Introduction to Mobile Robotics

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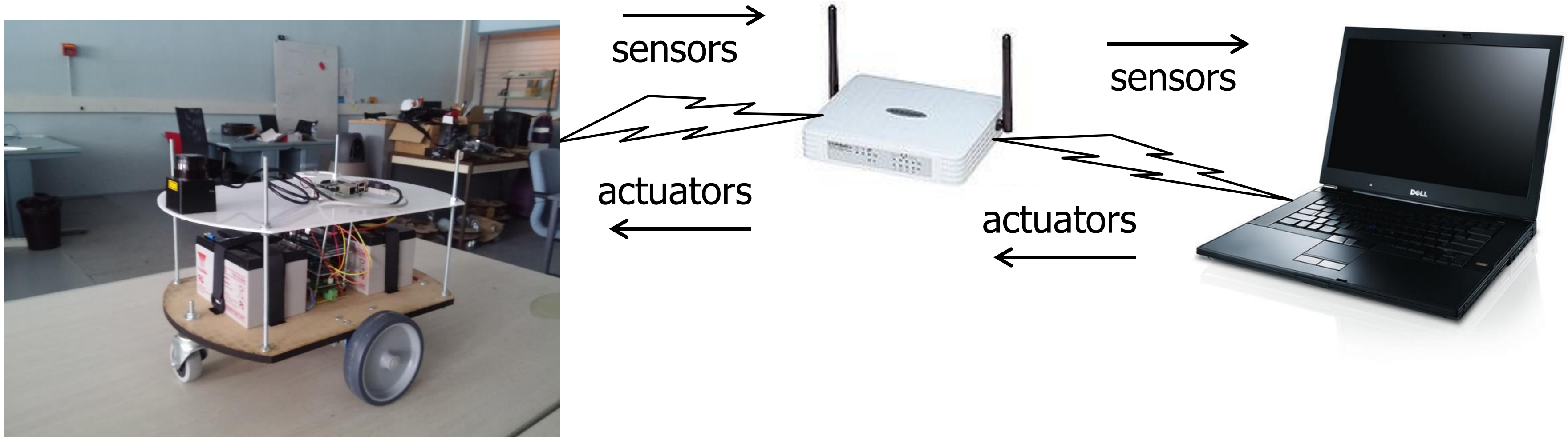
What is a robot ?

Robot = *mechatronic system with perception, decision and action skills,* capable of carrying out *different tasks in the real world, in an autonomous way.*

The robot of the day



- 1 raspberry pi3:
  - ubuntu + ROS
- Sensors
  - 1 laserscanner
- Actuators
  - 2 wheels driven by 2 motors + encoders

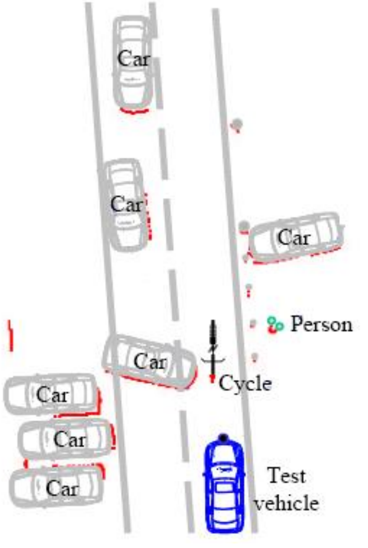
- 1 PC Ubuntu + ROS
  - In charge of sensor data acquisition, processing & visualization;
  - In charge of controlling actuators.

Outline

1. Sensors and actuators
2. ROS
3. Perception
4. Decision
5. Action
6. Examples of applications
7. Conclusion

Sensor (1/3)

- **A sensor** is an instrument measuring a physical property of the environment;
- Sensors are imprecise and limited;
- The environment of a robot is generally complex, changing, unpredictable and uncertain;
- Understanding the world in which a robot evolves remains a challenge.



Courtesy of sick

Sensor (1/3)

- **A sensor** is an instrument measuring a physical property of the environment;
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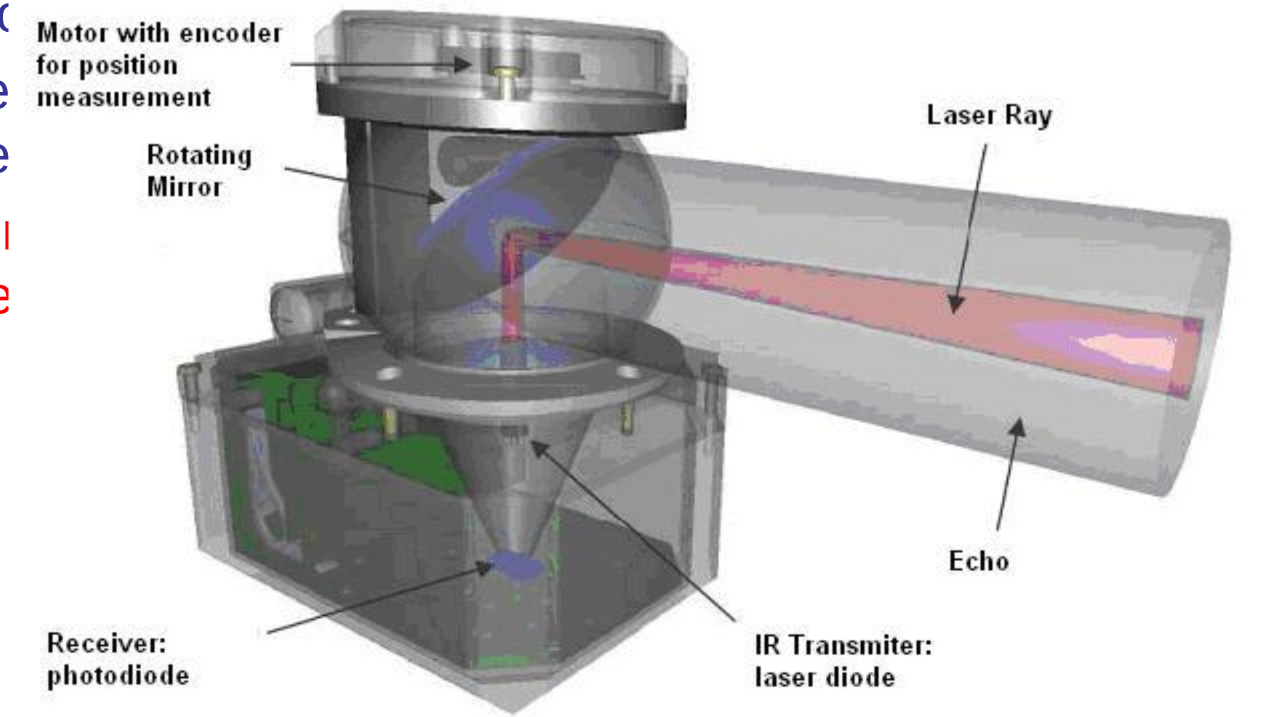
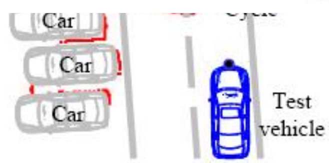
- The e unpre
- Under challe





