4SC020 Mobile Robot Control 2024: Introduction, tooling and worldmodeling

APRIL 24TH 2024

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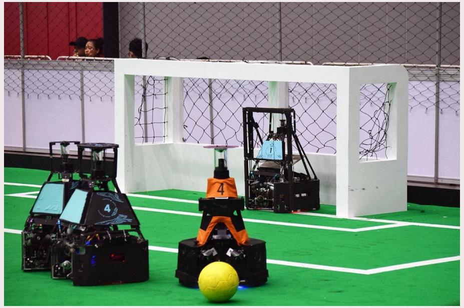
Mechanical Engineering, Control Systems Technology

EINDHOVEN UNIVERSITY OF TECHNOLOGY

Mobile Robot Control

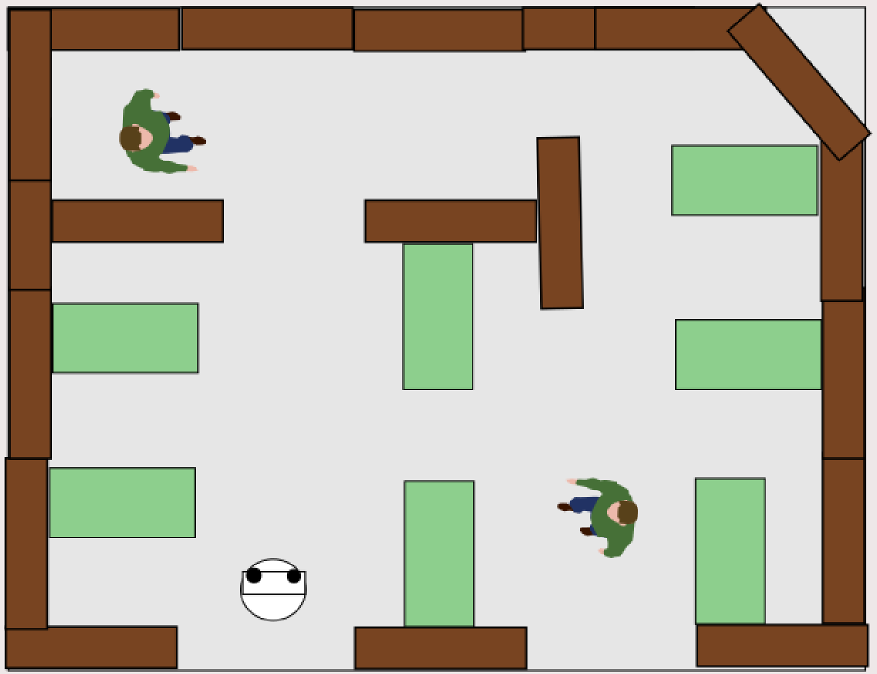


Do you have experience with autonomous mobile robots?

This course: Restaurant challenge

Bring orders to several tables in a restaurant.
Map of the environment is provided beforehand.

Goal: visit a number of tables as fast as possible.



Introducing your Robot: Hero

Human Support Robot (HSR) made by Toyota
2 Time world champion Robocup @home

Sensors:
- **laser range finder**
- **wheel encoders**
- rgbd camera

Actuators
- **Holonomic base**
- Pan tilt unit for head
- 5 DoF arm with gripper

Introducing your Robots: Bobo and Coco

Rosbot Pro
Adorable despite not having faces

Sensors
- **Laser range finder**
- **wheel encoders**
- rgbd camera

Actuators
- **Differential drive base**

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Learning goals

After this course you will be able to:

- Describe the challenges of autonomous mobile robots
- Describe and develop a local path planning algorithm, e.g. APF, Pure pursuit, DWA
- Describe and develop a global path planning algorithm, e.g. A*, RRT
- Describe develop a localization algorithm, a particle filter.
- Design an architecture that integrates different algorithms to enable a mobile robot to fulfill a given use-case
- Validate your system architecture on a physical robot
- Use tools common in robotics industry

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Course structure

Work in groups of 6

- Coached by tutor

Weeks 1-6

- Lectures + Guided self-study
- Focus on understanding and implementing algorithms for navigation and localization as components.

Weeks 7-9

- Group project + help sessions
- Design a system
- Focus on system design and development

Course structure

- MRC wiki: main hub of information
- MRC wiki - group pages: report on your exercises and project
- Gitlab: group repositories

Schedule

Date	What
24 April	Lecture: Introduction and world modeling
26 April	Lecture: Programming methods Guided selfstudy: hello world
1 May	Lecture: Local navigation
3 May	Guided selfstudy: local navigation
8 May	Lecture: Global Navigation
10 May	Holiday
15 May	Guided selfstudy: Global navigation
17 May	Lecture: Localization

Date	What
22 May	Guided selfstudy: Localization 1
24 May	Guided selfstudy: Localization 2
29 May	Lecture: System architecture
31 May	help sessions
31 May	Intermediate peer review
5 June	Design Presentations
7 June	help sessions
7 June	Exercises deadline
14 June	Guest lectures: robotics in practice
16 June	Help sessions
21 June	Final challenge
28 June	Wiki + peer review deadline

Grading and deadlines

Date	Deadline	grade
31 May	Intermediate Peer review	-
5 June	Design Presentation	-
7 June	Exercises	30%
21 June	Final challenge	30 %
28 June	Wiki (report)	40 %
28 June	Peer review	* Individual grade from group grade $G_i = G_g + PR_i$

Peer review:

- sum of individual grades is 0
- max(\|each individual grade\|)<=1
- if the difference between members is too great, contact your tutor

Practical sessions

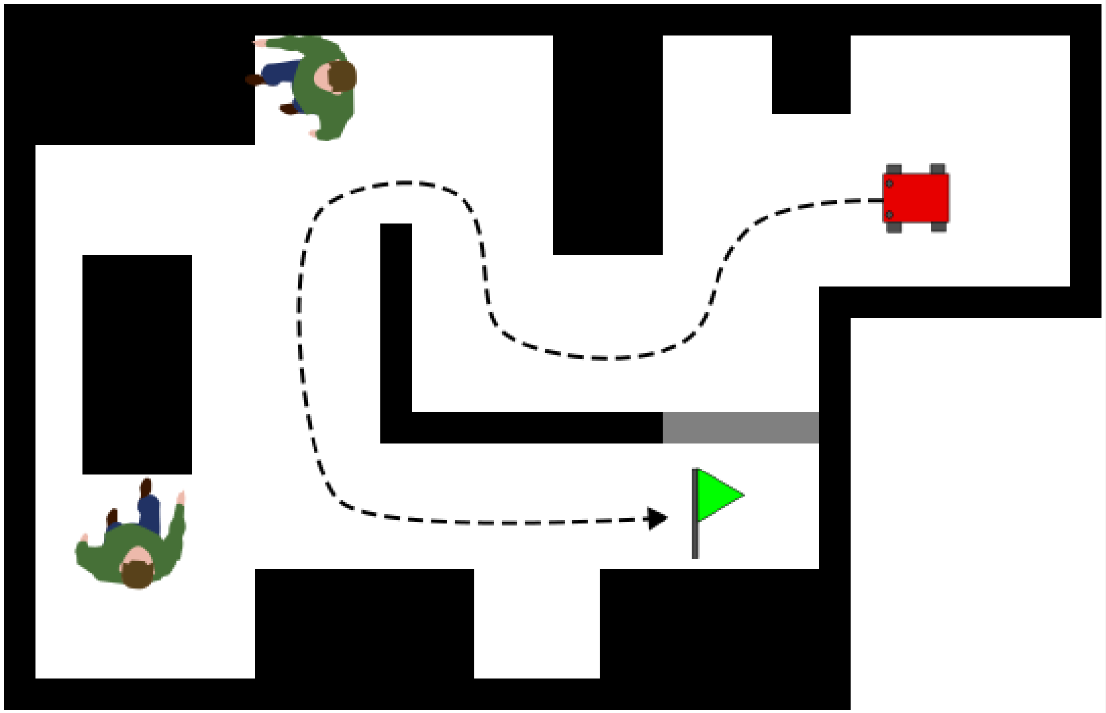
You will have to reserve a test slot to be able to test your code on the robot

- Use the course wiki to reserve a test slot
- Your group may only reserve 2 slots per week
- Deadline for reserving a slot is the day before
- Tests will take place in the Impuls building. Fill in this form to get access with your campus card
- Student assistants will supervise your test

Why is it challenging to create autonomous mobile robots?

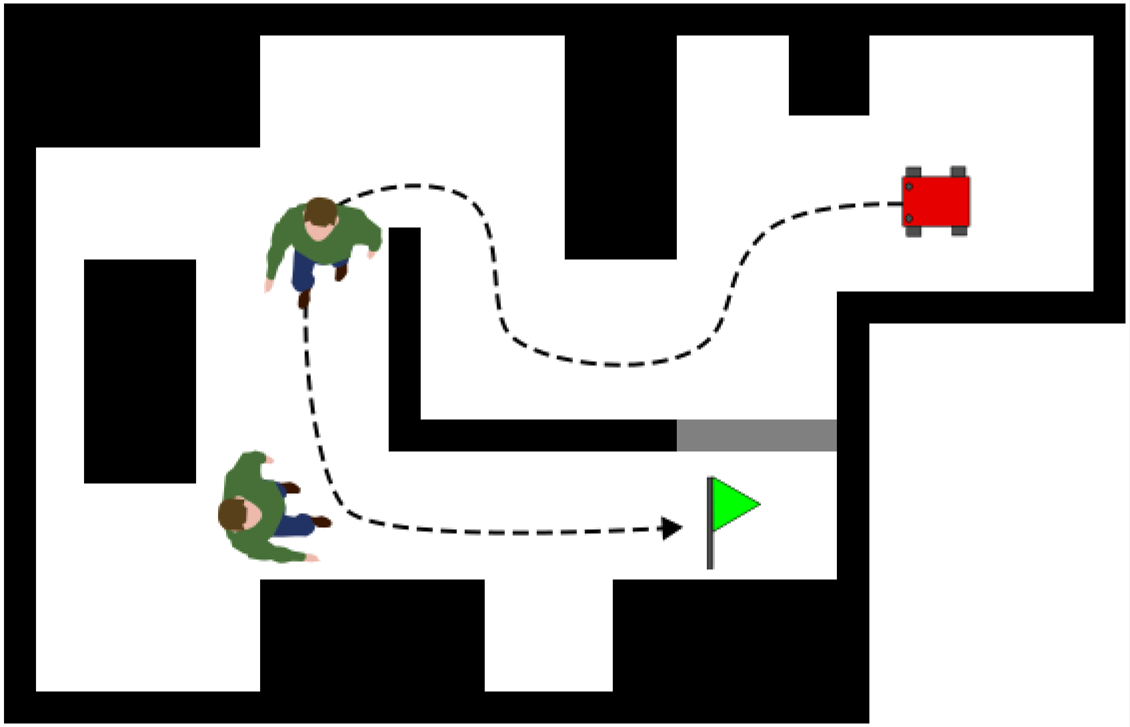
Non convex environment

Drivable space can have an arbitrary form.



