

# 1 Kontinuerliga stokastiska variabler

Discrete:

$$X : S \rightarrow C \subset \mathcal{R}$$

A countable set of real numbers.

Continuous:

$$X : S \rightarrow I \subseteq \mathcal{R}$$

I is an uncountable set = with the cardinality of the real numbers.

## 1.1 Definition

- X is called a continuous random variable if it can take all values from a real interval or union of F (finite) intervals.

Example: Lifespan of a lightbulb. Weight of a raindrop. Circumference of a randomly chosen tree.

- A function  $f_x : \mathcal{R} \rightarrow [0, \infty)$  which satisfies

$$P(a \leq X \leq b) = \int_a^b f_x(x) dx$$

is called "density" function.

- $F_X(x) = P(X \leq x) = \int_{-\infty}^x f_X(y) dy$  is called the "cumulative" distribution function.

$$P(a \leq X \leq b) = P(X \leq b) - P(X \leq a) = F_X(b) - F_X(a)$$

## 1.2 Properties

- $f_X(x) \geq 0$
- $\int_{-\infty}^{\infty} f_X(x) dx = 1$
- $P(a < X \leq b) = P(a < X < b) = P(a \leq X \leq b) = P(a \leq X < b)$

## 1.3 Remark

Since  $f_X(x)$  is non-negative  $\int f_X$  is an area

## 1.4 Example

Assume that X is a continuous random variable with density function

$$f(x) = \begin{cases} c(4x - 2x^2), & 0 < x < 2 \\ 0, & \text{otherwise} \end{cases}$$

Find the constant  $c$  and  $P(X > 1)$

$$\begin{aligned}\int_{-\infty}^{\infty} f(x) dx &= 1 \rightarrow 1 = \int_{-\infty}^{\infty} c(4x - 2x^2) dx - \int_0^2 c(4x - 2x^2) dx = \\ &= \left[ c(2x^2 - \frac{2}{3}x^3) \right]_0^2 = c(8 - \frac{16}{3}) = 1 \implies c = \frac{3}{8}\end{aligned}$$

Now our density is

$$f(x) = \begin{cases} \frac{3}{8}(4x - 2x^2), & 0 < x < 2 \\ 0, & \text{otherwise} \end{cases}$$

$$P(X > 1) = \int_1^2 f(x) dx = \frac{3}{8} \int_1^2 (4x - 2x^2) dx = \dots = \frac{1}{2}$$

## 2 Expectation and variance

### 2.1 Definitions

Let  $X$  be a continuous random variable.

- $E[X] = \int_{-\infty}^{\infty} x f_X(x) dx$   
is called expectation (or expected value) of  $X$ .
- $Var[X] = \int_{-\infty}^{\infty} (x - E[X])^2 f_X(x) dx$   
is called variance of  $X$ .
- $D[X] = \sqrt{Var(X)}$   
is called standard deviation

### 2.2 Remark

$$Var(X) = E[X^2] - E[X]^2 = \int_{-\infty}^{\infty} x^2 f_X(x) dx - \left( \int_{-\infty}^{\infty} x f_X(x) dx \right)^2$$

### 2.3 Theorem

The first and second properties are the same as in the discrete case.

- $E[a] = a, Var(a) = 0, \forall a \in \mathbb{R}$
- $E[aX + b] = aE[X] + b$
- $Var(aX + b) = a^2 Var(X)$
- $E[g(x)] = \int_{-\infty}^{\infty} g(x) f_X(x) dx$

