

Probability Review

Robot Localization and Mapping 16-833

Michael Kaess

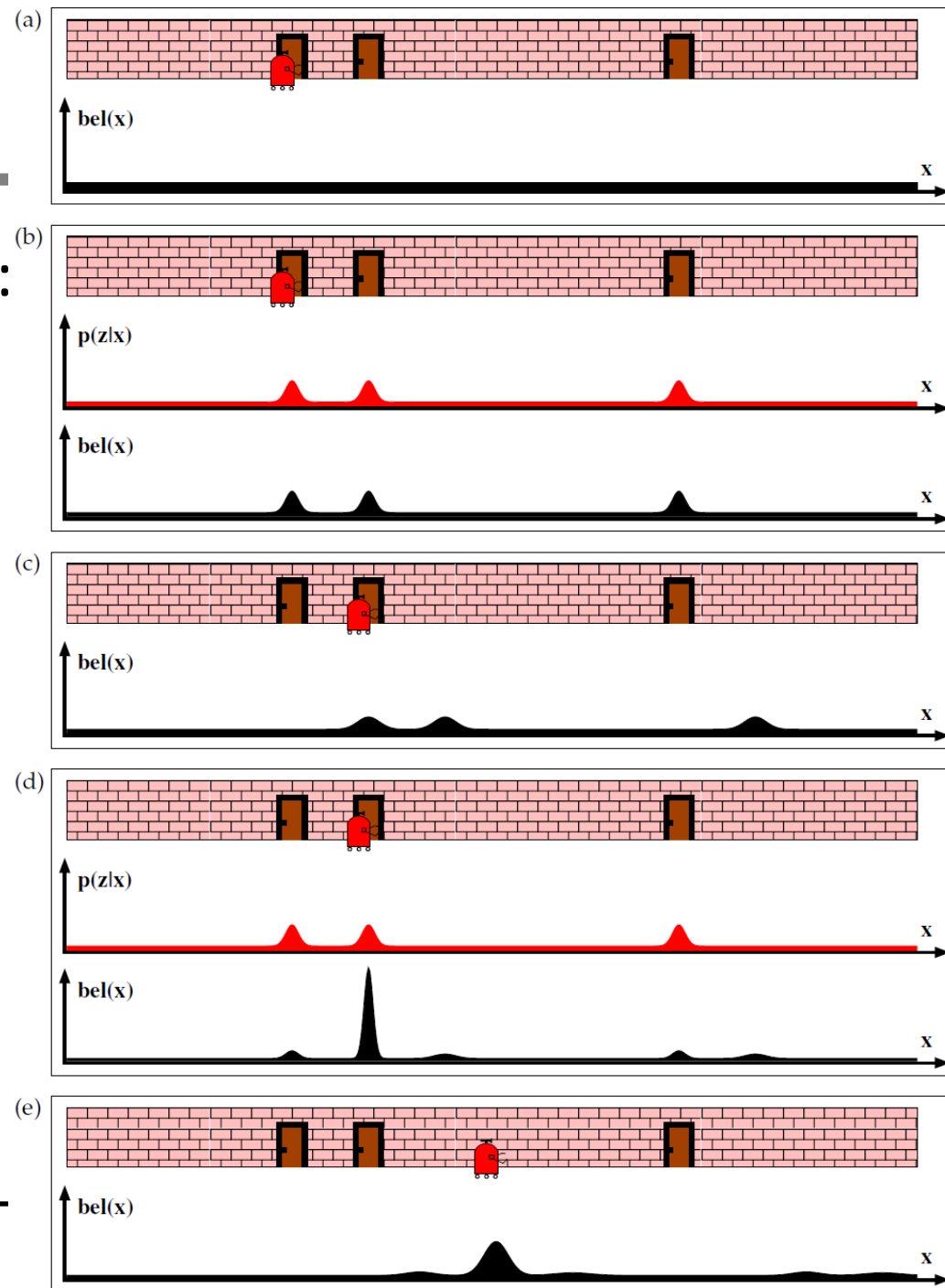
August 28, 2024

Slides based on probabilistic-robotics.org

Why Probabilities?