Dynamic environment

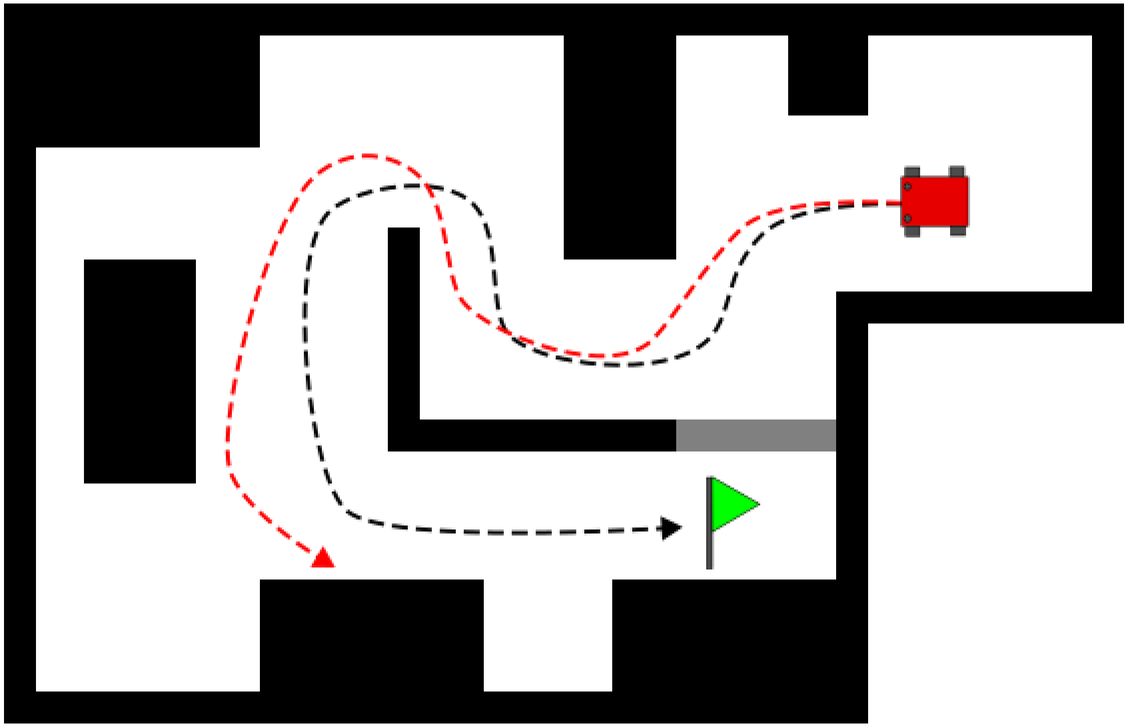
Objects in the environment may move



Nondeterministic environment

The actions of the robot have an uncertain result.

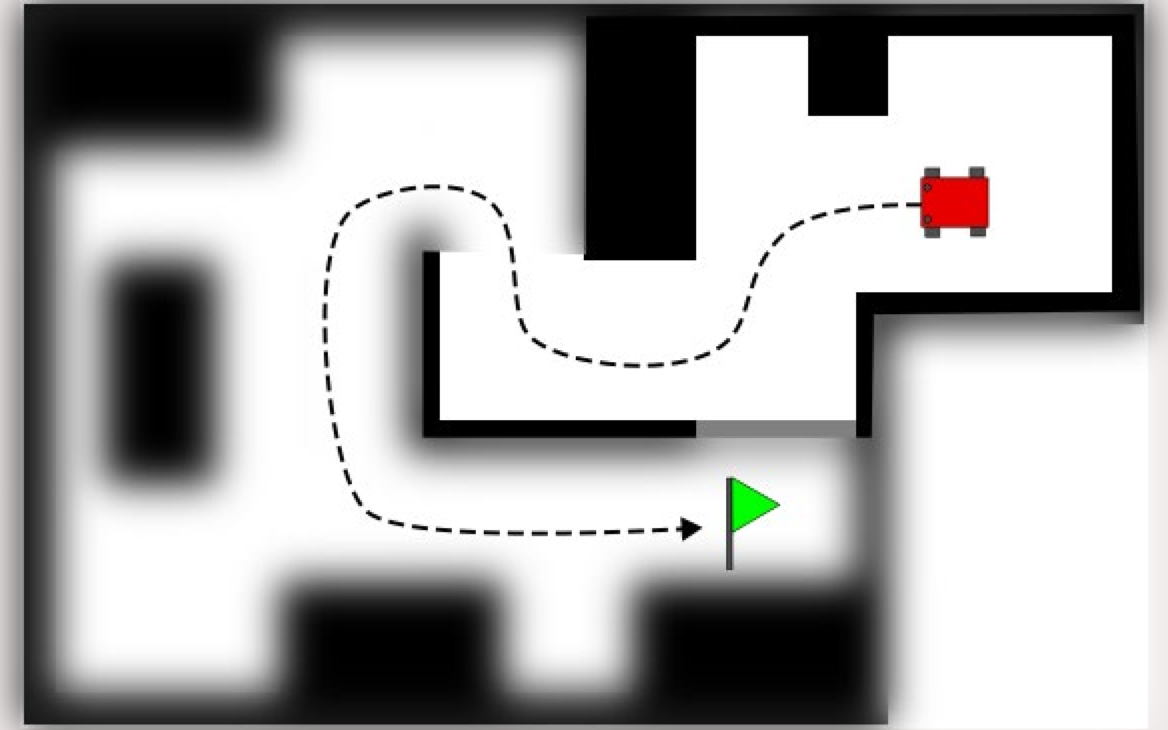
Wheel slip



Partially observable environment

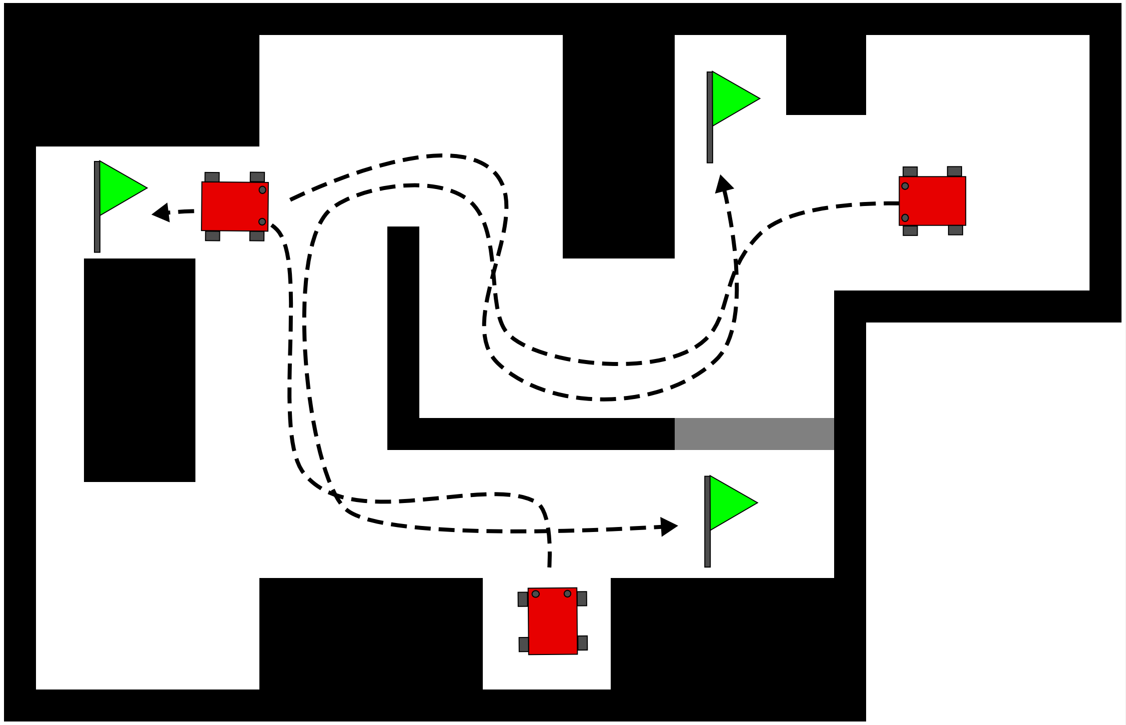
The state of the environment cannot be observed.

Robot must perceive the environment through sensors.



multi robot environment

Robot must coordinate its behavior with others.



Mobile Robot environments

Static/Dynamic

Deterministic/Nondeterministic

Fully observable/Partially observable

Single Robot/Multi Robot

Mobile Robot environments

Static/Dynamic -> How dynamic?

Deterministic/Nondeterministic -> How deterministic?
What is the size of the disturbances?

Fully observable/Partially observable -> How observable?
How much of the environment can the robot perceive?

Single Robot/Multi Robot -> How much do the robots need to cooperate?

