Introduction to Perception

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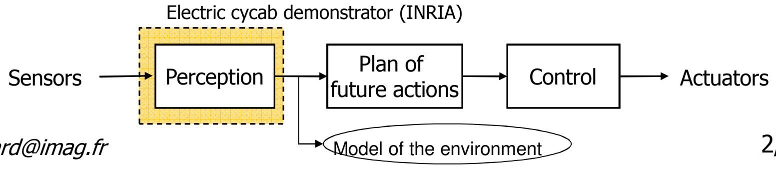
Introduction

What is an Intelligent Vehicle ?

- An Intelligent Vehicle is a vehicle designed to:
  - monitor a human driver and assist him in driving;
  - drive automatically.
- To solve these tasks, an intelligent vehicle is equipped with sensors to perceive its surrouding environment and with actuators to act in its environment.

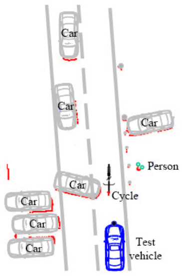
Electric cycab demonstrator (INRIA)



Introduction

Goal

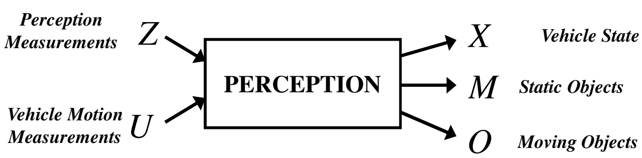
- Vehicle perception in open and dynamic environments
- **Laser scanner**
- Speed and robustness



Present Focus: interpretation of raw and noisy sensor data

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

Problem statement



Static environments | Dynamic environments

SLAM → **SLAM + Moving object detection** → **SLAM + DATMO**

$P(X,M \mid Z,U)$

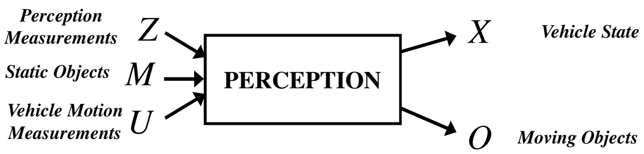
$$\begin{cases} Z = Z^{(s)} + Z^{(d)} \\ P(X,M \mid Z^{(s)},U) \end{cases}$$

$P(X,M,O \mid Z,U)$

$$\begin{cases} P(X,M \mid Z^{(s)},U) \\ P(O \mid Z^{(d)}) \end{cases}$$

Problem statement

If the map is known: a localization problem



Static environments — Dynamic environments

LOCALIZATION → **LOCALIZATION + Moving object detection** → **LOCALIZATION + DATMO**

$P(X \mid Z, U, M)$

$$\begin{cases} Z = Z^{(s)} + Z^{(d)} \\ P(X \mid Z^{(s)}, U, M) \end{cases}$$

$P(X, O \mid Z, U, M)$

$$\begin{cases} P(X \mid Z^{(s)}, U, M) \\ P(O \mid Z^{(d)}) \end{cases}$$

The 2 main perception problems

Localization problem: we want to find the position/state of a mobile robot in its environment

- A map of the environment is given
- The mobile robot moves in its environment
- The mobile robot perceives its environment

$$P(X \mid Z^{(s)}, U, M)$$

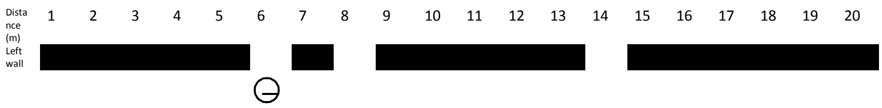
Tracking problem: we want to find the position/state of a moving object (or several moving objects) in its environment

- A map of the environment is not needed
- We estimate the motion of the moving objects
- We perceive the moving objects

$$P(O \mid Z^{(d)}) \\ = P(O \mid Z^{(d)}, (U), M)$$

Very similar practical problems
Similar theoretical problems
=> same tool/technique to solve them: Bayesian filters

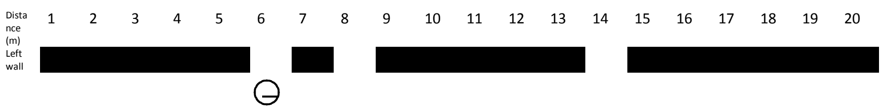
The localization problem



- Initial position perfectly known, motions are perfect

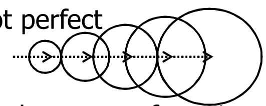
$P(S_0 = 6) = 1$
$P(S_1 = 7) = 1$
$P(S_2 = 8) = 1$
$P(S_3 = 9) = 1$
$P(S_4 = 10) = 1$
$P(S_5 = 11) = 1$

The localization problem



$P(S_0 = 6) = 1$

- But motions are not perfect



The robot is lost !!!