Courtesy of sick

Sensor (2/3)

- **Robair** is equipped with a 2D laser scanner;
- The laser scanner has:
  - a range of about 5.5 meters;
  - a field of view of 240 degrees;
  - an angular resolution of 1/3 degrees.
- **Output**: a table with 725 elements (r, ϴ)
- Laser data are acquired in the trigonometric way
- Polar to cartesian:
  - $X = r \cos(\theta)$;
  - $Y = r \sin(\theta)$.
- Quality of data depends on distance, angle…
- The frequence of acquistion is of about 40 Hz
- The laser scanner costs about 900 euros.

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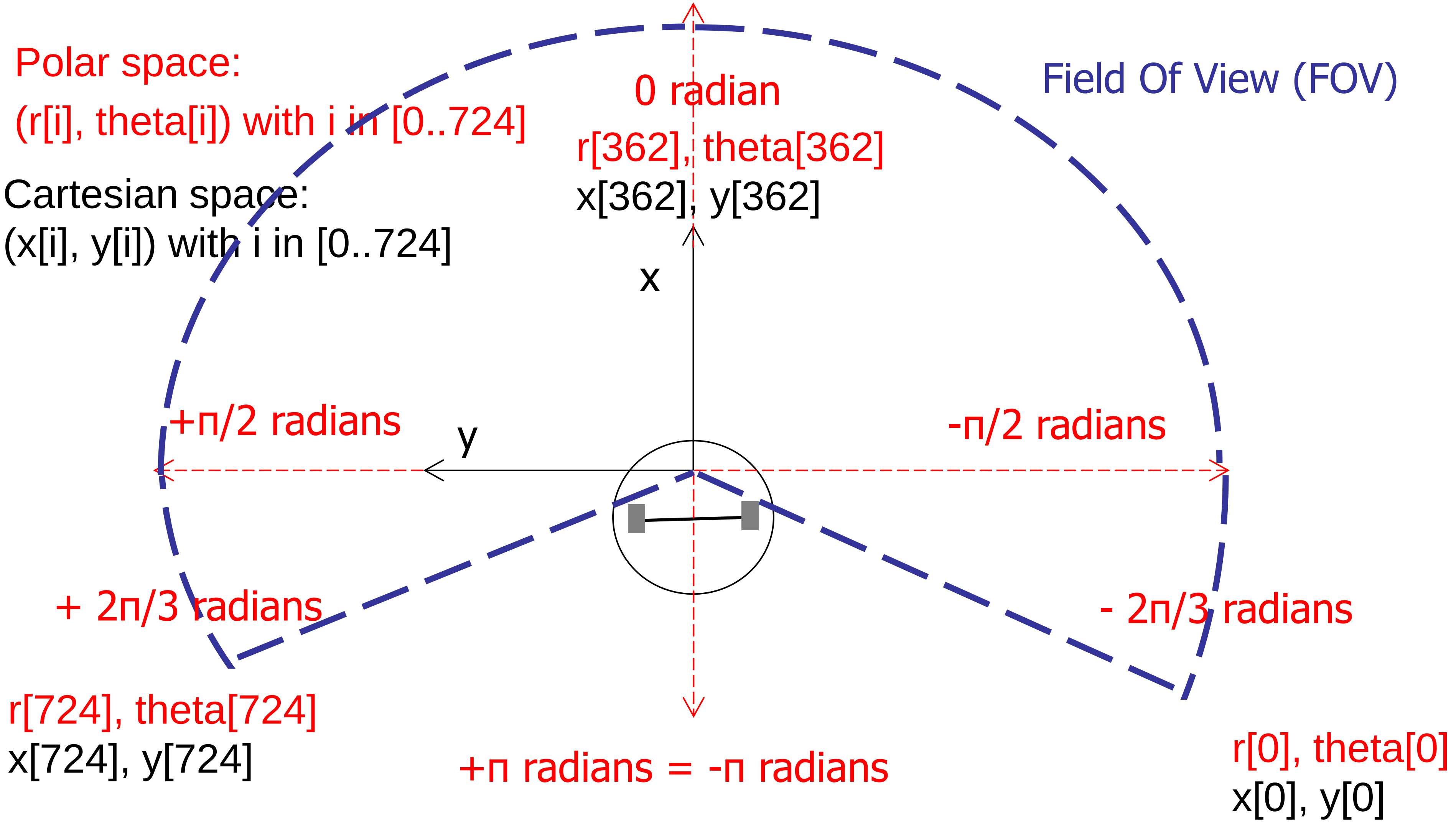
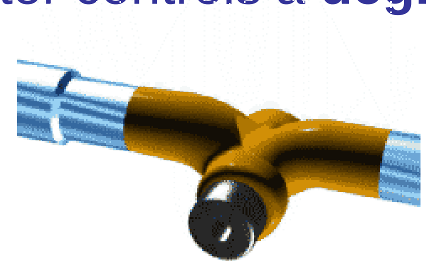
Sensor (3/3)

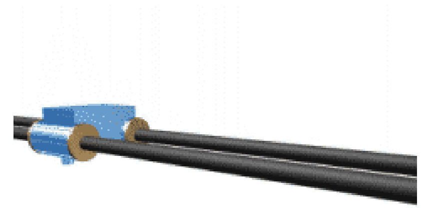


Polar space:
(r[i], theta[i]) with i in [0..724]
Cartesian space:
(x[i], y[i]) with i in [0..724]
0 radian
r[362], theta[362]
x[362], y[362]
Field Of View (FOV)
x
y
+π/2 radians
-π/2 radians
+ 2π/3 radians
- 2π/3 radians
r[724], theta[724]
x[724], y[724]
+π radians = -π radians
r[0], theta[0]
x[0], y[0]