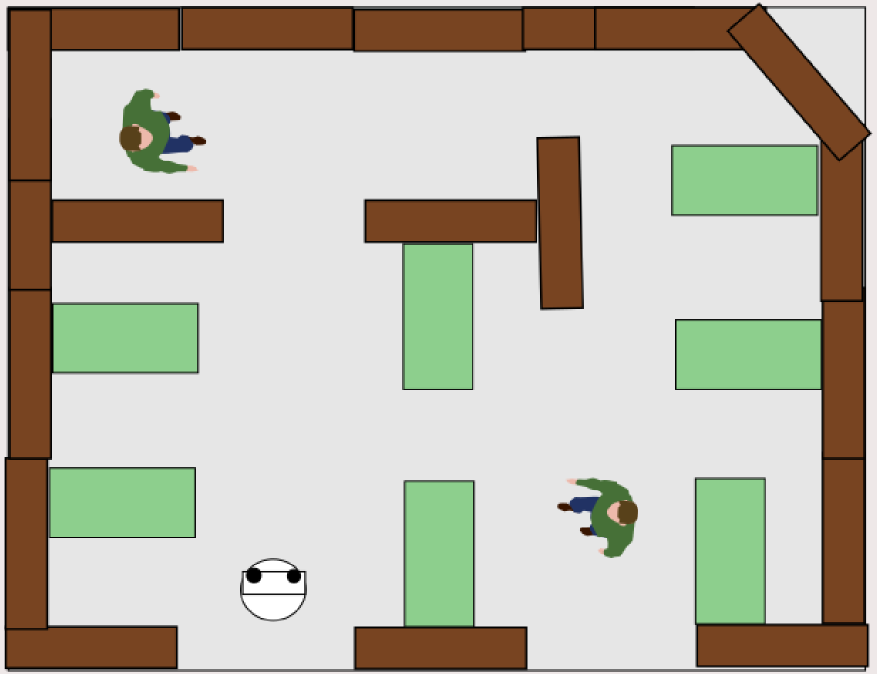
Restaurant environment

Dynamic

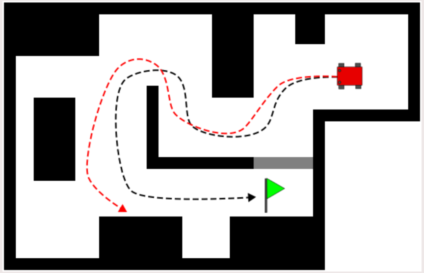
Nondeterministic

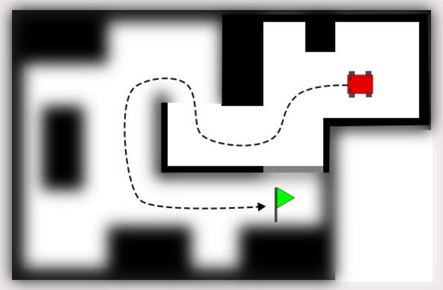
Partially observable

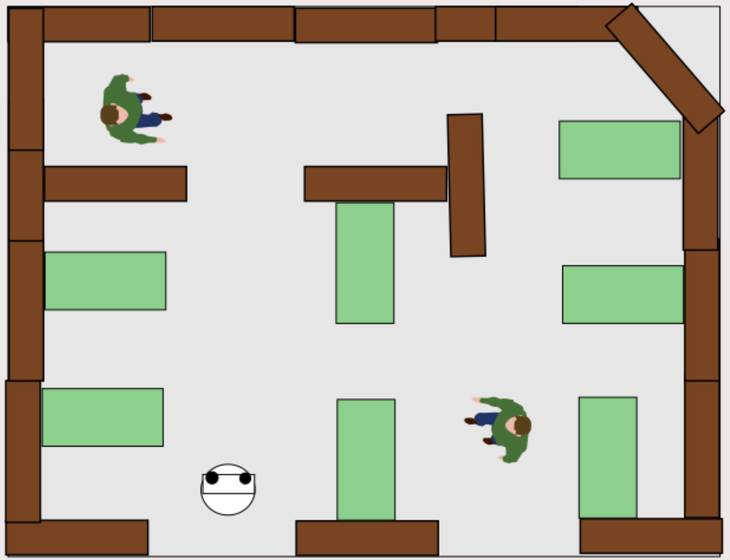
Single Robot



Break





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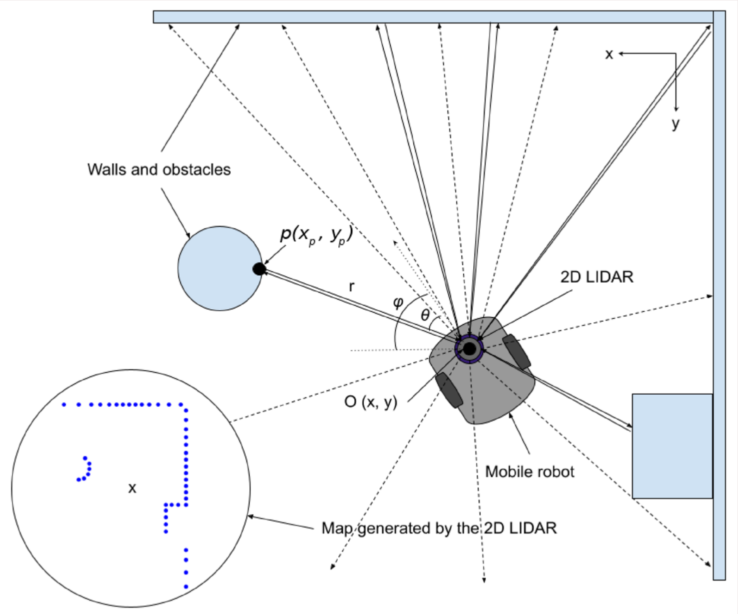
How do (our) robots perceive the world?

Sensors: Laser range finder

Measures distance (range) to nearest opaque object

Takes ranges from an array of angles.

Large measurement range up to 300m



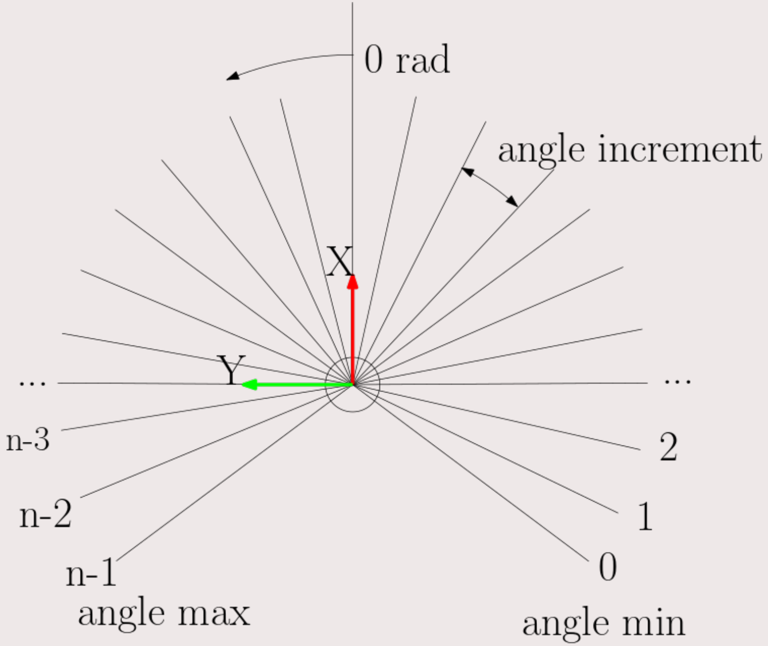
Bouazizi M, Lorite Mora A, Ohtsuki T. A 2D-Lidar-Equipped Unmanned Robot-Based Approach for Indoor Human Activity Detection. *Sensors*. 2023; 23(5):2534. https://doi.org/10.3390/s23052534

Sensors: Laser range finder

Measures distance (range) to nearest opaque object

Takes ranges from an array of angles.

$$\theta_i = angle\_min + i \ * angle\_increment$$



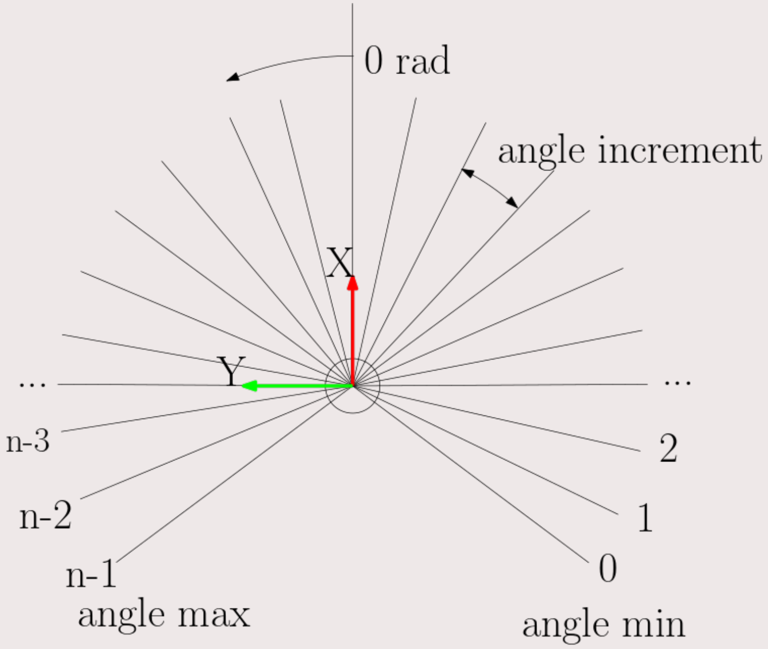
$$ranges = [d_0, d_1, d_2, \ldots d_{n-3}, d_{n-2}, d_{n-1}]$$

Sensors: Laser range finder

If I want to get the range at 0 radians, which index should I get?

A: 0
B: -angle_min/angle_increment
C: n-1-angle_max/angle_increment
D: n/2

*all answers are rounded to integers

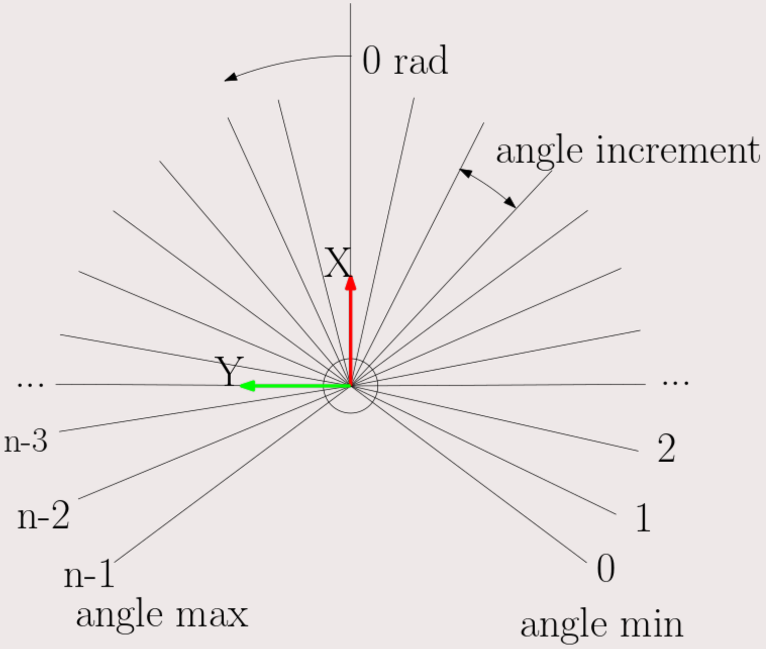


$$ranges = [d_0, d_1, d_2, ...d_{n-3}, d_{n-2}, d_{n-1}]$$

Sensors: Laser range finder

Useful operations on lidar data

Given range d_i what coordinates correspond tot his point?



