Aston University
BIRMINGHAM UK

Summer School in Robotics

Introduction + Locomotion

Örebro 2022

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Content

- Autonomous Robotics and Perception Laboratory
  - Me
  - Facilities
  - Oportunities
- Basic concepts
  - What are “intelligent robots”?
  - The components of an intelligent robot
  - Main types of robots
  - Applications and areas of robotics
- Different methods for robot locomotion (**ground robots**)
  - Holonomic *vs.* non-holonomic robots
  - Steering for **wheeled** robots
    - Synchro, **Differential**, Skid, Mecanum, Ackerman

Autonomous Robotics and Perception Laboratory

ARP

Autonomous Robotics and Perception Laboratory

- Luis Manso (l.manso@aston.ac.uk)
- Interests
  - Social robotics
  - Human-aware navigation
  - Deep learning (GNNs)
  - Active perception
  - AGI
- ARP - Room MB306
- Oportunities (Aston)
  - Informal learning
  - FYPs
- Oportunities (general)
  - RoboComp
    Google Summer of Code
- Facilities

Autonomous Robotics and Perception Laboratory

Basic concepts

What are intelligent robots

intelligent robot

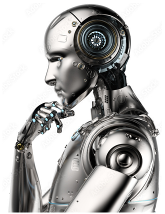
*"An **intelligent robot** is a physically situated intelligent agent"*

agent

- *An **agent** is anything that "can sense its surroundings and take actions"*
- *An **agent** is "the person or thing that does an action"*

intelligent agent

*An **intelligent agent** is "a system that perceives its environment and takes actions which maximise its chances of success"*



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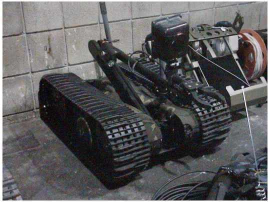
What are intelligent robots

robot

"A robot is a special type of agent; it is ***physically situated*** *in the "real world" while a software agent is situated in a virtual world defined by the World Wide Web, simulation or confines of a software system."*

physical situatedness

Refers to being present in the physical world, literally. Do not confuse with "awareness".



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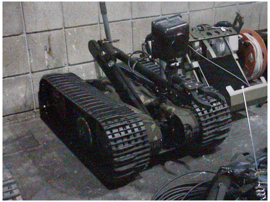

Components

The components of an intelligent robot

- The following is an **arbitrary** separation missing some elements, *e.g.* the strucure/chassis, ethics
- Some of the following combine hardware and software components

1. **Effectors**
   - *e.g.*, arms, grippers, robotic hands, wheels, legs, blades (hardware)
2. **Perception**
   - *e.g.*, cameras, LiDARs, touch senors (HW), and algorithms (software)
3. **Control**
   - computing hardware (HW) and control algorithms (SW).
   - this is what makes an intelligent robot intelligent!
4. **Communications**
   - NICs (HW) and algorithms to communicate with people, robots and other agents (SW)
5. **Power**
   - HW & SW to ensure that the robot has energy to keep working

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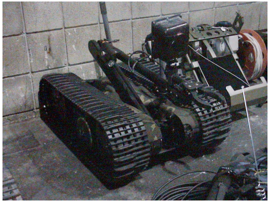
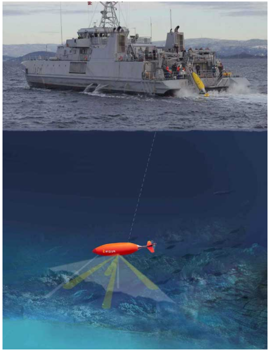
Types of robots

Main types of robots

- **Ground**
- **Aerial**
- **Water** (and underwater)

- **Other** which are not as straightforward (*e.g.* pipe inspection robots, legged drones)
- **Biomimetic** robots are robots that resemble animals. **Android** refers to human-like robots.





