اصول علم ربات – جلسه دوم

Fundamentals of Robotics – Lecture 02

Course Roadmap

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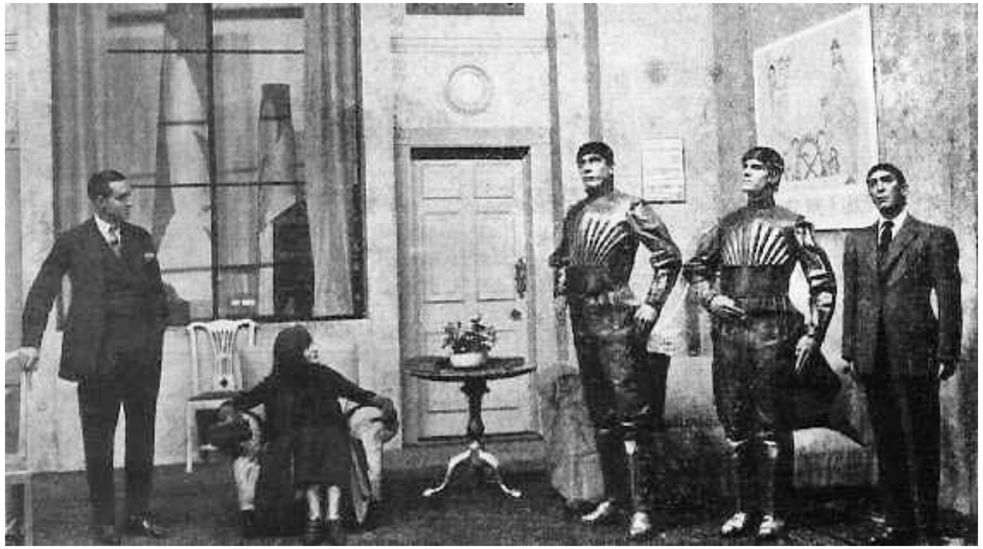
زمستان ۱۴۰۰

[slides adapted from Gianni Di Caro, @CMU with permission]

Etymology of the term robot



- R.U.R. (Rossum's Universal Robots): Theater science fic: on play of Czech Karel Čapek (1921)
  - *rabota* = "obligatory work"
  - *robotnik* = "serf"
- ALer R.U.R., the commonly used term *automaton* started to be substituted with **robot**

DOMIN: Sulla, let Miss Glory have a look at you.

HELENA: (*stands and offers her hand*) Pleased to meet you. It must be very hard for you out here, cut off from the rest of the world.

SULLA: I do not know the rest of the world Miss Glory please sit down

HELENA: (*sits*) Where are you from?

SULLA: From here, the factory

HELENA: Oh, you were born here.

SULLA: Yes I was made here.

HELENA: (*startled*) What?

DOMIN: (*laughing*) Sulla isn't a person, Miss Glory, she's a robot.

HELENA: Oh, please forgive me . . .

DOMIN: (*puts his hand on Sulla's shoulder*) Sulla doesn't have feelings. You can examine her. Feel her face and see how we make the skin.

HELENA: Oh, no, no!

DOMIN: It feels just the same as human skin. Sulla even has the sort of down on her face that you'd expect on a blonde. Perhaps her eyes are a bit small, but look at that hair. Turn around, Sulla.

HELENA: Stop it!

DOMIN: Talk to our guest. We're very honoured to have her here.

SULLA: Please sit down miss. (*both sit*) Did you have a good crossing.

More than 150 Years in the collective imaginary

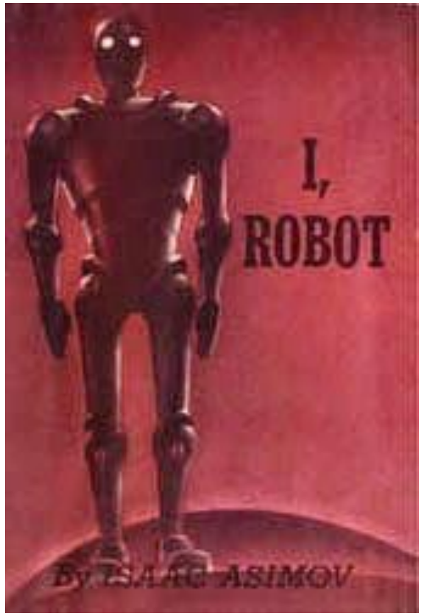
Sci-fi Robots & co.

A multitude of shapes,
attitudes, capabilities

Bubo, from the Clash of the Titans (1981)

The Steam Man of the Prairies (1868)

The Wizard of Oz (1939)



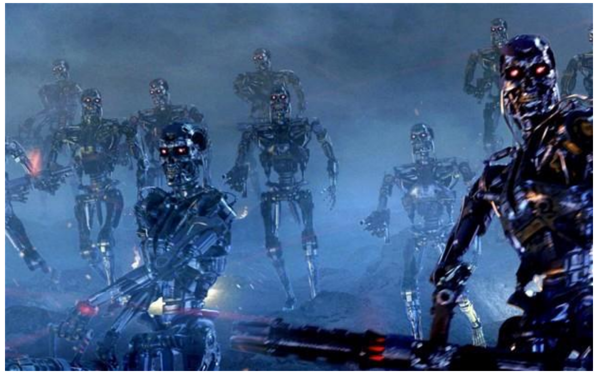
A complete illustrated history http://www.filmsite.org/robotsinfilm.html

More than 100 Years in the collective imaginary

Good robots
human / animal shaped

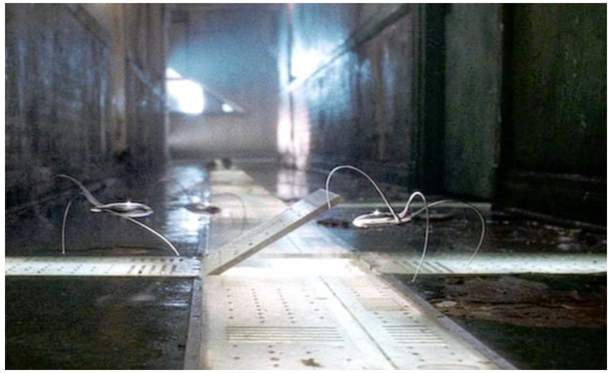
Nasty (more human?) robots
human / animal shaped

The Jetsons,
1962



Terminator,
1984

Star Wars,
1977



Minority Report,
2002

Road map

- Robots?
- Robotics as a field of study
- Robotics in this course
- What will you learn
- Practical aspects of the course

A robot….?

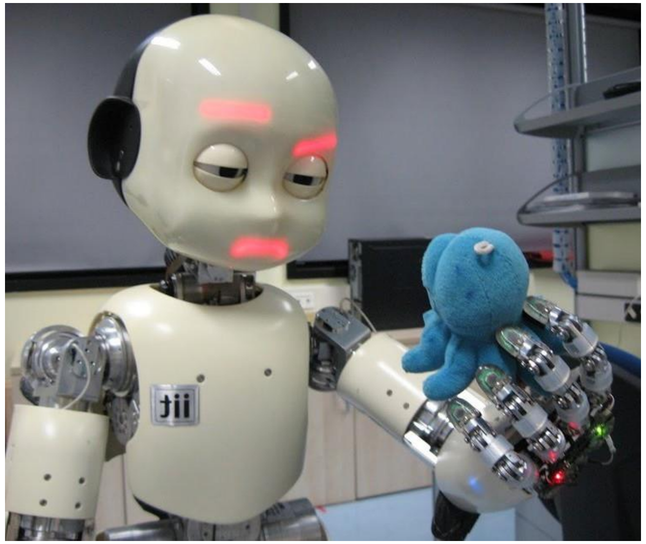
A robot….?

A **robot** (*mechanism*):

- is a machine which exists in the physical world,
- has movable parts,
- can sense its external and internal environment,
- can make decisions (fully or partially autonomous),
- acts upon the environment to achieve some goals,
- is designed to do a job by itself.

Links and joints

- **PHYSICALLY EMBEDDED**: exists in the 3D physical world, subject to the laws of physics (e.g., it does not live in a computer)
- **MOVEABLE PARTS**: made of multiple (rigid or soft) **bodies** (links) connected by **joints**, so that *relative motion* between adjacent links becomes possible.
  Actuation of the joints (e.g., by electric motors), causes the robot to move and exert forces in desired ways
- **ACT ON ITS ENVIRONMENT**: it has physical effectors/actuators, made out of links and joint



Links and joints

<u>Rigid body / link :</u>
The relative distance between any two points (e.g., in a link) remains unchanged

<u>Soft body / link :</u>
The relative distance between any two points can change

Effectors and Actuators

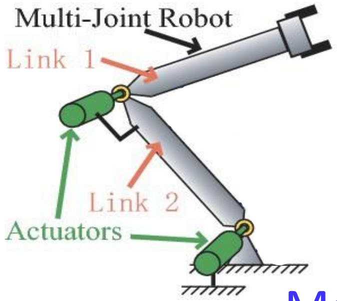
Action: Do physical things in the real world

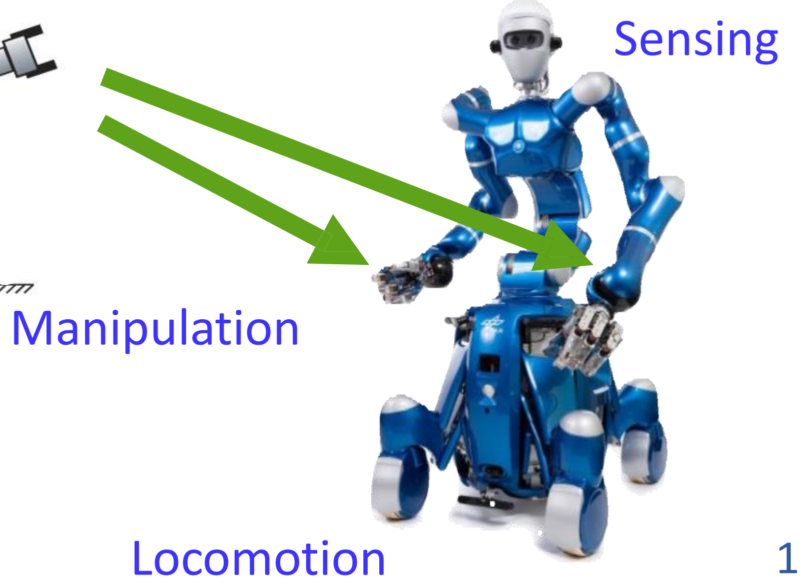
EFFECTORS: Electro-mechanical parts that enable a robot to act, such as wheels, tracks, legs, arms, grippers, fingers, wings, flippers, … also devices for soldering, cutting, heating, melting ... An effector determines an effect on the environment

ACTUATORS: The underlying electro-mechanical mechanisms that physically enable the effectors to execute an action or movement, such as motors, (artifitial) muscles, rotors, hydraulic or pneumatic cylinders, chemically-sensitive materials, …

Three main categories of activities:

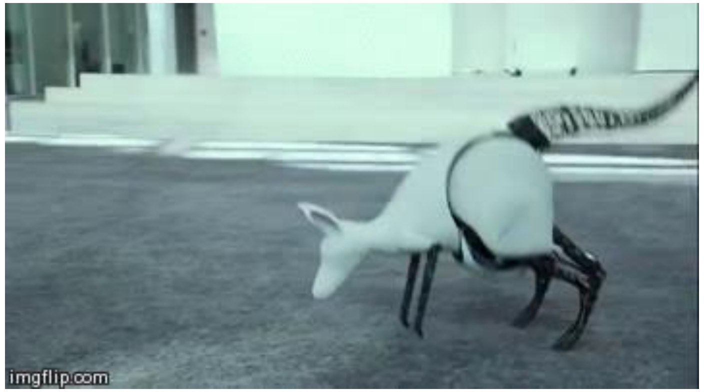
- ✓ **Locomotion**: moving around
- ✓ **Sensing**: gather environment's information
- ✓ **Manipulation**: handling, acting upon objects