- When the mobile robot moves from 1 meter, the mobile robot is located:
  - 1 meter further with a probability of 80%
  - at the same location with a probability of 10%
  - 2 meters further with a probability of 10%

$P(S_1 = 6 \mid A_1 = 1) = 0.1$
$P(S_1 = 7 \mid A_1 = 1) = 0.8$
$P(S_1 = 8 \mid A_1 = 1) = 0.1$

The localization problem

- After two actions:

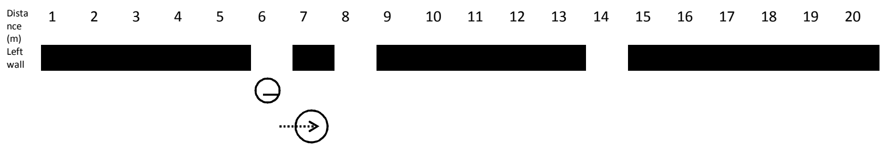
$P(S_2 = 6 \mid A_1 = 1, A_2 = 1) = 0.1 \times 0.1 = 0.01$
$P(S_2 = 7 \mid A_1 = 1, A_2 = 1) = 0.1 \times 0.8 + 0.8 \times 0.1 = 0.16$
$P(S_2 = 8 \mid A_1 = 1, A_2 = 1) = 0.1 \times 0.1 + 0.8 \times 0.8 + 0.1 \times 0.1 = 0.66$
$P(S_2 = 9 \mid A_1 = 1, A_2 = 1) = 0.8 \times 0.1 + 0.1 \times 0.8 = 0.16$
$P(S_2 = 10 \mid A_1 = 1, A_2 = 1) = 0.1 \times 0.1 = 0.01$

- After three actions:

$P(S_3 = 6 \mid A_1 = 1, A_2 = 1, A_3 = 1) = 0.01 \times 0.1 = 0.001$
$P(S_3 = 7 \mid A_1 = 1, A_2 = 1, A_3 = 1) = 0.01 \times 0.8 + 0.16 \times 0.1 = 0.024$
$P(S_3 = 8 \mid A_1 = 1, A_2 = 1, A_3 = 1) = 0.01 \times 0.1 + 0.16 \times 0.8 + 0.66 \times 0.1 = 0.195$
$P(S_3 = 9 \mid A_1 = 1, A_2 = 1, A_3 = 1) = 0.16 \times 0.1 + 0.66 \times 0.8 + 0.16 \times 0.1 = 0.56$
$P(S_3 = 10 \mid A_1 = 1, A_2 = 1, A_3 = 1) = 0.66 \times 0.1 + 0.16 \times 0.8 + 0.01 \times 0.1 = 0.195$
$P(S_3 = 11 \mid A_1 = 1, A_2 = 1, A_3 = 1) = 0.16 \times 0.01 + 0.01 \times 0.8 = 0.024$
$P(S_3 = 12 \mid A_1 = 1, A_2 = 1, A_3 = 1) = 0.01 \times 0.1 = 0.001$

- The robot is getting lost and lost…

The localization problem



$P(S_1 = 6 \mid A_1 = 1) = 0.1$
$P(S_1 = 7 \mid A_1 = 1) = 0.8$
$P(S_1 = 8 \mid A_1 = 1) = 0.1$

- The mobile robot is equipped with sensors
- If sensors are perfect:
  - when the robot is in front of a wall, it will perceive a wall;
  - when the robot is in front of a door, it will perceive a door.
- Suppose that after its first action ($A_1 = 1$), it perceives a wall ($O_1 = w$):

$P(S_1 = 6 \mid A_1 = 1, O_1 = w) = 0.1 \times 0 = 0$
$P(S_1 = 7 \mid A_1 = 1, O_1 = w) = 0.8 \times 1 = 1$
$P(S_1 = 8 \mid A_1 = 1, O_1 = w) = 0.1 \times 0 = 0$

The localization problem

$P(S_1 = 7 \mid A_1 = 1, O_1 = w) = 1$

- The robot moves again from 1 meter:

