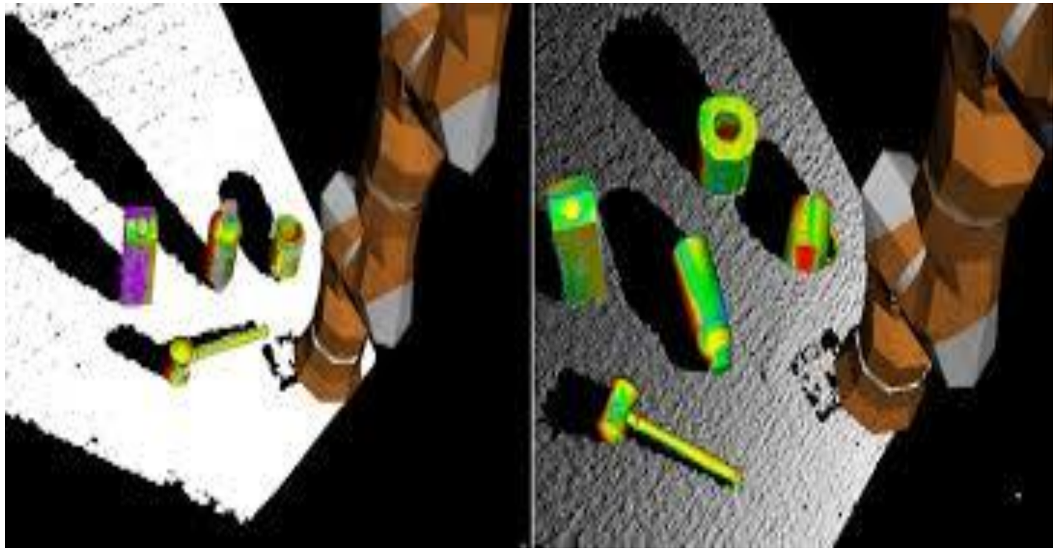
- Reorganization

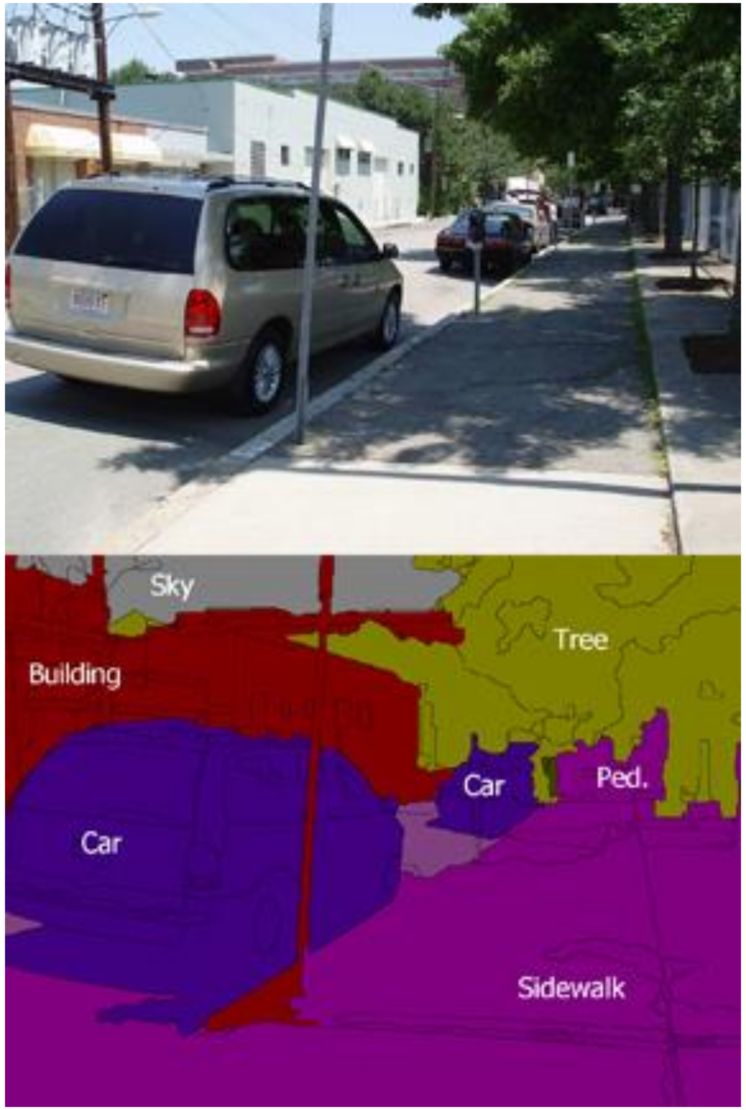




Perception

- Recognition

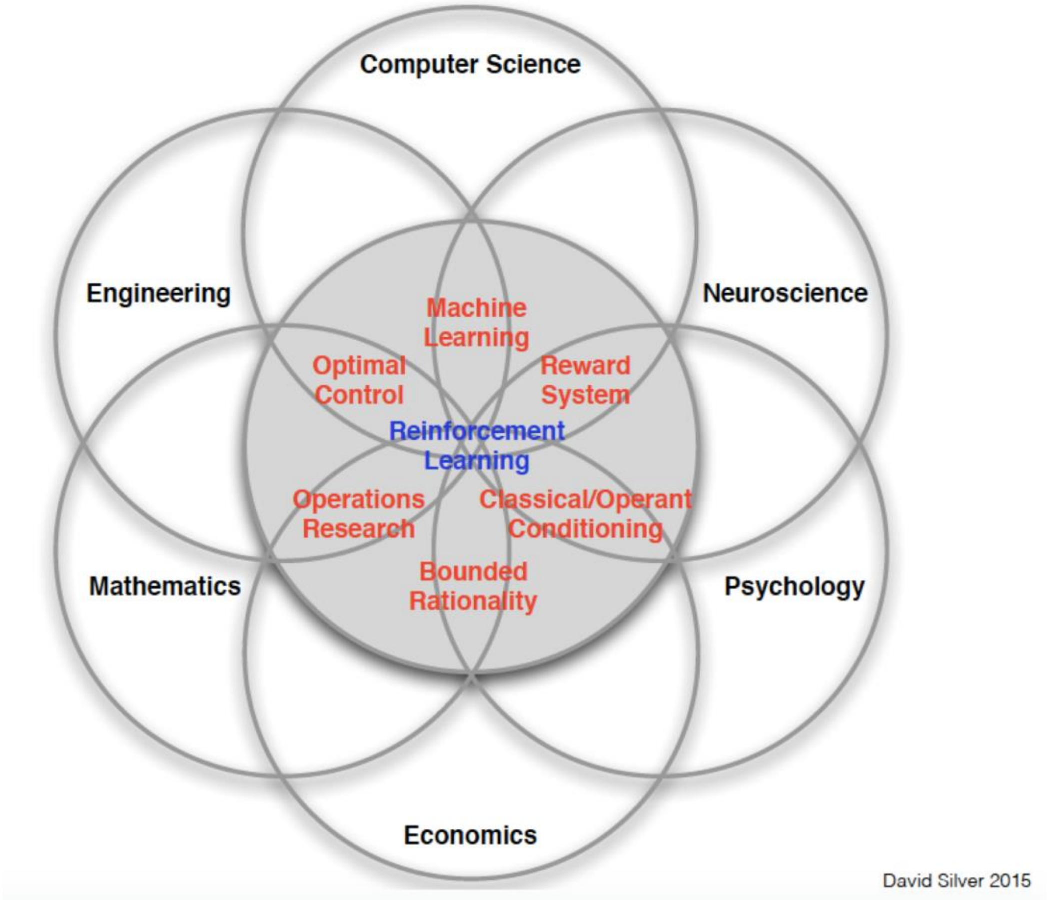




Robot Learning - Reinforcement Learning

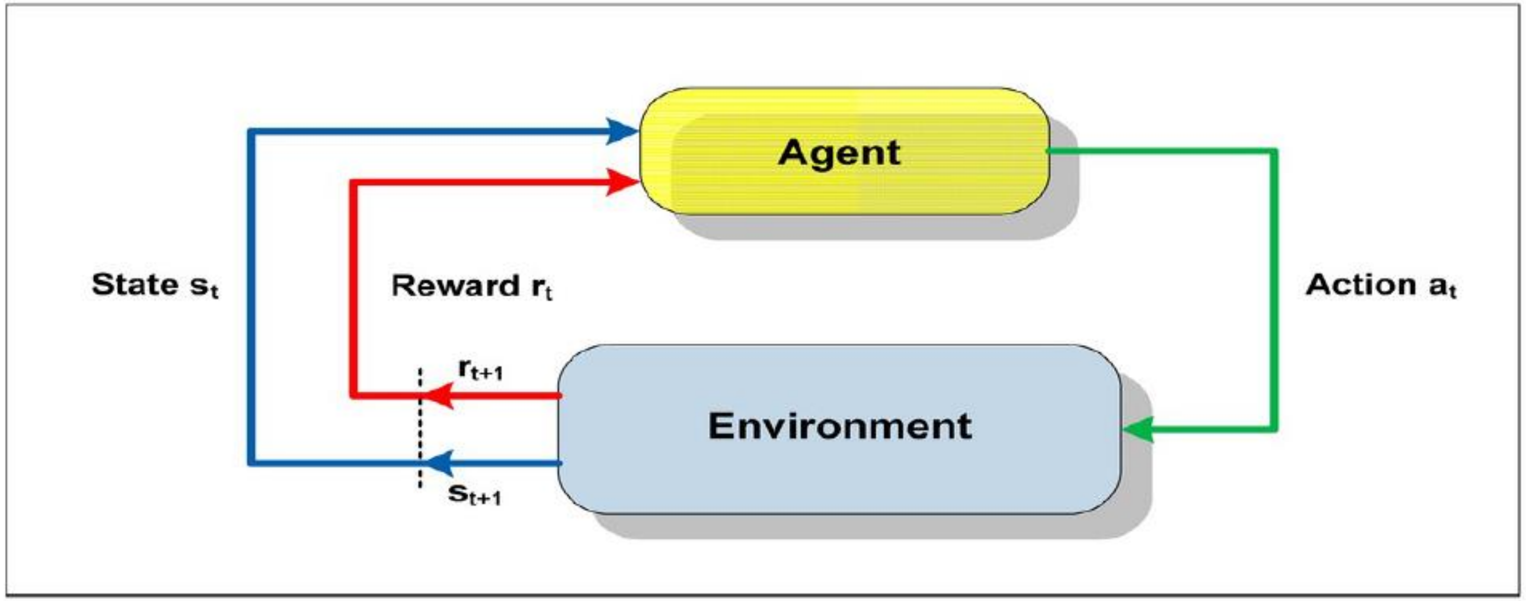
- Agent-oriented learning—learning by interacting with an environment to achieve a goal
  - more realistic and ambitious than other kinds of machine learning
- Learning by trial and error, with only delayed evaluative feedback (reward)
  - machine learning technique most like natural learning