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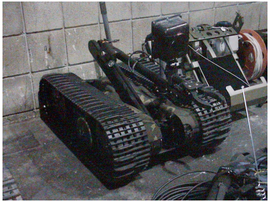
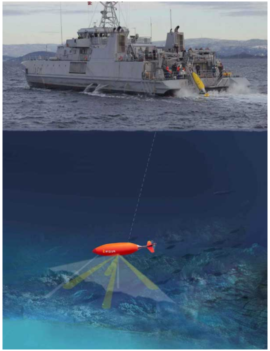
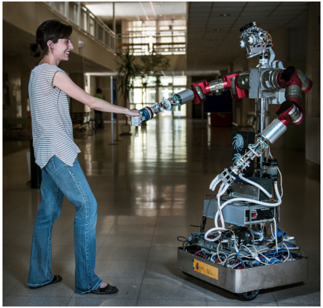
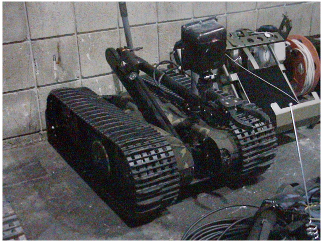




Main types of robots: Ground

- Wheels
- Legs
- Tracks
- Snake-like



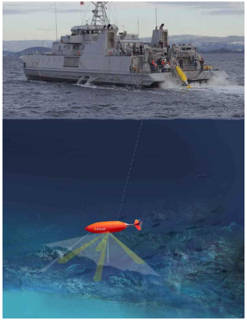


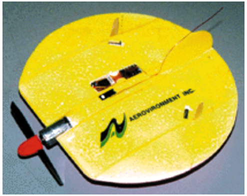
Main types of robots: Aerial

- Fixed-wing
- Rotor-based:
  quadcopters, helicopters
- Wing-flapping

Main types of robots: Water and underwater

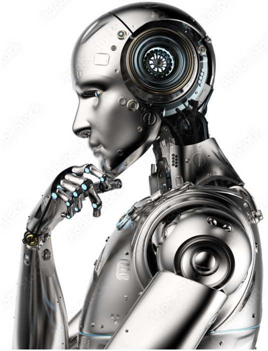
- Unmanned Surface Vessel (**USV**)
- Autonomous Underwater Vehicle (**AUV**)
- AUV are frequently tethered





Applications

- **Robots can also be classified by their application**
  - Tools (*i.e.*, replacing humans, 3Ds)
  - Telepresence (*e.g.*, videoconferencing, surgery)
  - Assistance (*e.g.*, eldercare, rehabilitation)
  - Amusement & companionship (e.g., Paro)
  - Education (*e.g.*, Thymio, Cozmo)
  - Research



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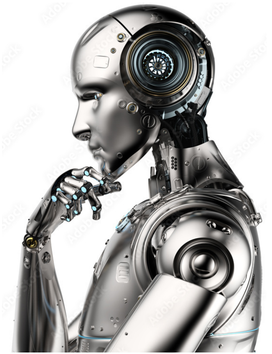

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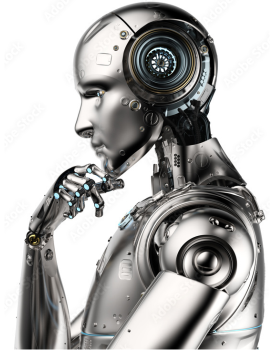

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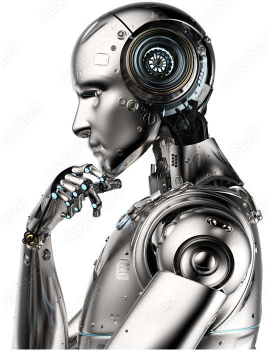

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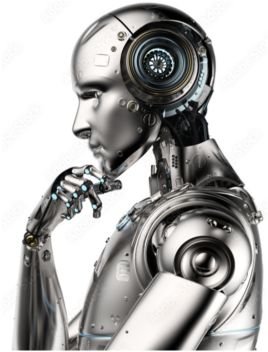

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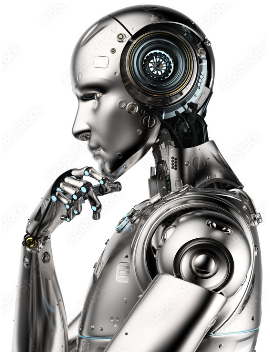

