Robot Autonomy

Dealing with Unknown Environments

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Unknown Environment

- What is a robot environment?

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- What do we mean by *unknown environment*?

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- What do we mean by *unknown environment*?

- Are unknown environments structured or unstructured?

What is robot mapping?

- Robot – moves through the environment collecting observations

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What is robot mapping?

- Robot – moves through the environment collecting observations
- Sensors – LiDARs, RGB-D Cameras
- Observations – Laser Scans, RGB and Depth Images, Point Clouds
- Mapping – using the collected data to model the environment

Related Terms

State Estimation	Localization
Mapping	SLAM
Navigation	Motion Planning

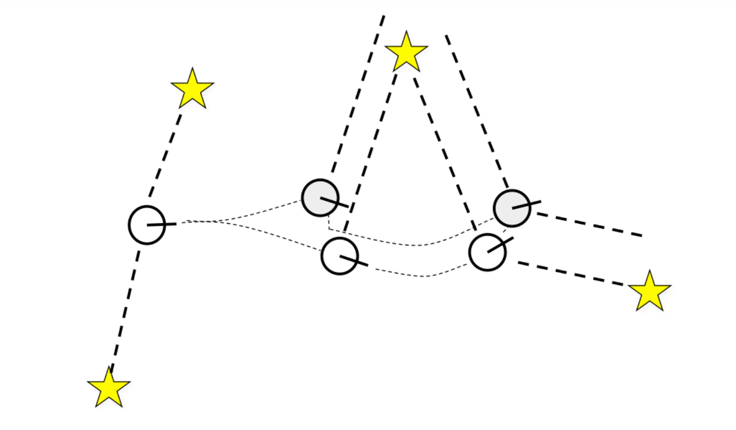
What is slam?

- Computing the robot state (i.e. its pose) and the environment map at the same time

- **Localization:** estimate the robot state (i.e. its location)
- **Mapping:** building the map
- **SLAM:** building the map and localizing the robot simultaneously

Localization Example

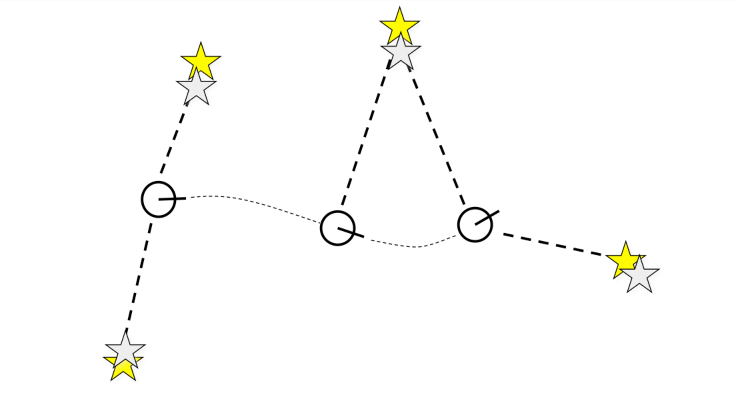
- Estimate robot's poses given landmarks



Images taken from Robot Mapping Course [2] by Cyrill Stachniss

Mapping Example

- Estimate landmarks given robot the robot poses



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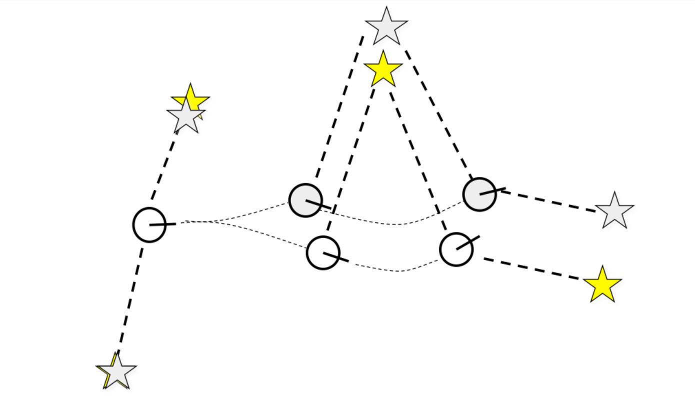
SLAM Example

