ShanghaiTech University 上海科技大学 School of Information Science and Technology 信息科学与技术学院

Introduction to Information Science and Technology (EE 100)
Part II: Intelligent Machines and Robotics

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ShanghaiTech University

Organization

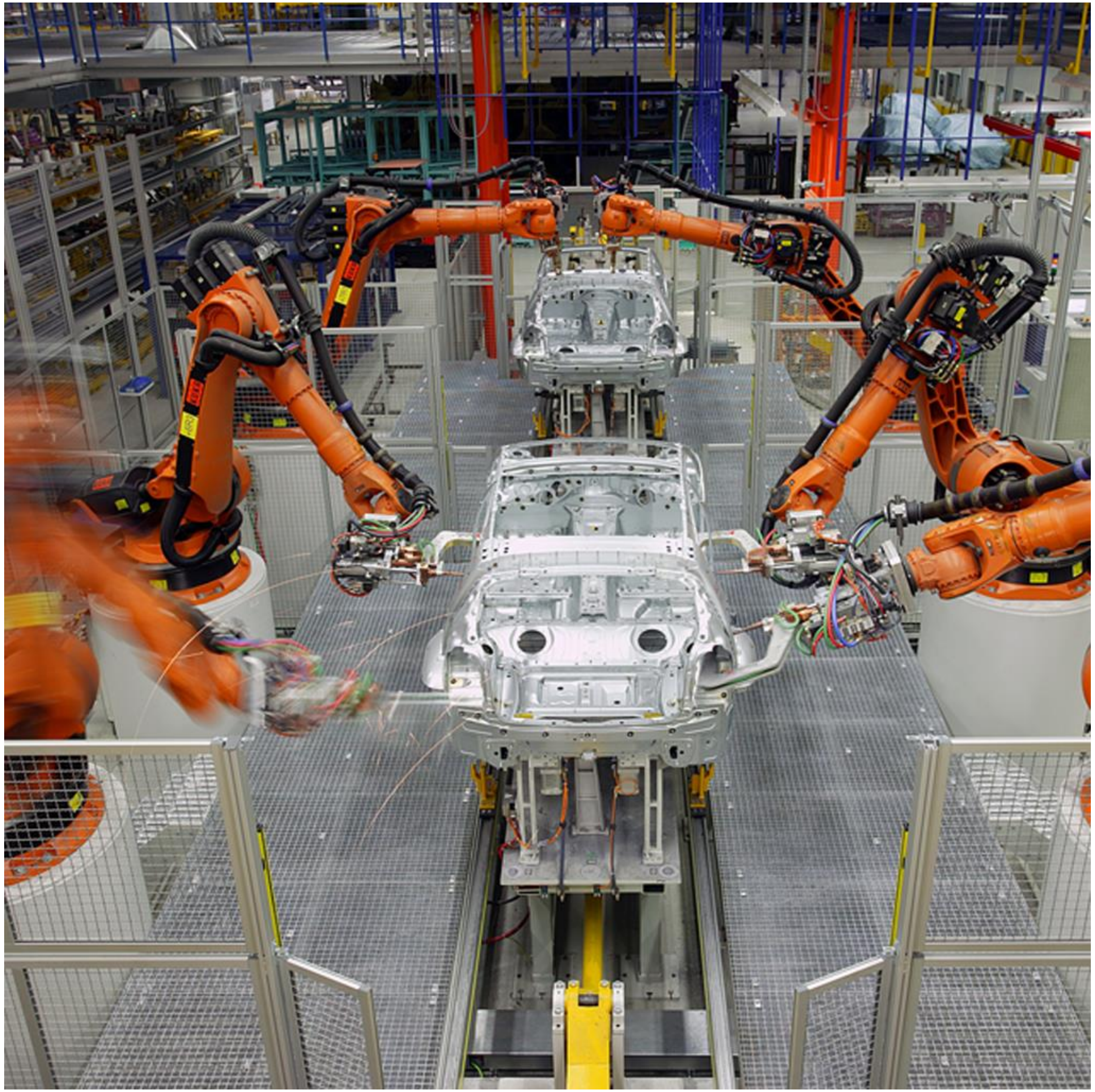
- Organized by School of Information Science and Technology (SIST)
- Four parts: Programming; Intelligent Machines and Robotics; Signals and Systems; Electronics
  - Each part has four weeks
- All students continue with programming assignment for the whole course

Outline

- What is a Robot?
- Why Mobile Robotics?
- Why Autonomous Mobile Robotics?
- Brief History
- Kinematics

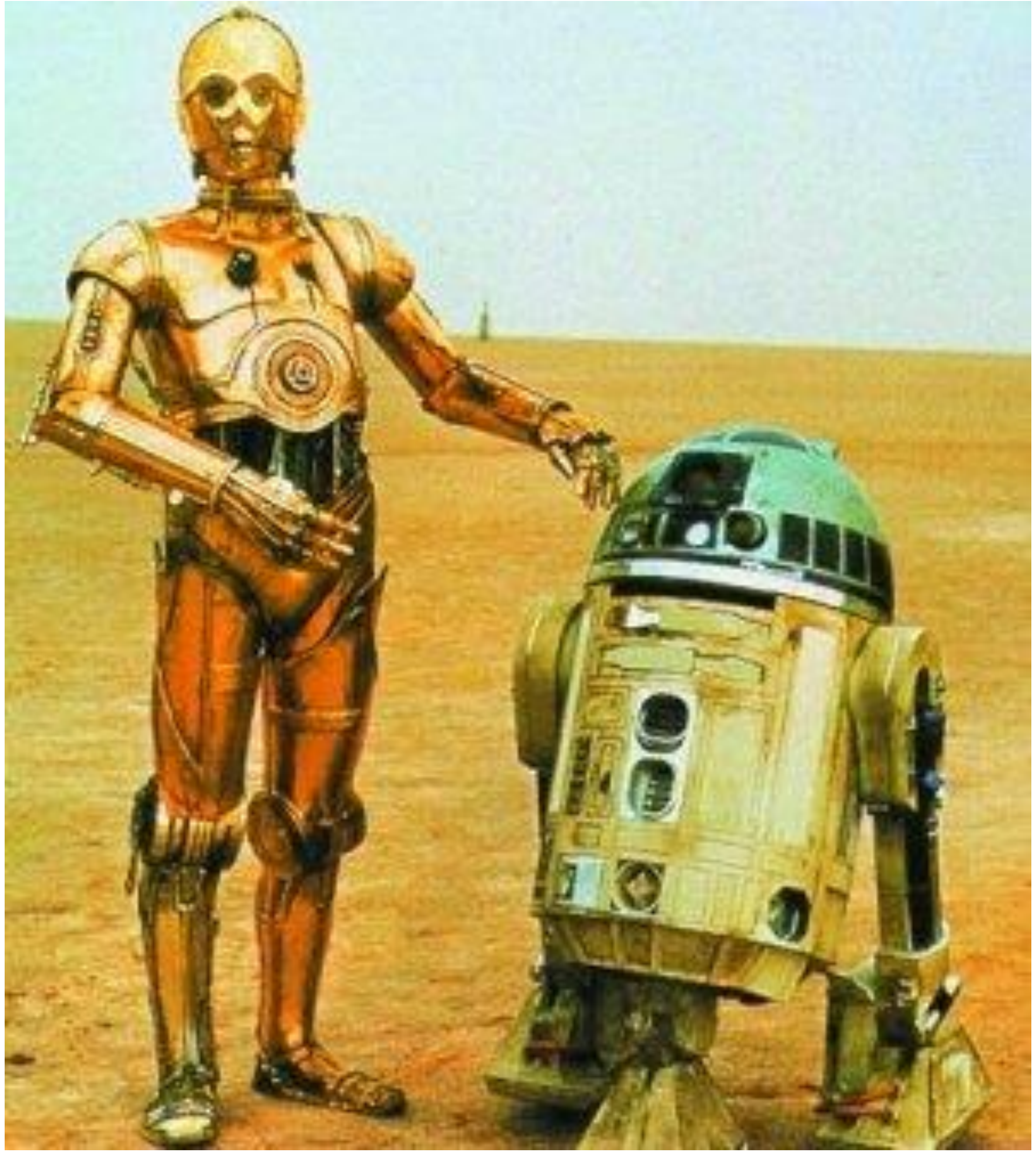
What is a Robot?

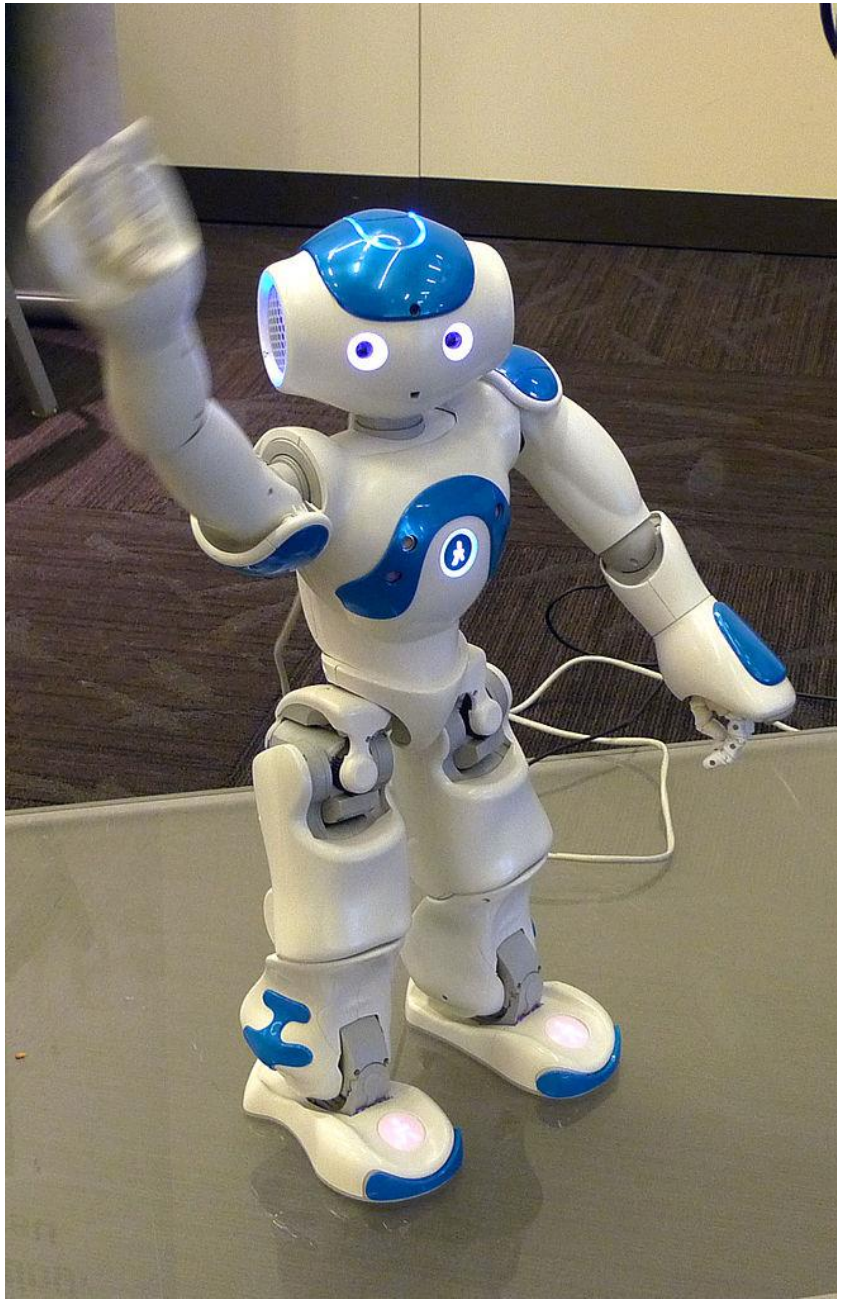
Pictures on the following slides all from http://commons.wikimedia.org