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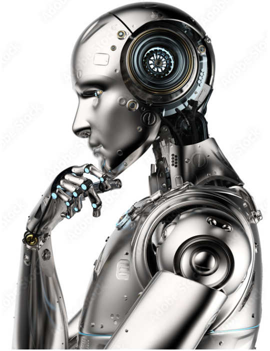

(Main) Applications of robots: Tools

- **3Ds:**
  - **D**irty
  - **D**ull
  - **D**angerous
- **Applications**
  - Pipe cleaning and inspection
  - Vacuuming
  - Industrial robots
  - Explosive disposal (demining)
  - Nuclear plants
  - Rescue robots

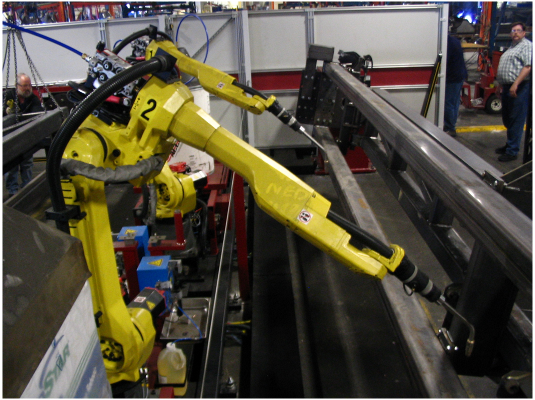

Figure: CC BY 3.0: Industrial robot. https://bit.ly/3G25yCW

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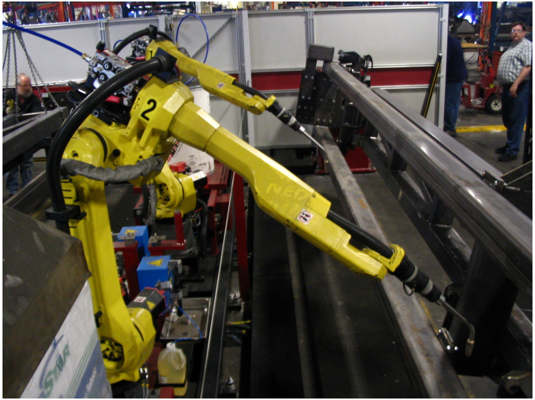

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(Main) Applications of robots: Telepresence

- Professional
  - surgery
  - rovers
  - military
- Personal use
  - videoconferencing
- Anywhere from **taskable agents** to zero autonomy

taskable agent

An agent is said to be ***taskable*** if it can be *"given a complex task or mission, executes it without supervision, an then returns or informs the human"*.

- Some of the **main challanges:** improving user feedback, reducing latency, reducing cognitive fatigue

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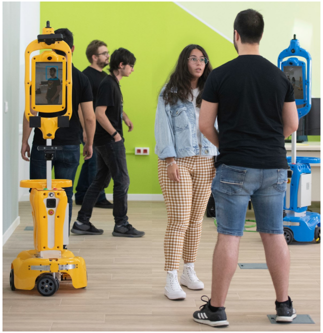

(Main) Applications of robots: Assistance

- **Applications**
  - elder care
  - rehabilitation
  - nursing
- **Challenges**: too many!
  - perception
  - context awareness
  - human-robot interaction
  - automated task planning (considering humans & perceptual tasks)

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(Main) Applications of robots: Amusement & companionship

- **Therapeutic companionship** (e.g., Paro)
  - basic pet-like behaviours
  - seeks for affection
- **Toy-like companionship** (e.g., Vector, Aibo)
  - basic pet-like behaviours
  - "embodied Amazon's *Alexa*"
- **Multi-purposed companionship** (e.g., Ribbit)
  - "mobile domotic system"
  - locate & bring objects
  - monitor users
  - play games

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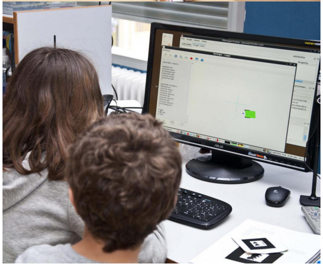
(Main) Applications of robots: Other

- **Education**
  - Teaching programming
  - Teaching electronics, mechanics
  - Other topics as well
  - *e.g.*, Thymio, Cozmo
- **Research**
  - In all of the areas of robotics (see next slides!)