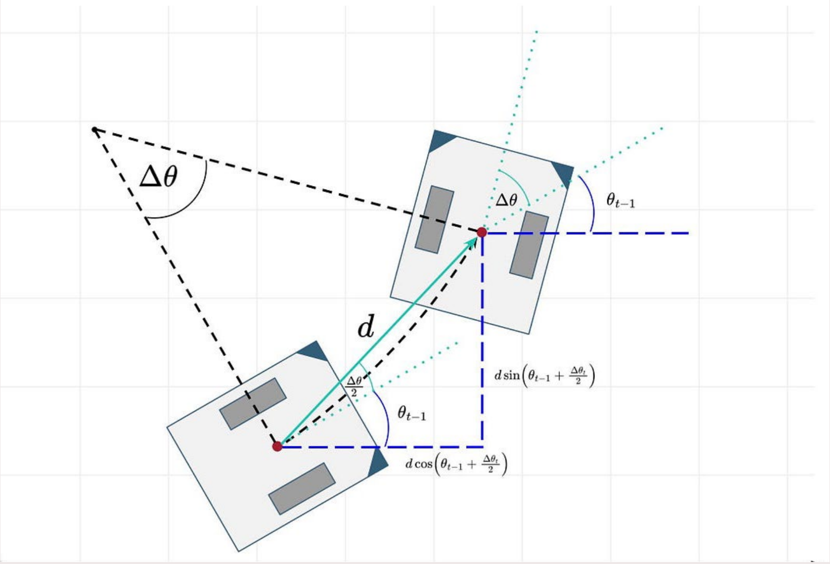
$$ranges = [d_0, d_1, d_2, ...d_{n-3}, d_{n-2}, d_{n-1}]$$

Sensors: Odometry

the use of data from motion sensors to estimate **change in position** over time

Often used motion sensors include:

- Wheel encoders
- Laser Range Finder
- Video (visual odometry)

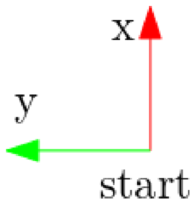


Sensors: Odometry

At t=0
Position of the robot is (0,0,0)

At t=1 Odom = $(1, 0, \frac{\pi}{2})$

Which is the robot?



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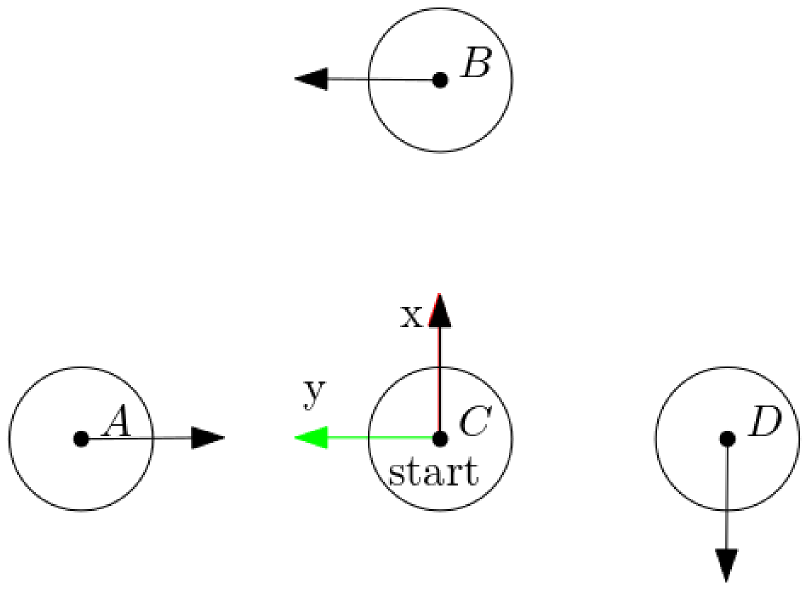

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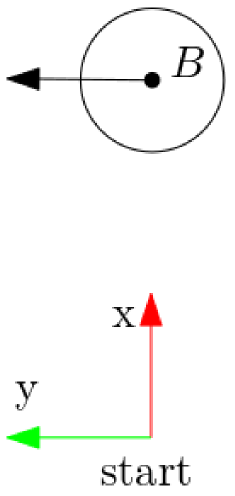
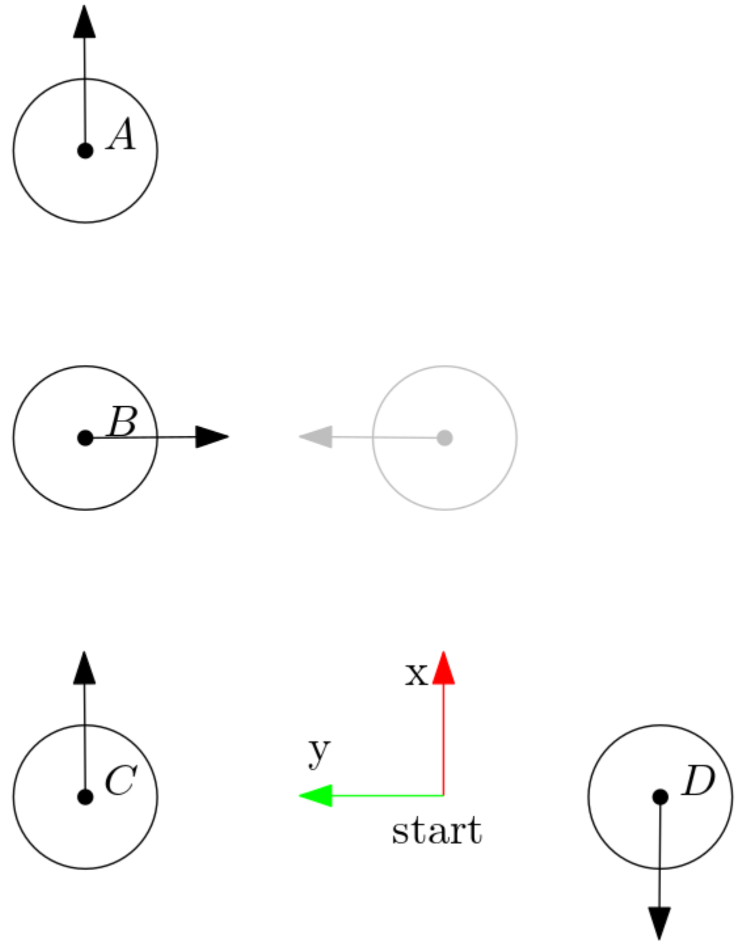


Sensors: Odometry

At t=0
Position of the robot is (0,0,0)

At t=1 Odom = $(1, 0, \frac{\pi}{2})$
At t=2 Odom = $(1, 1, -\frac{\pi}{2})$

Which is the robot?



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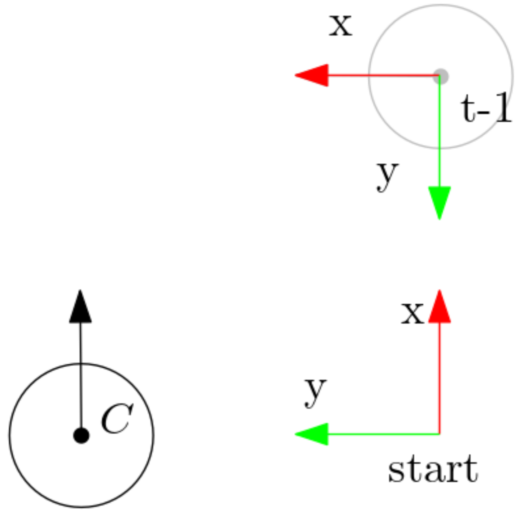
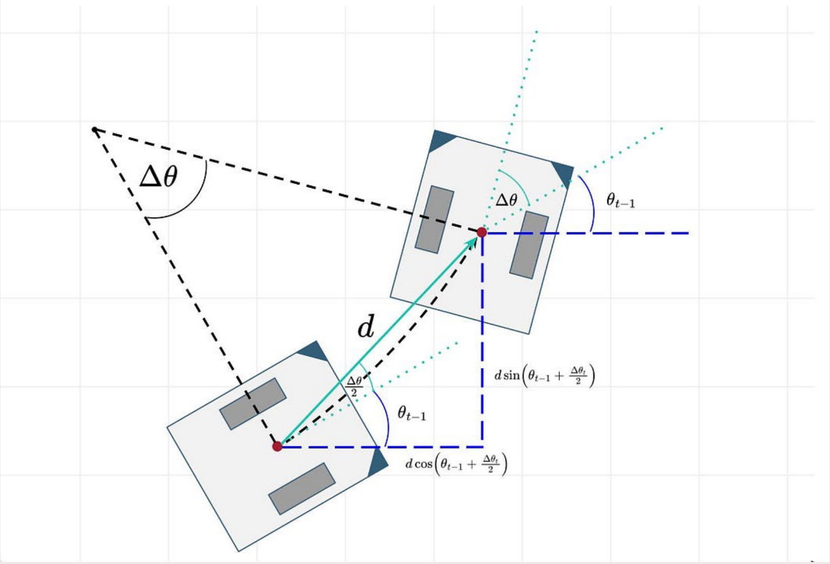
Which is the robot?



Sensors: Odometry

Suffers from drift due to wheel slip

Does not measure position but displacement!