- Estimate robot's poses and the landmarks at the same time



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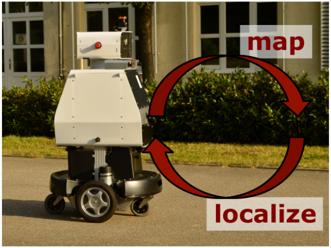
The SLAM Problem

Chicken-or-egg problem:

- a map is needed for localization
- a pose estimate is needed for mapping



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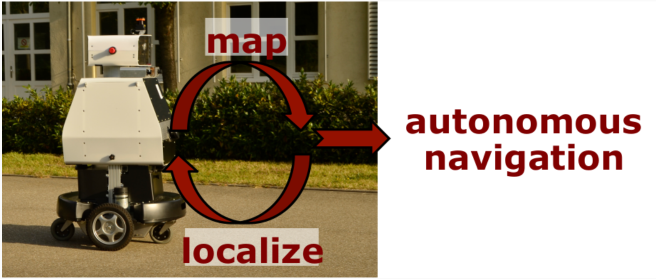
The SLAM Problem

- It's a fundamental problem for truly autonomous robots
- Basis for most navigation systems



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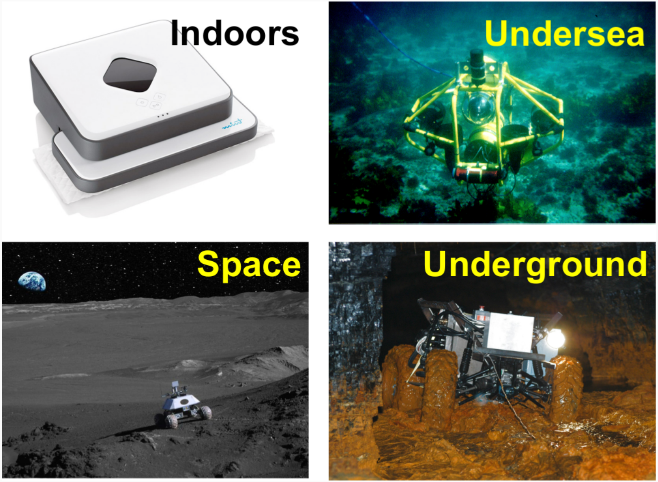
SLAM Applications

- SLAM is central to a range of indoor, outdoor, air, underwater and space applications for both manned and autonomous vehicles

  Examples:

  - At home: vacum cleaner, lawn mower
  - Air: surveillance with unmanned vechiles
  - Underwater: reef monitoring
  - Underground: exploration of mines
  - Space: terrain mapping for localization

SLAM Applications



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SLAM Applications

SLAM Problem Definition

Given

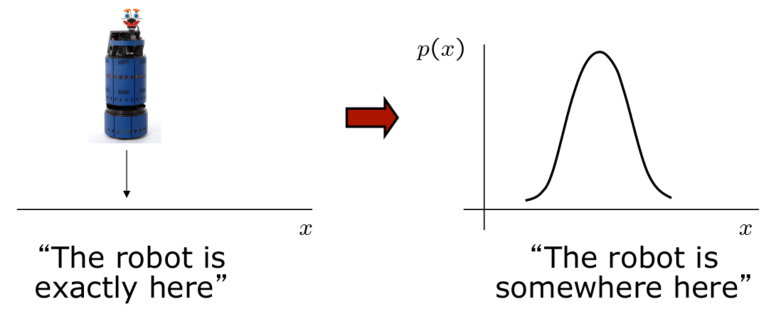
- The robot controls (i.e. commands):
  $u_{0:T} = \{u_0, u_1, u_2, \ldots, u_T\}$
- Observations:
  $z_{0:T} = \{z_0, z_1, x_2, \ldots, z_T\}$

Wanted

- Map of the environment:
  m
- Path of the robot:
  $x_{0:T} = \{x_0, x_1, x_2, \ldots, x_T\}$

SLAM Probabilistic Approach

- Uncertainty is present in both robot motion and observation
- Use probability theory to explicitly represent uncertainty