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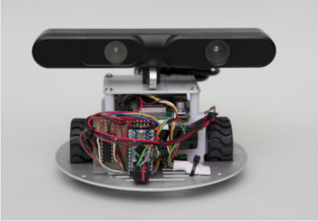

The seven areas of AI

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- **Knowledge representation**
- **Understanding natural language**
- **Learning**
- **Planning and problem solving**
- **Inference**
- **Search**
- **Vision**

We are going to see how these areas relate to robotics

(remember that this is a rather arbitrary number)

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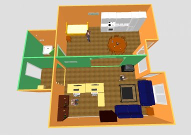
The seven areas of AI: Knowledge representation

- Very important in robots.
- They need to represent
  - the **world**
  - the **context** (including their goals and other agents' goals)



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Humans are also considered agents.

  - and its **own state**!
- We will learn more about this in the next units

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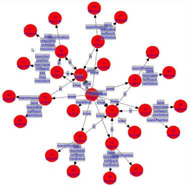

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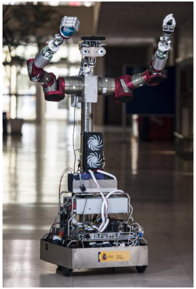

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- **As chatbots do**, robots need to *understand*:
  - the **meaning of words**
  - the meaning of the words **in the sentence**
  - and the **whole context**!
- **Annecdote** interpreting car as patient: Symptoms? What colours are the spots? On the back? $\longrightarrow$ Measles
- Robots also have **additional issues**:
  - **identify** words
  - work with background **noise**
  - **identifying** and **filtering** voices
  - **locating** voices

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  - the **meaning of words**
  - the meaning of the words **in the sentence**
  - and the **whole context**!
- **Annecdote** interpreting car as patient: Symptoms? What colours are the spots? On the back? → Measles
- Robots also have **additional issues**:
  - **identify** words
  - work with background **noise**
  - **identifying** and **filtering** voices
  - **locating** voices

The seven areas of AI: Understanding natural language

- **As chatbots do**, robots need to *understand*:
  - the **meaning of words**
  - the meaning of the words **in the sentence**
  - and the **whole context**!
- **Annecdote** interpreting car as patient: Symptoms? What colours are the spots? On the back? $\rightarrow$ Measles
- Robots also have **additional issues**:
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The seven areas of AI: Learning

- Robots are frequently **expected to learn**...
  - their **environment** (mapping)
    - and to make predictions about how it works
  - to **identify** their users
  - new tasks by **imitating** humans (and other robots)
  - to **adapt** to their users preferences
- **And many more**: unit covering learning in intelligent robots

The seven areas of AI: Planning and problem solving

- All robotics applications, except completely teleoperated robots, need to perform some problem solving or planning.
- Many believe that intelligence can only be demonstrated through action.

behaviourism

The belief that mental processes (*e.g.* intelligence) **must** be studied through actions and other objective measures (*e.g.*, physical actions, Functional Magnetic Resonance Imaging -fMRI). Behaviourists assume that introspection is of little or no use to analyse or understand intelligence.

- We will have a unit dedicated to this.

Book's definition of inference

"Generating an answer when there is no complete information."

- We can try to be a little bit more precise.
- We use inference when we have the *information*, but not the *data*.

Wikipedia definition (https://en.wikipedia.org/wiki/Inference)

"Inferences are steps in reasoning, moving from **premises** to **logical consequences**; etymologically, the word infer means to *carry forward*."

- It is **sometimes** related to **planning**. Executing perceptual plans might be necessary to perform some inferences (e.g., "I don't know if that dark area is my shadow or a hole in the floor. If I can touch it, it is my shadow.").

- As inference, **search** is related to **planning**.
- Not related to searching in physical areas, but in search spaces.
- Usually we search for a solution to a problem, or a (near) optimal action.