## 2.4 Example

$$f_X(x) = \begin{cases} 1, & 0 \leq x \leq 2 \\ 0, & \text{otherwise} \end{cases}$$

$$g(x) = e^x \cdot E[e^x] = ?, \text{Var}(e^x) = ?$$

- $E[e^X] = \int_{-\infty}^{\infty} (e^x)(f_X(x))dx = \int_0^1 e^x * 1dx = e - 1$
- $\text{Var}(X) = E[X^2] - E[X]^2$   
 $E[X^2] = E[(e^x)^2] = E[e^{2x}] = \int_0^1 e^{2x} * 1dx = \left[\frac{1}{2}e^{2x}\right]_0^1 = \frac{1}{2}(e^2 - 1)$   
 $\text{Var} = \frac{1}{2}(e^2 - 1) - (e - 1)^2$

## 3 Common distributions

### 3.1 Uniform distribution

Uniform distribution on  $[a, b]$  (the symbol  $U([a, b])$ )

#### 3.1.1 Definition

$$f_X(x) = \begin{cases} \frac{1}{b-a}, & a \leq x \leq b \\ 0, & \text{otherwise} \end{cases}$$

#### 3.1.2 Theorem

- $f_X(x) = \begin{cases} 0, & -\infty \leq x < a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ 1, & x \geq b \end{cases}$
- $E[X] = \frac{a+b}{2}, \text{Var}(X) = \frac{(b-a)^2}{12}$

Proof not included

### 3.2 Exponential distribution

$$X \sim \text{Exp}(\lambda)$$

Given a  $0 < \lambda \in \mathbb{R}$

$$f_X(x) = \begin{cases} \lambda e^{-\lambda x}, & x \geq 0 \\ 0, & \text{otherwise} \end{cases}$$

#### 3.2.1 Theorem

- $F_X(x) = \begin{cases} 0, & -\infty \leq x < 0 \\ 1 - e^{-\lambda x}, & x \geq 0 \end{cases}$
- $E[X] = \frac{1}{\lambda}; \text{Var}(X) = \frac{1}{\lambda^2}$

### 3.2.2 Theorem (Memoryless property)

Let  $X \sim \text{Exp}(\lambda)$ . We have that  $P(X > t + x | X > t) = P(X > x)$

### 3.2.3 Proof

$$P(X > t+x | X > t) = \frac{P(X > t+x; X > t)}{P(X > t)} = \frac{P(X > t+x)}{P(X > t)} = \frac{1 - F_X(t+x)}{1 - F_X(t)} = \frac{e^{-\lambda(t+x)}}{e^{-\lambda t}} = e^{-\lambda x} = 1 - F_X(x) = P(X > x) \quad \blacksquare$$

## 3.3 Standard normal distribution

$$X \sim \mathcal{N}(0, 1)$$

The random variable has symbol  $Z$ , the density function is defined as

$$f_X(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}}, x \in \mathbb{R} = (-\infty, \infty)$$

$F_X(x)$  doesn't have an explicit formula.

The symbol  $F_X$  is  $\Phi(x) = P(X \leq x)$

### 3.3.1 Theorem

Let  $Z \sim \mathcal{N}(0, 1)$  then

$$E(Z) = 0, \text{Var}(Z) = 1$$

Proof comes later in the course.

### 3.3.2 Example

$$Z \sim \mathcal{N}(0, 1)$$

- $P(Z < 2.11) = \Phi(2.11) = 0.9826$ , from table
- $P(Z \leq -2.11) = \Phi(-2.11) = 1 - \Phi(2.11) = 1 - 0.9826$
- $P(-2.21 \leq Z \leq 2.11) = P(Z \leq 2.11) - P(Z \leq -2.21) = 0.9826 - 0.0163 = 0.9663$

## 4 Standard deviation

$$X \sim f_X(x) = \frac{1}{(2\pi)\sigma} e^{-\frac{x-\mu}{2\sigma^2}}$$

$$X \sim \mathcal{N}(\mu, \sigma^2)$$

## 4.1 Theorem

$$E[X] = \mu, \text{Var}(X) = \sigma^2$$

How do we compute  $F_X(x)$ ?

Standardization: we transform X in Z

$$Z = \frac{x - \mu}{\sigma} \sim \mathcal{N}(0, 1)$$