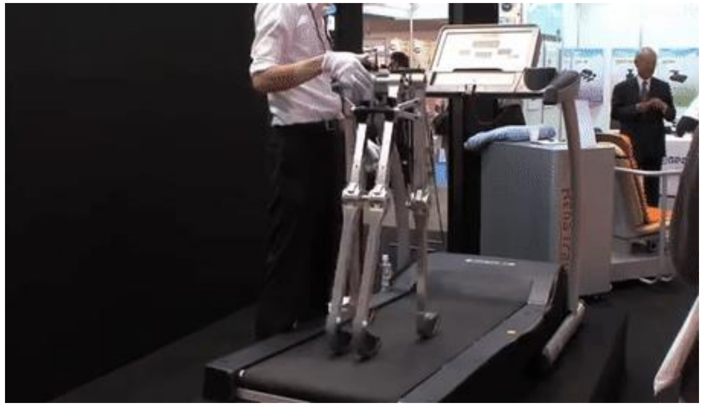
Active vs. passive actuation

ACTIVE ACTUATION: the action of effectors and actuators is performed through the direct consumption of energy to provide power, in the forms of fuel, batteries, springs, …



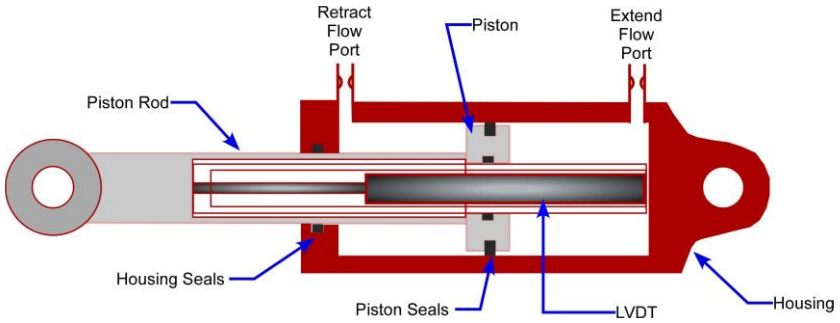
PASSIVE ACTUATION: exploiting the potential energy in the mechanics of the effector and its interaction with the environment instead of active power consumption

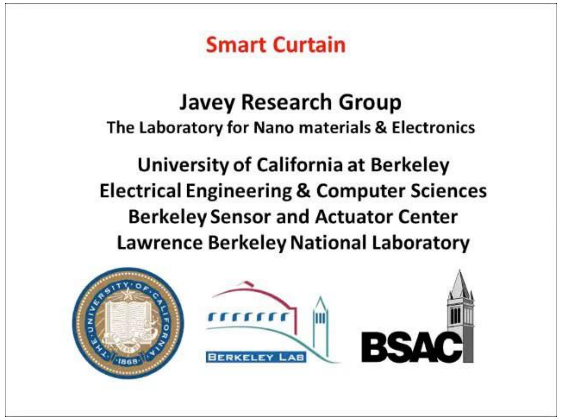
It needs a downward slope!

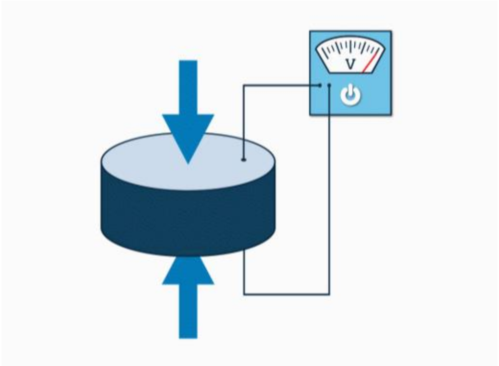


Types of actuators

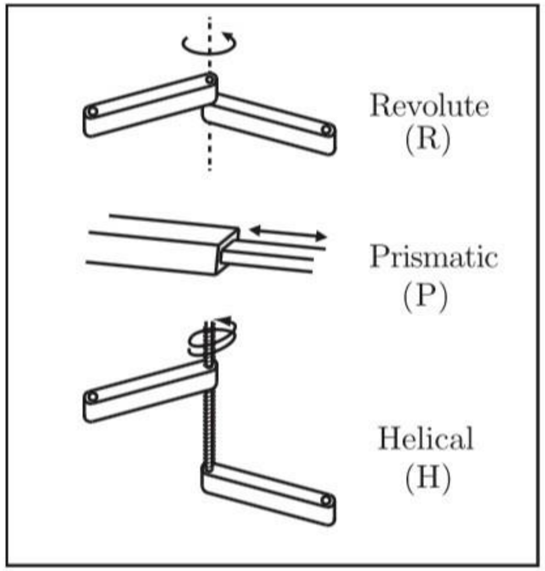
- ELECTRIC MOTORS
- HYDRAULICS
- PNEUMATICS
- MAGNETIC FIELDS
- PHOTO-REACTIVE MATERIALS
- CHEMICALLY-REACTIVE MATERIALS
- THERMALLY-REACTIVE MATERIALS
- PIEZOELECTRIC MATERIALS