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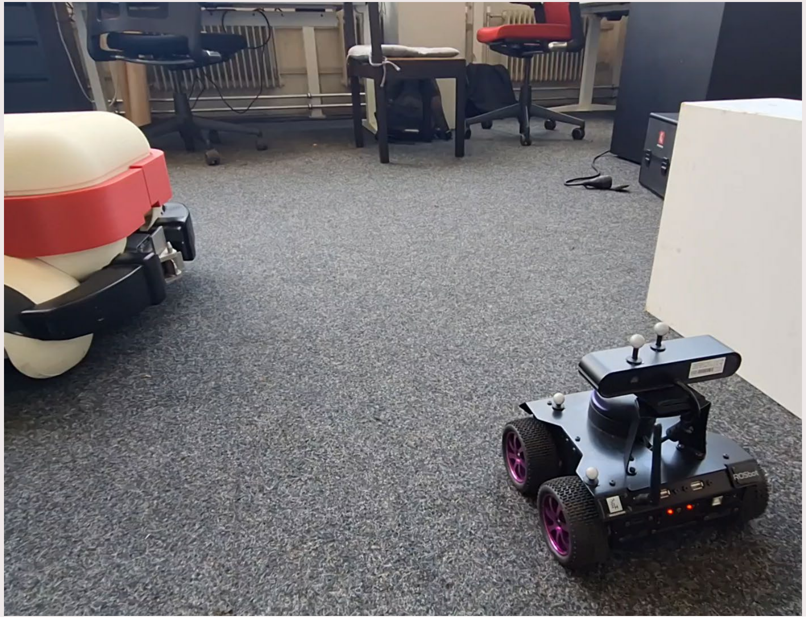
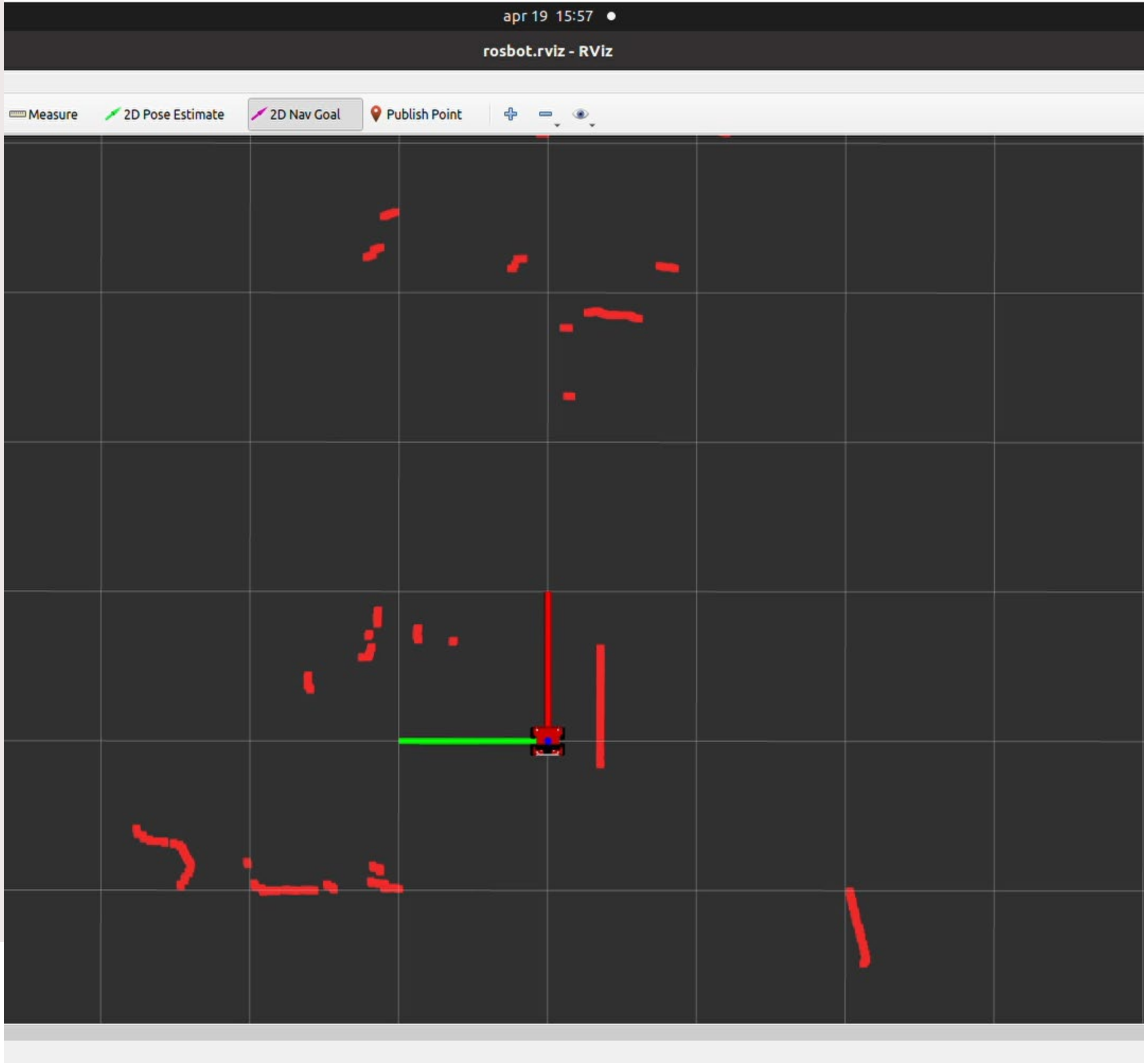
Robot Sensors: Demonstration

Robot sensors: Demonstration



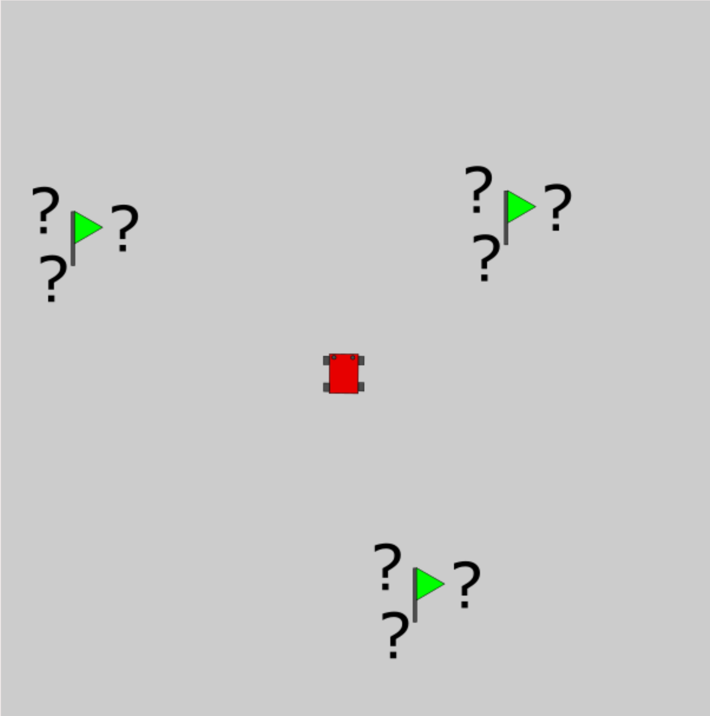
Robot sensors: Demonstration



Let’s do a thought experiment

You are a robot, I take you out of your box and put you in my house.

I ask you to go to Bob’s room.
Why can’t my robot do this?



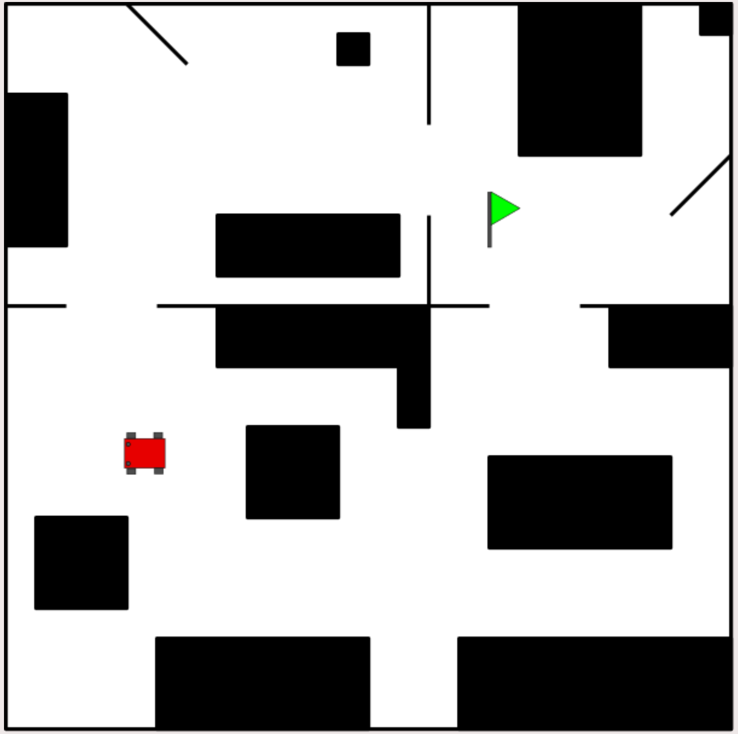
Let’s do a thought experiment

For many tasks the robot will need a model of its environment. Such a model is often called a map.