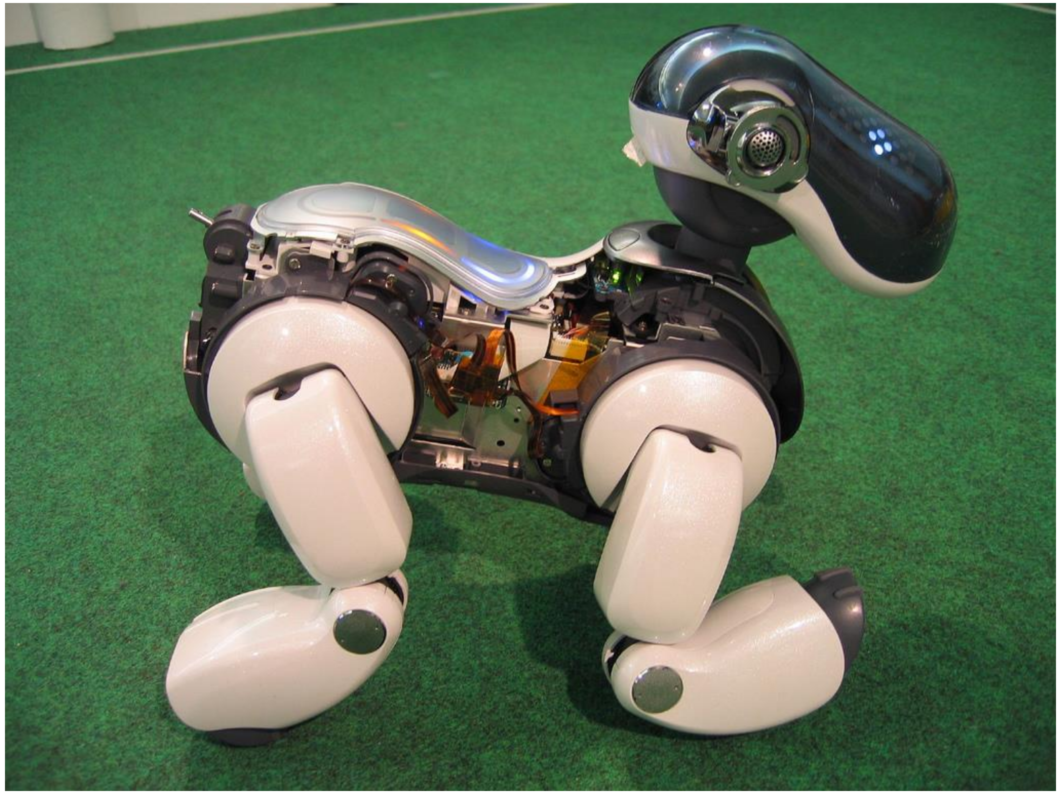



ASIMO
HONDA


WALL-E



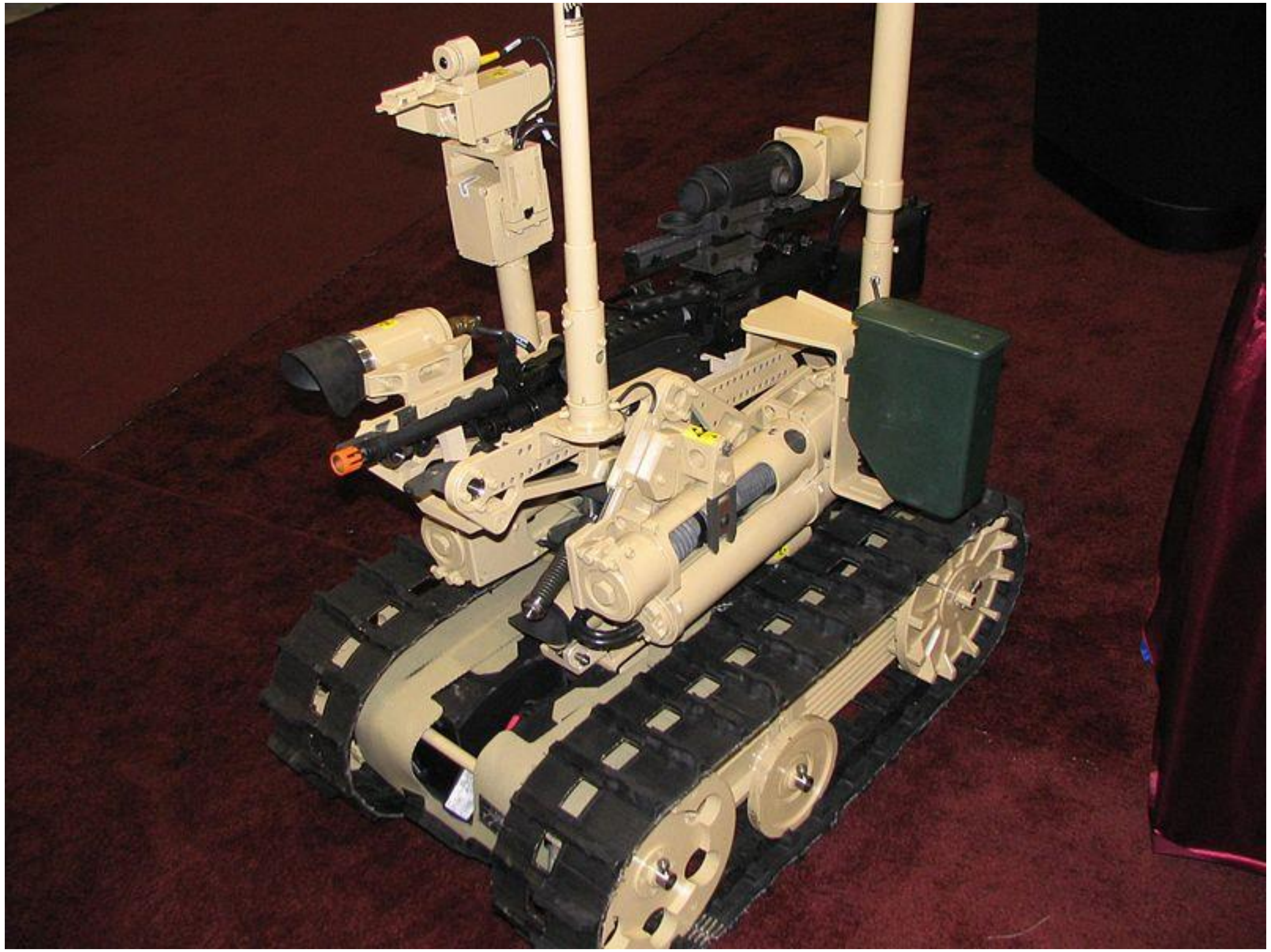




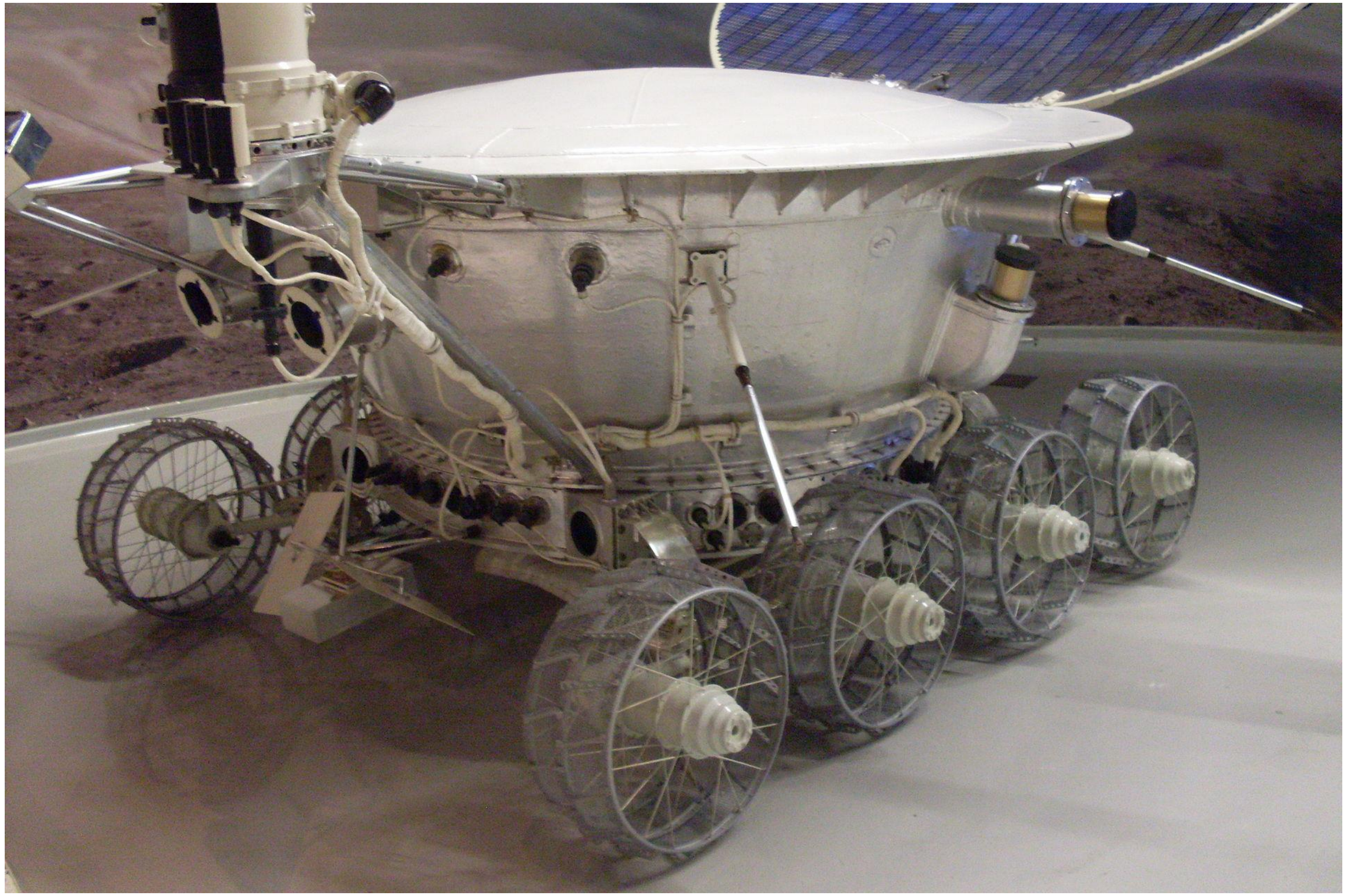

KEEP CLEAR

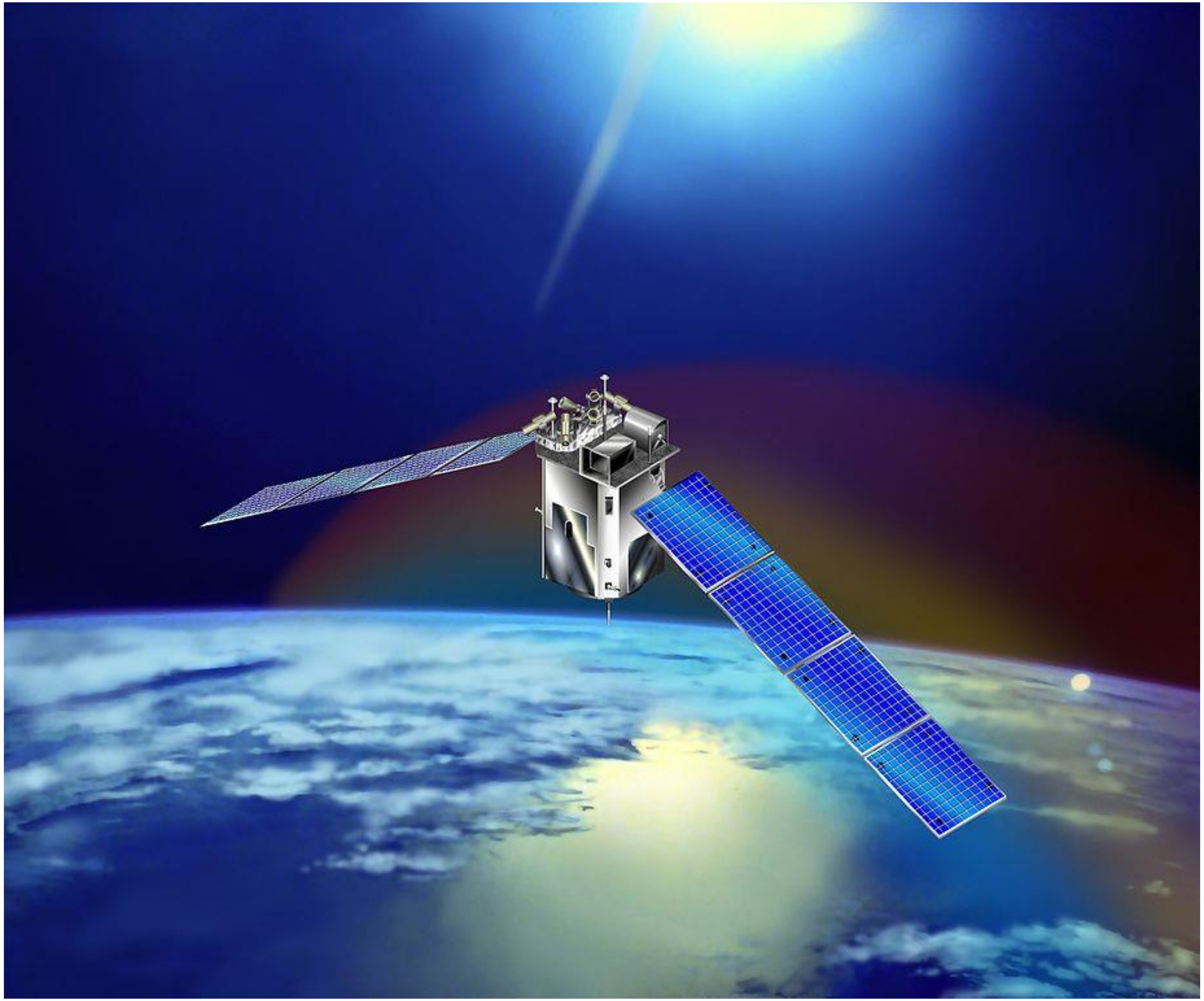

iRobot
Roomba
Robotic FloorVac
S
M
L
Select Room Size to Start / Stop

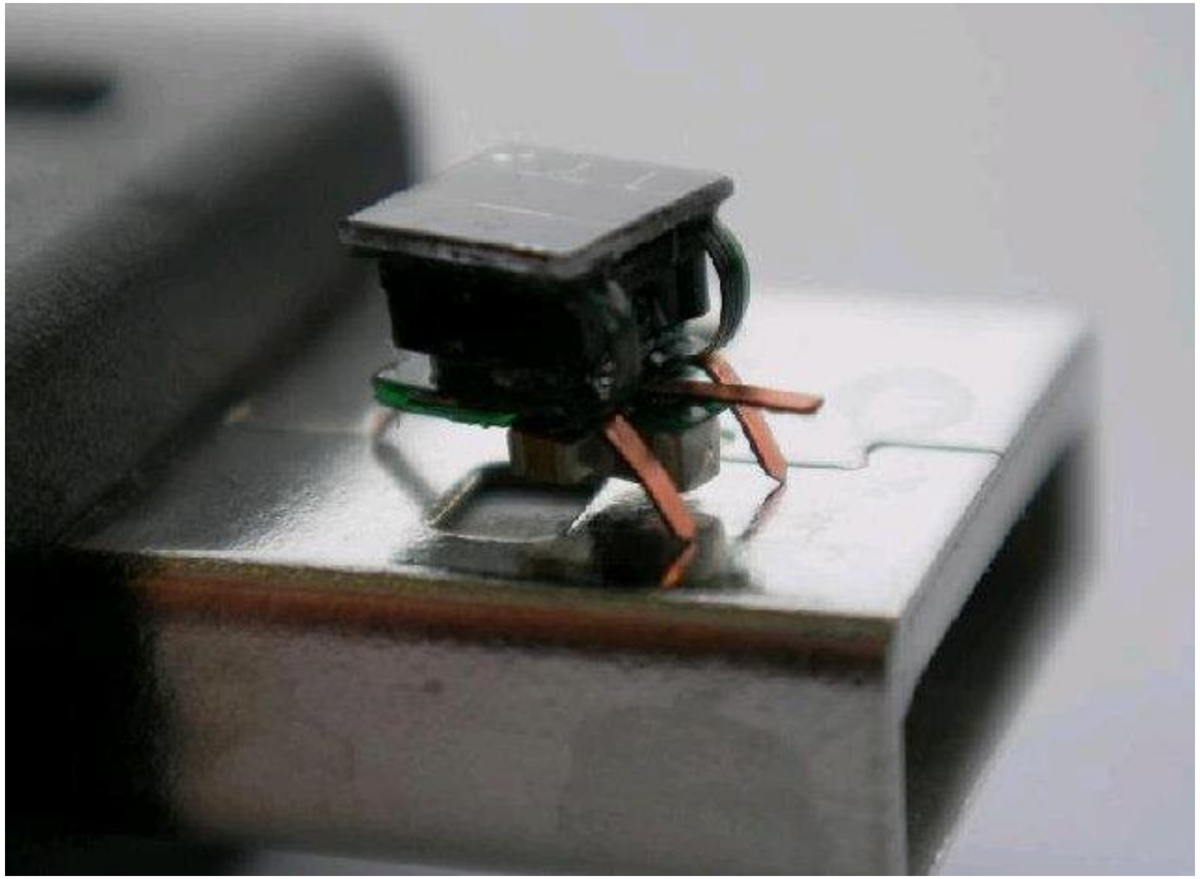

Robotics Technology
Development and Commercialization
Robots that Work in the Real World
Unmanned Vehicle
Systems Engineering
Engineering the Future of Unmanned Vehicles
Navigation Systems
NREC