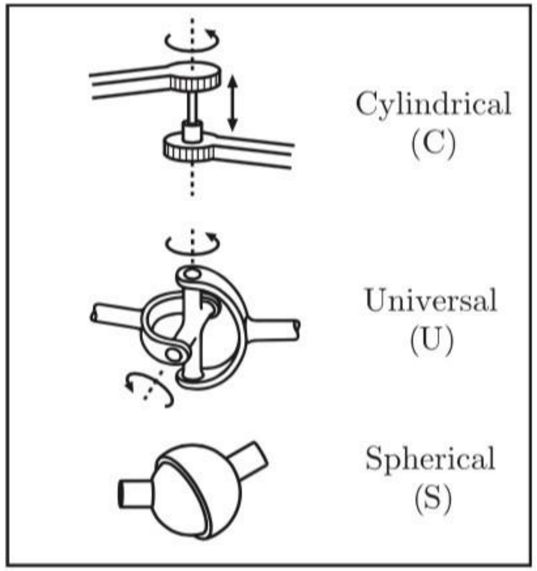


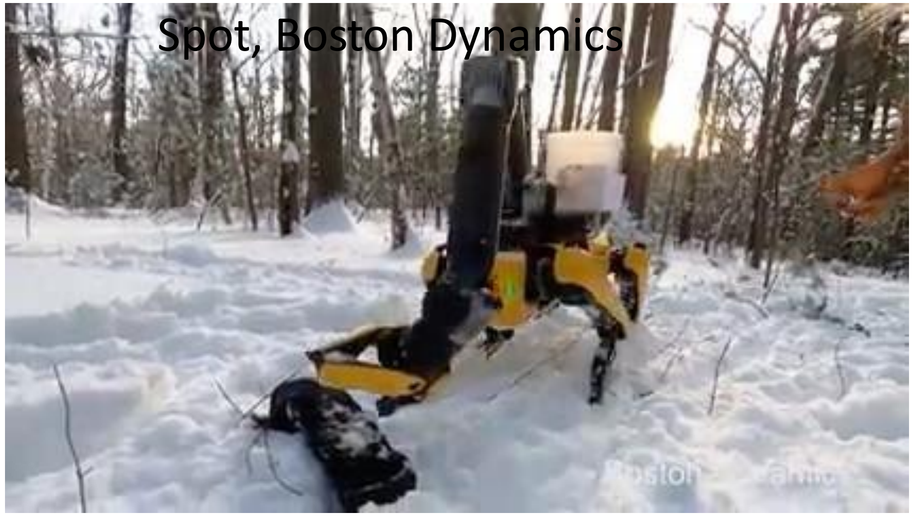


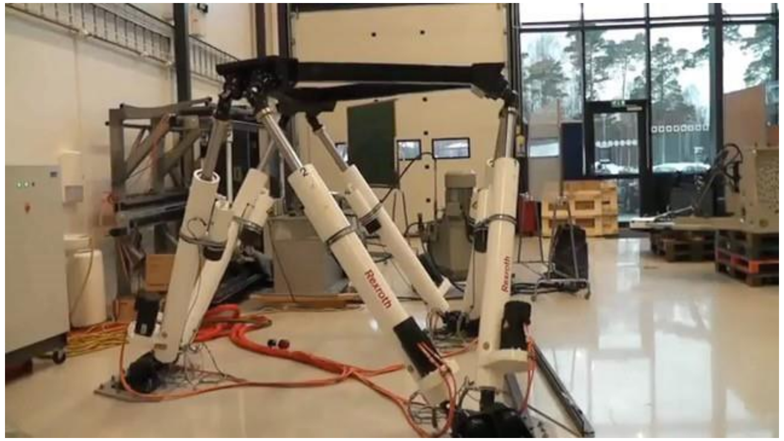


Typical robot joints and arrangements



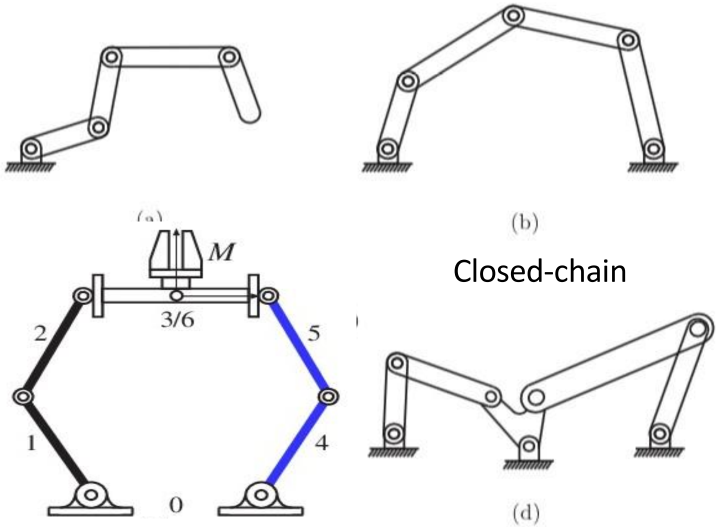






Stewart–Gough platform

Open-chain

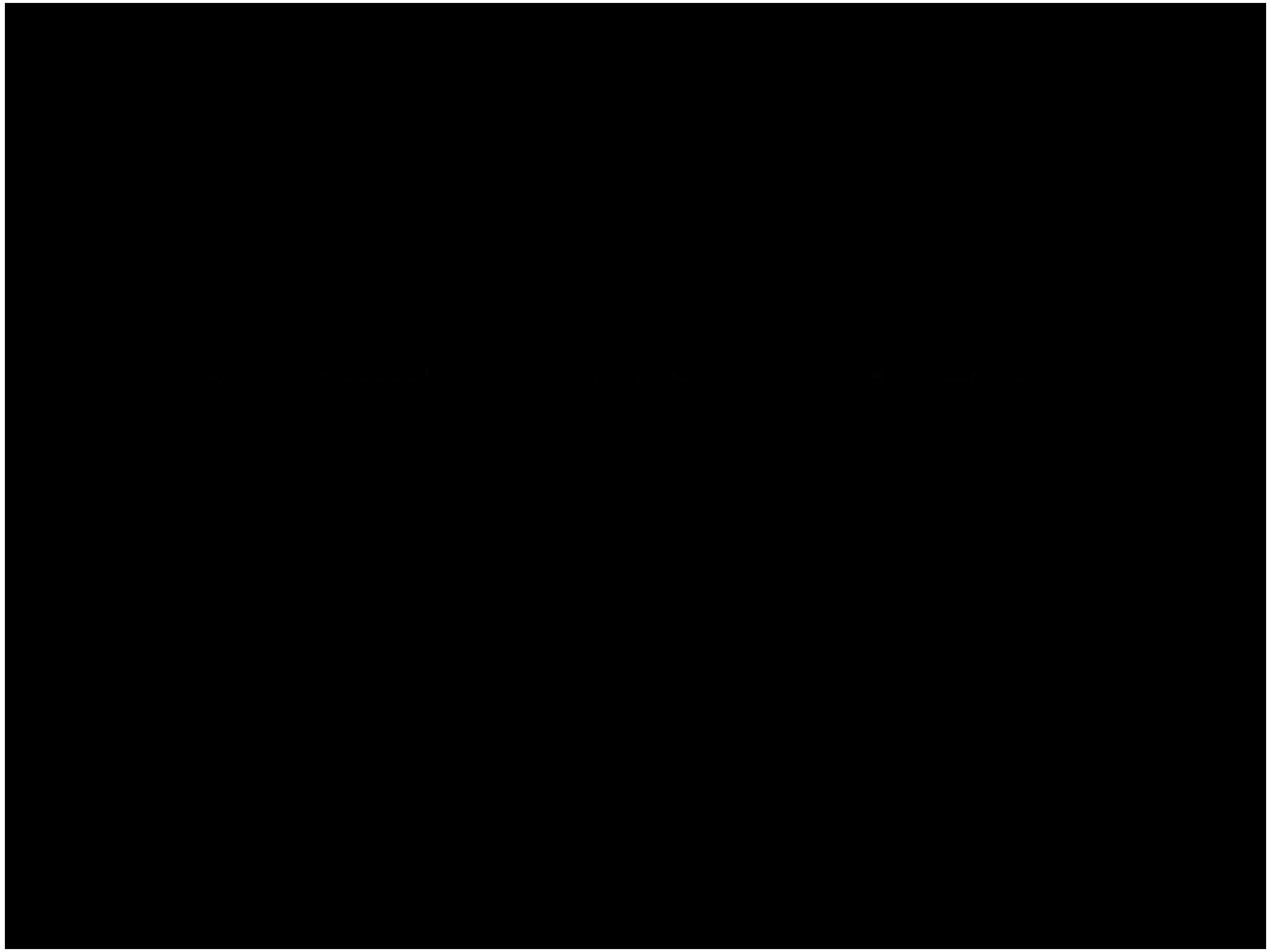


Closed-chain

Parallel-chain

Locomotion can be obtained in many ways …

- Walk
- Run
- Fly
- Swim
- Dive
- Drive
- Jump
- Crawl
- Roll
- Slide
- Flow
- ….



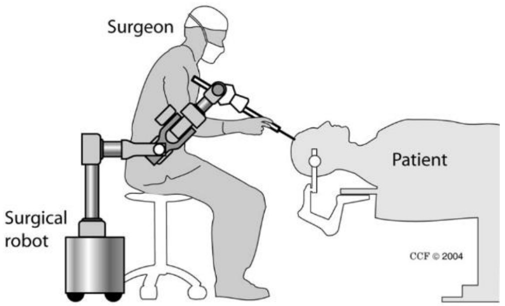
On purpose and autonomy of the robot

- **ACHIEVE GOALS:** it is not a random or meaningless entity, it has *purpose*
- ***AUTONOMOUS* SYSTEM:** acts based on its own (programmed or learned) decisions, and is not (*fully*) controlled by a human
  - **MANUAL CONTROL:** Fully operated by a human (maybe not a *true* robot)

✓ **Augmented system:**
- enhanced sensory data
- haptic feedback

  - **AUTONOMOUS CONTROL:** No human intervention is possibly required for deciding and performing actions
  - **SHARED CONTROL:** Part is on the robot side, part is on the human side

Shared Control System

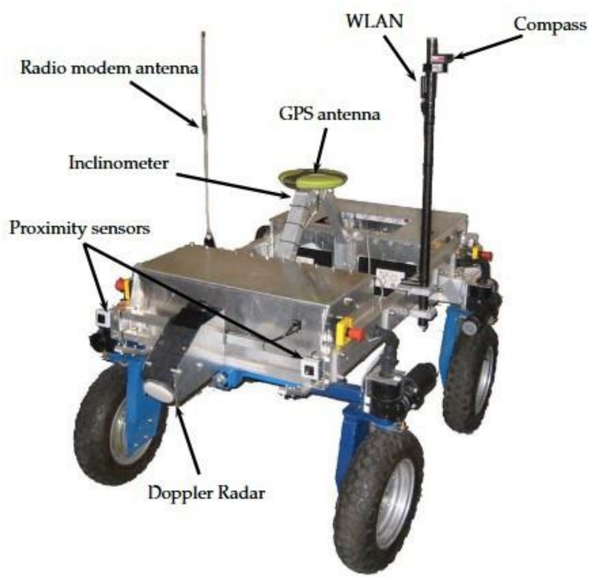


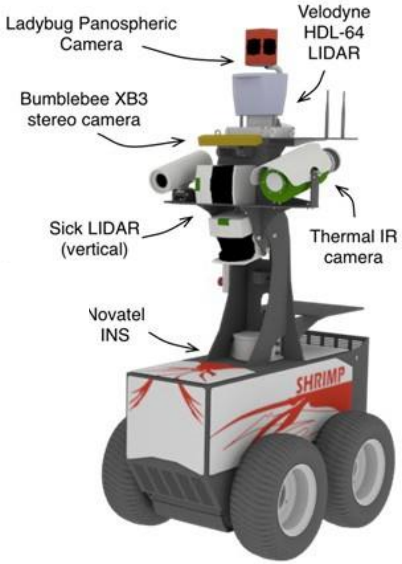
Robot and surgeon remains jointly in control. The surgeon remains in control of the procedure while the robot provides steady-hand manipulation of the instrument.

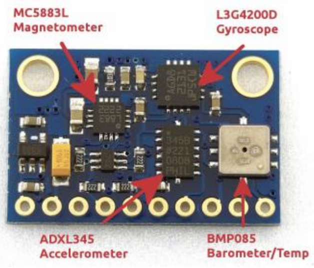
Control and sensing

- **OPEN-LOOP CONTROL:** Sensory input (feedback) from the environment the robot is acting upon is not considered, decisions are issued as **pre-programmed**
  - ➢ Environment should be practically deterministic, the robot should move with high precision, the cost of gathering and processing data should be high, … no surprises!

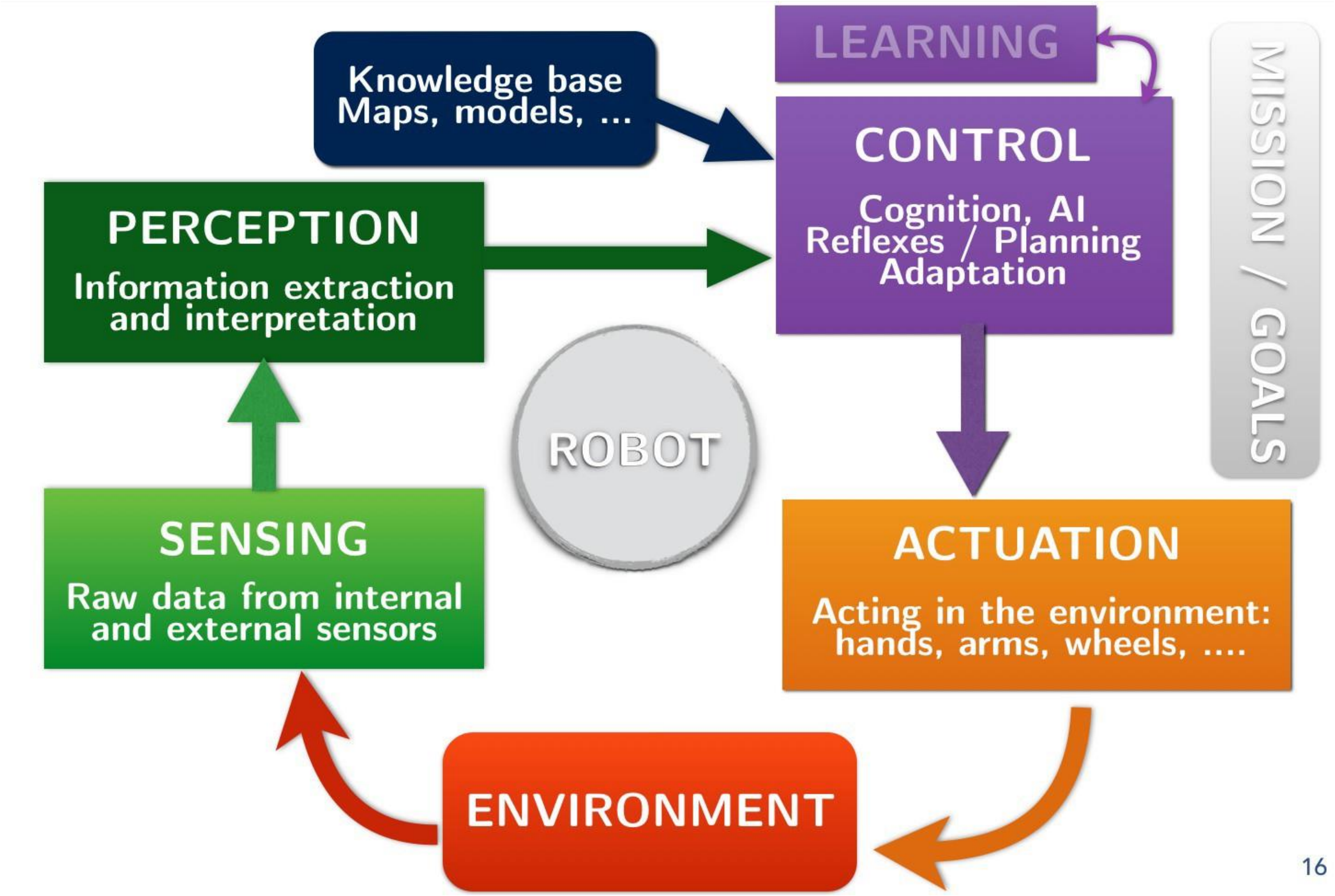
- **CLOSED-LOOP CONTROL:** Sensory feedback information from the environment (**exteroceptive sensing**) and from the robot itself (**proprioceptive sensing**) is used to **adapt decision-making** accordingly



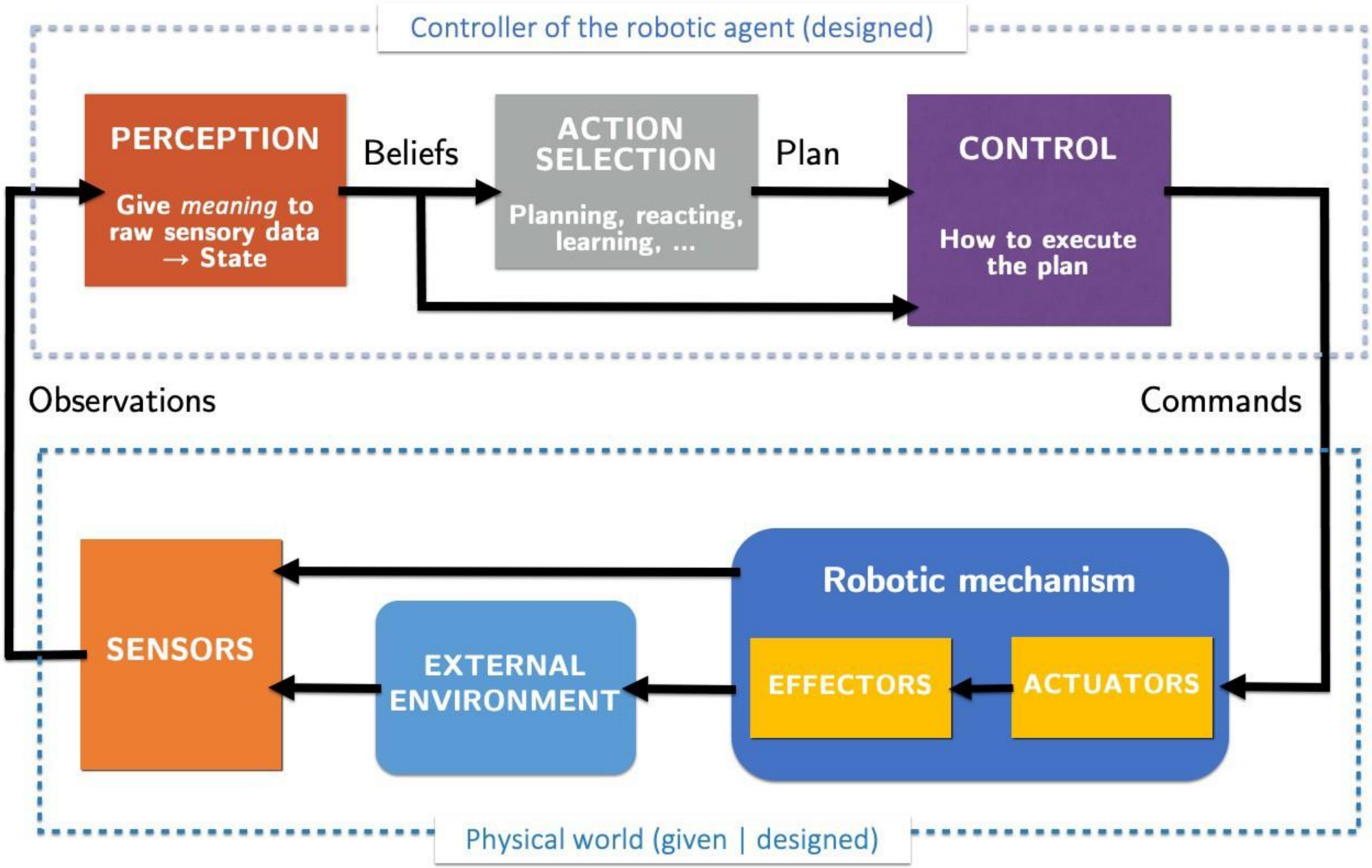




A general view of a robotic system architecture



Embodied agent + (intelligent) controller



So, what robotics is about?