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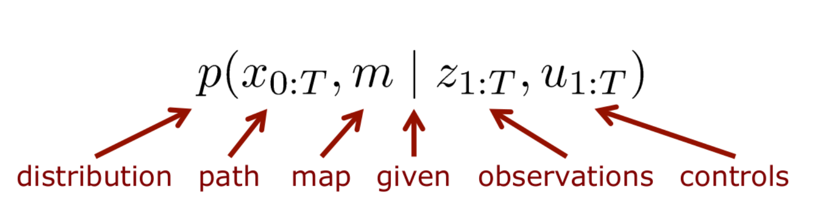
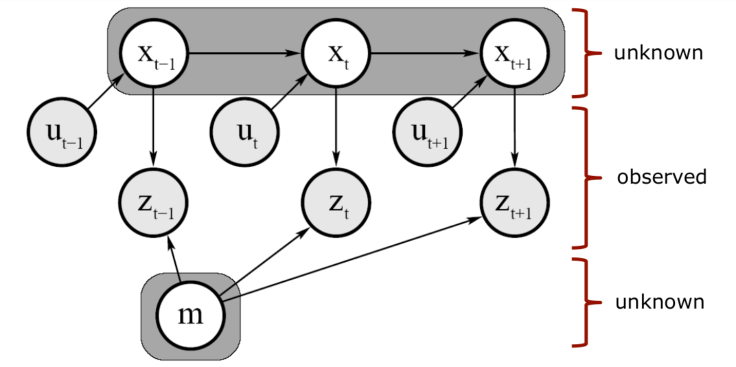
SLAM in the Probabilistic World

Estimate the robot's path and the map

$$p(x_{0:T}, m \mid z_{1:T}, u_{1:T})$$



Full SLAM Graphical Model



$$p(x_{0:T}, m \mid z_{1:T}, u_{1:T})$$

Full vs. Online SLAM

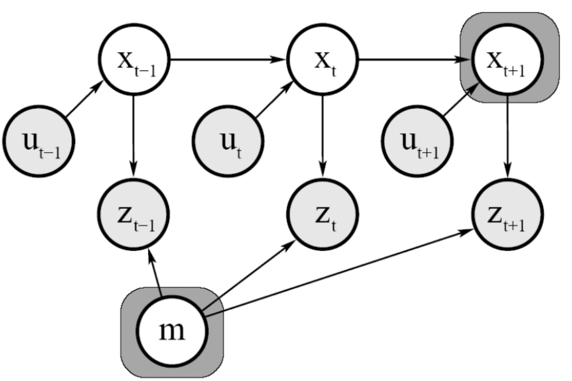
- Full SLAM estimates the entire path

$$p(x_{0:T}, m \mid z_{1:T}, u_{1:T})$$

- Online SLAM seeks to recover only the most recent pose

$$p(x_t, m \mid z_{1:t}, u_{1:t})$$

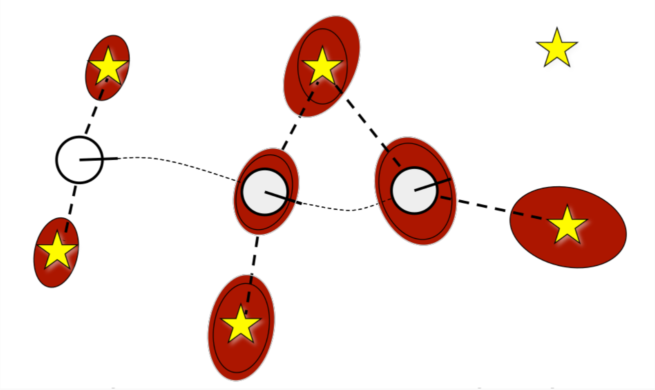
Oline SLAM Graphical Model



$$p(x_{t+1}, m \mid z_{1:t+1}, u_{1:t+1})$$

Why is SLAM a Hard Problem?