  - learning that can tell for itself when it is right or wrong

Reinforcement Learning



Reinforcement Learning

- Focus on Learning Behaviors to Maximize Reward



Adapted from Sutton and Barto, 2017

Reinforcement Learning in Robotics

Video	Source
Cart-Pole Swing-up	YouTube, Cart-Pole Swing-up, PilcoLearner, Published on May 26, 2011
Pancake Flipping Robot	YouTube, Robot Learns to Flip Pancakes, PetarKormushev, Published on Jul 26, 2010
Robotic Soccer Goal Keeper	YouTube, Reinforcement learning for a robitic soccer goalkeeper, africlean, Published on Oct 20, 2008
Autonomous Drifting	YouTube, Autonomous Drifting using Machine Learning, Aerospace ControlsLab, Published on Aug 11, 2015
Stanford Autonomous Helicopter	YouTube, Autonomous Helicopters Teach Themselves to Fly Stunts, Stanford Published on Aug 28, 2008

Part 3

- Hardware tools in Robotics

Hardware in Robotics

- Some Basic sensors
  - Ultrasonics
  - PIR
  - Time of Flight sensors
- Advanced sensors
  - 2D and 3D LIDARs
  - Stereo Cameras, RGBD Cameras
  - Inertial Measurement Units (IMUs)
  - Encoders
  - IR Cameras

Cont.