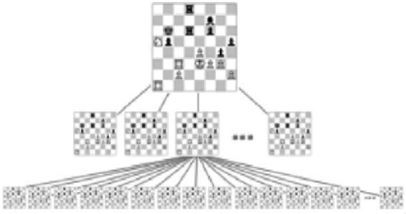

Figure: https://stanford.edu/ cpiech/cs221/apps/deepBlue.html

The seven areas of AI: Vision

- Achieve some *understanding* from images
- Classic problem: object detection and recognition
- Others:
  - Scene recognition
  - Action recognition
  - Identification of human users

Locomotion

Different methods for robot locomotion

- How do robots move?
  - **Aerial**
    - Rotors
    - Propeller and wings
    - Flapping wings
  - **Water**
    - Propellers
    - Tails & limbs
  - **Ground**
    - Wheeled
    - Biomimetic (e.g., legged)
    - Static *vs.* dynamic balance
  - We will cover the most common **steering** system for **wheeled** ground robots

steering

Steering refers to the mechanics used to drive the robots.

Different methods for robot locomotion

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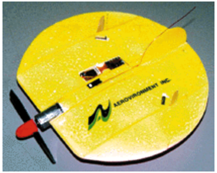

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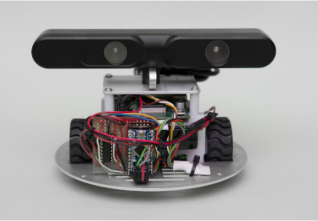
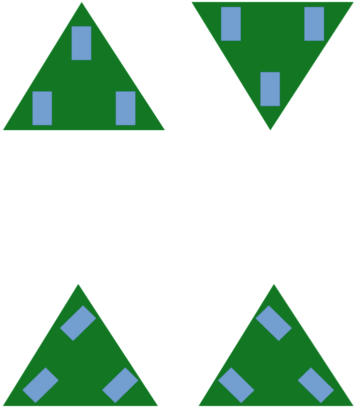


steering

Steering refers to the mechanics used to drive the robots.

Synchro

- Usually **three** (potentially more) synchronised wheels
- **All** of them can **rotate** and **spin** at the same time
  - Synchronised rotation
  - Synchronised spinning
- That allows the robot to move in **any direction**
  - (after manoeuvring)
- The robot can **move linearly**, or **slowly changing direction**
- How do **they rotate?**
  - They do **not**!
  - They have a rotating torso
- ✓ Simple control
- ✓ Can describe any trajectory
- X Complex and expensive mechanics
- X It can take time to change direction



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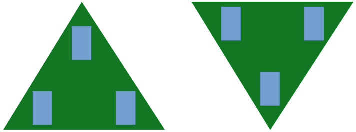
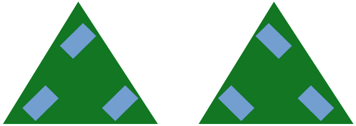
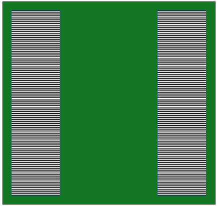




Skid

- Two motorised belts (or pairs of wheels), one on each side
- Each side moves independently (left-right)
- It works like a “tank”
- That allows the robot to move
  - Back and forth
  - Rotate
  - A combination of both
- ✓ Still simple
- ✓ Can describe any trajectory **(requires rotation)**
- ✓ Good for outdoor terrains
- X It takes time to change direction
- X Skids a lot, bad odometry



odometry

System used to estimate how a vehicle moves based on the movement of its effectors.

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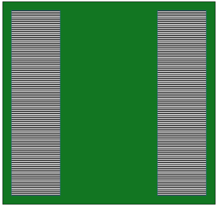

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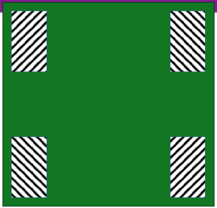
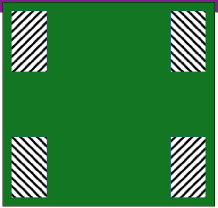
Mecanum



- Four independent wheels with tangential traction
- It works like... nothing I saw before!
- That allows the robot to move
  - Back and forth
  - Sideways
  - Rotate
  - Any previous combination
- ✓ Can describe any trajectory
- ✓ Allows any rotation and translation!
- X Does not work well outdoors
- X Expensive wheels