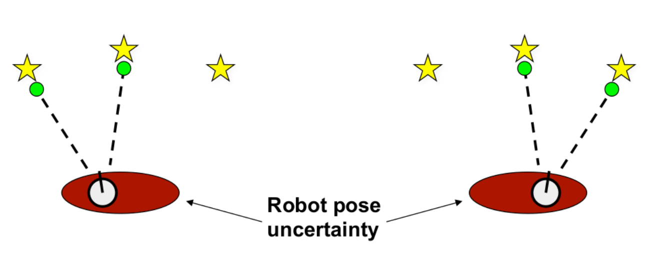
- Robot path and map are both unknown



- Map and pose estimates are correlated

Why is SLAM a Hard Problem?

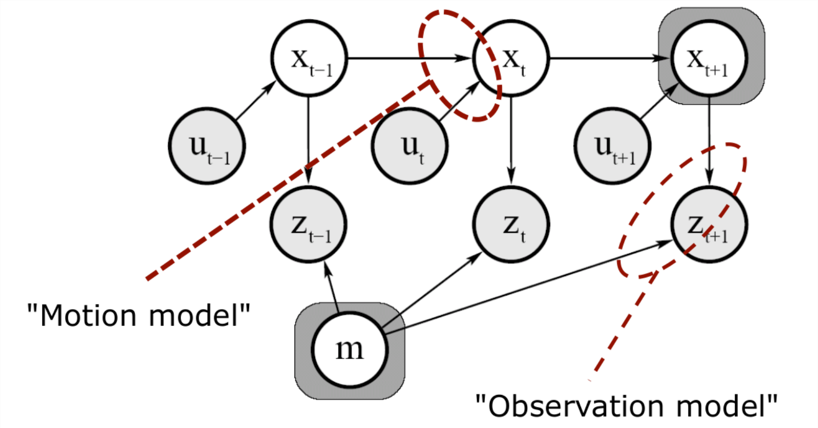
- The **correspondence between the observations and the map is unknown**
- Selecting wrong data associations leads to catastrophic divergence



Main SLAM Approaches

- Kalman Filters
- Particle Filters
- Graph-based (Smoothing)

Motion & Observation Model



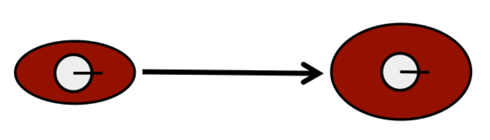
Motion Model

- Describes the relative motion of the robot

$$p(x_t \mid x_{t-1}, u_t)$$

Motion Model Examples

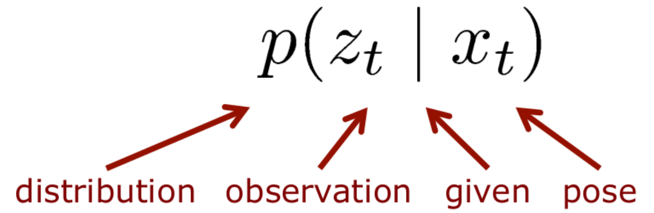
- Gaussian model



- Non-Gaussian model

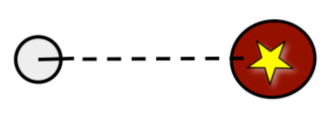
Observation Model

- Relates measurements with the robot's pose
- It is also called the sensor model

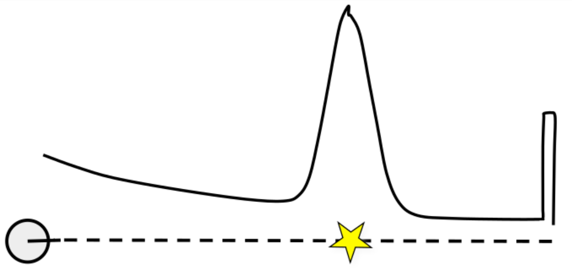


Observation Model Examples

- Gaussian model



- Non-Gaussian model



Summary

- Mapping is the task of modeling the environment
- Localization means estimating the robot pose
- SLAM stands for Simultaneous localization and mapping
- Full SLAM vs. Online SLAM
- Explicitly model uncertainty in both motion and observations
- More Information in Literature: [1, 3, 2]

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