- Advanced sensors
  - Tactile sensors
  - Force Sensors

Micro Controller Units - MCUs

- Arduino MCUs – has a wide range of micro controllers
- Teensy MCUs – has a wide range of micro controllers offering great repeatability, quality and features
- Raspberry Pi Pico – and variants
- ESP32 – huge series of low-power MCUs – very popular too

Micro Processor Units

- Raspberry Pi – has multiple variants of Single Board Computers(SBC) offering different processing capabilities
- Jetson devices – has multiple variants of SBCs offering high processing power especially for Machine Learning tasks including Deep Learning inferencing.
- Radxa – alternative to the above, industrial grade
- There are more SBCs coming out with inspiration from Raspberry Pi which offer more customization, speeds, security and durability

Special controllers

- Many special controllers and boards exist offering various specialized features
  - PixHawk flight controllers – for drone controls
  - Motor Drivers – to driver wheeled motors

Part 4

- Software tools in Robotics

Software Tools

Some of the software tools primarily used in Robotics

- Robot Operating System
    - RViz
    - Gazebo Simulator
    - Issac Simulator
    - Moveit
    - Nav2
- Linux Distributions
    - Ubuntu
    - WSL
    - VMS

Cont.

- Development Tools
  - Docker
  - CLion
  - QT Console
  - VSCode
    - PlatformIO
    - WSL Clients
  - Arduino IDE
  - PlatformIO
  - TinkerCAD