Mecanum



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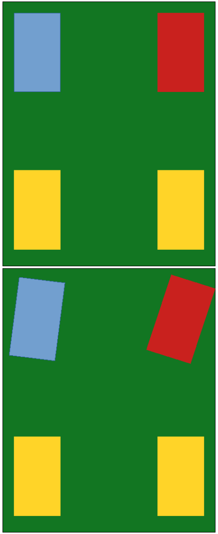
Ackerman

- The traction can be either in the front or back wheels
- Rotation is controlled by rotating the front wheels (to a different extent)
- That is exactly how cars (and autonomous vehicles!) work
- That allows the robot to move
  - Back and forth, rotating to a controllable extent
  - Cannot rotate on the spot
- ✓ Suitable for cars, lower friction in the wheels
- ✓ Cheap and durable wheels, that's why cars don't use mecanum!



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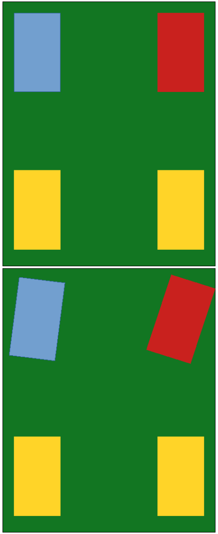

Differential

- Two motorised wheels plus one or more castor wheels
- The motorised wheels spin independently
- It works like a “wheelchair”, “balancing scooter”
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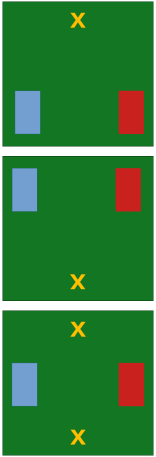

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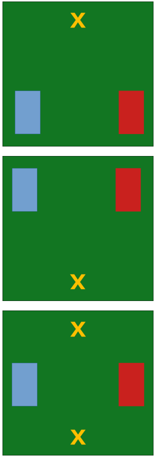
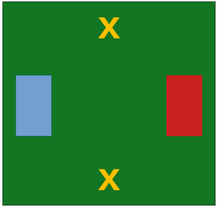


- We will be using a differential driven robot, worth looking in more detail
- How do we control differential platforms and their wheels?
    - Wheels usually have **optical encoders** that allow to measure how much they move
    - We measure it with a **high frequency**, and that allows to estimate their **spinning velocity**
    - In short periods of time, we can approximate the movement as **arcs of a circumference**
- We can look at two problems:
    - Given the wheels' velocities, how did the robot move?
    - Given a desired movement, how to move the wheels?



Holonomic *vs.* non-holonomic robots

- Most ground robots have 3 DoFs: (x, y, θ)
- Very few robots can controll the 3 DoFs without manoeuvring (e.g., mecanum omnidirectional robots).
- Robots that can are referred to as **holonomic**.

holonomic

A robot is holonomic iif it can control all its DoF without manoeuvring. Holonomic UGV can move back and forth, sideways and rotate at the same time, in any combination, without manoeuvring.

Biomimetic

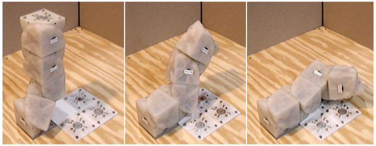


Figure: CC-BY-SA 3.0 https://bit.ly/3oHEDFP

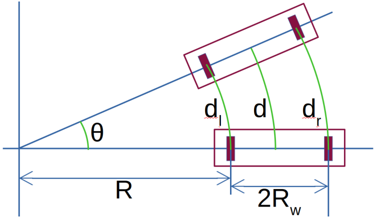
- Crawling robots
- Sliding robots
- Legged robots (most common)
  - biped
  - quadruped
  - hexapod, octopod...

Exercise

- I thought that you'd prefer putting things in practice!
  - It is a summer school, not a Uni module...
  - Theory is still important!
- Google Colab: `https://bit.ly/3mOoZHm`
- Slides (check the last page): `https://bit.ly/3Occ2mv`

Differential: Given the wheels' velocities, how did the robot move?