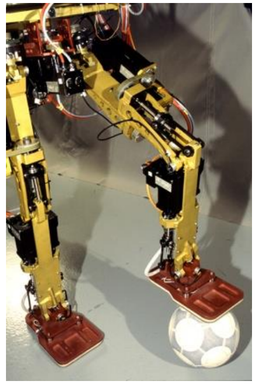
Actuators of a mobile robot

- An **actuator** is a component of a machine that is responsible for moving or controlling a mechanism or system;
- An actuator controls a **degree of freedom** (rotation, translation);





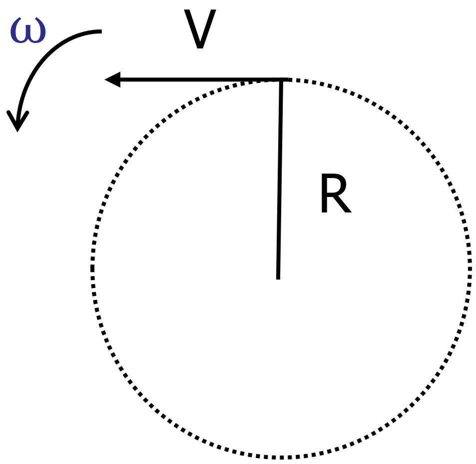
- Actuators could be complex.



Courtesy of Thierry Fraichard

Actuators of robair (1/3)

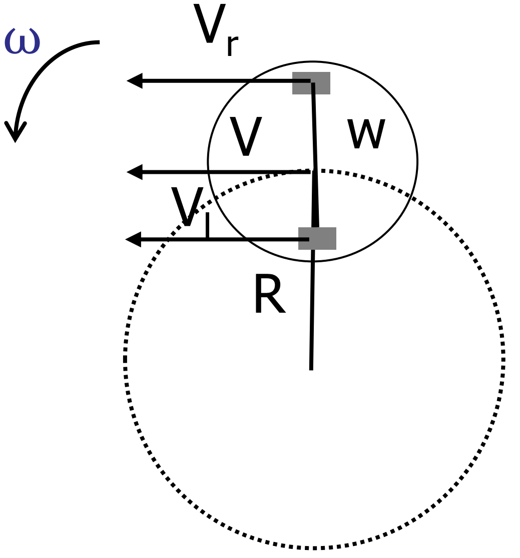
- **Robair** has 2 wheels controlled by 2 motors;
- Robair is a differential drive robot;
- Simplest and most used kinematic model of robot.



- **A monocycle** describes a virtual circle of radius R;
- We have $V = R\,\omega$

Actuators of robair (2/3)

- **Robair** has 2 wheels controlled by 2 motors;



- We have V = R ω
- We have $V_r = (R + w/2)\,\omega$
- We have $V_l = (R - w/2)\,\omega$

- We find:

$$R = \frac{W}{2}\frac{V_l + V_r}{V_r - V_l}$$

Actuators of robair (3/3)

- Finally, we have the direct kinematic model:

$$\omega = \frac{V_r - V_l}{w} \quad (1) \qquad V = \frac{V_l + V_r}{2} \quad (2)$$

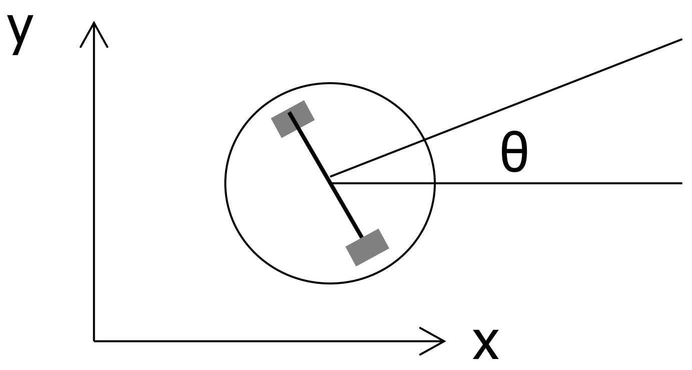
- Controlling (V_l, V_r), we can determine (V, ω)
- But it is easier and more intuitive to control (V, ω) and determine (V_l, V_r) (inverse kinematic model)

$$V_r = V + \frac{w}{2}\omega \qquad V_l = V - \frac{w}{2}\omega$$

- To simplify the control (at the beginning), we will perform translation OR rotation in place

Estimation of motion: encoder

- While Robair is moving in its environment, we would like to know its position in this environment;
- Its position is determined by its position (x, y) in the environment + its orientation θ: (x, y, θ)
- X-axis is aligned with the angle 0 of the laser



- On each wheel, there is a system (named encoder) able to estimate the distance traveled by each wheel over a short time Δt

Estimation of position: odometry (1/7)

- We call d_l and d_r the distance traveled by each wheel over Δt;

$$d = \frac{d_r + d_l}{2} \text{ using (2)} \qquad \theta = \frac{d_r - d_l}{w} \text{ using (1)}$$

- Where d is the distance traveled and θ is the angle traveled

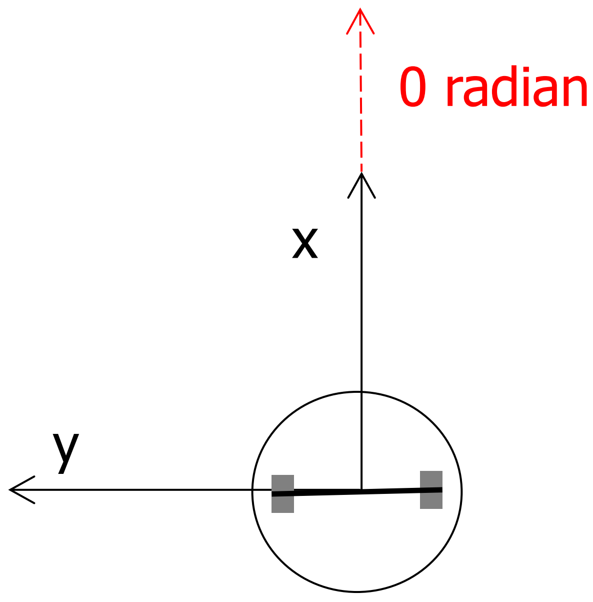
- $x_t = x_{t-1} + \mathrm{d}\cos(\theta)$
- $y_t = y_{t-1} + \mathrm{d}\sin(\theta)$
- $\theta_t = \theta_{t-1} + \theta$