Part 5

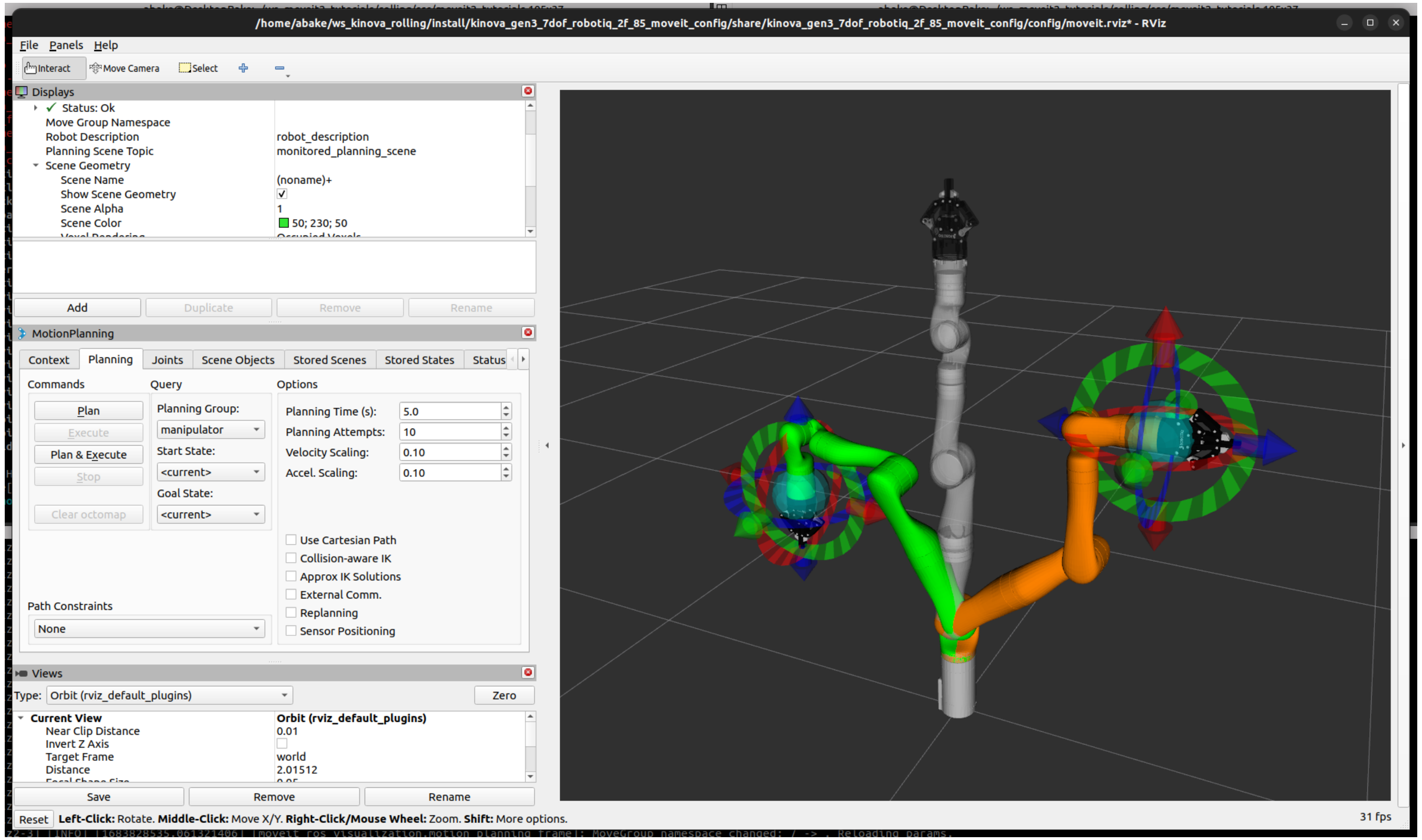
- Introduction to ROS2

Robot Operating System

- Robot Operating System (ROS or ros) is an open-source robotics middleware suite. ROS is not an operating system (OS) but a set of software frameworks for robot software development
- It provides services designed for a heterogeneous computer cluster such as
  - hardware abstraction,
  - low-level device control,
  - implementation of commonly used functionality,
  - message-passing between processes,
  - and package management.