$P(S_2 = 7 \mid A_1 = 1, O_1 = w, A_2 = 1) = 0.1$
$P(S_2 = 8 \mid A_1 = 1, O_1 = w, A_2 = 1) = 0.8$
$P(S_2 = 9 \mid A_1 = 1, O_1 = w, A_2 = 1) = 0.1$

- Suppose that after its second action ($A_2 = 1$), it perceives a wall ($O_2 = w$):

$P(S_2 = 7 \mid A_1 = 1, O_1 = w, A_2 = 1, O_2 = w) = 0.1 \times 1 = 0.5$
$P(S_2 = 8 \mid A_1 = 1, O_1 = w, A_2 = 1, O_2 = w) = 0.8 \times 0 = 0$
$P(S_2 = 9 \mid A_1 = 1, O_1 = w, A_2 = 1, O_2 = w) = 0.1 \times 1 = 0.5$

- Observations are used to correct actions

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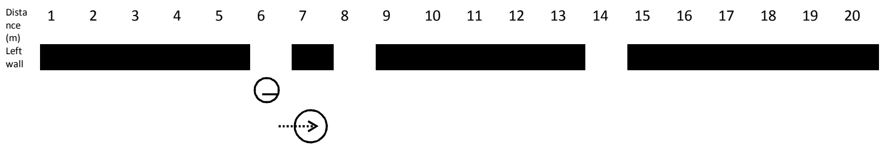
The localization problem



- But the sensors are not perfect
- When the mobile robot is located in front of a door, it perceives:
  - a door with a probability of 80%
  - a wall with a probability of 20%
- When the mobile robot is located in front of a wall, it perceives:
  - a wall with a probability of 90%
  - a door with a probability of 10%

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The localization problem

$P(S_1 = 6 \mid A_1 = 1) = 0.1$
$P(S_1 = 7 \mid A_1 = 1) = 0.8$
$P(S_1 = 8 \mid A_1 = 1) = 0.1$

- Suppose that after its first action ($A_1 = 1$), it perceives a wall ($O_1 = w$):

$P(S_1 = 6 \mid A_1 = 1, O_1 = w) = 0.1 \times 0.2 = 0.02 = 1/38$
$P(S_1 = 7 \mid A_1 = 1, O_1 = w) = 0.8 \times 0.9 = 0.72 = 18/19$
$P(S_1 = 8 \mid A_1 = 1, O_1 = w) = 0.1 \times 0.2 = 0.02 = 1/38$

The localization problem

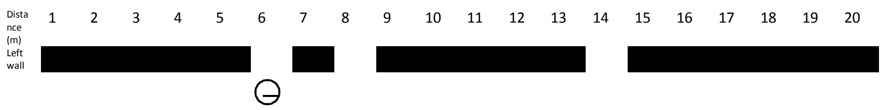
- After two actions:

$P(S_2 = 6 \mid A_1 = 1, O_1 = w, A_2 = 1) = 0.03 \times 0.1 = 0.003$
$P(S_2 = 7 \mid A_1 = 1, O_1 = w, A_2 = 1) = 0.03 \times 0.8 + 0.94 \times 0.1 = 0.118$
$P(S_2 = 8 \mid A_1 = 1, O_1 = w, A_2 = 1) = 0.03 \times 0.1 + 0.94 \times 0.8 + 0.03 \times 0.1 = 0.758$
$P(S_2 = 9 \mid A_1 = 1, O_1 = w, A_2 = 1) = 0.94 \times 0.1 + 0.03 \times 0.8 = 0.118$
$P(S_2 = 10 \mid A_1 = 1, O_1 = w, A_2 = 1) = 0.03 \times 0.1 = 0.003$

- Suppose that after its second action ($A_2 = 1$), it perceives a wall ($O_2 = w$):

$P(S_2 = 6 \mid A_1 = 1, O_1 = w, A_2 = 1, O_2 = w) = 0.003 \times 0.2 = 0.01$
$P(S_2 = 7 \mid A_1 = 1, O_1 = w, A_2 = 1, O_2 = w) = 0.118 \times 0.9 = 0.29$
$P(S_2 = 8 \mid A_1 = 1, O_1 = w, A_2 = 1, O_2 = w) = 0.758 \times 0.2 = 0.4$
$P(S_2 = 9 \mid A_1 = 1, O_1 = w, A_2 = 1, O_2 = w) = 0.118 \times 0.9 = 0.29$
$P(S_2 = 10 \mid A_1 = 1, O_1 = w, A_2 = 1, O_2 = w) = 0.003 \times 0.9 = 0.01$