- This is an estimation: with time the error associated to this estimation increases
  - ➢ Drift problem

Estimation of position: odometry (2/7)

- When we start robair, odometry is (x=0m, y=0m, θ=0radian)

1. If it translates from 1m, what is the position of robair ?



Estimation of position: odometry (3/7)

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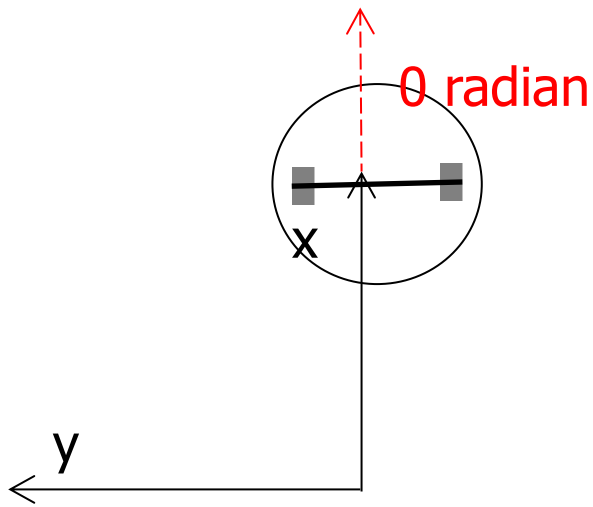
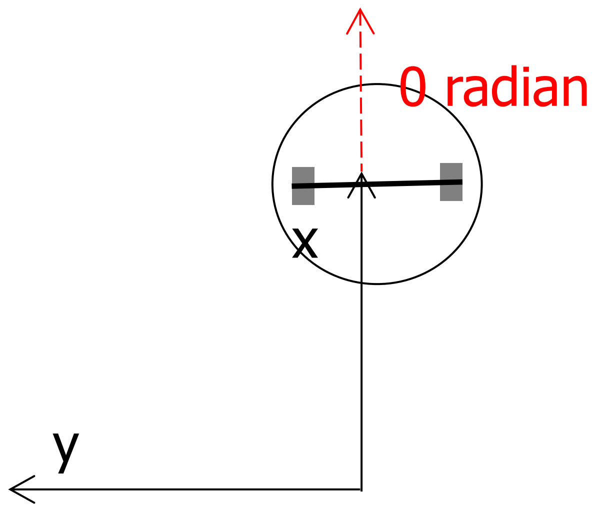


Estimation of position: odometry (4/7)

- When we start robair, odometry is (x=0m, y=0m, θ=0radian)

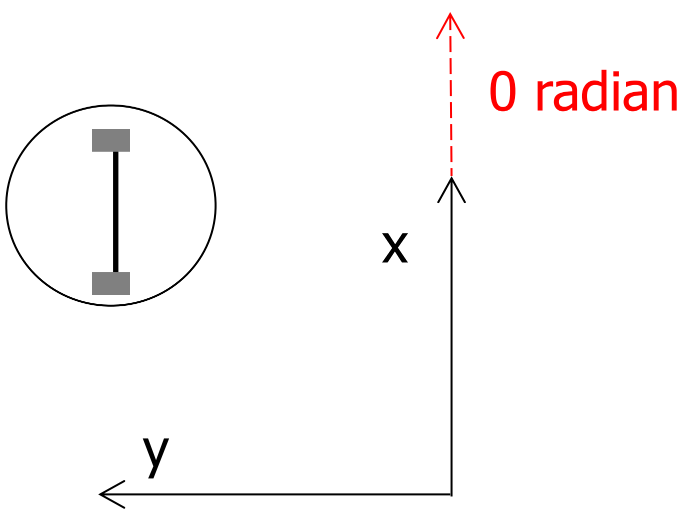
2. If it rotates from $\pi/2$ radians and translates of 1m, what is the position of robair ?



Estimation of position: odometry (5/7)

- When we start robair, odometry is (x=0m, y=0m, θ=0radian)

2. If it rotates from $\pi/2$ radians and translates of 1m, what is the position of robair ?
   - (x=1m, y=1m, θ= $\pi/2$ radian)



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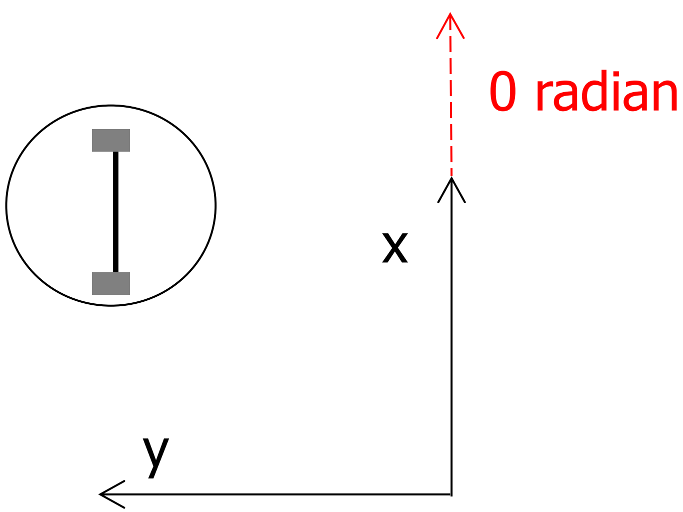
Estimation of position: odometry (6/7)

- When we start robair, odometry is (x=0m, y=0m, θ=0radian)

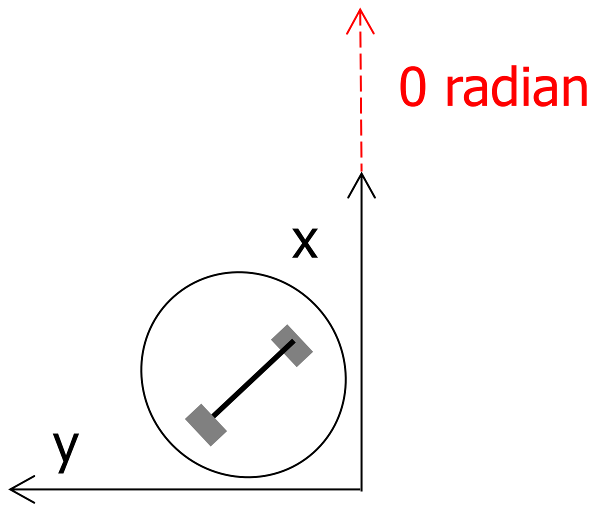
3. If it rotates from $-\pi/4$ radians and translates of -1m, what is the position of robair ?