- **Robot making**
  - Design
  - Mechatronics
  - Materials
  - Sensors
  - Actuators
  - …

- **Actuation**
  - Wheels
  - Arms
  - Hands
  - Joints
  - Legs
  - Heads
  - Rotors, blades
  - Motors
  - …

- **Robot control**
  - Cybernetics
  - Control theory
  - Automation
  - Artificial Intelligence
  - Knowledge representation
  - Probabilistic reasoning
  - Estimation theory
  - Decision-making Self-
  - organization

- **Sensing and perception**
  - Machine vision
  - Speech recognition/generation
  - Range finders
  - Dead reckoning
  - Localization techniques
  - Mapping
  - …

- **Software, interfaces, testing**
  - Device drivers
  - Inter-process communications
  - Multi-process arbitration
  - Interfaces for status access
  - Status / data logging
  - Simulation of robot(s) and environment physics
  - Benchmarks, data analysis
  - Safety and security
  - Dependability
  - …

We can't do everything!!!!

General topics considered in the course

Robot making

- Design
- Mechatronics
- Materials
- Sensors
- Actuators
- ...

Actuation

- Wheels
- Arms
- Hands
- Joints
- Legs
- Heads
- Rotors, blades
- Motors
- ...

Robot control

- Cybernetics
- Control theory
- Automation
- Artificial Intelligence
- Knowledge representation
- Probabilistic reasoning
- Estimation theory
- Decision-making
- Self-organization

Sensing and perception

- Machine vision
- Speech recognition/generation
- Range finders
- Dead reckoning
- Localization techniques
- Mapping
- ...

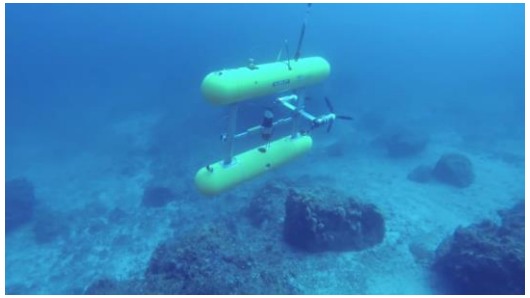
Software, interfaces, testing

- Device drivers
- Inter-process communications
- Multi-process arbitration
- Interfaces for status access
- Status / data logging
- Simulation of robot(s) and environment physics
- Benchmarks, data analysis
- Safety and security
- Dependability
- ...

What type of robots should we study?

Industrial / Arm Robotics:
Complex, but fundamental

Humanoid / Legged Robotics:
Very complex and specialistic

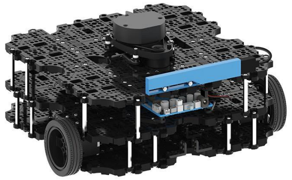


Aerial / Water Robotics:
Ad hoc, require infrastructure

Mobile, wheeled robotics
+
Arm robotics (some)
+
AI robotics (some)
+
ROS, Gazebo

ROS
Open Source Robotics Found...

GAZEBO



Our robot hw /sw tools

TurtleBot 2

GAZEBO

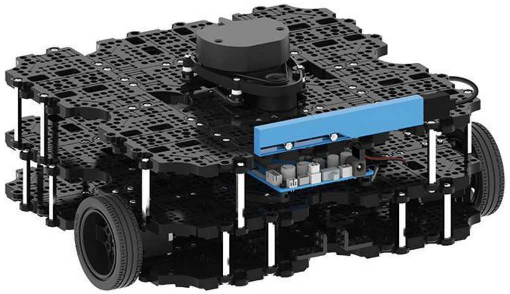
ROS

Open Source Robotics Foundation

PhantomX Reactor Robot Arm

ROS Melodic

Anki Cozmo



TurtleBot 3

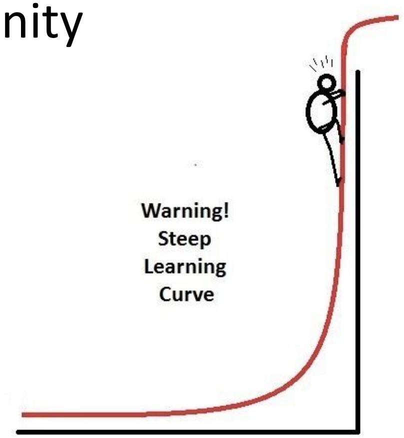
Erle Rover

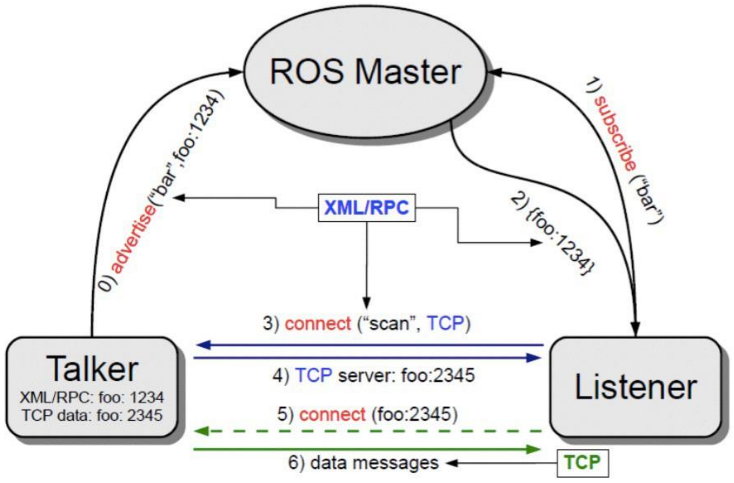
ROS (Robot Operating System)

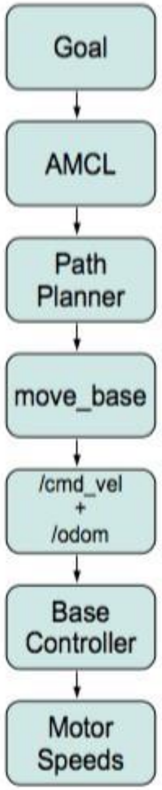
An open-source, middleware for your robot

Tools for programming robots. Its primary goal was/is to enable code reuse in robotics research and development

- Implementation of commonly-used functionality
- Inter-process communication (middleware)
- Hardware abstraction
- Visualization tools
- Package management
- ROS community