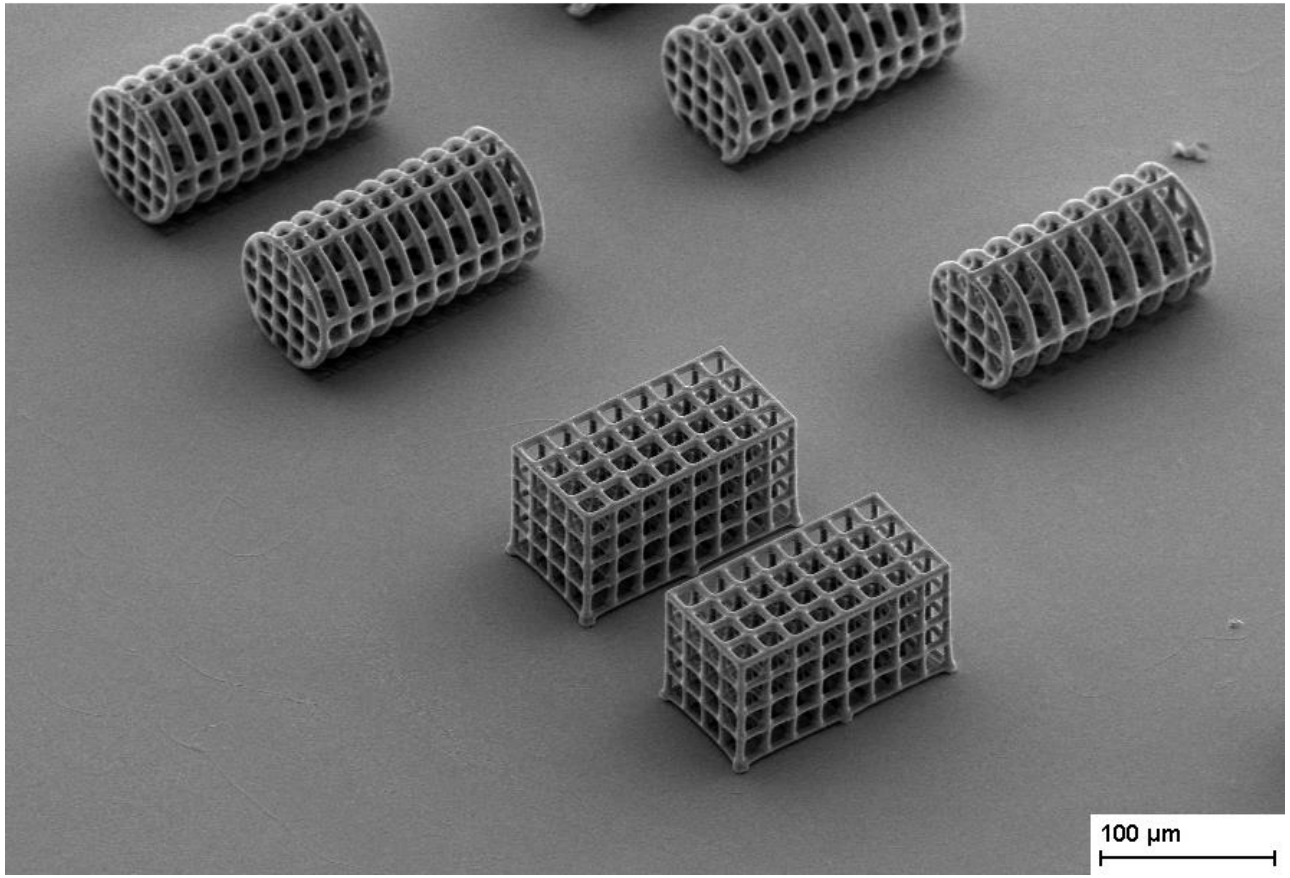



U.S. AIR FORCE
GLOBAL HAWK



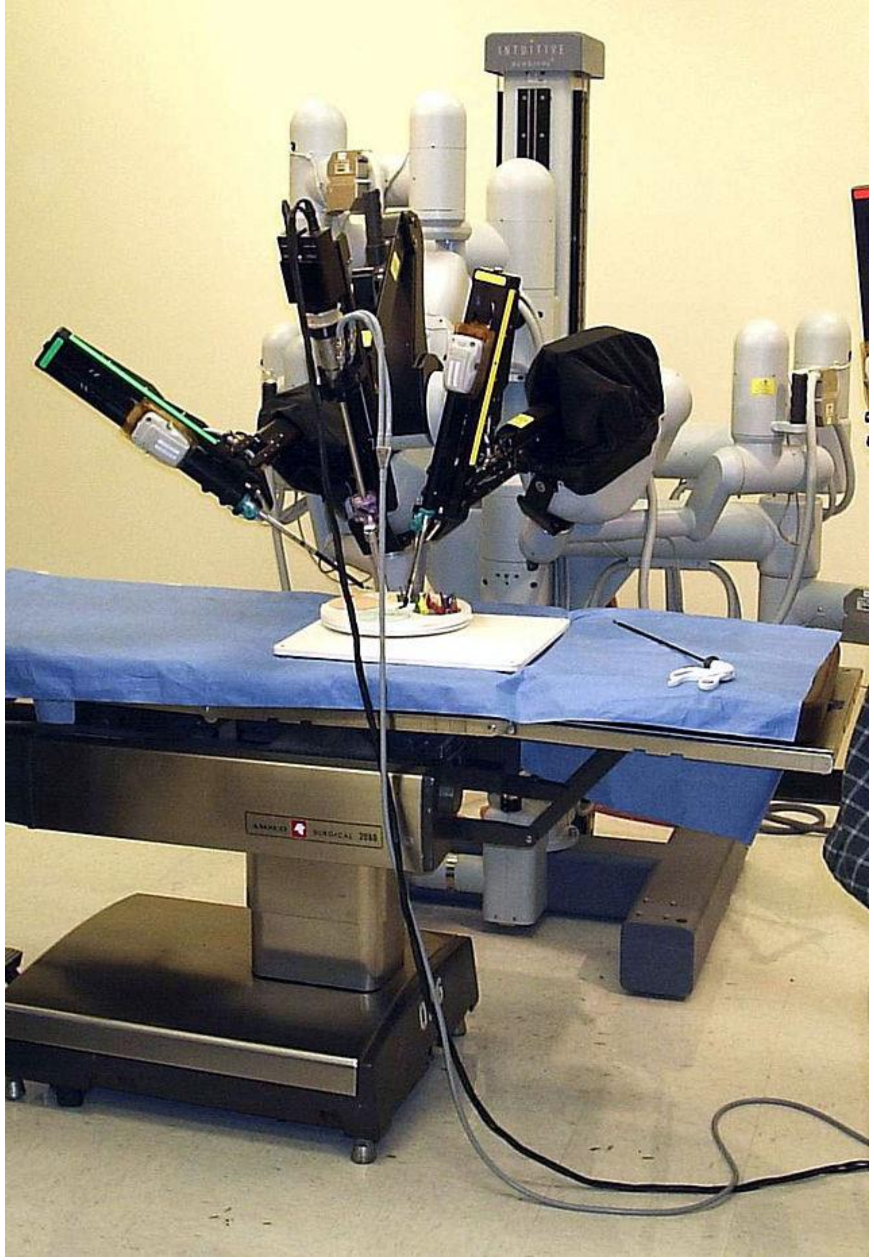





100 µm


EXPLOSIVE


JASON
WOODS HOLE
OCEANOGRAPHIC INSTITUTION


INTUITIVE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CATERPILLAR


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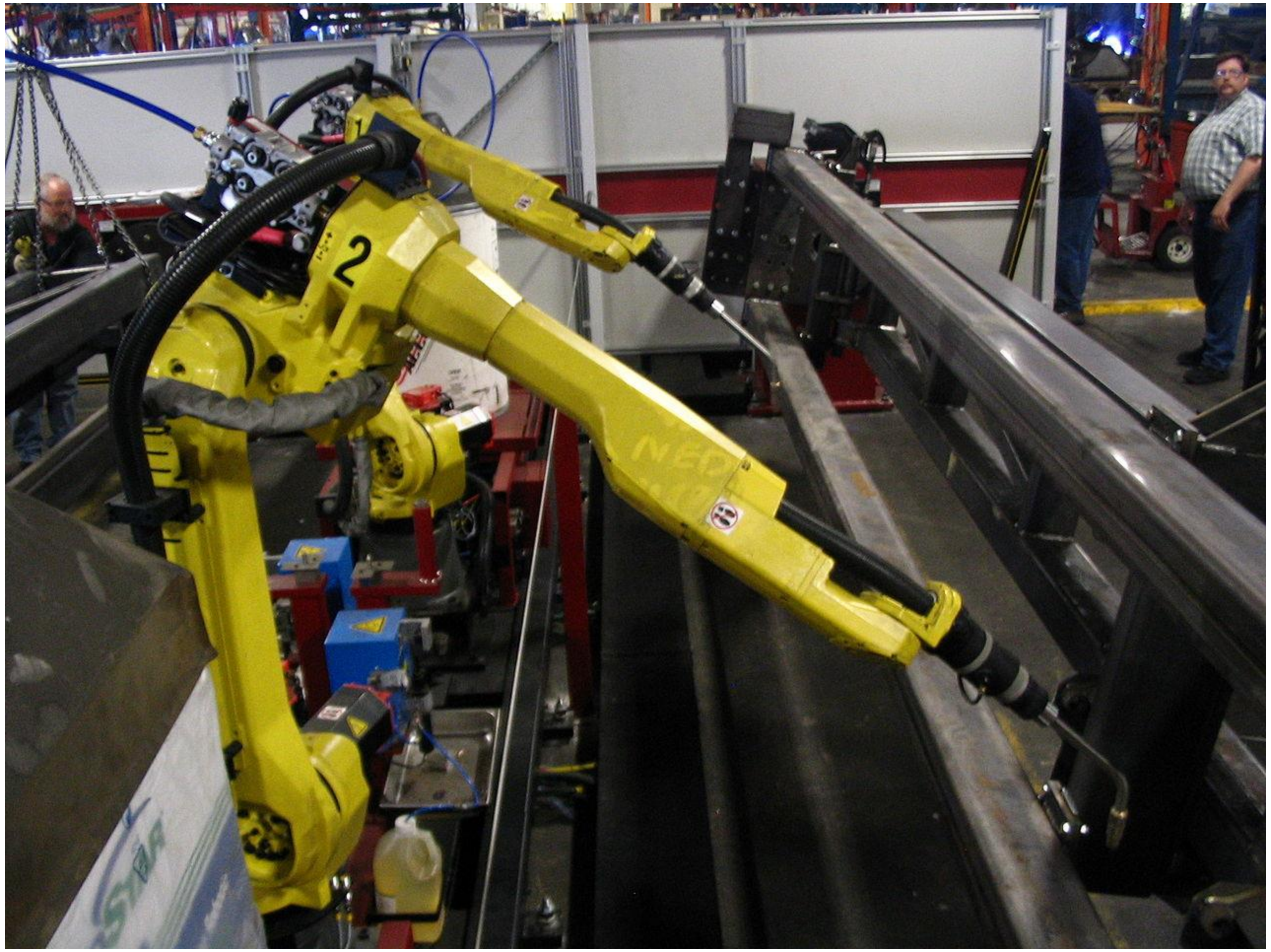
What is your definition for the term

ROBOT ?

Definitions: A Robot is ...

A machine
capable of performing complex tasks
in the physical world,
that is using sensors to perceive the environment
and acts tele-operated or autonomous.

Industry vs Mobile Robots



- Industrial Robots rule:
  - 2013: 179,000 industrial robots sold
  - Over 1.4 million industrial robots installed
  - China biggest robot market regarding annual sales - also fasted growing market worldwide
- Industrial Robots stay at one place!
- Almost all other robots move => **Mobile Robotics**

Why **Autonomous** Mobile Robotics?

- Tele-operating robots: boring and inefficient
- Autonomous robots: Robots that act by their own reasoning
  - Human operator might be present: Gives high level tasks
- Why autonomy?
  - Autonomous behaviors might be **better** than remote control by humans
  - Remote control might be **boring** or **stressful** and **tiresome**
  - Human operators might be a **scarce** resource or **expensive**
  - Multi robot approaches: One operator for many robots
- Semi-autonomy:
  - Autonomous behaviors that help the operator, for example:
  - Way-point navigation, autonomous stair climbing, assisted manipulation
  - Gradual development from tele-operation to full autonomy possible

- Autonomous mobile robots move around in the environment. Therefore **ALL** of them:
  - They need to know **where** they **are**.
  - They need to know **where** their **goal** is.
  - They need to know **how** to get there.