Estimation of position: odometry (7/7)

- When we start robair, odometry is (x=0m, y=0m, θ=0radian)

3. If it rotates from -π/4 radians and translates of -1m, what is the position of robair ?
   - (x=1-(√2/2) m, y=1-(√2/2)m, θ= π/4 radian)



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Outline

1. Sensors and actuators
2. ROS
3. Perception
4. Decision
5. Action
6. Examples of applications
7. Conclusion

ROS in a nutshell

- **ROS (Robot Operating System)** is a middleware for controlling robotic components from a PC: robots.ros.org;
- ROS is open source and a standard for software architecture development in robotics;

- ROS is based on 2 important concepts:
  1. A number of independent nodes;
  2. Messages (or topics) that are published by some nodes and subscribed by some nodes;
     => Messages are used to exchange information between nodes;

ROS in a nutshell

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- ROS is based on 2 important concepts:
  1. A number of independent nodes;
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- Next slides introducing ROS are based on 89-685: Introduction to Robotics (biu.ac.il) (lecture 1, slide 8-11)

Robots using ROS

- http://wiki.ros.org/Robots

	Fraunhofer IPA Care-O-bot		Videre Erratic		TurtleBot
	Aldebaran Nao		Lego NXT		Shadow Hand
	Willow Garage PR2		iRobot Roomba		Robotnik Guardian
	Merlin miabotPro		AscTec Quadrotor		CoroWare Corobot
	Clearpath Robotics Husky		Clearpath Robotics Kingfisher		Festo Didactic Robotino

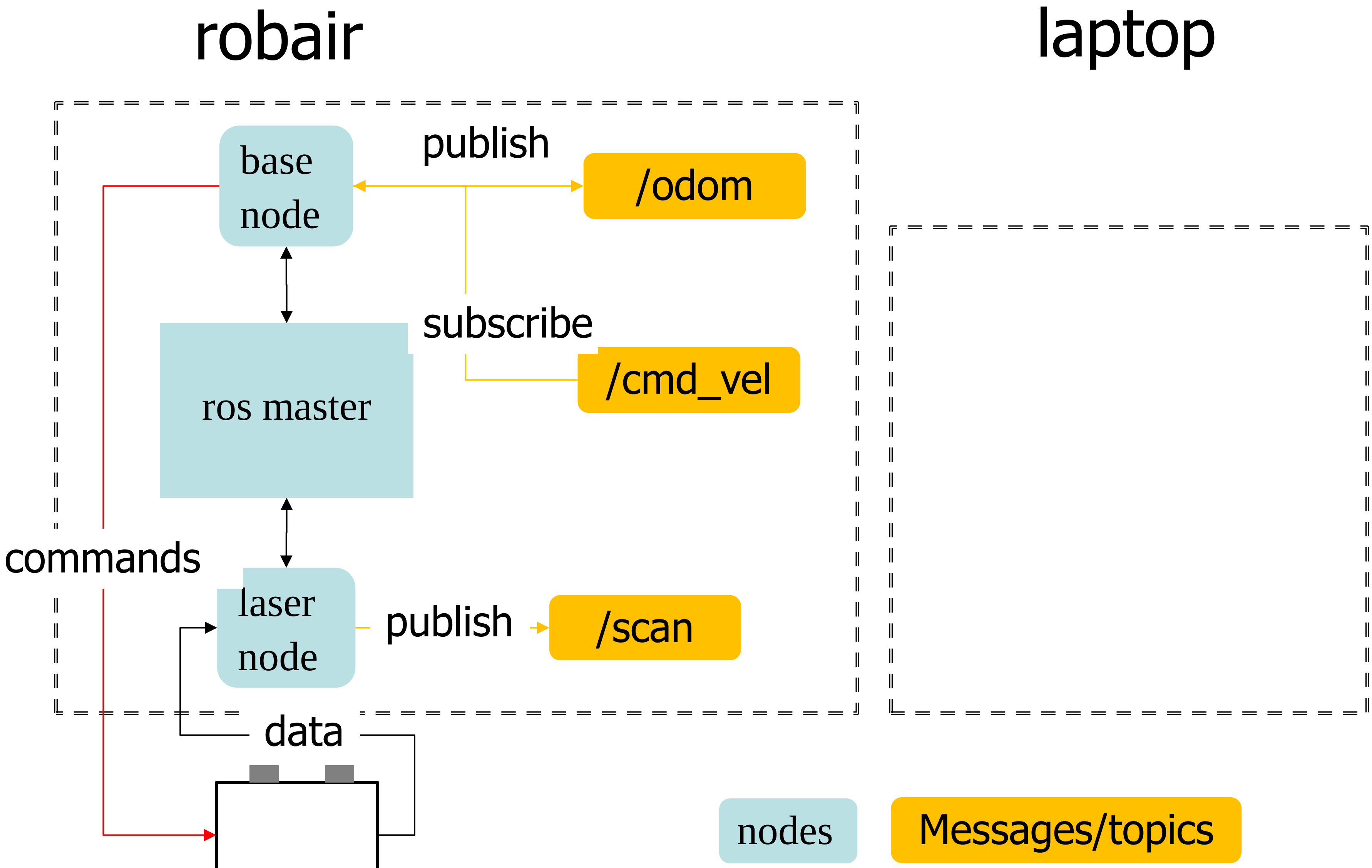
ROS nodes

- Single-purposed executable programs
  - e.g. sensor driver(s), actuator driver(s), mapper, planner, UI, etc.
- Individually compiled, executed, and managed
- Nodes are written using a ROS **client library**
  - C++ client library
  - python client library (not provided in this course)
- Nodes can publish or subscribe to a Topic