Autonomous mobile robotics

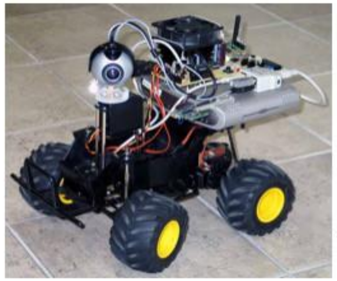
Mobile ■⟶ *Wheeled* robots

Design** and **Automatic Control **of a potentially large zoo of vehicles ...**

2- and 4-wheel
Differential driving

Tricyle

Murata Boy and Girl
Bicycle and Unicycle



Car-like
Ackermann

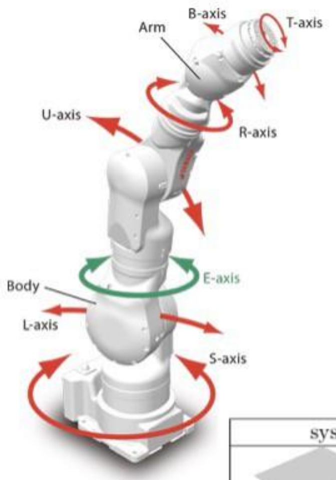
6-wheel
space rovers

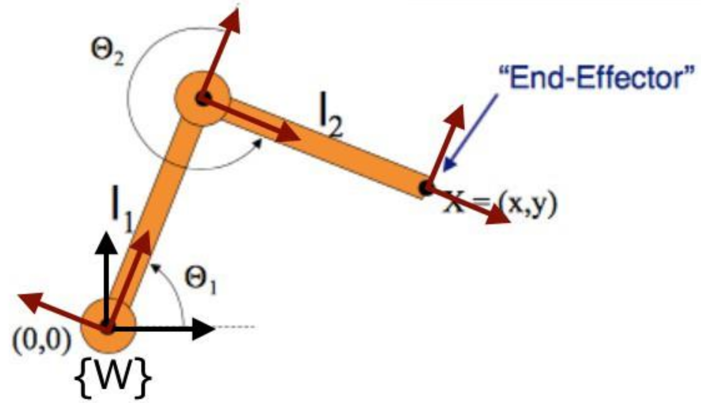
4-wheel
steering

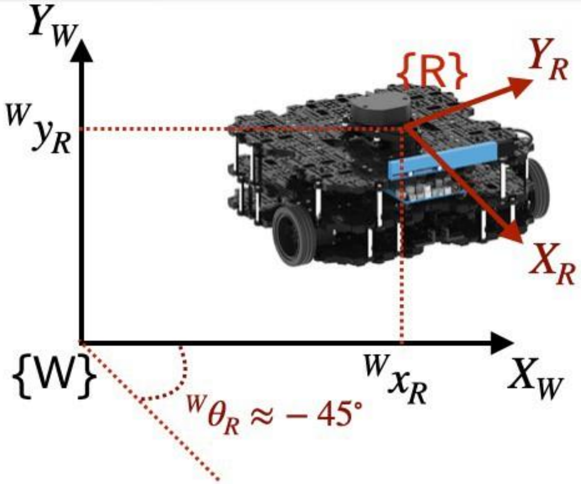
Tri-bots
Omniwheels

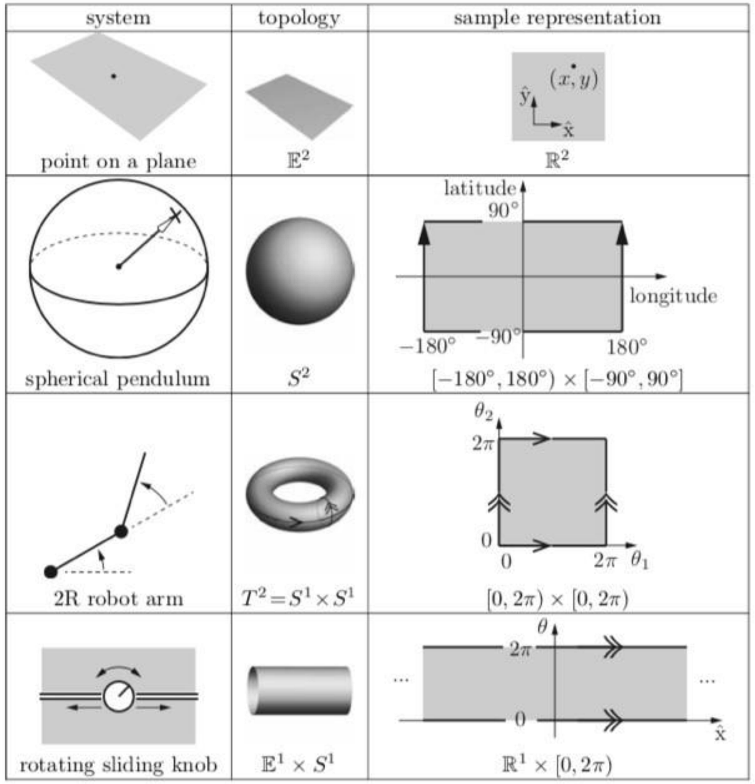
2

Journey starts by representing robot configuration, DOF, pose



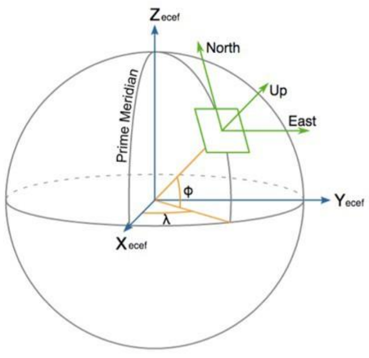




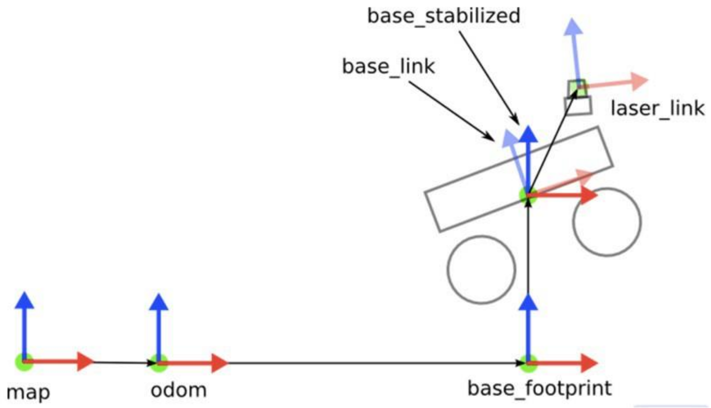


system	topology	sample representation
point on a plane	$\mathbb{E}^2$	$\mathbb{R}^2$
spherical pendulum	S^2	$[-180°, 180°) \times [-90°, 90°]$
2R robot arm	$T^2 = S^1 \times S^1$	$[0, 2\pi) \times [0, 2\pi)$
rotating sliding knob	$\mathbb{E}^1 \times S^1$	$\mathbb{R}^1 \times [0, 2\pi)$

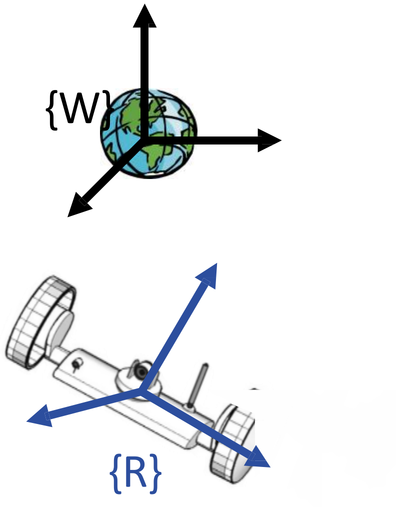
Journey starts by representing robot configuration, DOF, pose



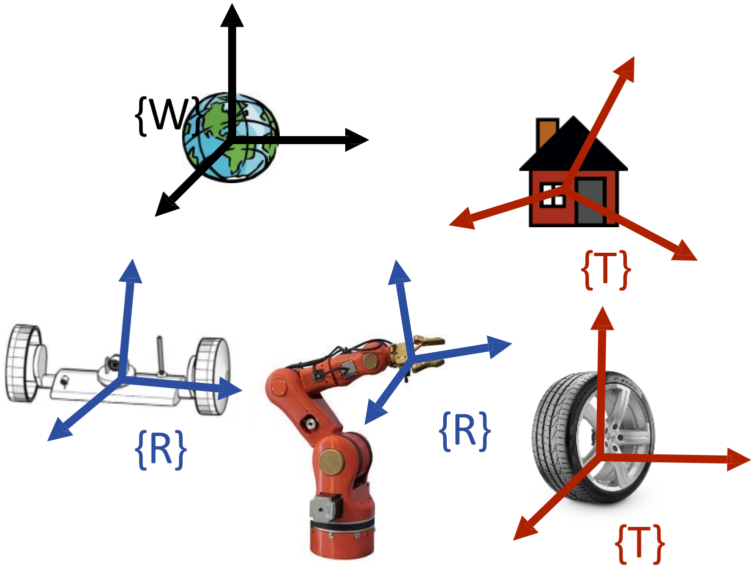
earth



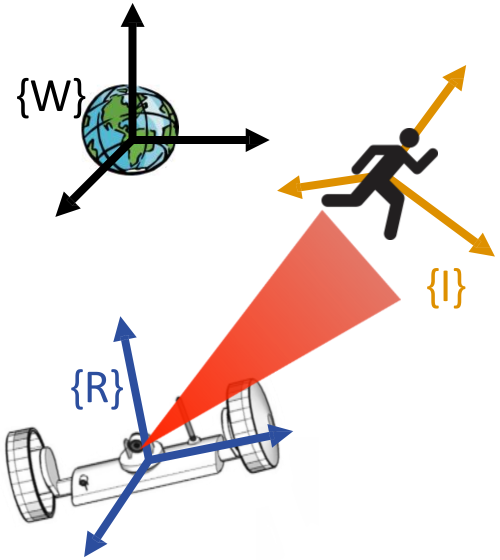
Where's the robot? What is robot's pose with respect to the world reference frame {W}?



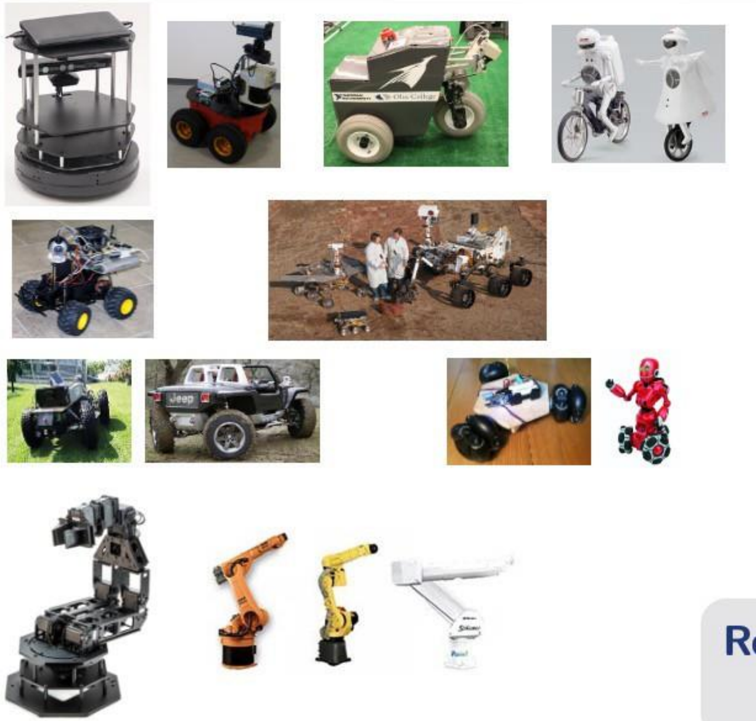
Robot's pose with respect to the external frame {T} (e.g., a target) ?



What is intruder's pose, observed using robot's lateral camera, in the world frame {W}?



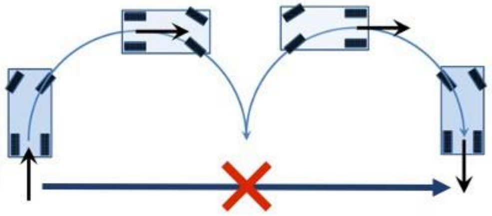
Next step: Kinematics models



Many types of wheels and of wheel arrangements

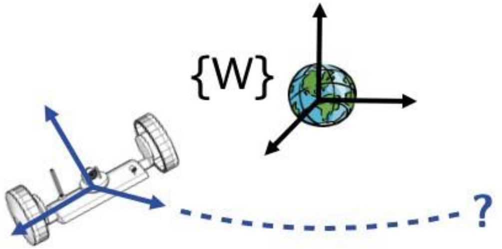
Different types of robotic arms

Kinematic constraints on the robot motion



Two-moves car parking: no side-way motion

Reference frame transformations Kinematic models



$$\dot{x} = v(t)\cos(\theta(t))$$
$$\dot{y} = v(t)\sin(\theta(t))$$
$$\dot{\theta} = \omega(t)$$

$$\dot{\xi}_W = R^{-1}(\theta)\dot{\xi}_R = R^{-1}(\theta)\begin{bmatrix}\dot{x}\\ \dot{y}\\ \dot{\theta}\end{bmatrix}$$

$$R(\theta) = \begin{bmatrix}\cos(\theta) & \sin(\theta) & 0\\ -\sin(\theta) & \cos(\theta) & 0\\ 0 & 0 & 1\end{bmatrix}$$

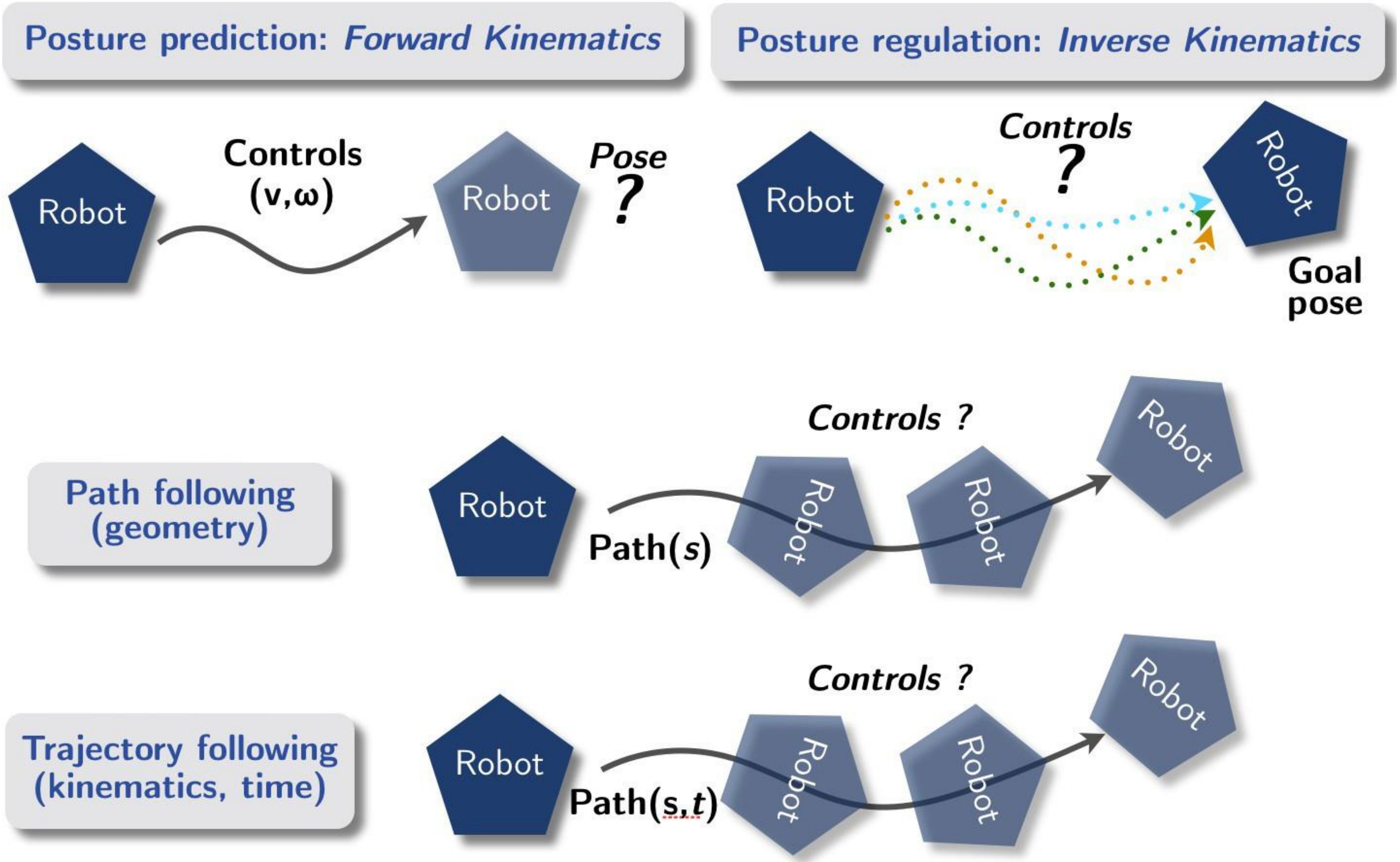
$$x(t) = \int_0^t v(t)\cos(\theta(t))dt$$
$$y(t) = \int_0^t v(t)\sin(\theta(t))dt$$
$$\theta(t) = \int_0^t \omega(t)dt$$