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- Where am I?
  - Global Positioning System: outdoor, error measured in meters
  - Guiding system: (painted lines, inductive guides), markers, iBeacon
  - Model of the environment:
    - Map, Localize yourself in this model
    - Mapping: Build the map while driving

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  - They need to know **where** they **are**.
  - They need to know **where** their **goal** is.
  - They need to know **how** to get there.

- Where is my goal?
- Two part problem:
  - What is the goal?
    - Expressed using the world model (map)
    - Using object recognition
    - No specific goal (random)
  - Where is that goal?
    - Coordinates in the map
    - Localization step at the end of the object recognition process
    - User input

- Autonomous mobile robots move around in the environment. Therefore **ALL** of them:
  - They need to know **where** they **are**.
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  - They need to know **how** to get there.

- Different levels:
  - Control:
    - How much power to the motors to move in that direction, reach desired speed
  - Navigation:
    - Avoid obstacles
    - Classify the terrain in front of you
    - Follow a path
  - Planning:
    - Long distance path planning
    - What is the way, optimize for certain parameters

Most important capability

(for autonomous mobile robots)

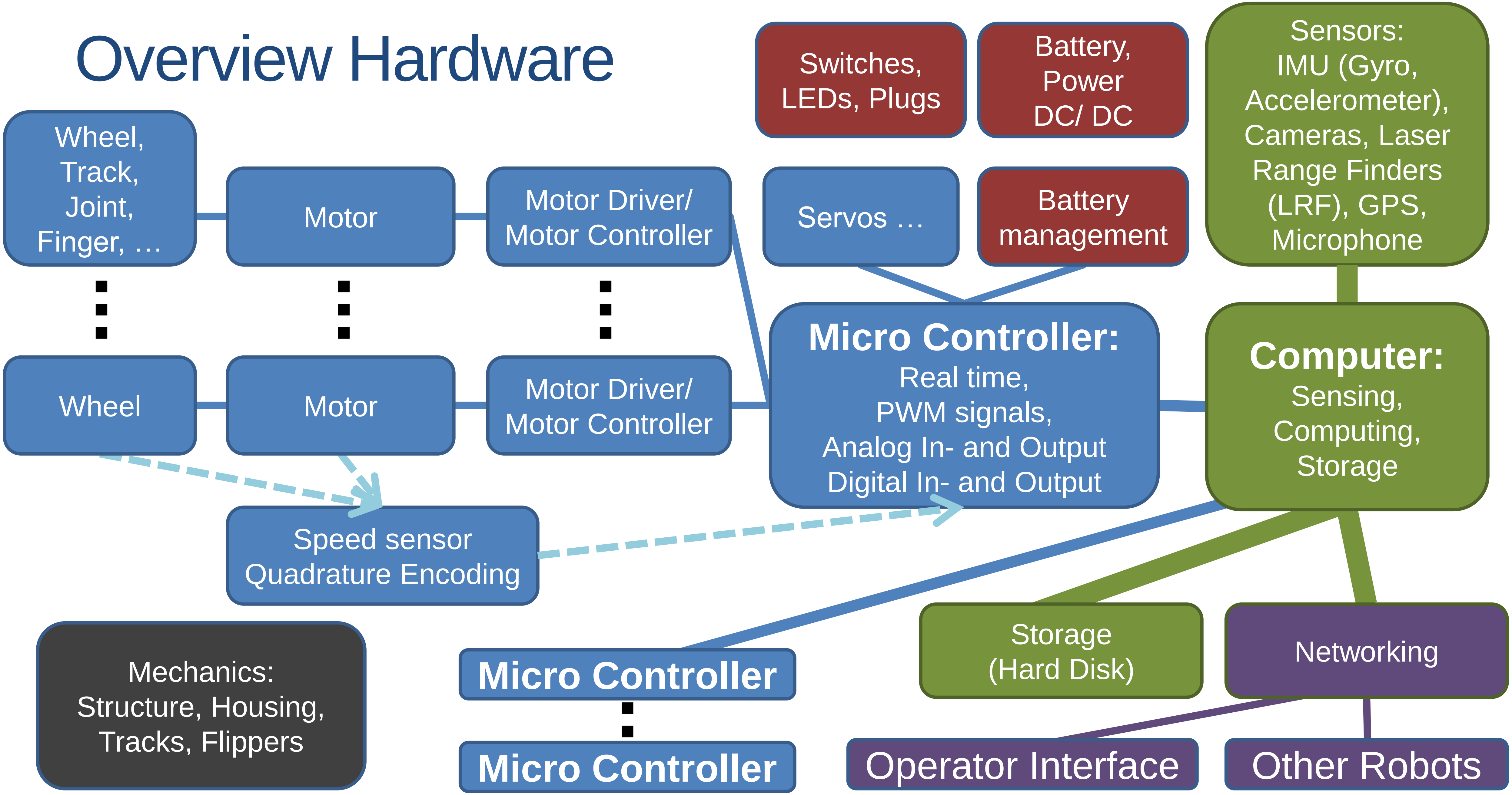
How to get from place A to place B?

(safely and efficiently)

How to get from A to B?

What are the components of a ROBOT?

Overview Hardware



Overview Hardware

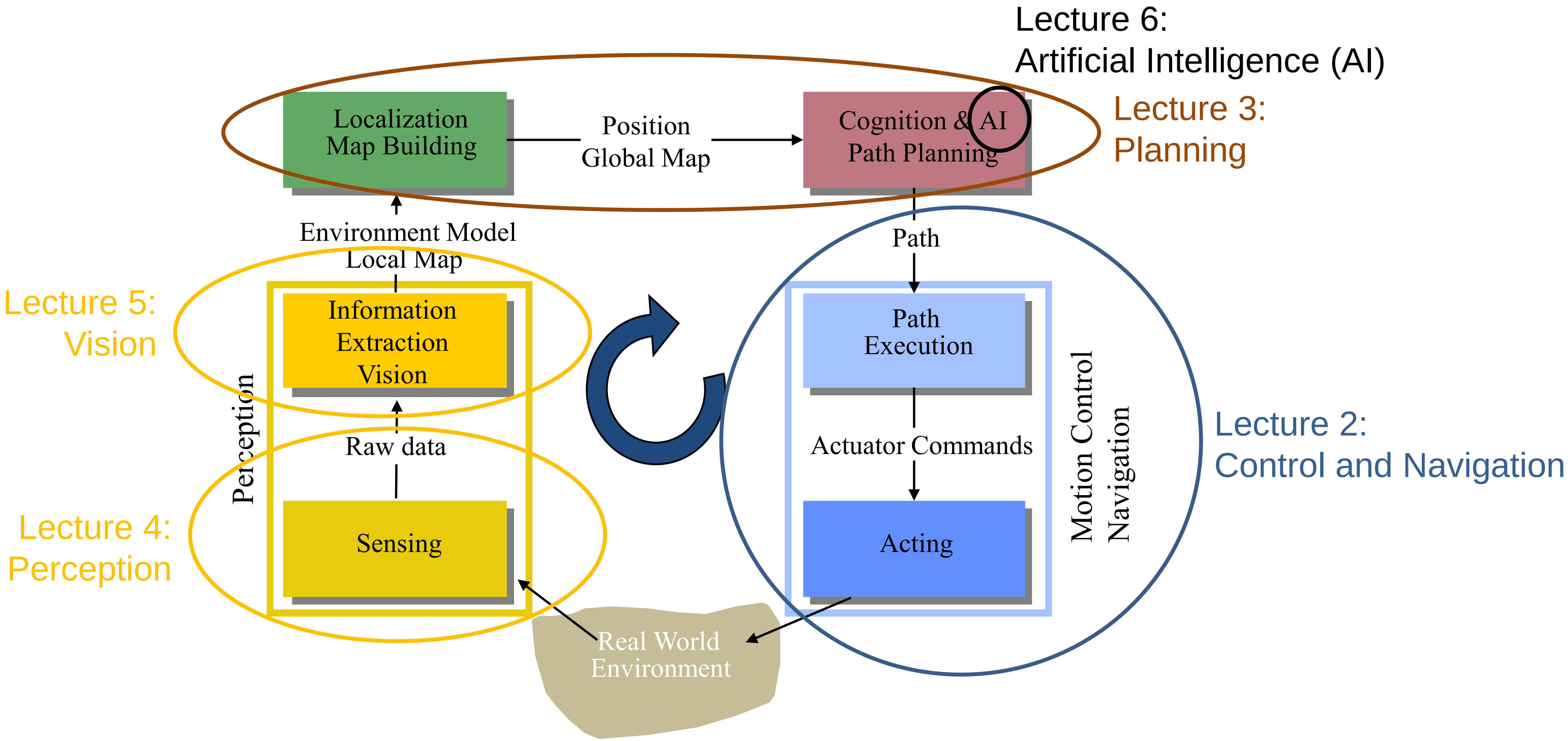
Computer:

Control and Navigation
Planning
Perception
Vision
Artificial Intelligence

How to get from A to B?

How to program an intelligent ROBOT to go from A to B?