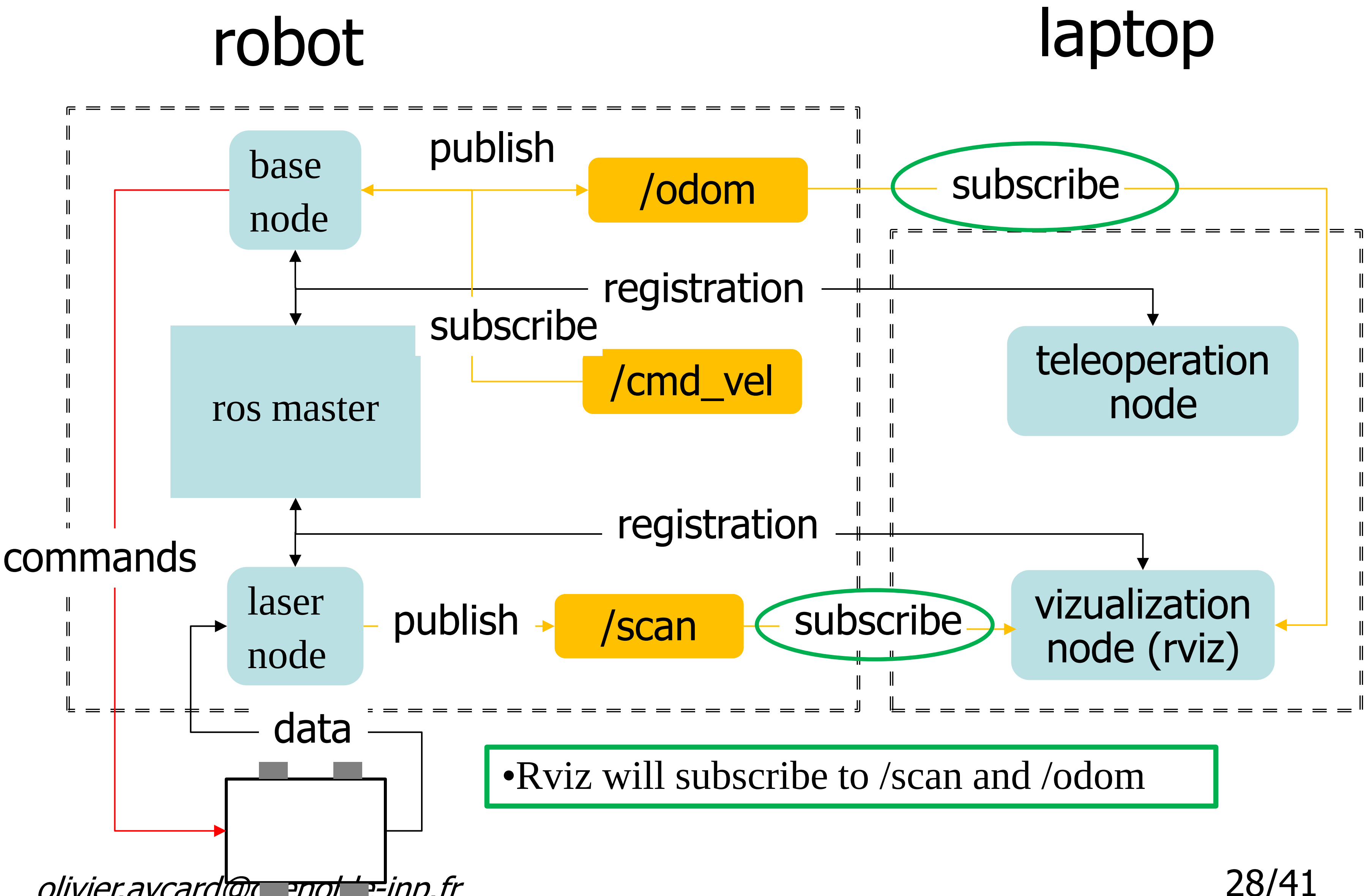
ROS topics

- A topic is a name for a stream of messages with a defined type
  - e.g., data from a laser range-finder might be sent on a topic called scan, with a message type of LaserScan
- Nodes communicate with each other by publishing messages to topics
- Publish/Subscribe model

ROS on robair(1/3)