Generic robot

$$x(t) = \frac{1}{2}\int_0^t (v_R(t) + v_L(t))\cos(\theta(t))dt$$
$$y(t) = \frac{1}{2}\int_0^t (v_R(t) + v_L(t))\sin(\theta(t))dt$$
$$\theta(t) = \frac{1}{2\ell}\int_0^t (v_R(t) - v_L(t))dt$$

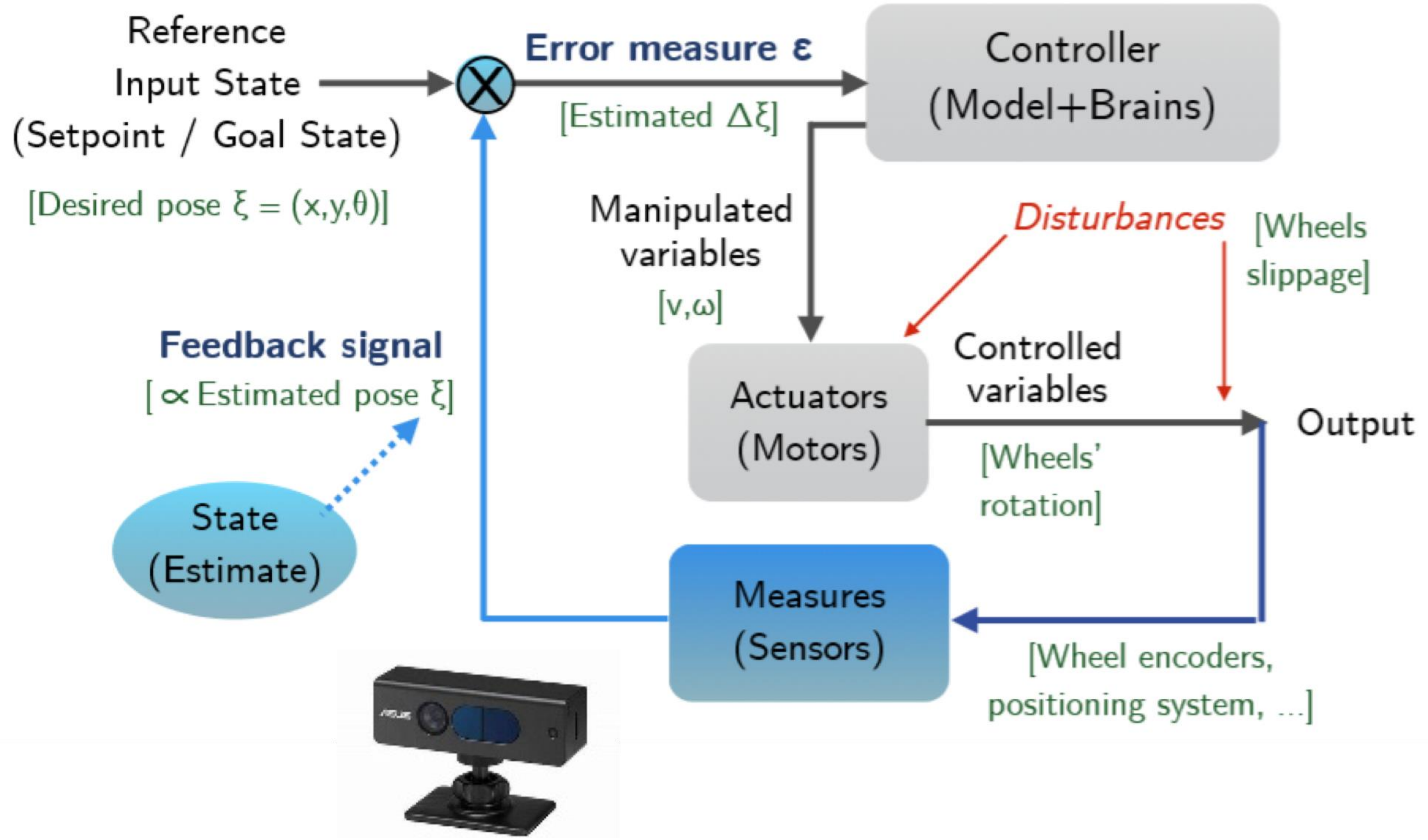
Differential steering robot

Forward / Inverse Kinematics + Controls

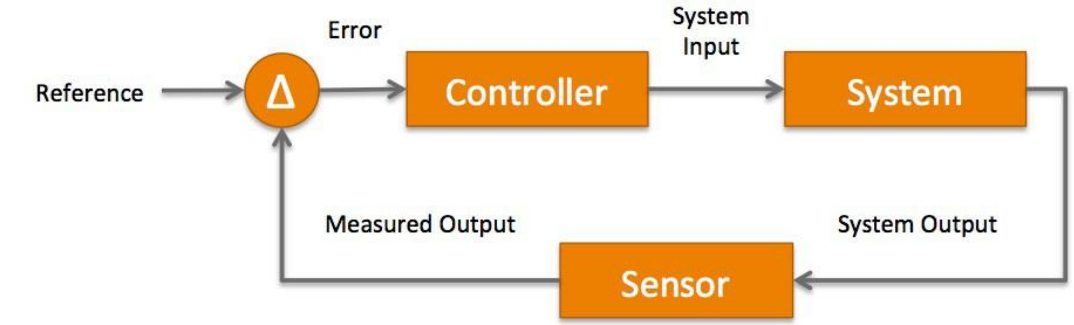


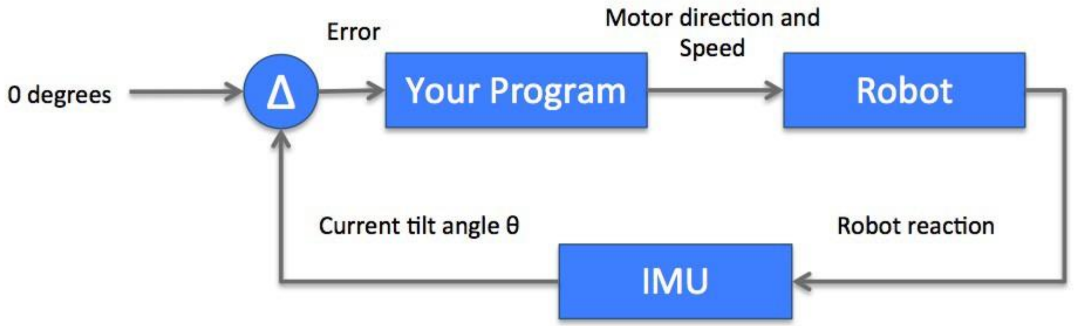
Next: Closed-loop control for error correction

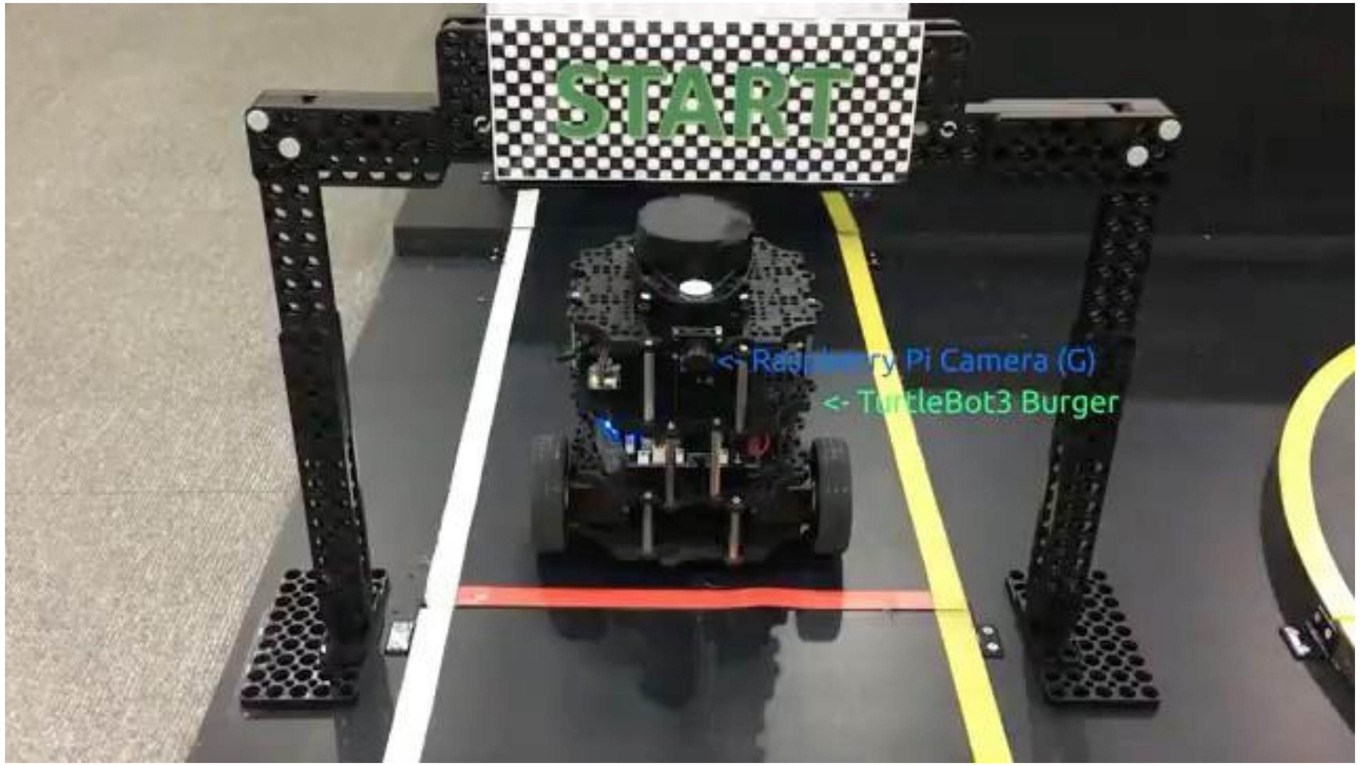
Things might (will!) go wrong, open-loop controls needs to be replaced by **closed-loop control** (using kinematic models)