- Global localization example:
- 1D world
- Map is known
- Sensors:
 - Door detector
 - Wheel odometry

Thrun, Burgard, Fox, 2005



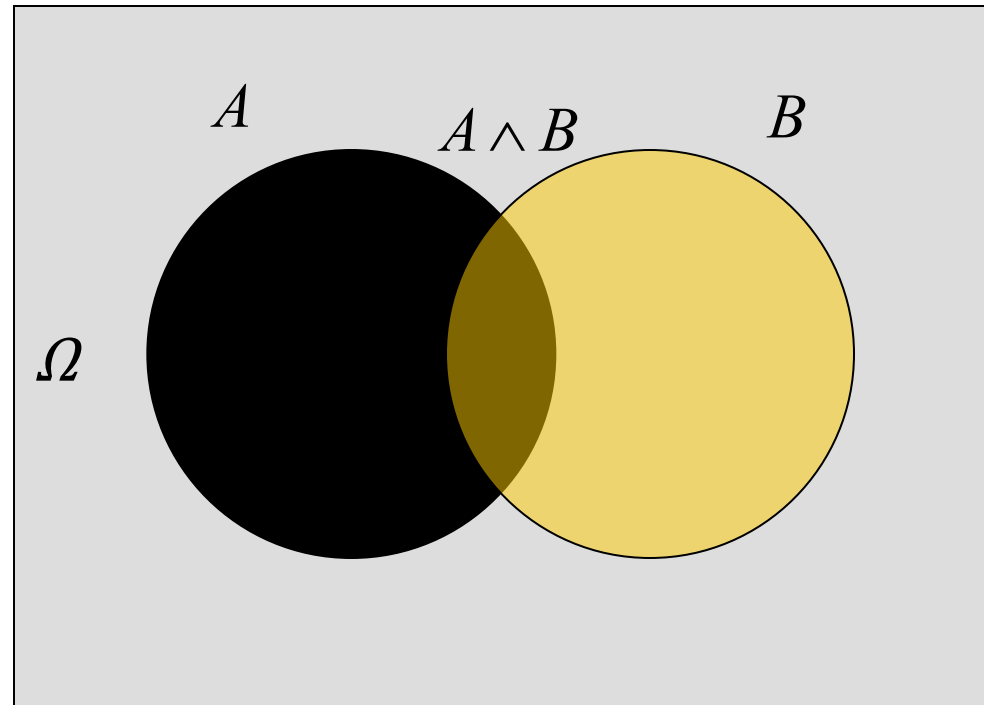
Axioms of Probability Theory

$\Pr(A)$ denotes probability that proposition A is true.

- $0 \leq \Pr(A) \leq 1 \quad \forall \text{ valid } A \in \Omega$
- $\Pr(\textit{True}) = 1 \quad \Pr(\textit{False}) = 0$
- $\Pr(A \vee B) = \Pr(A) + \Pr(B) - \Pr(A \wedge B)$

A Closer Look at Axiom 3

$$\Pr(A \vee B) = \Pr(A) + \Pr(B) - \Pr(A \wedge B)$$



Venn diagram

Using the Axioms

$$\Pr(A \vee \neg A) = \Pr(A) + \Pr(\neg A) - \Pr(A \wedge \neg A)$$

$$\Pr(\textit{True}) = \Pr(A) + \Pr(\neg A) - \Pr(\textit{False})$$

$$1 = \Pr(A) + \Pr(\neg A) - 0$$

$$\Pr(\neg A) = 1 - \Pr(A)$$

Discrete Random Variables

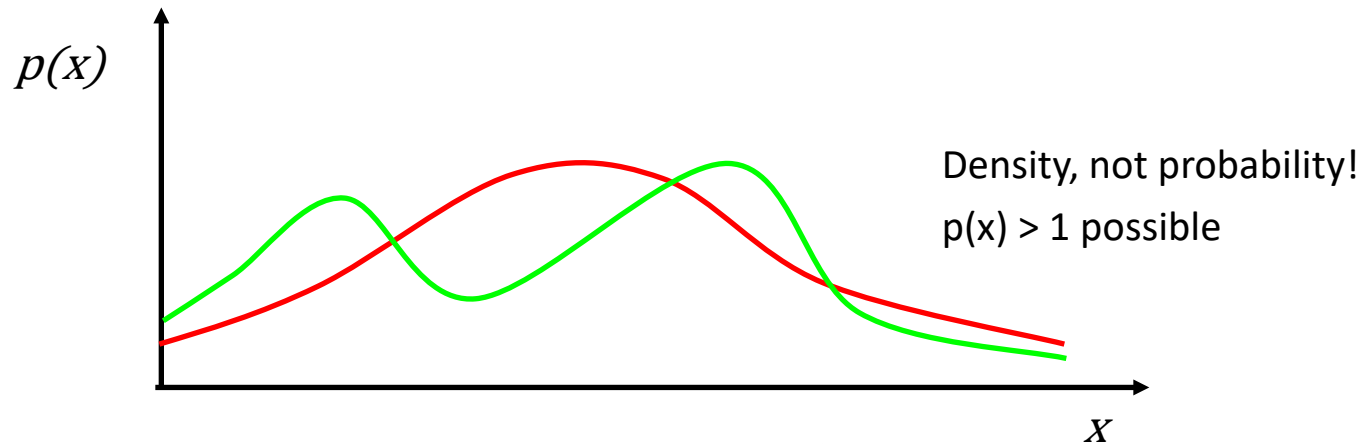
- X denotes a **random variable**.
- X can take on a countable number of values in $\{X_1, X_2, \dots, X_n\}$.
- $P(X=x_i)$, or $P(x_i)$, is the **probability** that the random variable X takes on value x_i .
- $P(\cdot)$ is called **probability mass function**.
- e.g. $P(Room) = \langle 0.7, 0.2, 0.08, 0.02 \rangle$