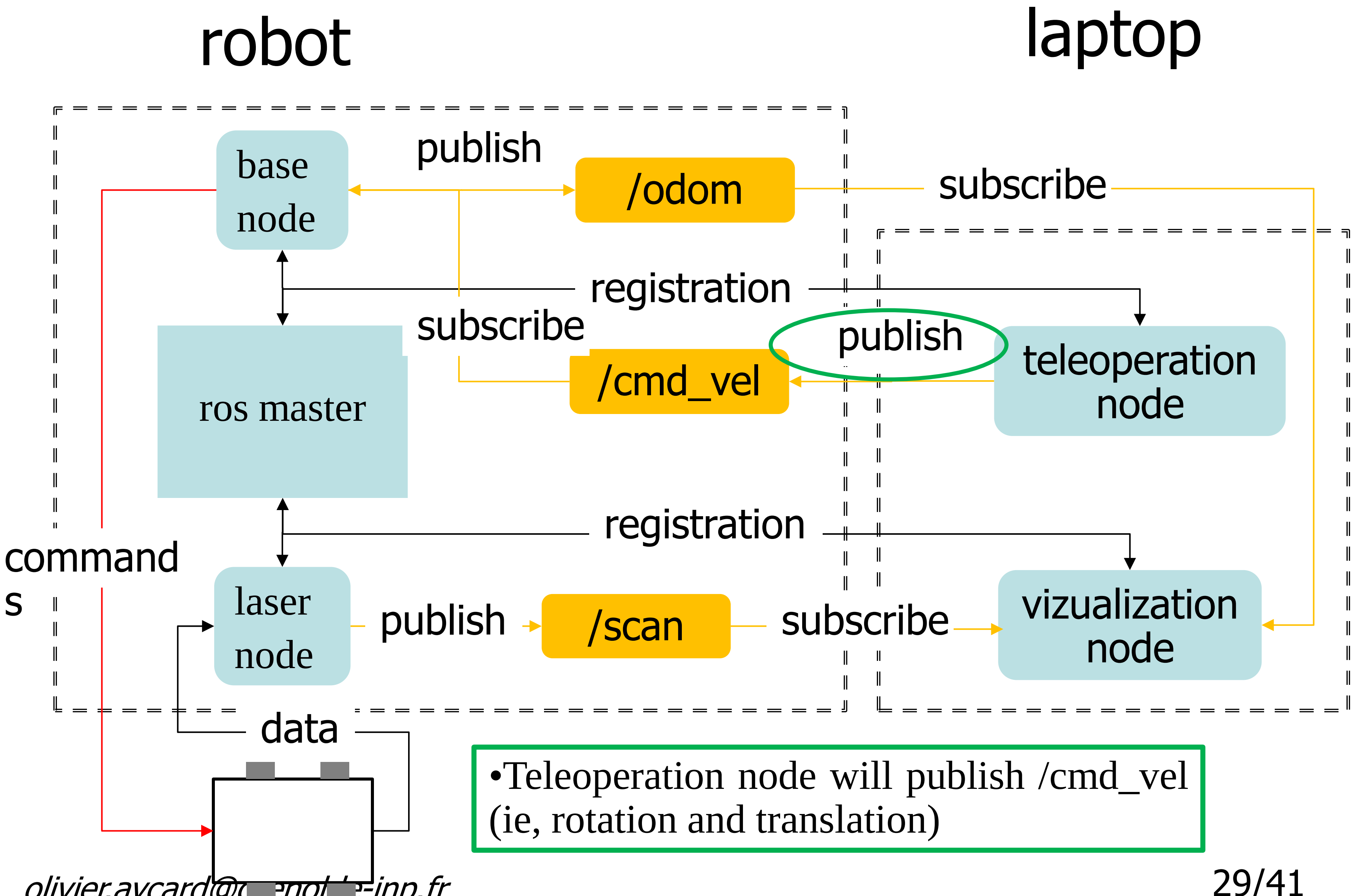


ROS on robair(2/3)



- Rviz will subscribe to /scan and /odom

ROS on robair(3/3)



•Teleoperation node will publish /cmd_vel (ie, rotation and translation)

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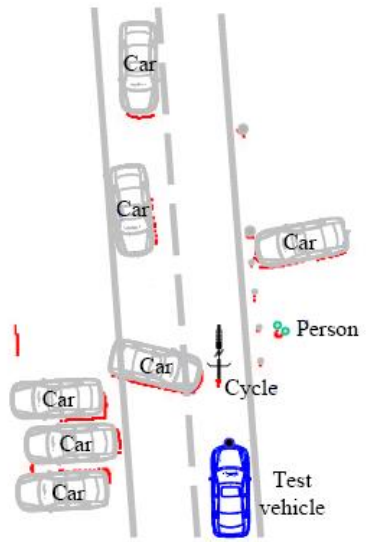
Perception

Goal

- Robot perception in dynamic environments
- **Laser scanner**
- Speed and robustness



Present Focus: interpretation of raw and noisy sensor data

- Identify static and dynamic part of sensor data
- Modeling dynamic part of the environment
  - Detection And Tracking of Moving Objects (DATMO)
- Modeling static part of the environment
  - Simultaneous Localization And Mapping (SLAM)

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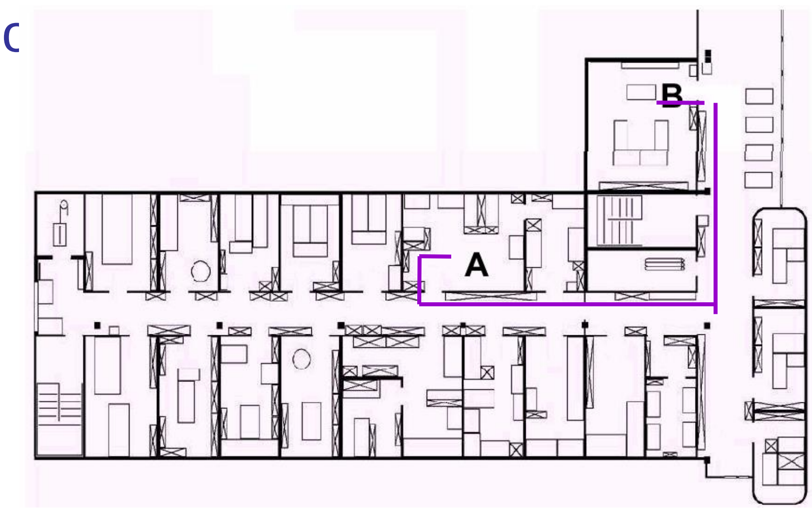
Decision/Plan of future actions

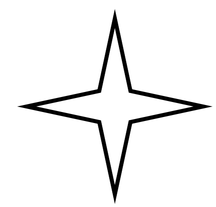
- Most of the time, a mobile robot has to move in its environment:
  - It needs to plan its future actions
- The mobile robot has a map and it knows where it is in the map

Only very basic aspects of decision will be used during projects

- Answer: sequence of actions to go from A to B that is feasible and without collisic



north



West, South, East (12 times), North (6 times), West (twice)

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Action/control/navigation

- The mobile robot has a sequence of actions to execute, to reach its goal: it has to execute this sequence of actions:
  - Typical action in our case: “move to (x, y)”;
  - Monitoring of execution: we monitor what happen and react if needed.
    - We need to be able to estimate actions/motions of the mobile robot;
  - Collision detection/avoidance: the mobile robot should be able to detect (and avoid) collision.

Examples of applications(1/3)

- Advanced driver assistant system (ADAS) or autonomous vehicles

Darpa Urban Challenge 2007

Google car 2010

IP Prevent 2008

Google car 2016

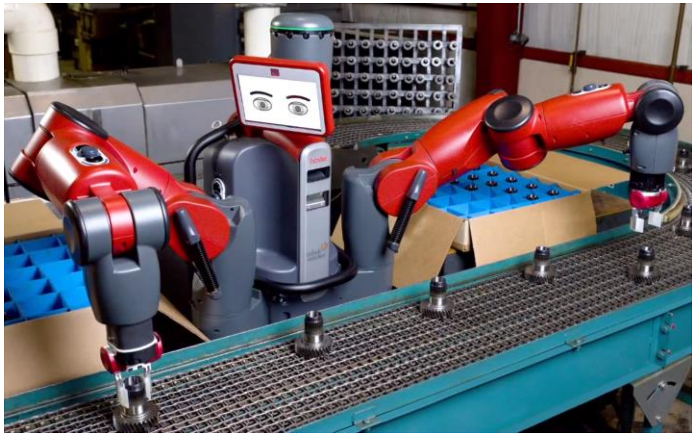
Examples of applications(2/3)

- Service robotics

Roomba

Robomow

Dyia One



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Examples of applications(3/3)