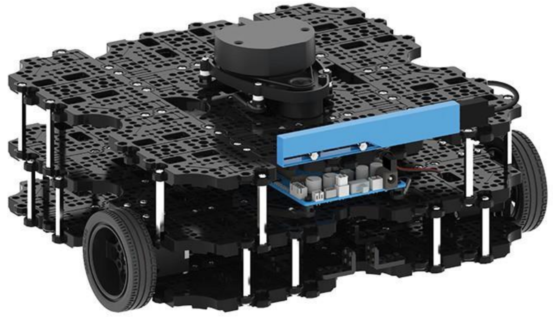
Feedback-based control







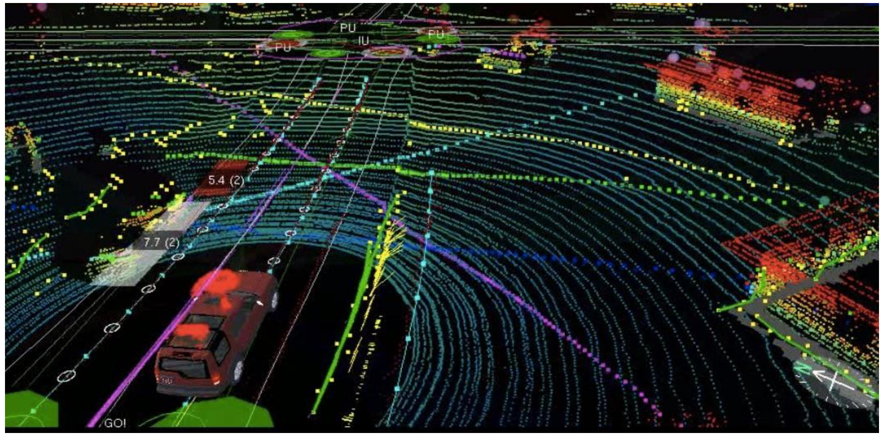
Feedback needs data! Sensors: from raw data to perception

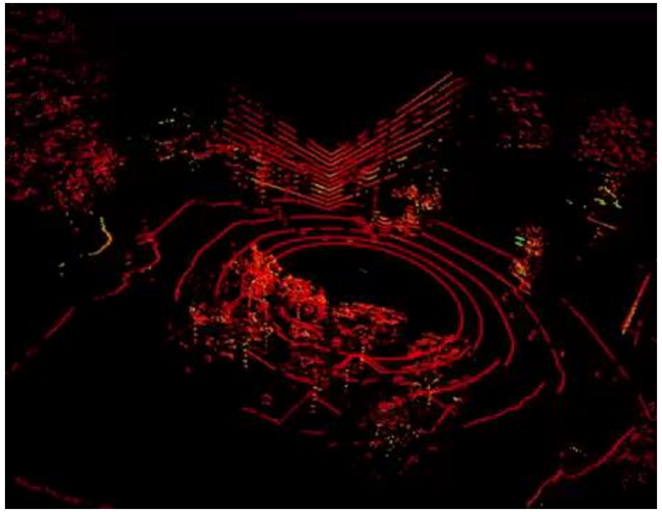


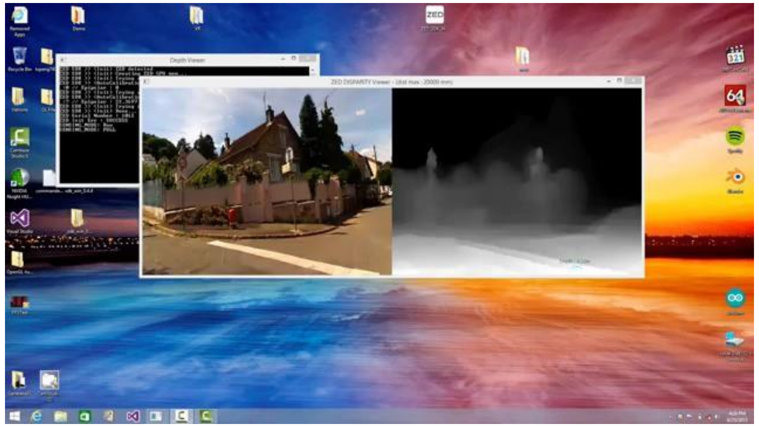
- Proprioceptive sensors
- Exteroceptive sensors

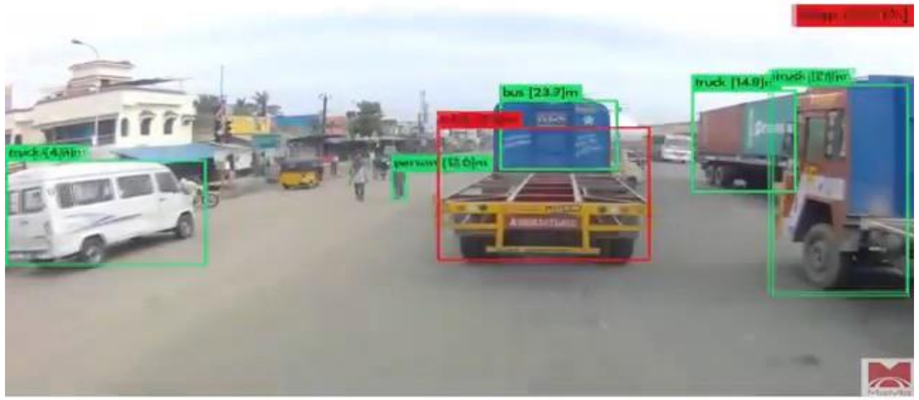
Sensors: from raw data to perception

1.3 million data points per second with a 360° horizontal field-of-view and a 26.8° vertical field-of-view.









Fundamental problems in mobile autonomous robotics

Where am I?

Localization + **Sensing**

(State estimation)

Kalman filter
Extended Kalman filter
Particle filter

Where am I going?

Representation
+
Landmark-based **Mapping** and **SLAM**

EKF, Monte Carlo, Perception

How do I get there?

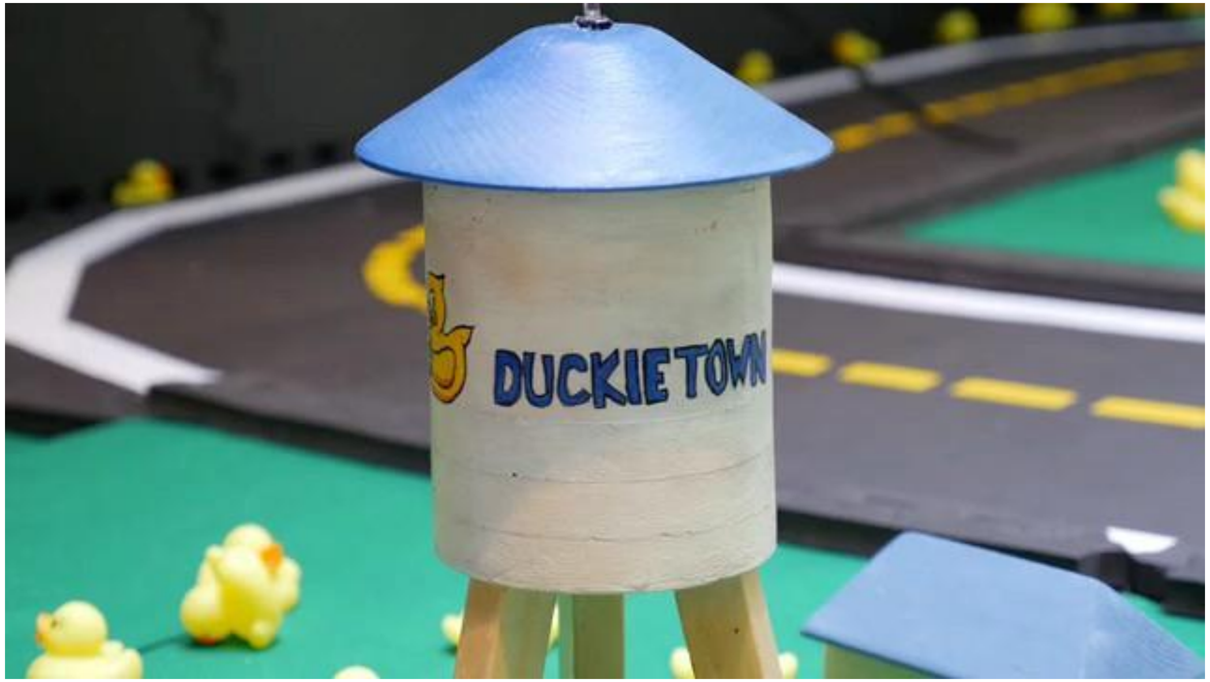
Planning (Deliberative) +
Path Execution

Exact and Probabilistic
Non-holonomic constraints
Closed-loop controls

To finish with a touch on AI Olympics

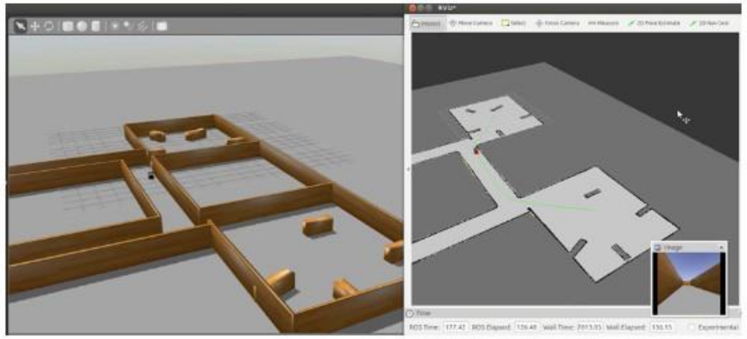
Robot navigation and control using:

Reinforcement learning, Supervised learning, Deep learning



Balancing theory & hands-on

Experiment with the models in physics-based realistic *simulation* learning and exploiting ROS and GAZEBO tools



ROS

Open Source Robotics Foundation

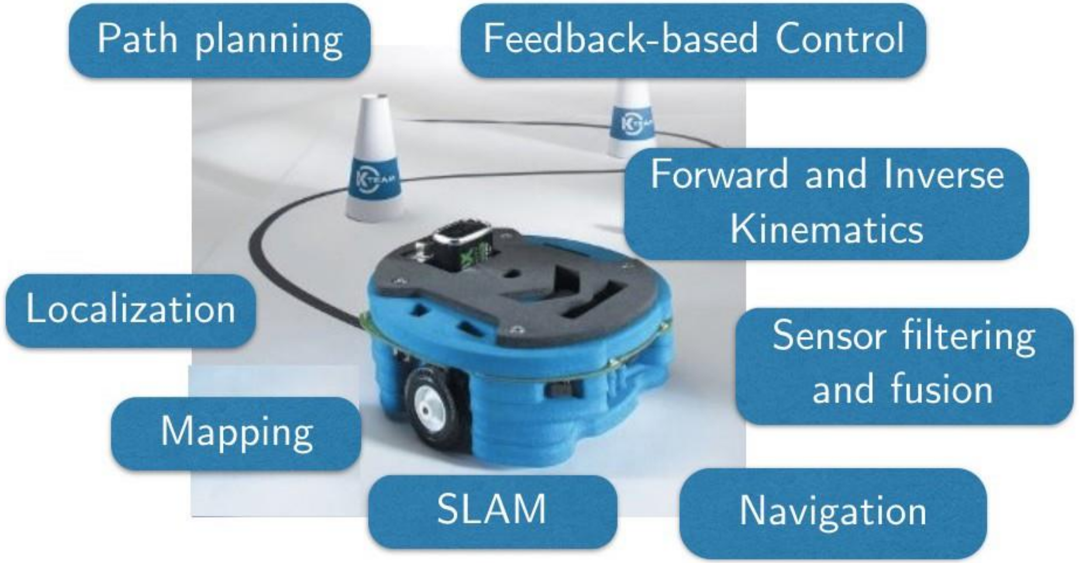
GAZEBO

Face the challenges of real-world

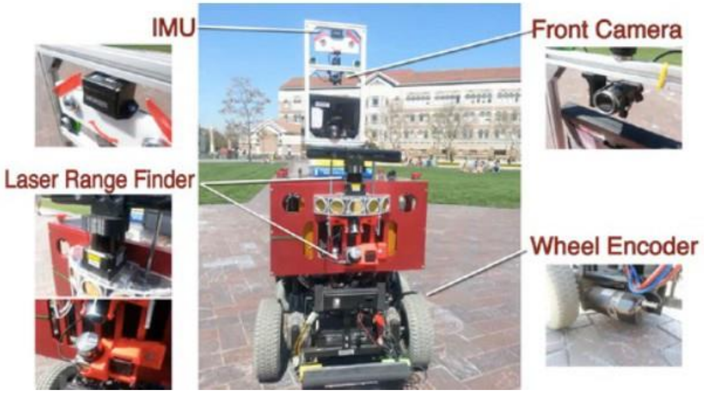
***Theory* classes on mathematical and computational *models* about *fundamental problems* in robotics**

What will you take-home?