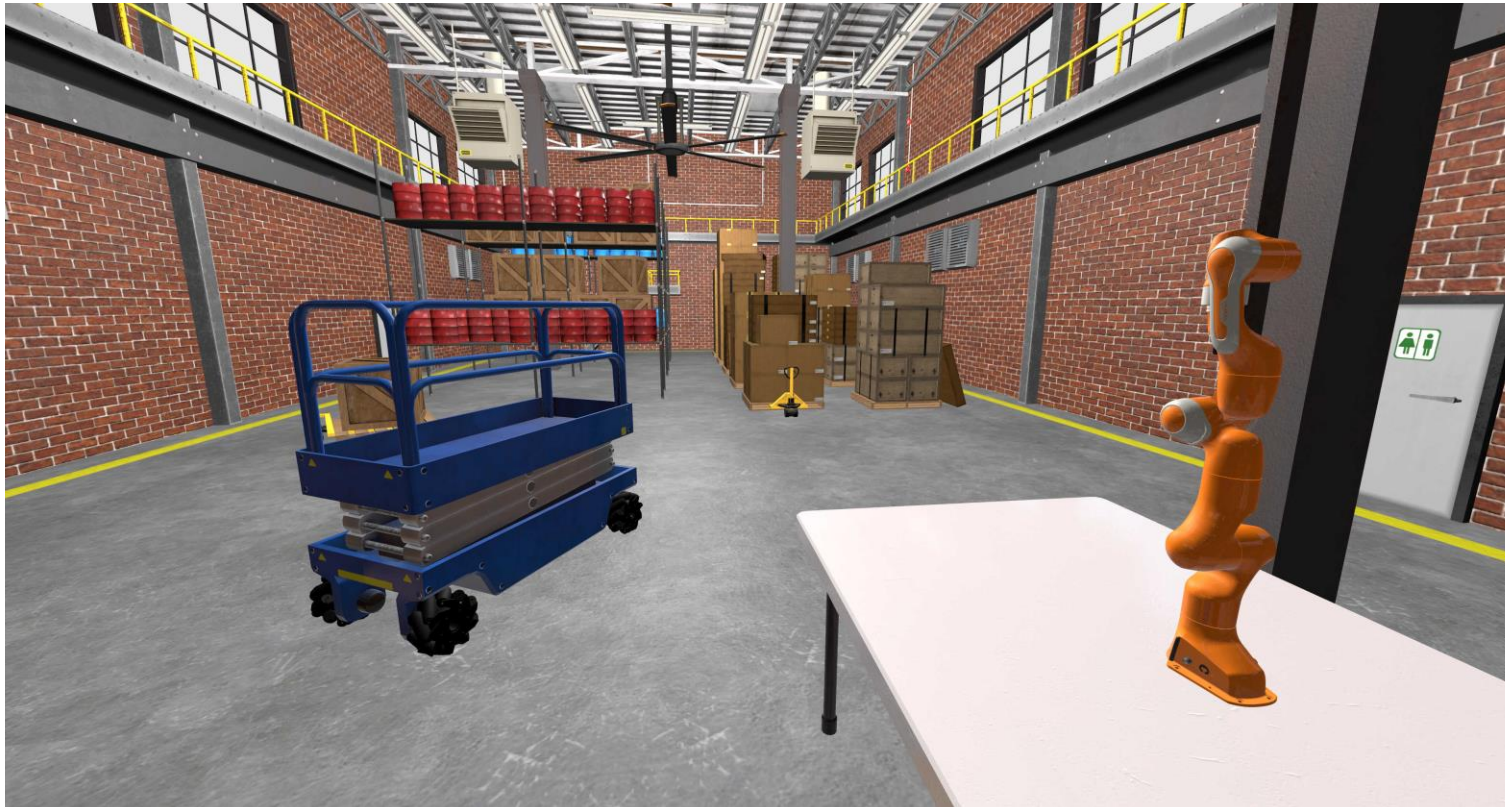
Robot Operating System

- RViz
  - RViz is a 3D visualization environment commonly used when developing software using ROS framework.
  - RViz let’s us view what the robot is seeing, thinking and doing.