- **GOAL:** estimate rotation (θ) and translation (d).
- We are going to assume that s_l and s_r represent how much the left and right wheel moved during the last period of time (in radians)
- r is the radius of the wheels
- **We know:** s_l, s_r, r, R_w
- The distance travelled by each of the wheels is $d_l = rs_l$ and $d_l = rs_l$ (because wheels are circular)
- We also know from the diagram that



$$d_l = R\theta$$

$$d_r = (R + 2R_w)\theta$$

$$d = (R + R_w)\theta$$

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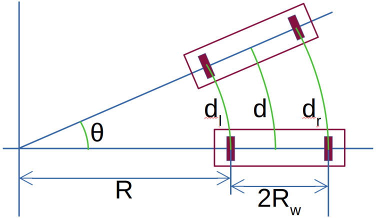

Differential: Given the wheels' velocities, how did the robot move?

- **GOAL:** estimate rotation (θ) and translation (d).

1. $d_r = (R + 2R_w)\theta \implies d_r = R\theta + 2R_w\theta$
2. Substituting d_l, we get $d_r = d_l + 2R_w\theta$
3. Reordering, we get $R_w\theta = \dfrac{d_r - d_l}{2}$
4. Reordering, we get $\theta = \dfrac{d_r - d_l}{2R_w}$

- **We got θ!**

We got:

$$d_l = R\theta$$

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Differential: Given the wheels' velocities, how did the robot move?

- **GOAL:** translation (r).

1. We start from $d = (R + R_w)\theta \implies d = R\theta + R_w\theta$
2. Substituting $R\theta$ with d_l, we get $d = d_l + R_w\theta$
   (hold that thought)
3. From the previous slide (2), we know that $d_r = d_l + 2R_w\theta$
4. That implies that $\dfrac{d_r - d_l}{2} = R_w\theta$
5. Substituting $R_w\theta$ with $\dfrac{d_r - d_l}{2}$ in the equation in (2), we get...
6. $d = d_l + \dfrac{d_r - d_l}{2} \implies d = \dfrac{d_l + d_r}{2}$

- **We got d!**

We got:

$$d_l = R\theta$$

$$d_r = (R + 2R_w)\theta$$

$$d = (R + R_w)\theta$$

$$\theta = \frac{d_r - d_l}{2R_w}$$

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$$d_r = (R + 2R_w)\theta$$

$$d = (R + R_w)\theta$$

$$\theta = \frac{d_r - d_l}{2R_w}$$

Differential: Given the wheels' velocities, how did the robot move?

- **GOAL:** Use only input variables (avoid d_l and d_r).

1. We only need to substitute d_l with rs_l and d_r with rs_r
2. **We get the final equations**:

$$\theta = \frac{(s_r - s_l)r}{2R_w}$$

$$d = \frac{(s_l + s_r)r}{2}$$

We got:

$$d_l = R\theta$$

$$d_r = (R + 2R_w)\theta$$

$$d = (R + R_w)\theta$$

$$\theta = \frac{d_r - d_l}{2R_w}$$

$$d = \frac{d_l + d_r}{2}$$

Differential: Given a desired movement, how to move the wheels?

- **GOAL:** Compute s_l and s_r assuming that we know θ and d
- It is very simple, we just need to solve the previous equations for s_l and s_r rather than θ and d.

We got:

$$\theta = \frac{(s_r - s_l)r}{2R_w}$$

$$d = \frac{(s_l + s_r)r}{2}$$

Differential: Given a desired movement, how to move the wheels?

- **GOAL:** Compute s_l and s_r assuming that we know θ and d

1. $2R_w\theta = s_r r - s_l r \implies s_l = \dfrac{s_r r - 2R_w\theta}{r}$
2. $2d = s_l r + s_r r \implies s_l = \dfrac{2d - s_r r}{r}$
3. $s_r r - 2R_w\theta = 2d - s_r r$
4. $2s_r r = 2d + 2R_w\theta$
5. $s_r r = d + R_w\theta$
   THEREFORE
6. $s_r = \dfrac{d + R_w\theta}{r}$
   PROCEEDING SIMILARLY WITH s_l
7. $s_l = \dfrac{d + R_w\theta}{r}$

- Remember d is for the travelled distance (or distance/time if we understand s_l and s_r as rotation/time)
- Remember r is for the wheels' radius

We got:

$$\theta = \frac{(s_r - s_l)r}{2R_w}$$

$$d = \frac{(s_l + s_r)r}{2}$$