Continuous Random Variables

- X takes on values in the continuum.
- $p(X=x)$, or $p(x)$, is a **probability density function**.

$$\Pr(x \in (a, b)) = \int_a^b p(x) dx$$

- e.g.



- **Cumulative distribution function** $P(X \leq x)$

Joint and Conditional Probability

- $P(x,y) = P(X=x \text{ and } Y=y)$
- If X and Y are **independent**, then
$$P(x,y) = P(x) P(y)$$
- $P(x/y)$ is the probability of x **given** y
$$\begin{aligned} P(x/y) &= P(x,y) / P(y) \\ &= P(y/x) P(x) / P(y) \end{aligned}$$
- If X and Y are **independent**, then
$$P(x/y) = P(x)$$

Law of Total Probability, Marginals

Discrete case

$$\sum_x P(x) = 1$$

$$P(x) = \sum_y P(x, y)$$

$$P(x) = \sum_y P(x | y) P(y)$$

Continuous case

$$\int p(x) dx = 1$$

$$p(x) = \int p(x, y) dy$$

$$p(x) = \int p(x | y) p(y) dy$$

Bayes Formula

$$P(x, y) = P(x | y)P(y) = P(y | x)P(x)$$

\Rightarrow

$$P(x|y) = \frac{P(y | x)P(x)}{P(y)} = \frac{\text{likelihood} \cdot \text{prior}}{\text{evidence}}$$

$$P(x|y) = \frac{P(y | x)P(x)}{\sum_{x'} P(y | x')P(x')} \quad \text{Via Law of Total Probability}$$

Normalization

$$P(x|y) = \frac{P(y|x) P(x)}{P(y)} = \eta P(y|x) P(x)$$

$$\eta = P(y)^{-1} = \frac{1}{\sum_x P(y|x)P(x)}$$

Algorithm:

$$\forall x : \text{aux}_{x|y} = P(y|x) P(x)$$

$$\eta = \frac{1}{\sum_x \text{aux}_{x|y}}$$

$$\forall x : P(x|y) = \eta \text{aux}_{x|y}$$

Bayes Rule with Background Knowledge

$$P(x \mid y, z) = \frac{P(y \mid x, z) P(x \mid z)}{P(y \mid z)}$$

Conditioning

- Law of total probability:

$$p(x) = \int p(x, z) dz$$

$$p(x) = \int p(x | z) p(z) dz$$

$$p(x | y) = \int p(x | y, z) p(z | y) dz$$

Conditional Independence

$$P(x, y | z) = P(x | z)P(y | z)$$

equivalent to

$$P(x | z) = P(x | z, y)$$

and

$$P(y | z) = P(y | z, x)$$

Checkpoint

#Legs	Species	$P(L=\#Legs, S=Species)$
2	Dog	0.001
2	Cat	0.001
2	Bird	0.2
3	Dog	0.057
3	Cat	0.04
3	Bird	0.001
4	Dog	0.4
4	Cat	0.3
4	Bird	0

- $P(\#legs = 2 \vee \#legs = 3 \vee \#legs = 4)$
- $P(Dog \vee Cat \vee Bird)$
- $P(Bird)$
- $P(Bird, \#legs = 2)$
- $P(Bird \mid \#legs = 2)$
- $P(\#legs = 2 \mid Bird)$

Summary

- Please review probability theory if this was new to you as it serves as basis for everything that follows
- Probabilistic Robotics book: 1.1, 2.2

- Next: Expectations and Covariances
Probabilistic Robotics book: 2.2