A general overview of the ***fundamental problems***, and of their standard solution, in ***autonomous mobile robotics, arm robotics, AI robotics***

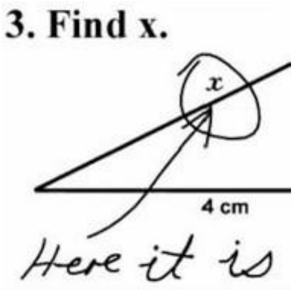


Some practical insights regarding ***robot design*** and the ***characteristics and the use of the basic sensors*** for relative and global localization, and for navigation



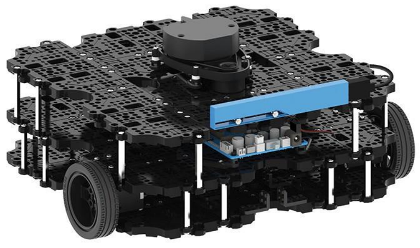
What will you take home?

Some general **mathematical tools** and techniques, and the “refreshment” of useful mathematical notions



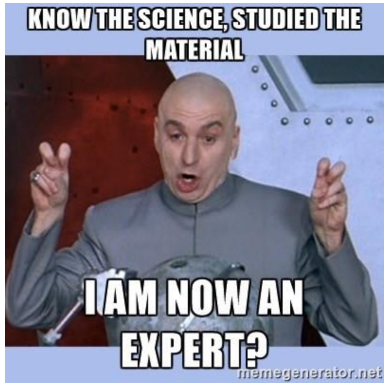
- Kinematics for controlled rigid bodies
- Statistical filters
- Kalman filter
- Extended Kalman filter
- Bayes + Monte Carlo techniques
- Jacobians
- Closed-loop control of dynamical systems
- Planning algorithms
- Topological notions

Basic working knowledge of ROS and GAZEBO

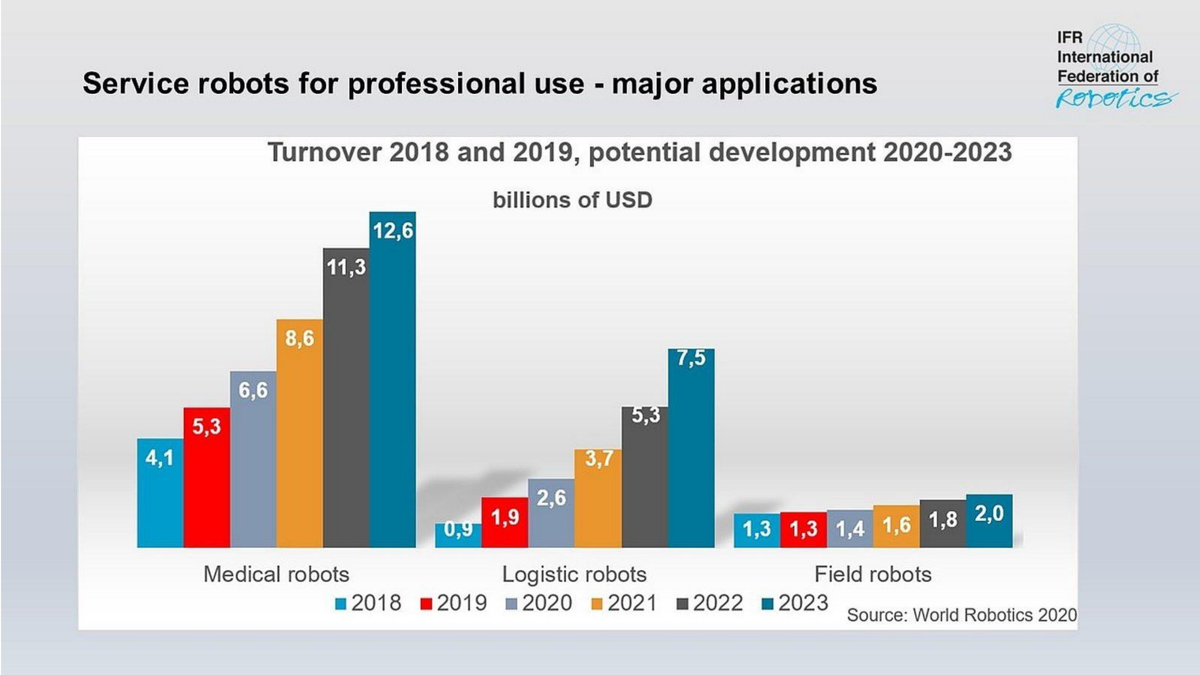


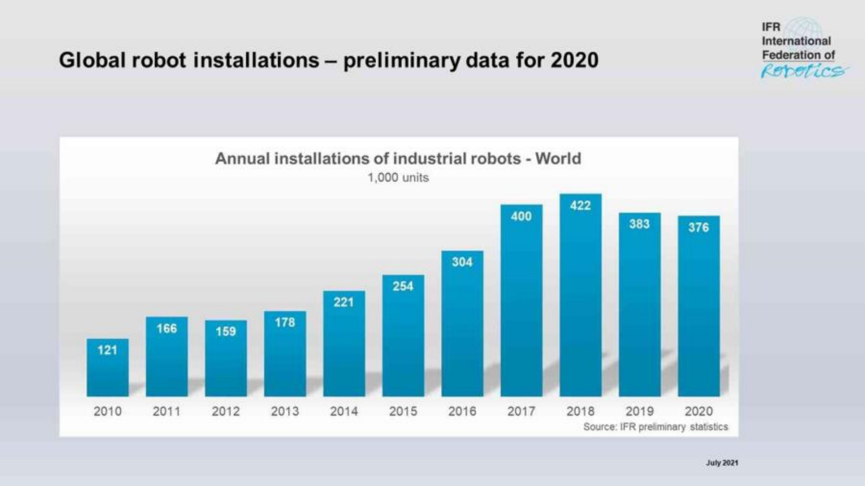
ROS
Open Source Robotics Foundation

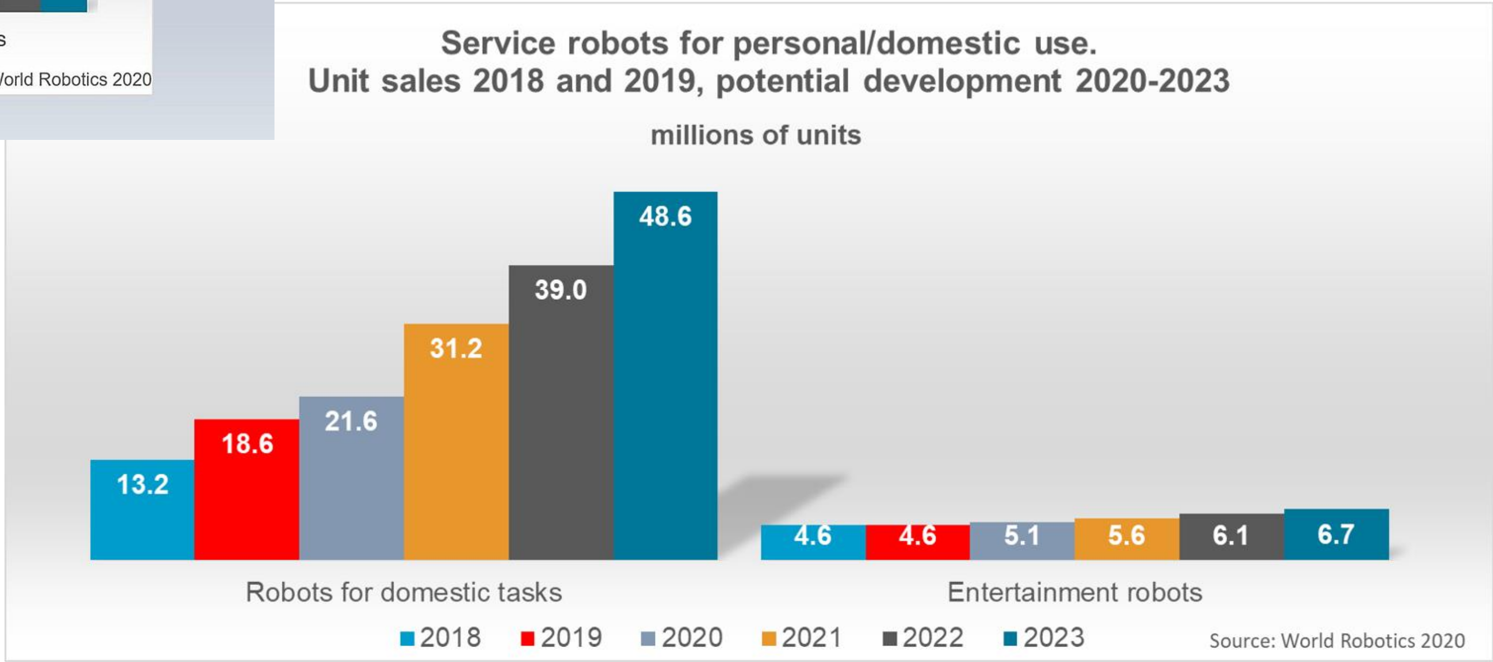
GAZEBO



Robotics hype: a growing world-wide trend!

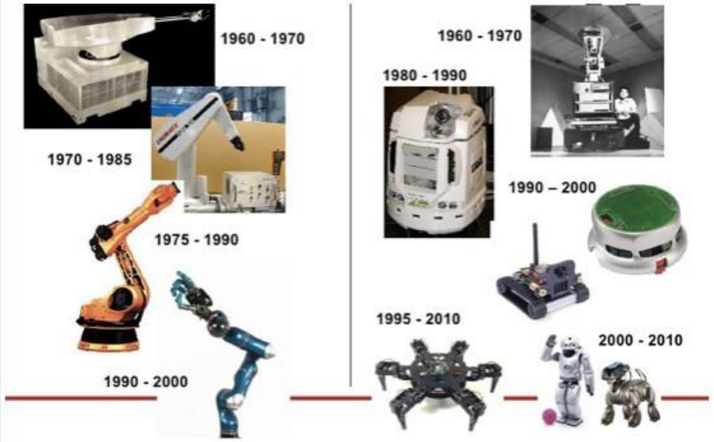






It was (is) a long way (to go)

1961	1968	1970	1977	1996	1999	2002	2005	2011
First robot arm went to work assembling cars at a General Motors plant, in NJ, USA	**First robot arm controlled by a digital computer**, from Marvin Minsky at MIT	Shakey, first **AI-based robot** that could move, sense, and reason on its environment, from SRI, Stanford	The Voyager 1 and 2 **NASA space probes** were launched to study Saturn and Jupiter	Honda researchers introduce P2/ASIMO, the **first complete human-like robot**	Sony developed AIBO, a **robotic dog** that could play and interact with people	Roomba, the **automatic vacuum** cleanear appears on the market	Boston Dynamics introduces BigDog, an **impressively stable quadrupede robot**	Willow Garage presents PR2, an **open source humanoid personal robot**



2012-	2013-2016 -	2016 -	2012 -
 **Baxter** industrial robot: learn, collaborate	 BD's **Atlas** humanoid robot for indoors and outdoors	 Uber starts **self-driving car service**	 Major **ROS** distributions

نحوه نمره دهی

- حضور در کلاس
  - تعداد غیبت مجاز: ۶ جلسه
- تمرین‌ها ۷ نمره ------------ ۴ سری تمرین شامل بخش تئوری (۲۰ درصد) و عملی (۸۰درصد)
- امتحان میان‌ترم ۴ نمره ------ از مباحث تئوری، مفهومی و محاسباتی بصورت حذفی
- امتحان پایان ترم ۴ نمره ----- از مباحث تئوری، مفهومی و محاسباتی
- پروژه ۴ نمره ------------- بصورت گروه دو نفره شامل پیاده‌سازی – گزارش – فیلم
- فعالیت کلاسی ۱ نمره ------- حضور فعالانه در کلاس‌های درس و تدریسیاری

- آموزش ROS و GAZEBO در کلاس تدریسیاری انجام می‌گیرید و حضور الزامیست

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