This map is used to find

1. where things are
2. where the robot itself is

These are the same thing



Let’s do a thought experiment

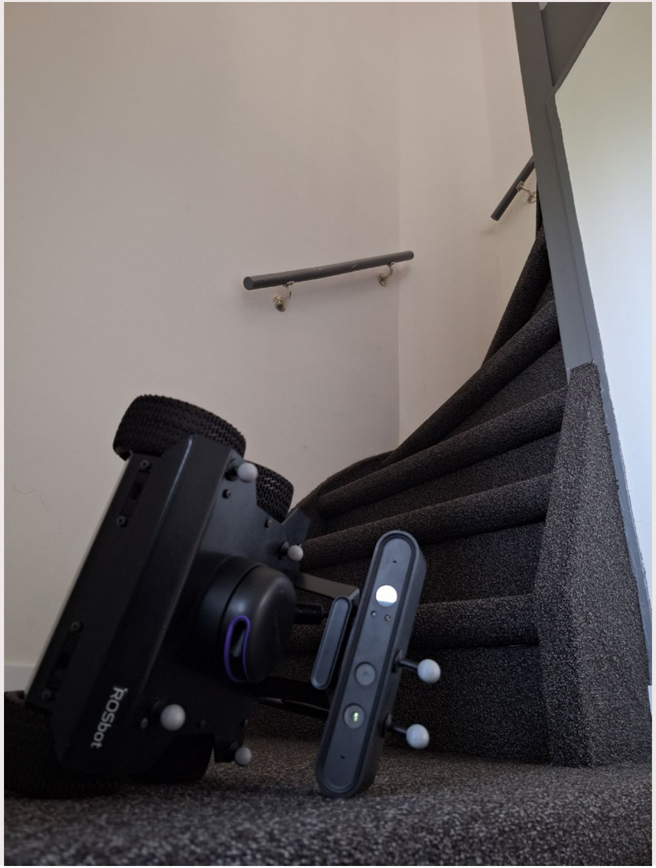
At some point your odometry tells you you are going forward but the laser data stays the same.

What happened?

Let’s do a thought experiment

At another point your laser measurements become erratic and then stop.

What happened?



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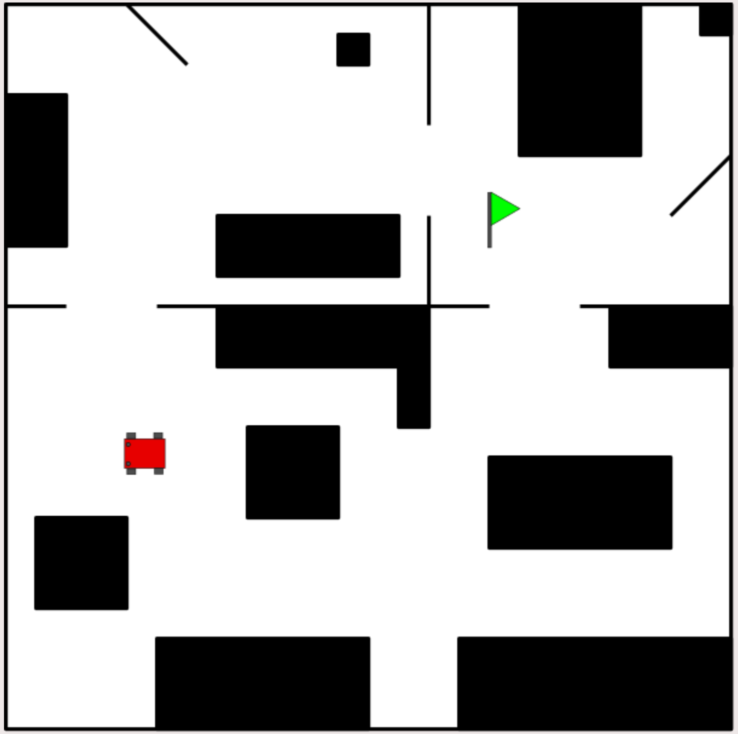
Let’s do a thought experiment

Is our map wrong?

No, we simply did not specify what this was a map of. It is a map of objects at the height of our laser.

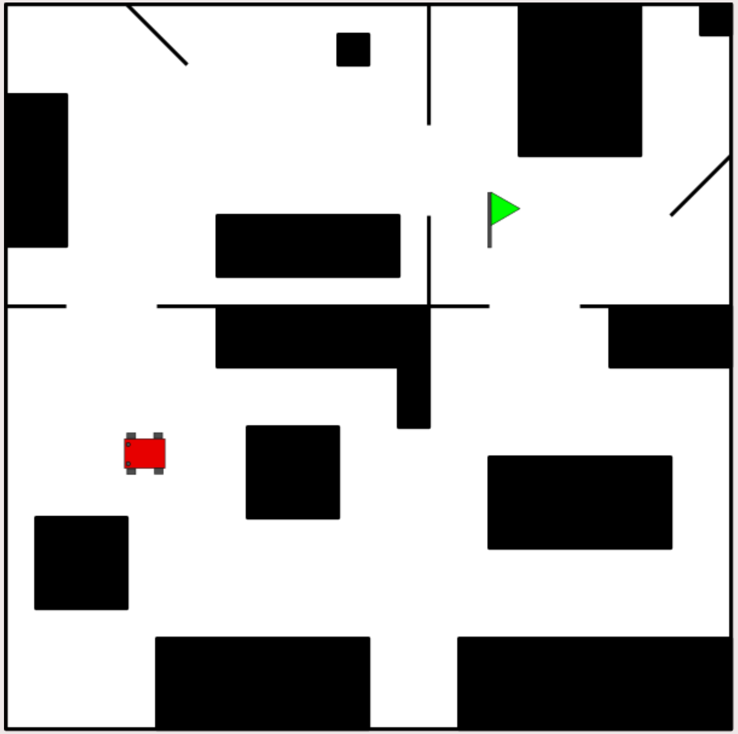


World model

The robot's knowledge of the environment.

What do we use it for?

- Know where everything is
- Figure out where you yourself are
- Know the affordances of your environment
  - affordance: how can something be used
- Know what objects will look like to your sensors

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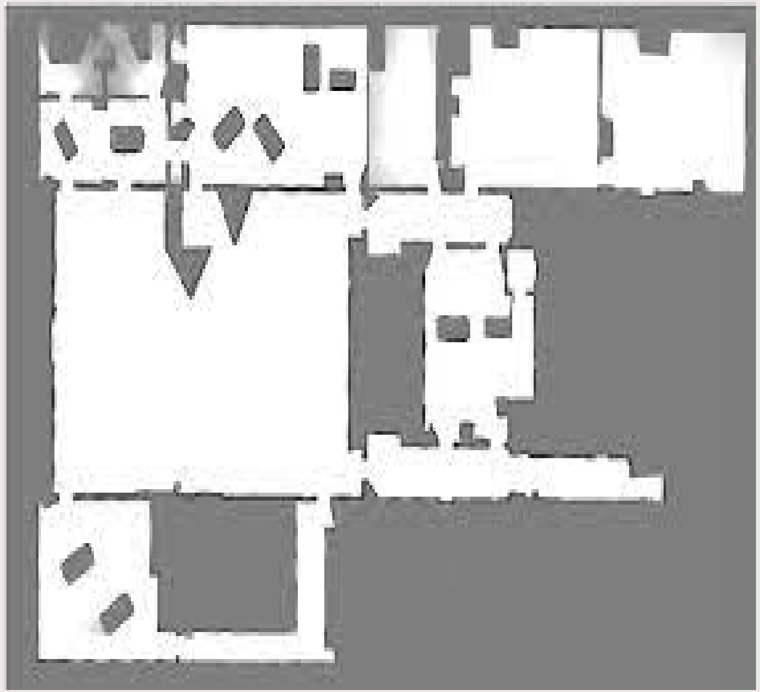
World model formats

Occupancy Gridmap:

Label space on a regular grid of fixed cells with a fixed resolution.

Often used to mark occupied vs not occupied.

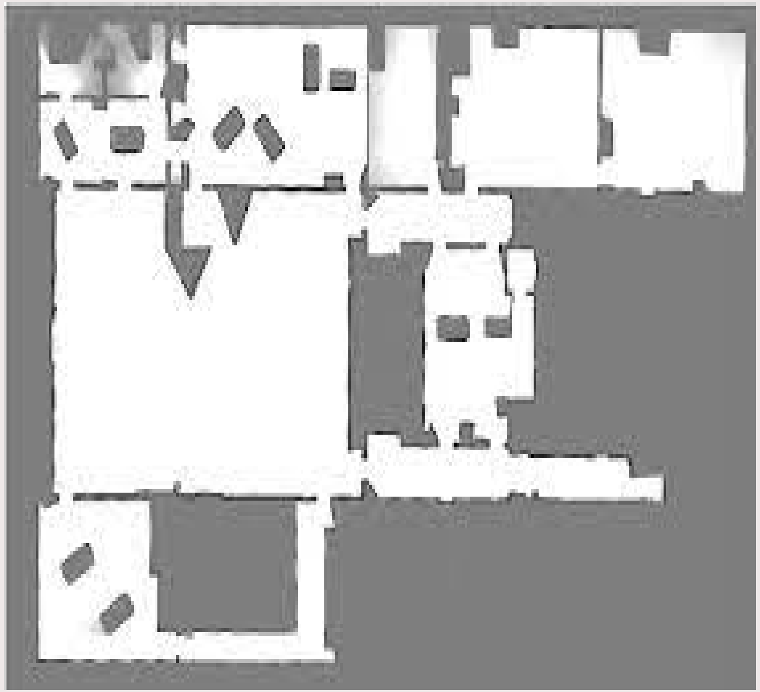


World model formats

Occupancy Gridmap:
Accuracy limited by gridsize

Does not contain information on:

- Which cells belong together.
- What these pixels represent, i.e. their semantics*
- Often limited to 2D or 2.5D information due to memory usage.



*it can be done but requires additional data.

World model formats

Object based models

Contains discrete objects whose geometry is modelled using vectors

Infinite accuracy*

Easy to attach semantic labels to objects

*up to the modeling effort

World model formats

Object based models

Using the model is can be more complex.
-one point in space can belong to zero, one, or multiple entities.

World model formats

Photorealistic digital twin

Large amount of data

What to use the information for?