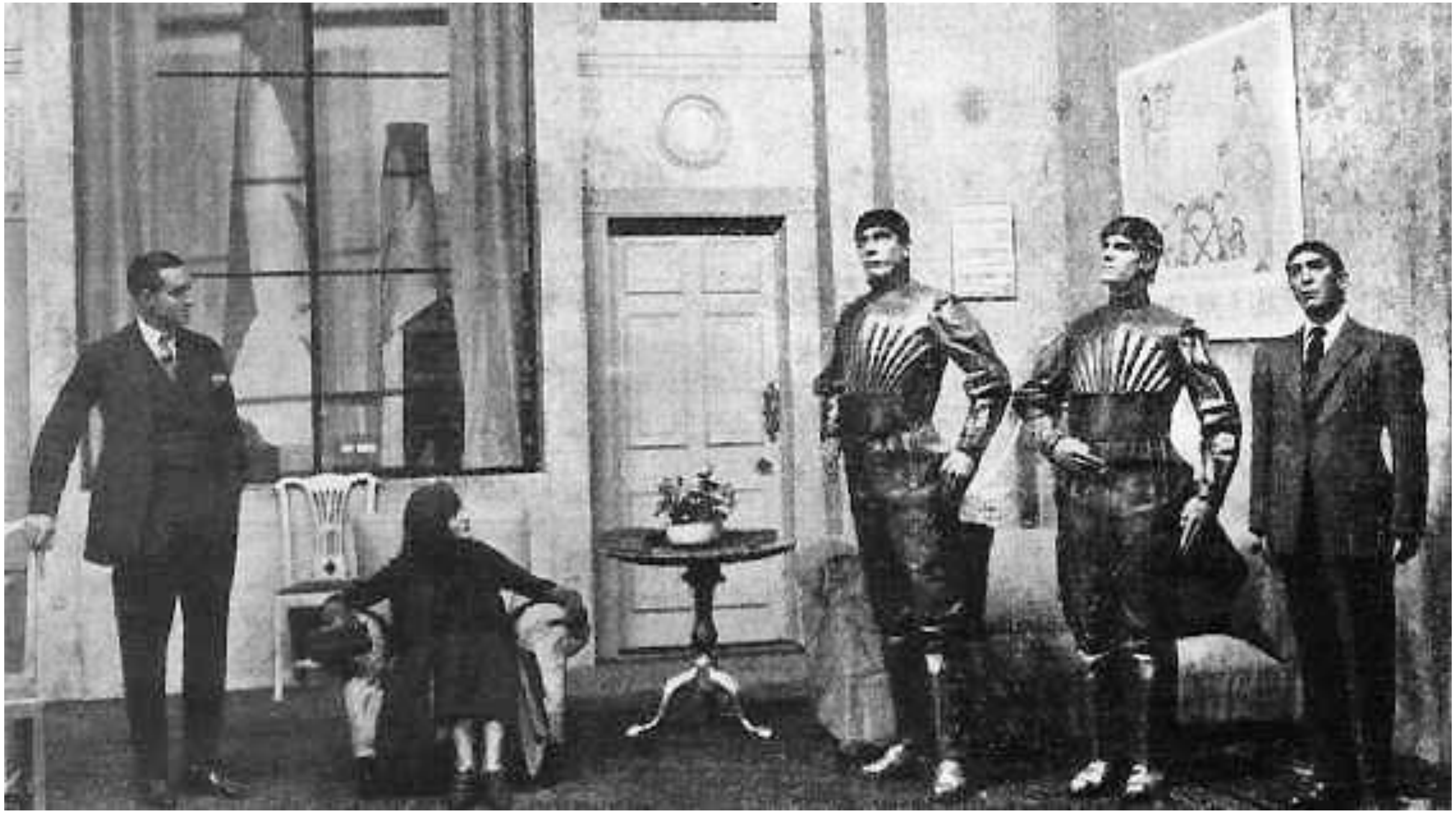
General Control Scheme for Mobile Robot Systems



With material from Roland Siegwart and Davide Scaramuzza, ETH Zurich

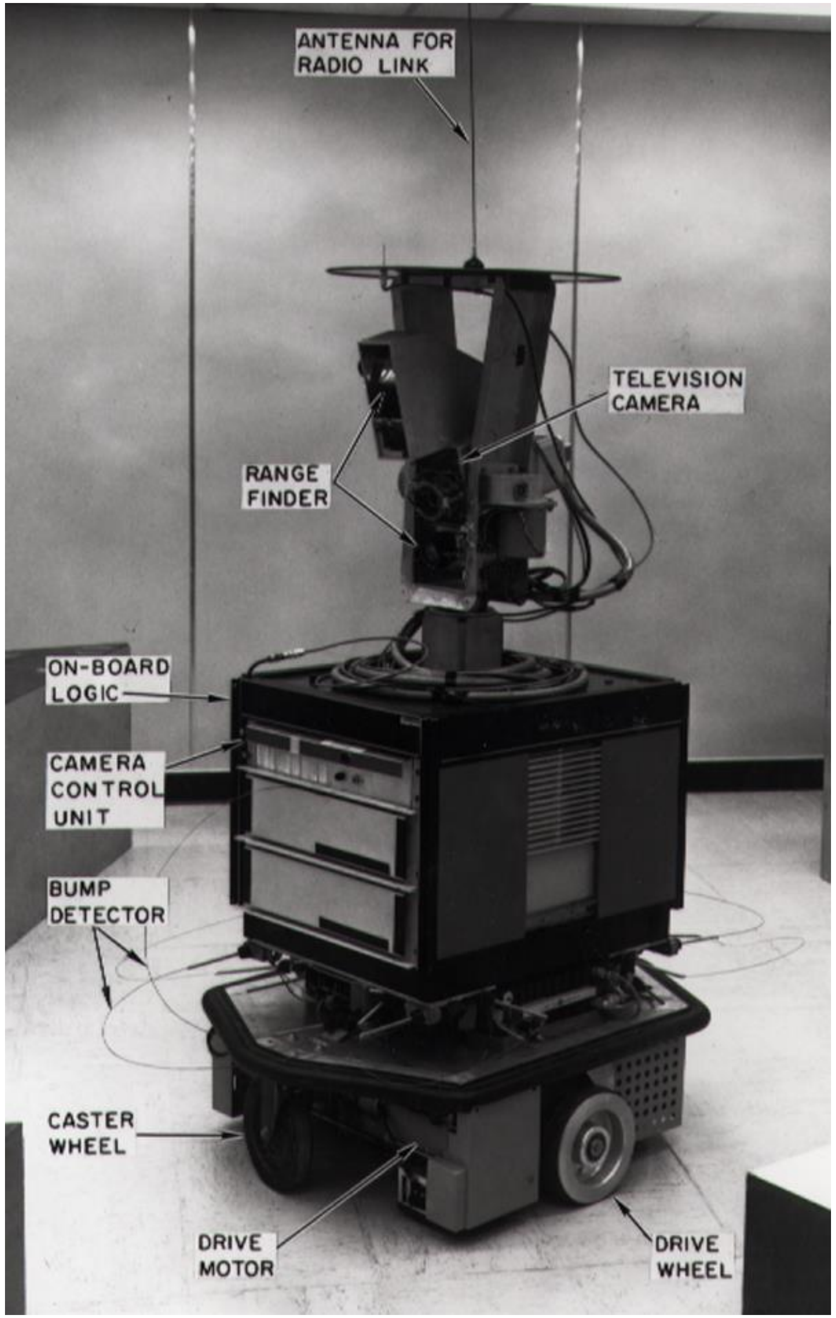
Brief History

Robota “forced labor”: Czech (捷克共和國), Karel Čapek R.U.R. 'Rossum's Universal Robots' (1920).



Shakey the robot (1970)

- First general-purpose mobile robot to be able to reason about its own actions
- Advanced hardware:
  - radio communication
  - sonar range finders
  - television camera
  - on-board processors
  - bump detectors
- Advanced software:
  - Sensing and reasoning
- Very big impact
- Video: http://robotics.shanghaitech.edu.cn/videos/external/Shakey.mkv



KINEMATICS

How to get from A to B?

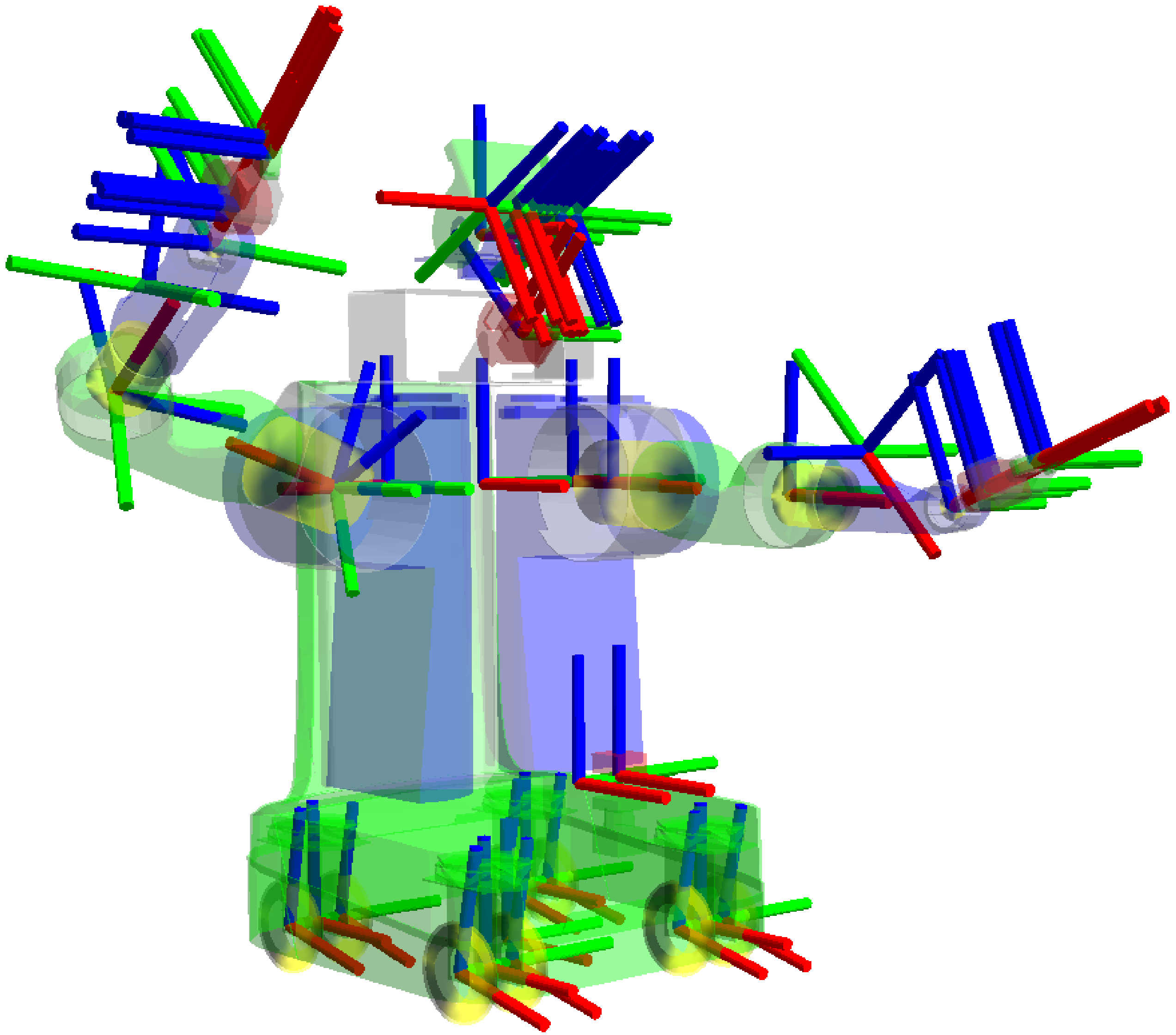
Which (physical) methods can be used to move a robot?