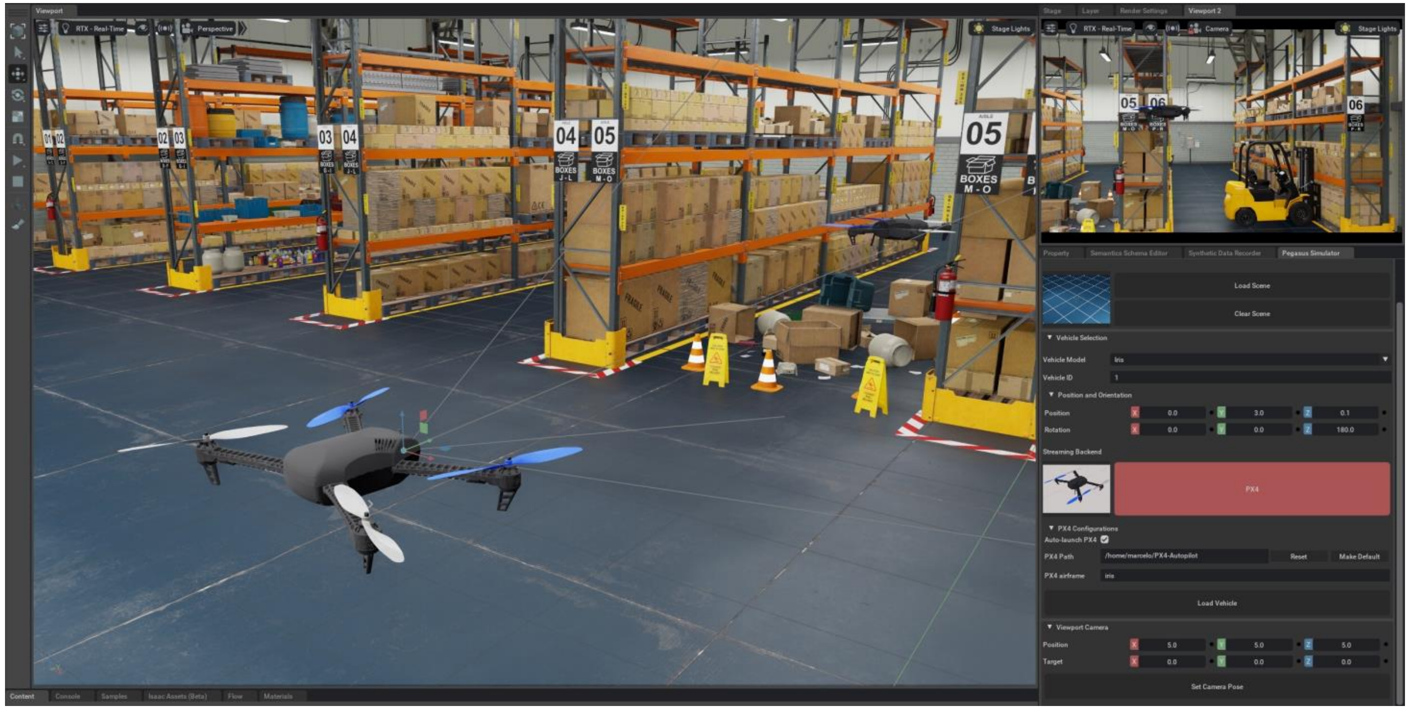
Robot Operating System

- Gazebo Simulator
  - Gazebo is an open-source 2D/3D robotics simulator. This is different from RViz. Gazebo offers high performance Physics engine too.



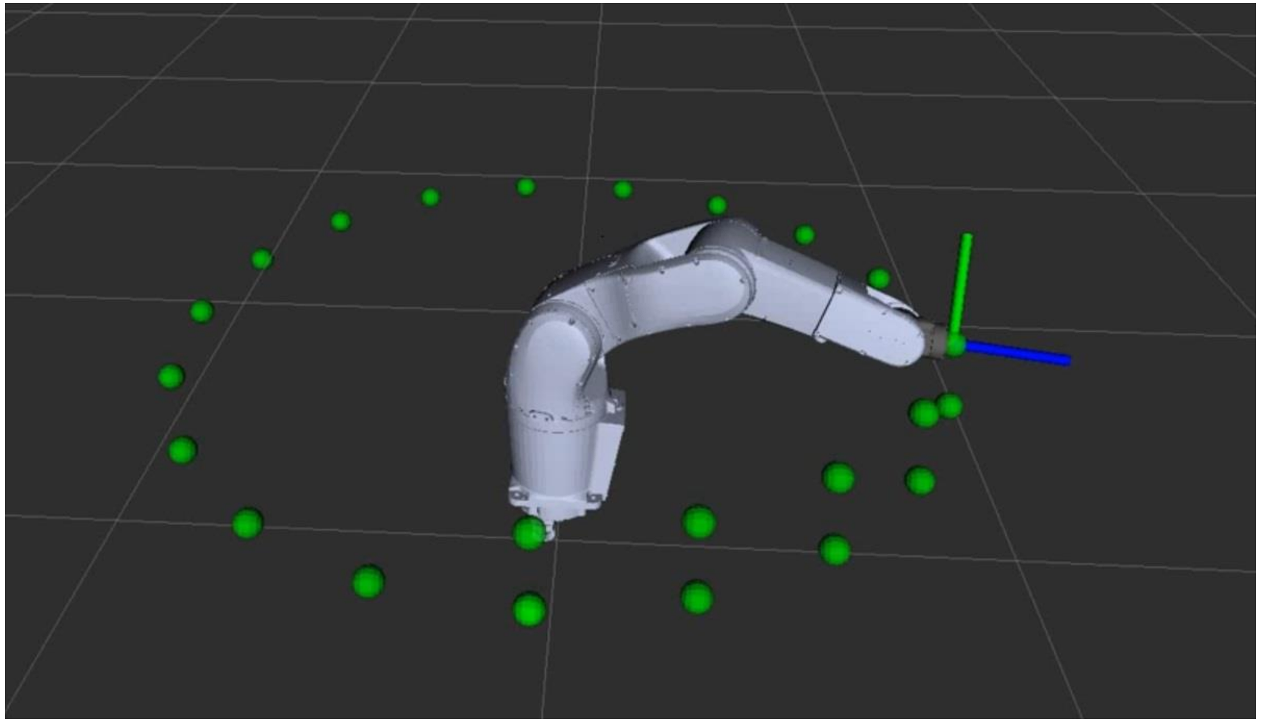
Robot Operating System

- Issac Simulator
  - NVIDIA Isaac Sim™ is a reference application enabling developers to design, simulate, test, and train AI-based robots and autonomous machines in a physically-based virtual environment.