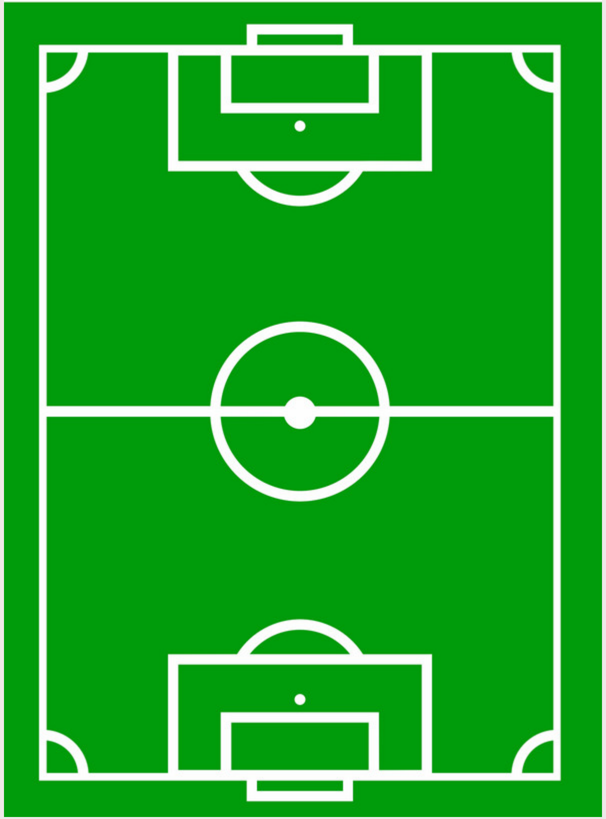
Hard to maintain

When interacting with the environment the robot can perceive it

World model formats

Invariant based

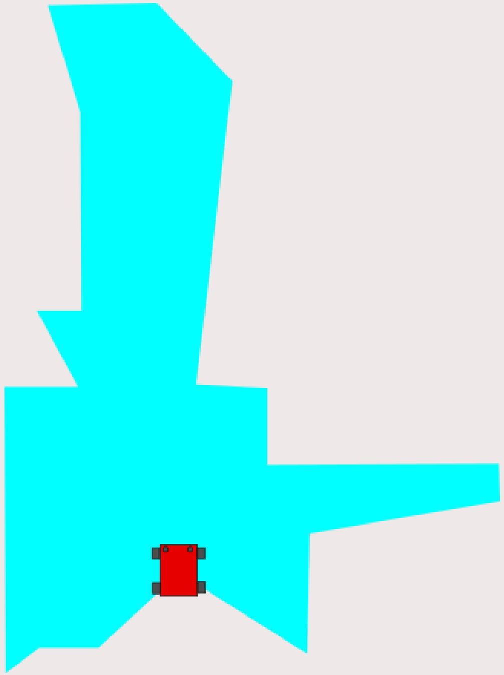
Don't rely on exact dimensions but patterns.



World model sources

Sources of information

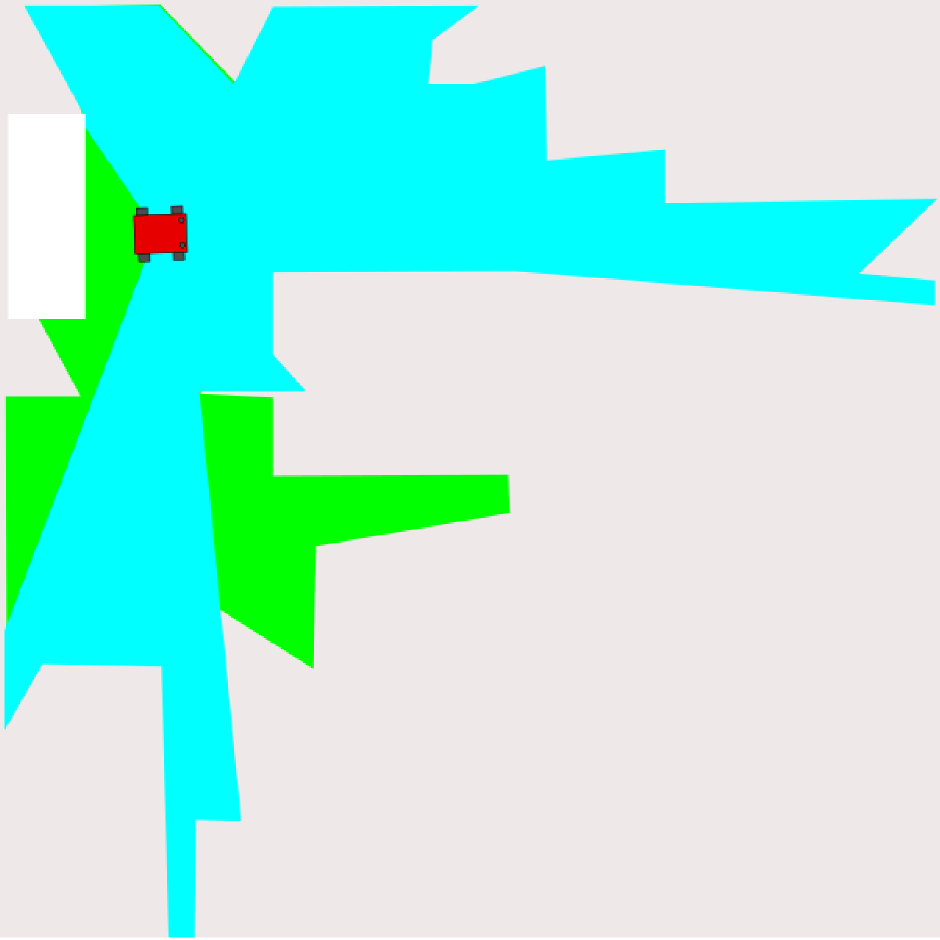
- Sensordata e.g. lidarscan



World model sources

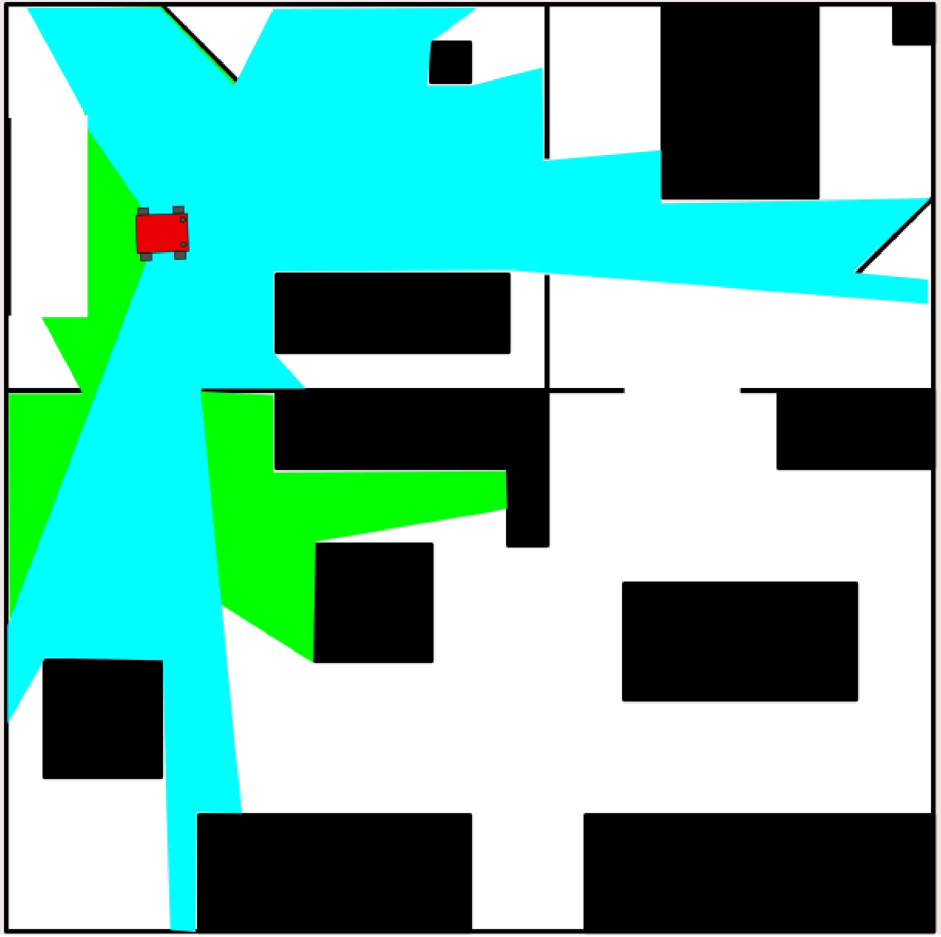
Sources of information

- Sensordata e.g. lidarscan
- Memory e.g. previous lidarscans



World model sources

Sources of information
- Sensordata e.g. lidarscan
- Memory e.g. previous lidarscans
- Prior knowledge e.g. map of the environment



World model sources

Sources of information

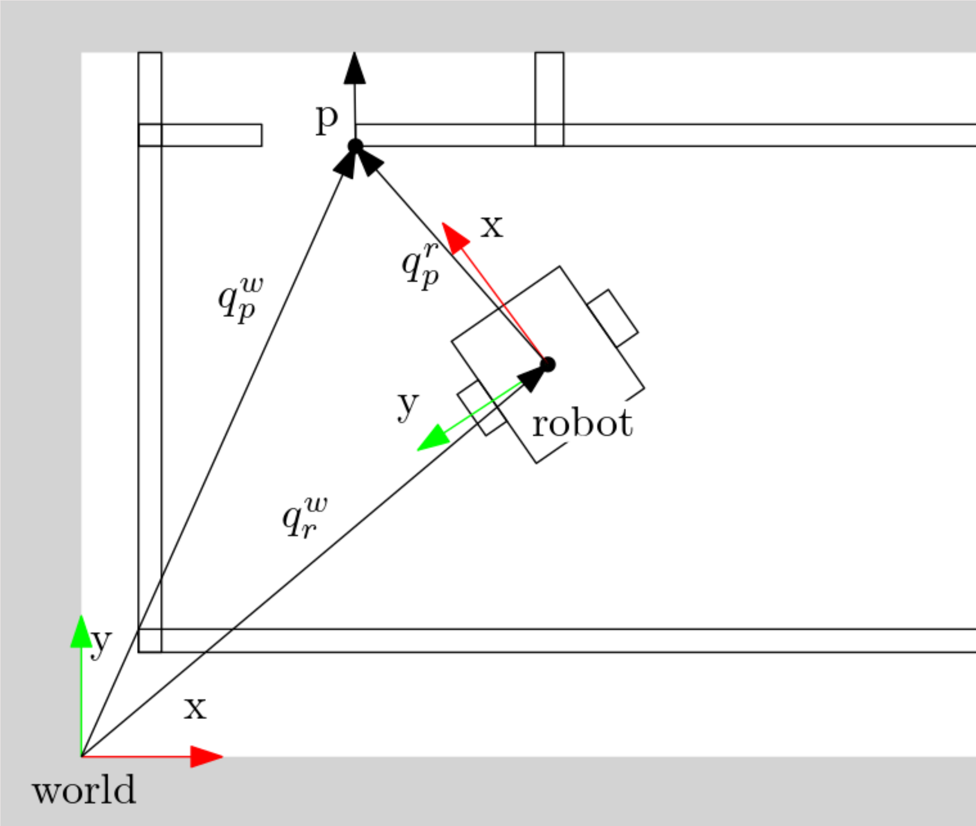
- Don’t assume your map contains all information. Use your sensors.