(Propulsion Systems)

Means of Propulsion

- Land:
  - Wheels (1, 2, 3, 4, 6, ….)
    - Different types!
  - Tracks (1, 2, 3, 4, ….)
    - Like (military) tanks
  - Legs (1, 2, 4, 6, ….)
  - Snake robots
- Air:
  - VTOL (Vertical Take Off and Landing)
    - Rotor (2, 4, ….)
    - Jet (1)
  - Fixed wing plane (Rotor + Jet)
  - Blimp (plus rotor)
- Water
  - Propellers
  - Sails
  - Jets
- Underwater
  - Propellers
  - Gliders:
    - Change buoyancy to move up and down; use wings to move forward
- Space
  - Chemical rocket engine
  - Electric (ion) thrusters

Robot Kinematics



- Geometric description of propulsion
- Robot Arm:
  - Rigid bodies connected by
  - Joints with pure rotation or translation
- Mobile Robot:
  - One rigid body moved by
  - Actuators interacting with the environment

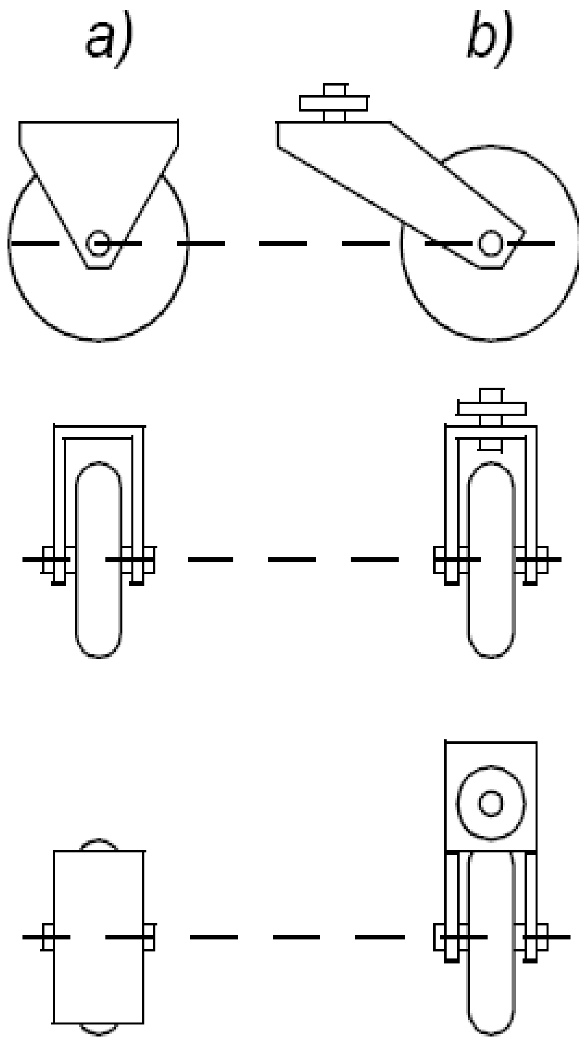
- Forward Kinematics:
  - Given the motion of the actuators:
  - Where is the robot (hand)?
- Inverse Kinematics:
  - Given a goal position:
  - Who do I have to move my motors to get there?

Mobile Robots with Wheels

- Wheels: best solution for most applications
- Three wheels sufficient to guarantee stability
- More than three wheels => suspension (springs) is needed
- Different types of wheels! => Select best for application

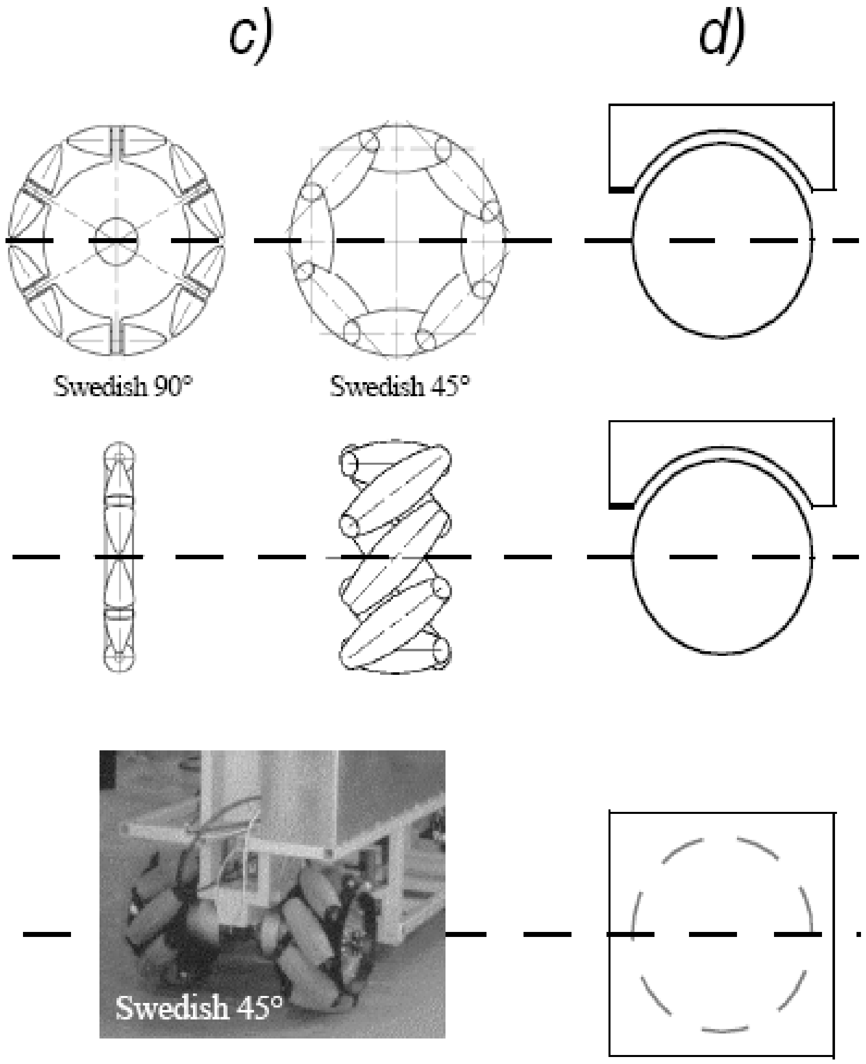
The Four Basic Wheels Types

- a) Standard wheel:
  - 2 degrees of freedom: Rotation:
    - around the (motorized) wheel axle
    - around contact point
- b) Castor wheel:
  - 3 degrees of freedom: Rotation:
    - around the wheel axle
    - contact point
    - castor axle



The Four Basic Wheels Types

- c) Swedish wheel:
  - 3 degrees of freedom: Rotation
    - around the (motorized) wheel axle,
    - around the rollers
    - around the contact point
- d) Ball or spherical wheel:
  - Suspension technically not solved



Characteristics of Wheeled Robots and Vehicles

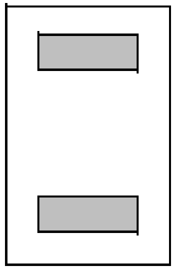
- Vehicle stability is guaranteed with 3 wheels
  - Center of gravity in triangle of wheels.

- Stability is improved by 4 and more wheel
  - Need flexible suspension system (springs).