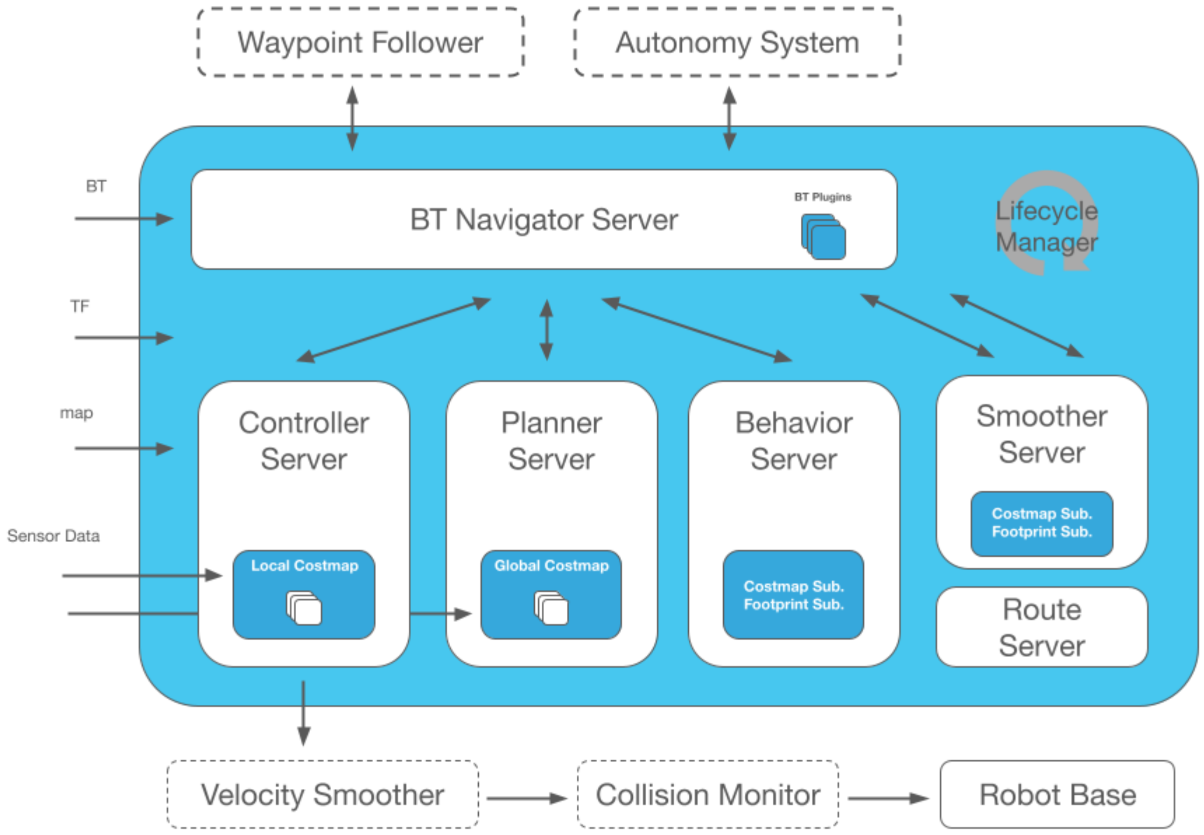
Robot Operating System

- Moveit
  - It is the robotic manipulation platform for ROS 2 and incorporates the latest advances in motion planning, manipulation, 3D perception, kinematics, control, and navigation



Robot Operating System

- Nav2
  - It is a ROS Navigation Stack for mobile and surface robotics. This project allows for mobile robots to navigate through complex environments to complete user-defined application tasks with nearly any class of robot kinematics



ROS based robots

- robots.ros.org
- ROS Robots Montage ROS 10 Year Montage on Vimeo

Recommended Readings

- Robot_Architectures.pdf (cmu.edu)
- Planning by Lavalle
- Probabilistic Robotics
- A Gentle Introduction to ROS (rpi.edu)
- Robot Modeling and Control

Assignment #1

- Assignment due on 13/09/2024 - 7:00 PM
- Assignment document can be found here

Reach out to us

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Thanks for Listening