Frame conventions

We have the position of objects in a world model.

We have the position of our robot in the world model.

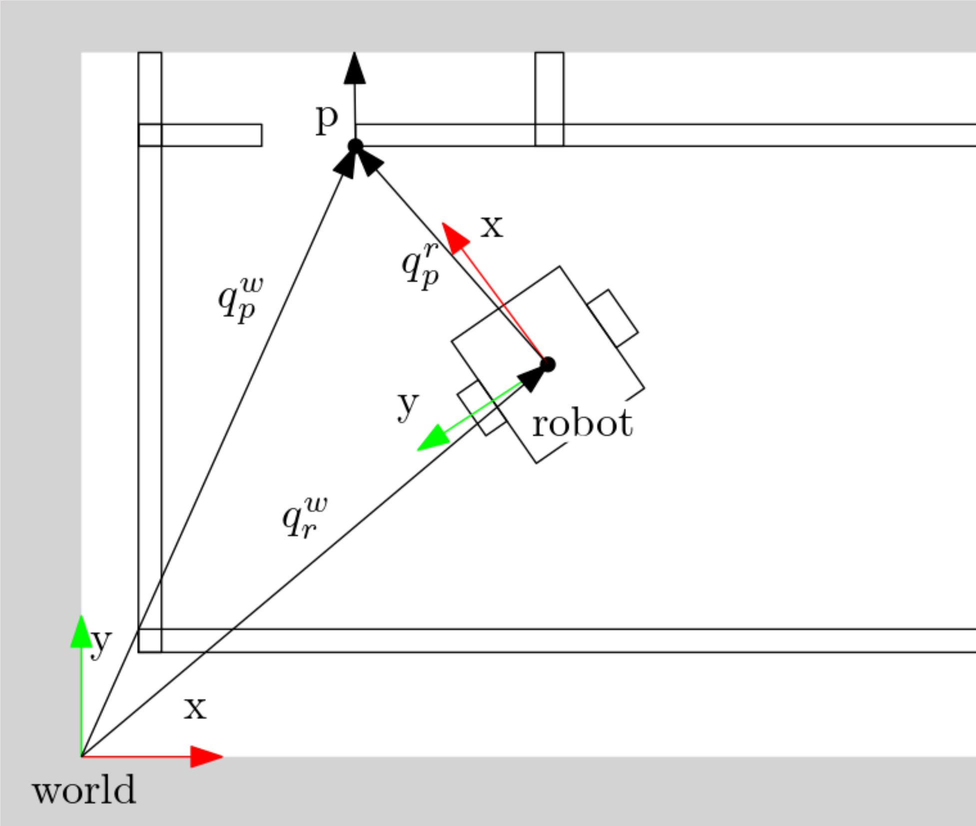
What is the position of the object with respect to our robot?



Frame conventions

$$q_p^w = \begin{bmatrix} x_p^w \\ y_p^w \\ \theta_{p/w} \end{bmatrix}$$

Make explicit in which frame things are expressed.



Frame transformations

Pose in map given pose w.r.t. robot

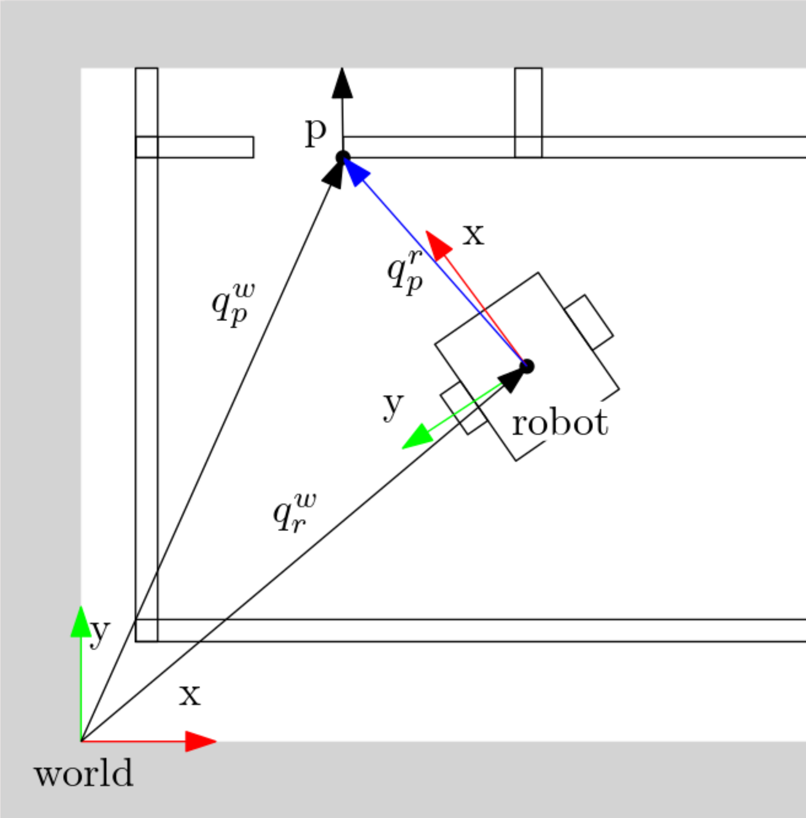
$$\begin{bmatrix} x_p^w \\ y_p^w \end{bmatrix} = \begin{bmatrix} c_{\theta_{r/w}} & -s_{\theta_{r/w}} \\ s_{\theta_{r/w}} & c_{\theta_{r/w}} \end{bmatrix} \begin{bmatrix} x_p^r \\ y_p^r \end{bmatrix} + \begin{bmatrix} x_r^w \\ y_r^w \end{bmatrix}$$

$$\theta_{p/w} = \theta_{p/r} + \theta_{r/w}$$

Pose w.r.t. robot given pose in map.

$$\begin{bmatrix} x_p^r \\ y_p^r \end{bmatrix} = \begin{bmatrix} c_{\theta_{r/w}} & s_{\theta_{r/w}} \\ -s_{\theta_{r/w}} & c_{\theta_{r/w}} \end{bmatrix} \begin{bmatrix} x_p^w - x_r^w \\ y_p^w - y_r^w \end{bmatrix}$$

$$\theta_{p/r} = \theta_{p/w} - \theta_{r/w}$$



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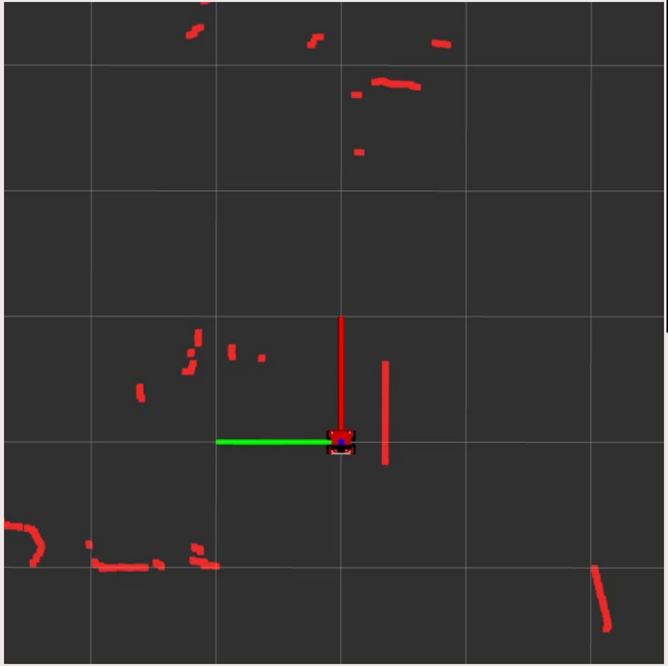
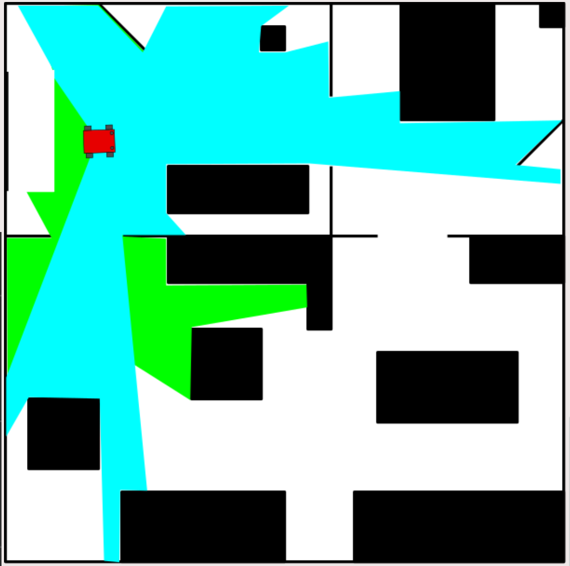
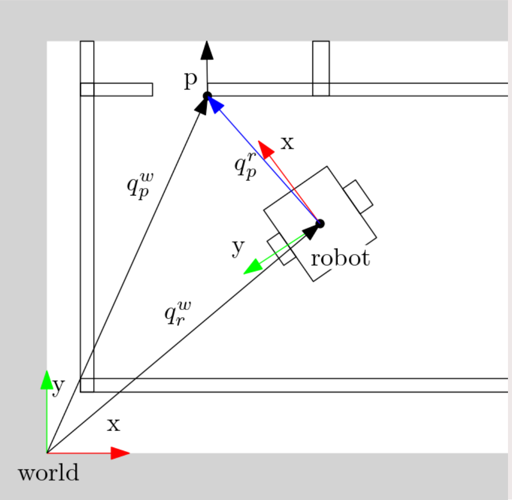
Summary







What to do now?

- Form groups of 6
- Register your groups on the CST wiki
- Start with exercises 1
- Register for a practical session on the CST wiki
- Contact your tutor

To get access to the Gitlab repository:

Send an email to your tutor
Subject: MRC group <group name> gitlab

Body:
Provide gitlab account names of group members