- Bigger wheels allow to overcome higher obstacles
  - But require higher torque

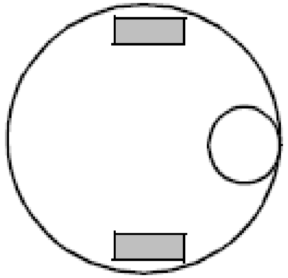
Different Arrangements of Wheels I

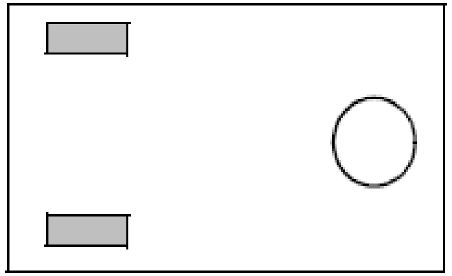
- Two wheels

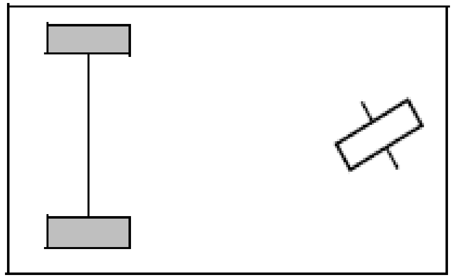


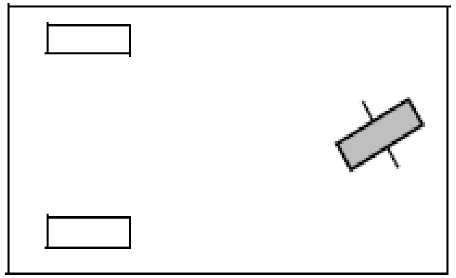
Center of gravity below axle

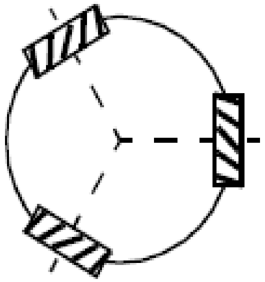
- Three wheels



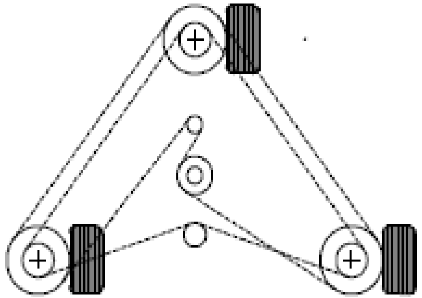








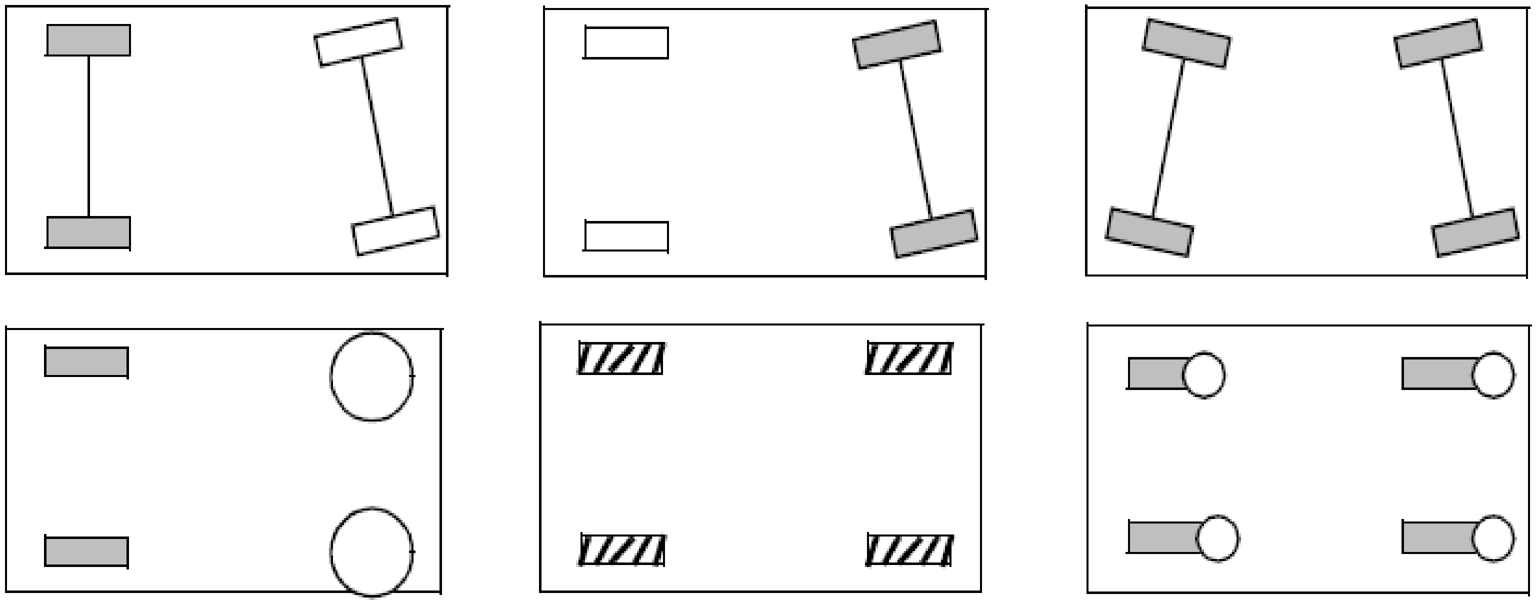
Omnidirectional Drive

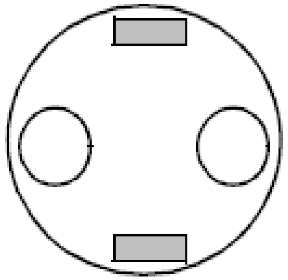


Synchro Drive

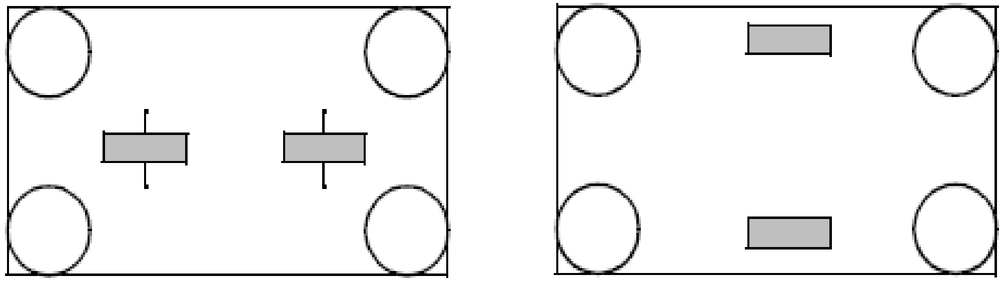
Different Arrangements of Wheels II

- Four wheels



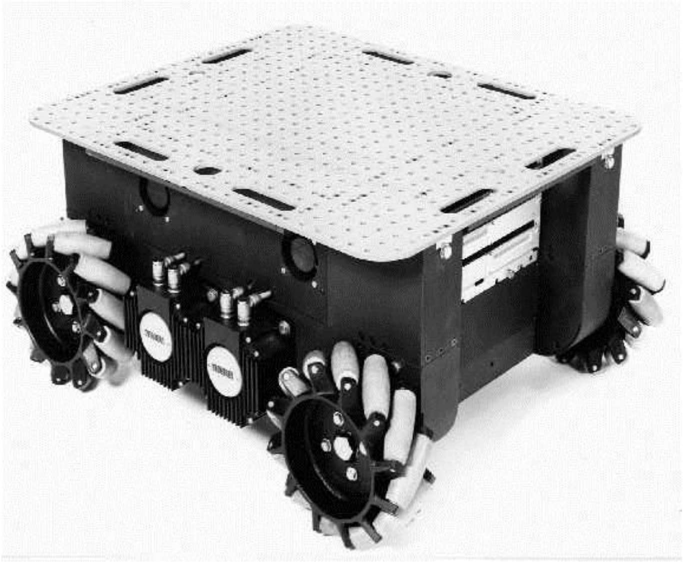


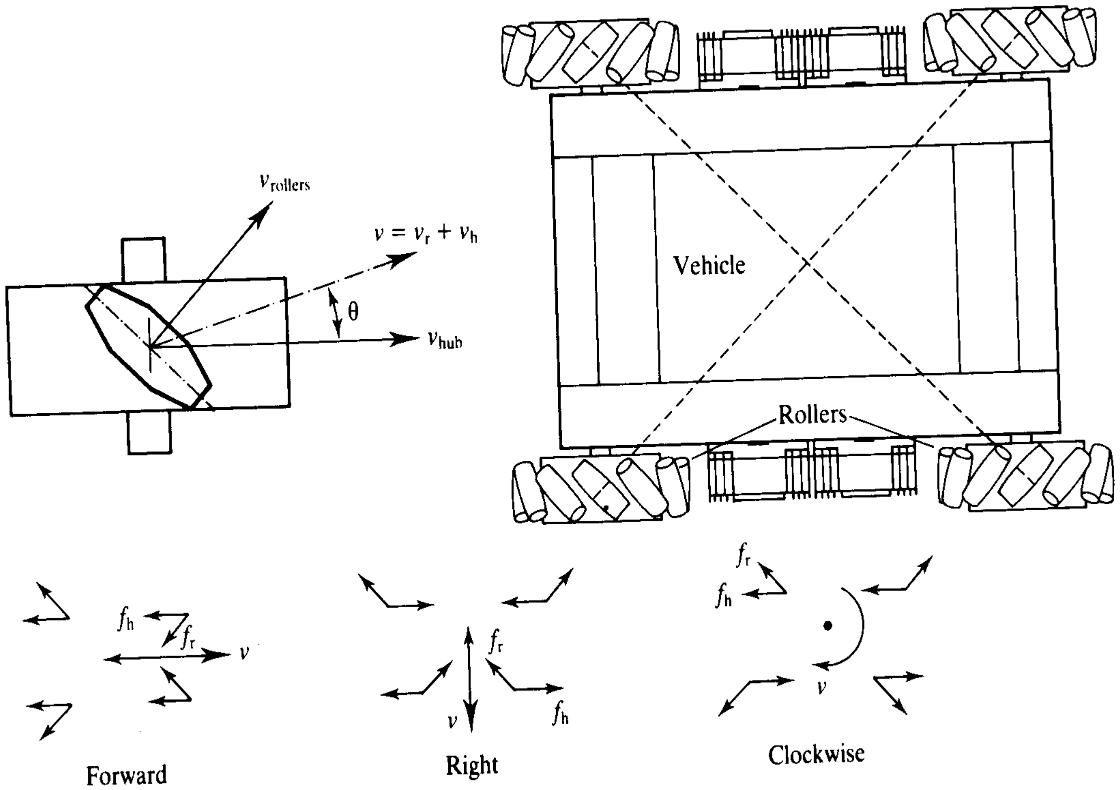
- Six wheels



Uranus, CMU: Omnidirectional Drive with 4 Wheels

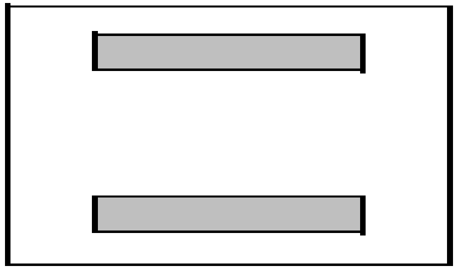
- Movement in the plane has 3 DOF
  - thus only three wheels can be independently controlled
  - It might be better to arrange three swedish wheels in a triangle





Rugbot, Jacobs Robotics: Tracked Differential Drive

- Kinematic Simplification:
  - 2 Wheels, located at the center



GEOMETRY

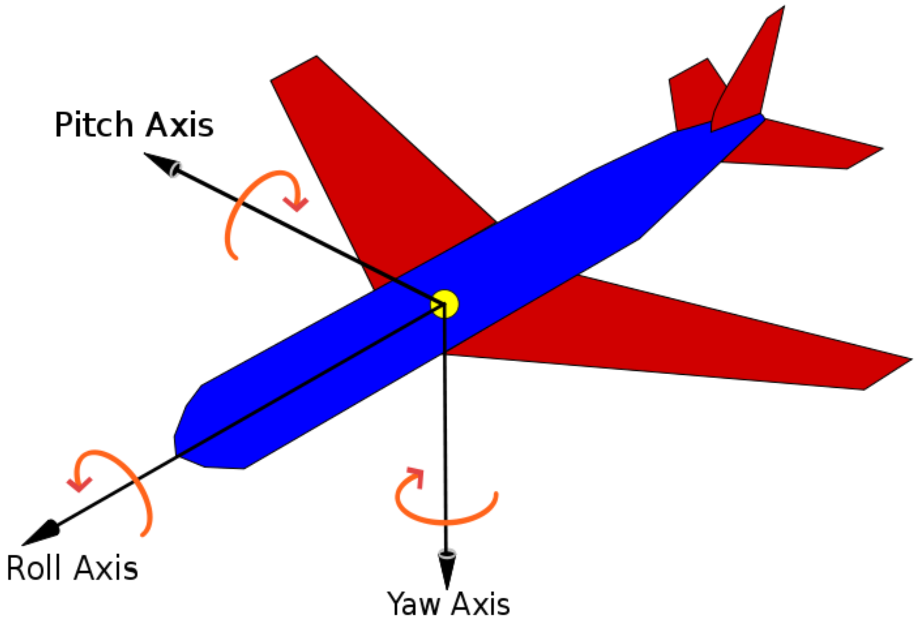
Position, Orientation, Pose – Translation, Rotation, Transform

- Position:
  - Coordinates in a frame of reference (for example x, y)
- Orientation:
  - Direction of the robot (for example theta θ)
- Pose:
  - Position and Orientation

- Translation:
  - Motion from one frame of reference to another
- Rotation:
  - Change of orientation from one reference frame to another
- Transform:
  - Translation and Rotation

- Transform and Pose are mathematically the same – difference in semantics!

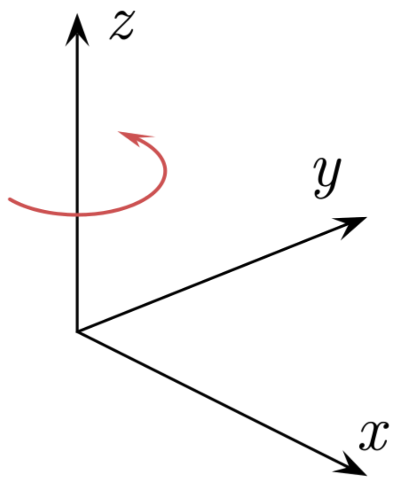
2 Dimensions (2D) and 3D

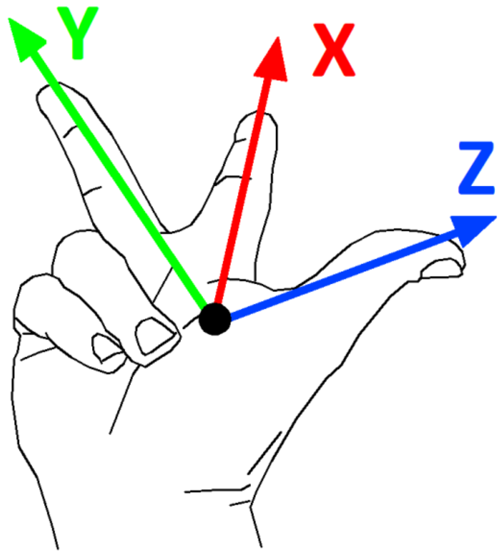


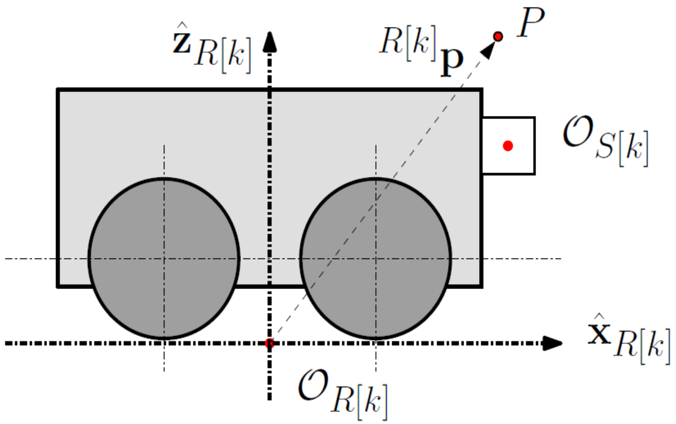
- Represent
    - kinematics (motion) and/ or
    - measurements (sensor readings) and/ or
    - environment model (surroundings)
  - in two dimensions or three dimensions
- 2D:
  - Robot on a plane, move in x and y, plus rotation => three degrees of freedom (3DoF)
  - Often enough, for example: Route planning in car, transport robot in factory
- 3D:
  - Position: x, y, z (height, depth (underwater))
  - Orientation (direction): roll, pitch, yaw
  - => six degrees of freedom (6DoF)
  - Needed for advanced robots

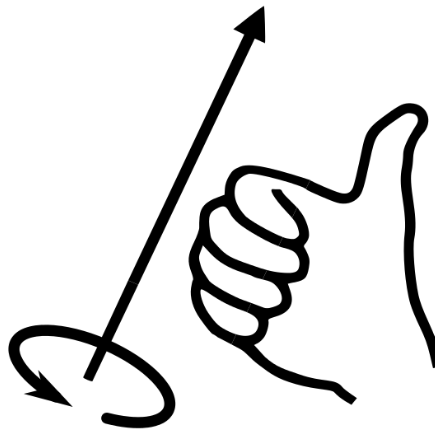
3D: Right Hand Coordinate System

- Standard in Robotics
- Positive rotation around all axes is anti-clockwise
- Right-hand rule mnemonic:
  - Thumb: z-axis
  - Index finger: x-axis
  - Second finger: y-axis
  - Rotation: Thumb = rotation axis, positive rotation in finger direction
- Robot Coordinate System:
  - X front
  - Z up (Underwater: Z down)
  - Y ???