The localization problem



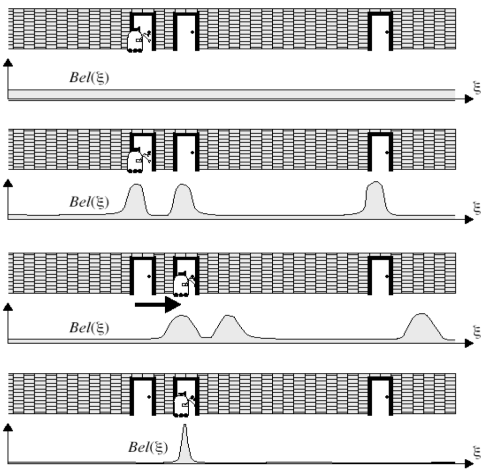
- If the initial position is unknown:

$P(S_0 = i) = 0.05$ for $i = 1$ to 20

- The mobile robot will make an observation before moving, it perceives a door ($O_0 = d$):

$P(S_0 = i \mid O_0 = d) = 0.05 \times 0.8 = 0.19$ for $i = 6, 8$ or 14
$P(S_0 = i \mid O_0 = d) = 0.05 \times 0.1 = 0.025$ for $i \neq 6, 8$ or 14

The localization problem



•[Fox'98]

The localization problem

Initialization:

$P(S_0|O_0)=\frac{1}{Z}P(S_0)\times P(O_0|S_0)$

Input: $P(S_{T-1}|O_{0:T-1},A_{1:T-1})$ (previous probability distribution), A_T, O_T

for all $s\in S_T$

$P(S_T=s|O_{0:T-1},A_{1:T})=\sum_{S_{T-1}} P(S_T=s|S_{T-1},A_T)\times P(S_{T-1}|O_{0:T-1},A_{1:T-1})$ (prediction)

for all $s\in S_T$

$P(S_T=s|O_{0:T},A_{1:T})=\alpha' P(O_T|S_T=s)\times P(S_T=s|O_{0:T-1},A_{1:T})$ (estimation : confrontation prediction - observation)

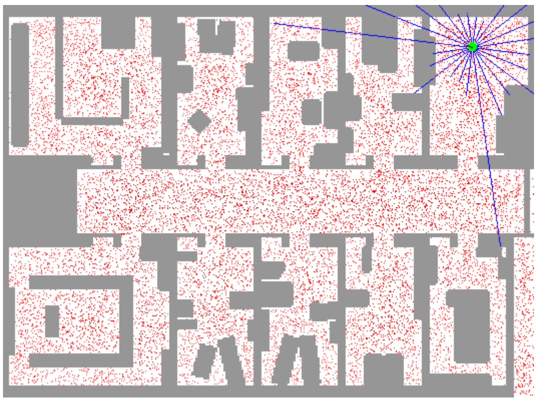
Endfor

return $P(S_T|O_{0:T},A_{1:T})$

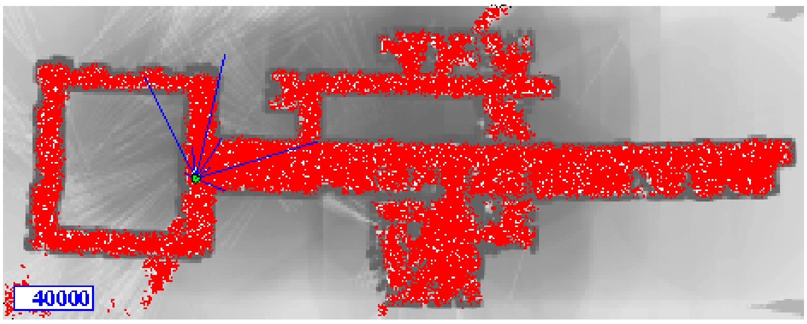
$P(S_T=s|S_{T-1},A_T)$ is known as the dynamic model and model the uncertainty associated with actions.

$P(O_T|S_T)$ is known as the sensor model and model the uncertainty associated with sensors.

Initial position unknown: ultrasonic sensor[Fox'98]



Initial position unknown: ultrasonic sensor[Fox'98]



Initial position unknown: laser sensor[Fox'98]