- Companion robots

Paro

Aibo

Buddy

Nao

Pepper

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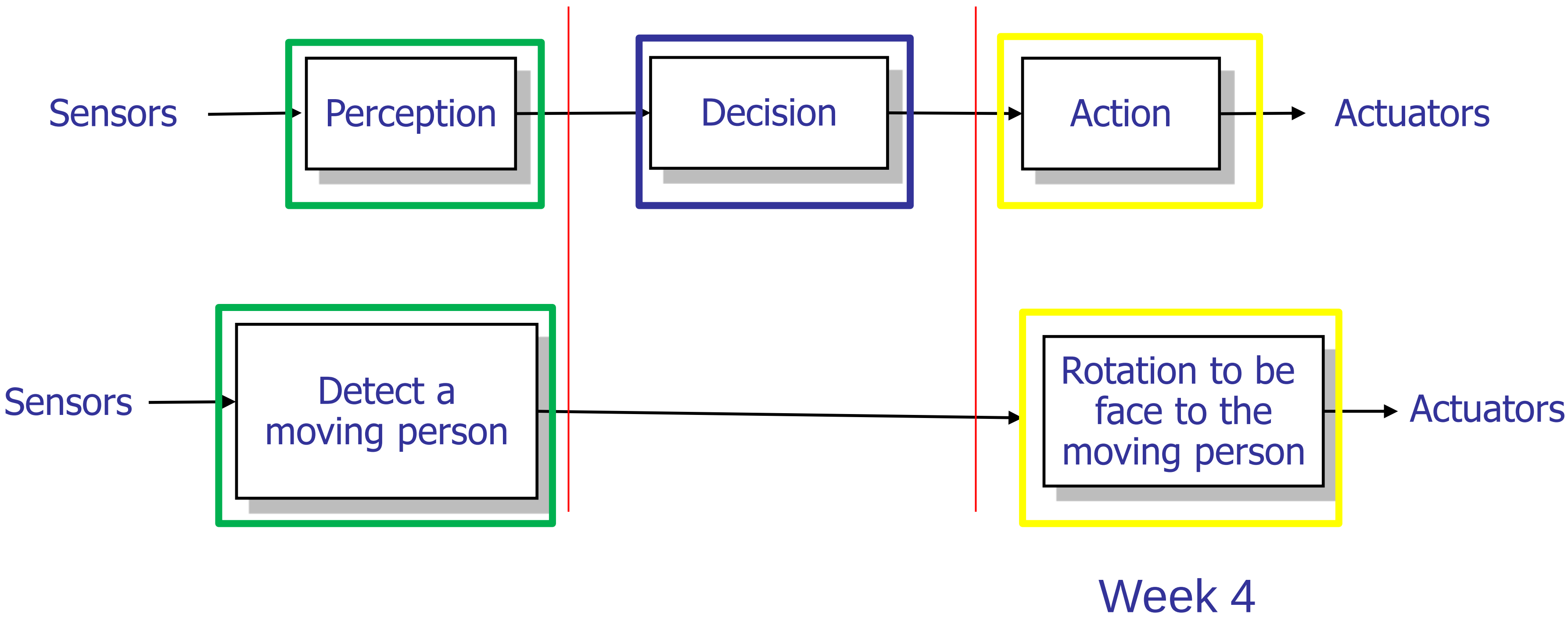
Conclusion

- A mobile robot is equipped with 2 kind of sensors:
  - **Exteroceptive sensors** that give information about the environment (ie, laser scanner);
  - **Proprioceptive sensors** that give information about the internal state of the robot (ie, odometer);
- A mobile robot is equipped with some actuators characterized by their degree of freedom;
  - Robair is a differential drive robot;
- Sensors and actuators are imprecise and limited;
- The environment of a robot is generally complex, changing, unpredictable and uncertain.

Follow me behavior (1/2)

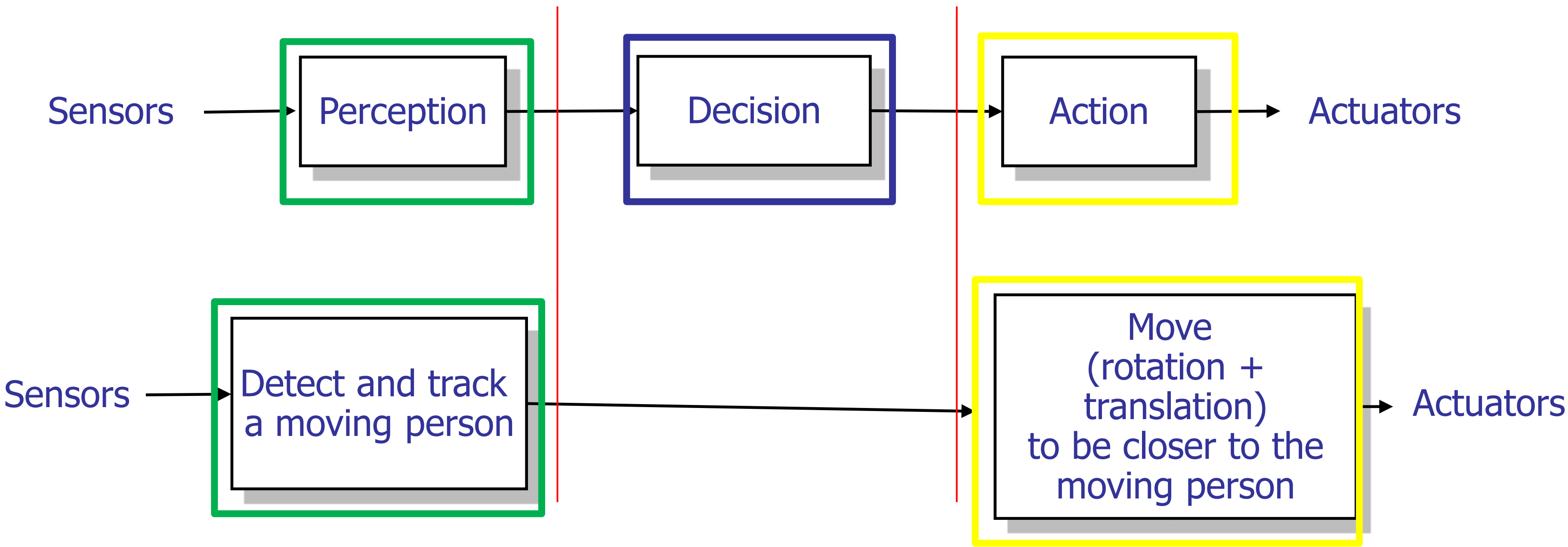
- We design, implement and test a simple “follow me” behavior in the next weeks in 2 steps



- 1st release of “follow me” behavior

Follow me behavior (2/2)

- We design, implement and test a simple “follow me” behavior in the next weeks in 2 steps



- 2nd release of “follow me” behavior