Right Hand Rule http://en.wikipedia.org/wiki/Right-hand_rule

APPLICATIONS OF MOBILE ROBOTS

Current applications

- Industry
  - Manufacturing, Transportation, **Logistics**
- Service
  - Transportation (in Hospitals)
  - Clean windows
  - **Pipeline inspection** (tele operated)
- Medical
  - Surgery
- Household
  - Carpet cleaning, lawn mowing
- Toys
- Military
- Research (**Space, Underwater**)

Future applications

- Autonomous cars
- Mobile manipulation/ manufacturing
- Autonomous delivery using drones
- Atomic Power Plant decommissioning
- Humanoid household robots
- Military
  - Autonomous air combat
  - Autonomous ground robots
  - Autonomous underwater robots (Torpedo 2.0)
- **Search and Rescue Robotics**

Pipeline inspection

- Tele operated tracked robot
- Inspect pipelines
- Main sensor: video camera with light source
- Additional sensors: laser measurement (diameter)

- Why use robot?
- Inaccessible to men
(non-destructive)

Automated Guided Vehicles (AGV) in Industry and Service

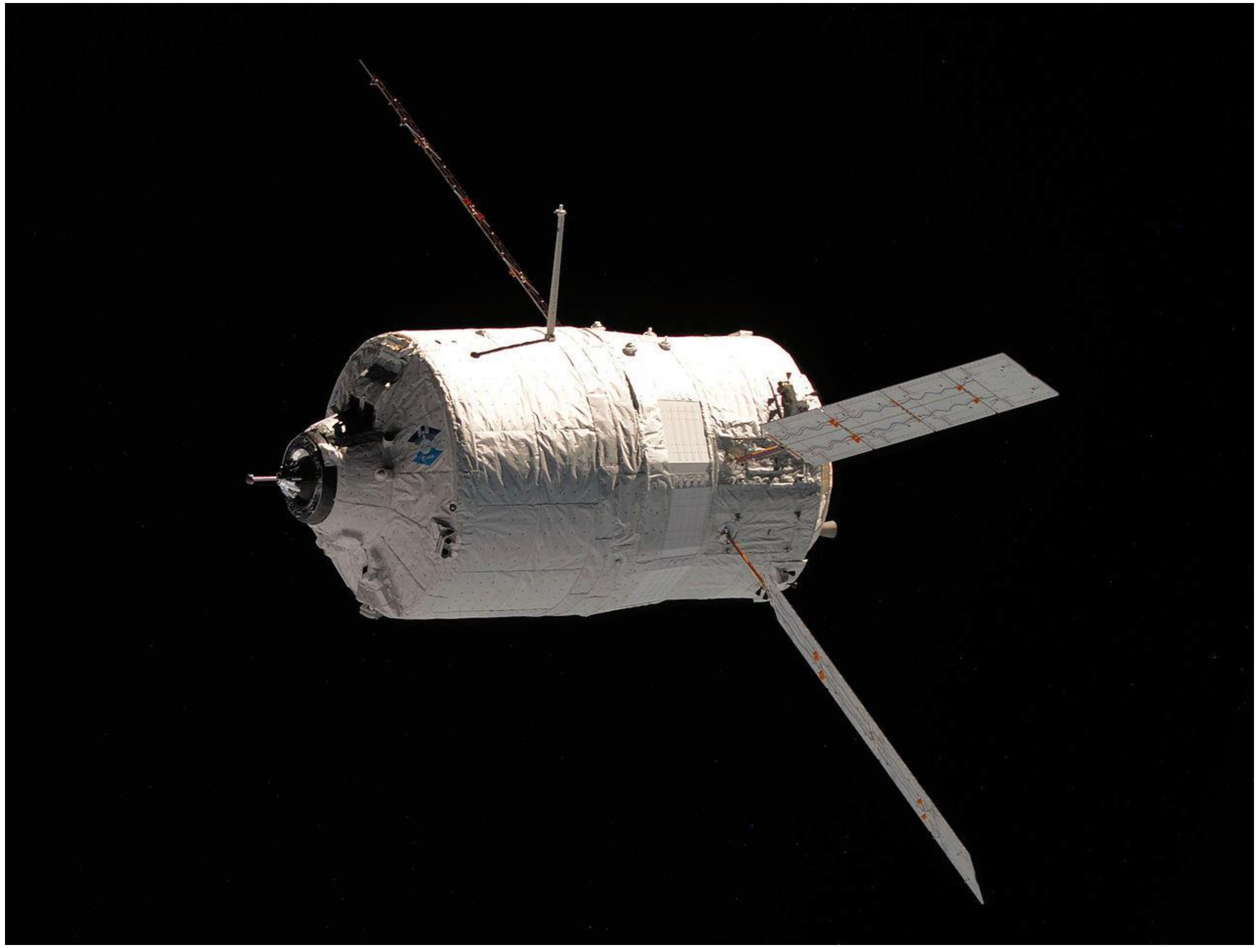
- Transport things from A to B
- In a warehouse, factory or hospital, lab …
- Navigation: guided – wires, tape, reflective markers localized with lasers, using map (SLAM)
- Safety measures when working together with humans!
- Why?
  - Efficiency
  - Speed
  - Safety

Automation of Logistic Processes: Container unloading

- Object Recognition of heterogeneous goods
- Grasp and motion planning
- Fully autonomous unloading of containers
- Using a single RGB-D camera

Automated Transfer Vehicle (ATV)

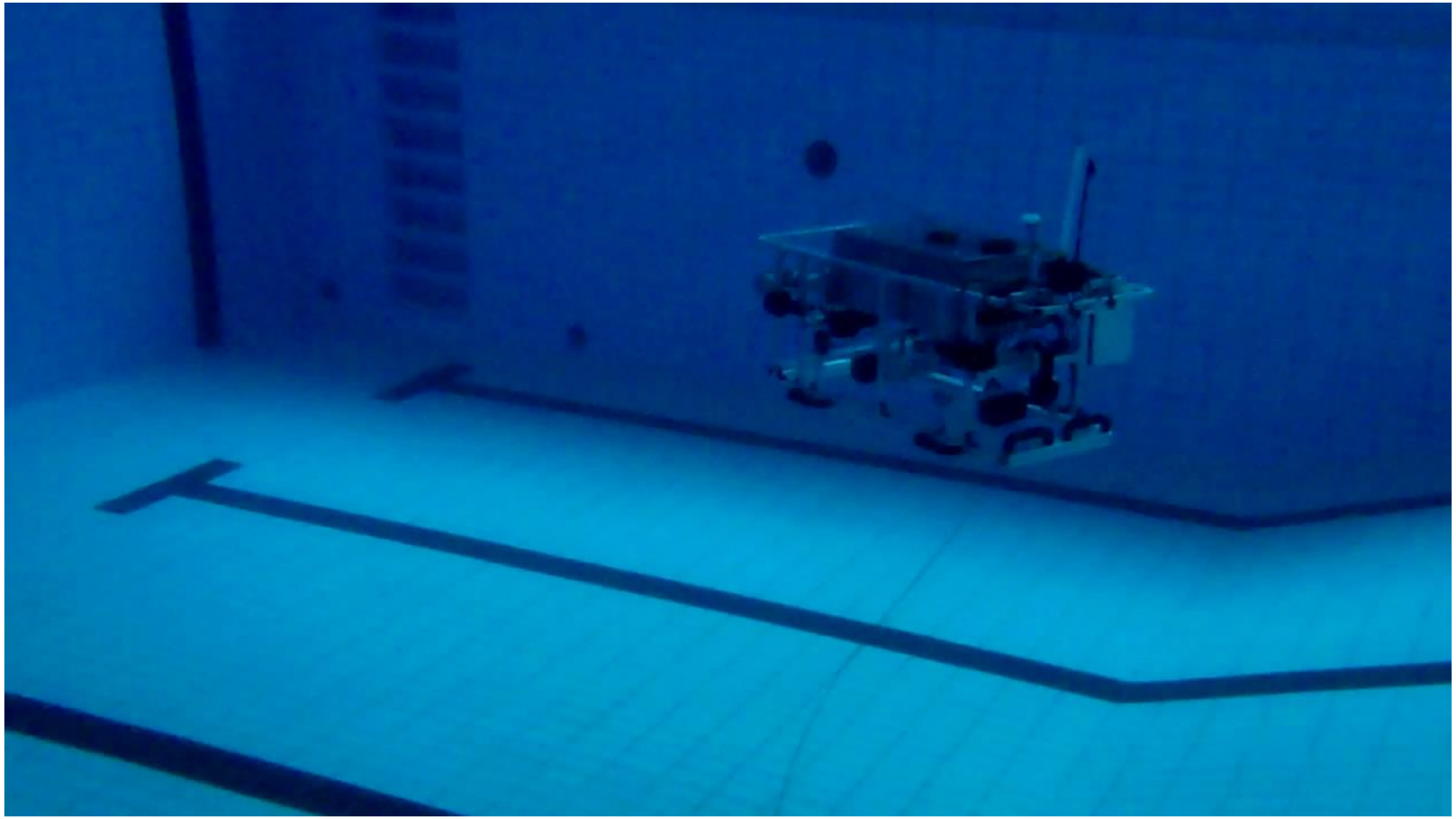
- Supply the International Space Station (ISS) with propellant, water, air, payload and experiments
- Autonomously flies towards the ISS
- Autonomously docks onto the ISS



- GPS and star tracker for localization
- From 250m distance: vision for object recognition (dock) and tracking
- Why automation: Saver than human control!

Applications for Underwater Robotics

- Oil industry: Remotely Operated Vehicles (ROV) – construction and maintenance of Oil drilling platforms
- Research: Biology, Oceanography, Geology
  - Explore the subsea
  - Mapping (2D and 3D)
  - Autonomy
- Military
  - Surveillance
  - Harbor security
  - Mine hunting
  - Attack
- Inspection
- Search and Rescue



Urban Search and Rescue Robots

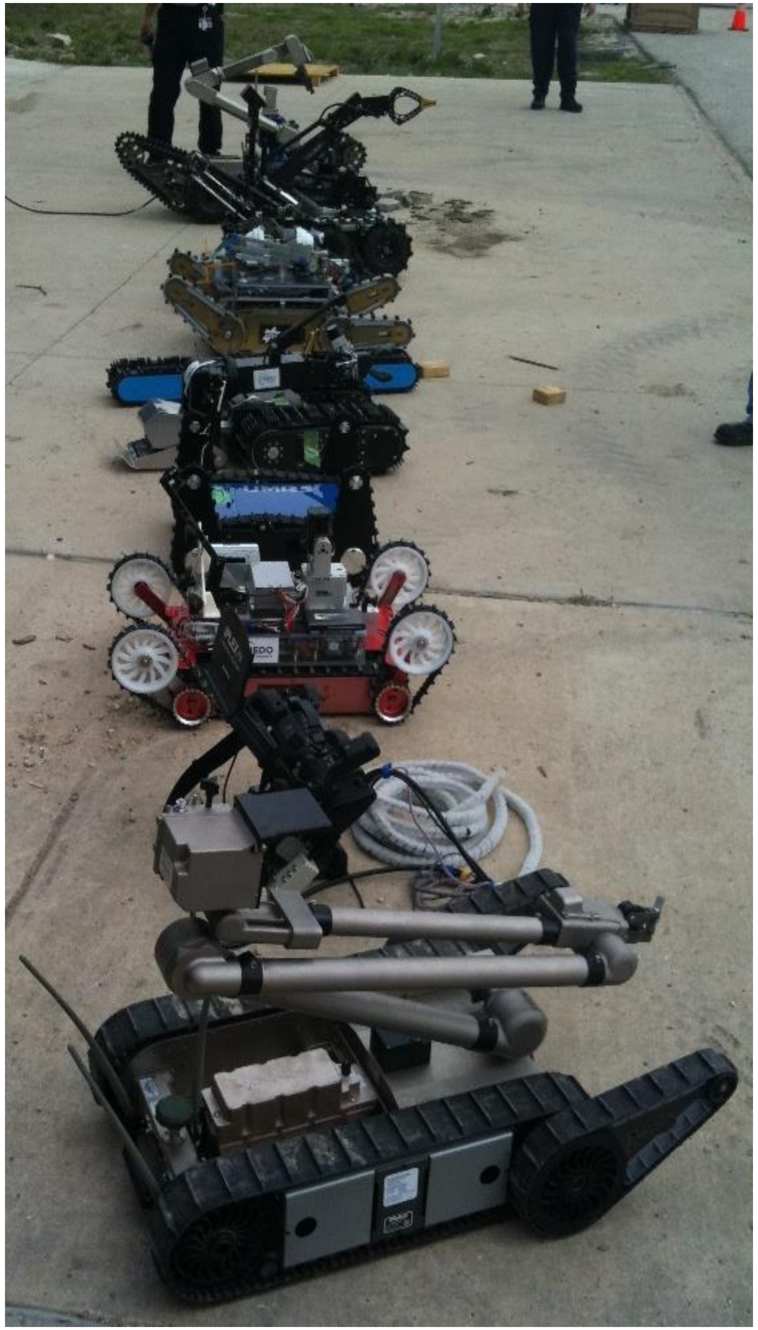
- Scenarios:
  - Earthquakes
  - Gas, bomb explosions
  - Hazardous material accidents
  - Nuclear accidents
- Tasks
  - Locating victims, their state or absence
  - Locating hazards (gas, fire, smoke)
  - Provide information (maps & situational awareness)
- Advantages of Robots
  - Can take high risks
  - Many sensors & network connections
- Most critical disadvantages of robots (currently):
  - locomotion
  - cost
  - usability

Rescue Robot in Fukushima

- Fukushima Daiichi nuclear disaster 2011
- RoboCup Rescue Robot Quince:
  - Developed in Tohoku University, Japan
  - 2 Units deployed to Fukushima plant
  - One robot stranded on third floor of reactor Number 2

Rescue Robots

- Different shapes
- But: All tracked!
- Flippers/ sub-tracks for advanced mobility
- Arms for directed sensing and manipulation
- Mobile manipulation big topic => combines industrial robots with mobile robots!



Flying search and rescue robot

- AirRobot - Quadcopter
- To get overview images
- Image stitching algorithm to create big birds-eye maps

- Currently still teleoperated
- Analog video transmission
- Radio distance: up to 500m

Aerial Map

- Rubble pile and train
- 435 frames
- Real time generation of map