

# Random Variable Generation, AI1110

Rajiv Shailesh Chitale (cs21btech11051)

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**Abstract**—This manual provides solutions to simple examples of generation of random numbers

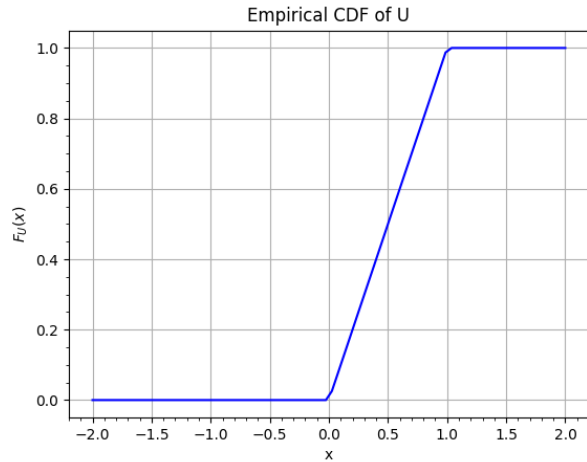


Fig. 1.2. The CDF of  $U$

## 1 UNIFORM RANDOM NUMBERS

Let  $U$  be a uniform random variable between 0 and 1.

- 1.1 Generate  $10^6$  samples of  $U$  using a C program and save into a file called uni.dat .

**Solution:** Download the following c code. Run it to generate samples of  $U$ .

```
wget https://github.com/cs21btech11051Rajiv/AI1110_assignments/blob/main/manual1/q1/1p1.c
```

- 1.2 Load the uni.dat file into python and plot the empirical CDF of  $U$  using the samples in uni.dat. The CDF is defined as

$$F_U(x) = \Pr(U \leq x) \quad (1.1)$$

**Solution:** The empirical CDF of  $U$  is plotted in 1.2 using the code below

```
wget https://github.com/cs21btech11051Rajiv/AI1110_assignments/blob/main/manual1/q1/1p2.py
```

- 1.3 Find a theoretical expression for  $F_U(x)$ .

**Solution:** The PDF has a uniform distribution,

$$p_U(x) = \begin{cases} \frac{1}{1-0} & 0 \leq x \leq 1 \\ 0 & \text{otherwise} \end{cases} \quad (1.2)$$

$$F_U(x) = \int_{-\infty}^x p_U(x) dx \quad (1.3)$$

$$F_U(x) = \begin{cases} 0 & x < 0 \\ \int_0^x 1 dx & 0 \leq x \leq 1 \\ \int_0^1 1 dx & 1 < x \end{cases} \quad (1.4)$$

$$F_U(x) = \begin{cases} 0 & x < 0 \\ x & 0 \leq x \leq 1 \\ 1 & 1 < x \end{cases} \quad (1.5)$$

**Solution:** The theoretical CDF of  $U$  is plotted in 1.3 using the code below

```
wget https://github.com/cs21btech11051Rajiv/AI1110_assignments/blob/main/manual1/q1/1p3.py
```

- 1.4 The mean of  $U$  is defined as

$$E[U] = \frac{1}{N} \sum_{i=1}^N U_i \quad (1.6)$$

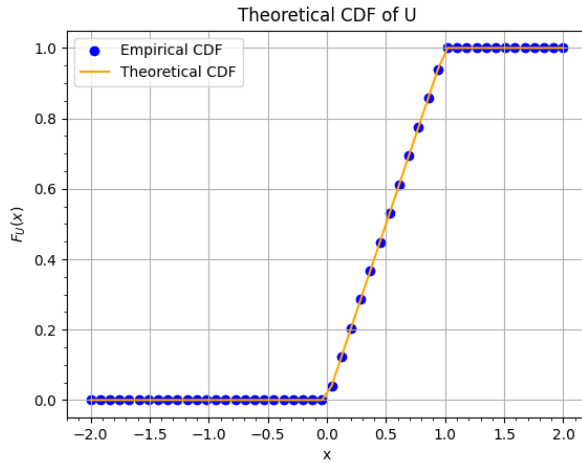


Fig. 1.3. The CDF of  $U$

and its variance as

$$\text{var}[U] = E[(U - E[U])^2] \quad (1.7)$$

Write a C program to find the mean and variance of  $U$ .

**Solution:** Run the following C file

```
wget https://github.com/cs21btech11051Rajiv/
  AI1110_assignments/blob/main/manual1/
  q1/1p4.c
```

Results were,

$$E[U] = 0.500007 \quad (1.8)$$

$$\text{var}[U] = 0.083301 \quad (1.9)$$

1.5 Verify your result theoretically given that

$$E[U^k] = \int_{-\infty}^{\infty} x^k dF_U(x) \quad (1.10)$$

**Solution:** Taking  $k$  as 1,

$$E[U] = \int_{-\infty}^{\infty} x dF_U(x) \quad (1.11)$$

Using expression (1.5), this simplifies to

$$E[U] = \int_0^1 x dx \quad (1.12)$$

$$E[U] = \frac{x^2}{2} \Big|_0^1 \quad (1.13)$$

$$E[U] = 0.5 \quad (1.14)$$

To calculate variance we take  $k=2$

$$\text{var}[U] = E[(U - E[U])^2] \quad (1.15)$$

$$\text{var}[U] = E[(U - 0.5)^2] \quad (1.16)$$

$$\text{var}[U] = E[U^2 - U + 0.25] \quad (1.17)$$

$$\text{var}[U] = E[U^2] - E[U] + E[0.25] \quad (1.18)$$

$$\text{var}[U] = \int_{-\infty}^{\infty} x^2 dF_U(x) - 0.5 + 0.25 \quad (1.19)$$

$$\text{var}[U] = \int_0^1 x^2 dx - \frac{1}{4} \quad (1.20)$$

$$\text{var}[U] = \frac{x^3}{3} \Big|_0^1 - \frac{1}{4} \quad (1.21)$$

$$\text{var}[U] = \frac{1}{12} = 0.0833 \quad (1.22)$$

$$(1.23)$$

## 2 CENTRAL LIMIT THEOREM

2.1 Generate  $10^6$  samples of the random variable

$$X = \sum_{i=1}^{12} U_i - 6 \quad (2.1)$$

using a C program, where  $U_i, i = 1, 2, \dots, 12$  are a set of independent uniform random variables between 0 and 1 and save in a file called gau.dat

**Solution:** Download the following c code. Run it to generate samples of  $X$ .

```
wget https://github.com/cs21btech11051Rajiv/
  AI1110_assignments/blob/main/manual1/
  q1/2p1.c
```

2.2 Load gau.dat in python and plot the empirical CDF of  $X$  using the samples in gau.dat. What properties does a CDF have?

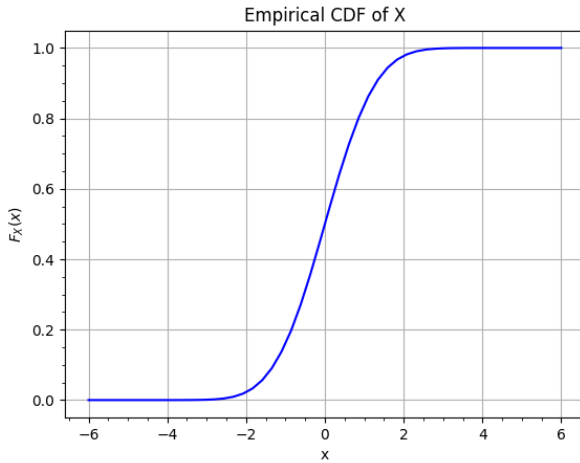
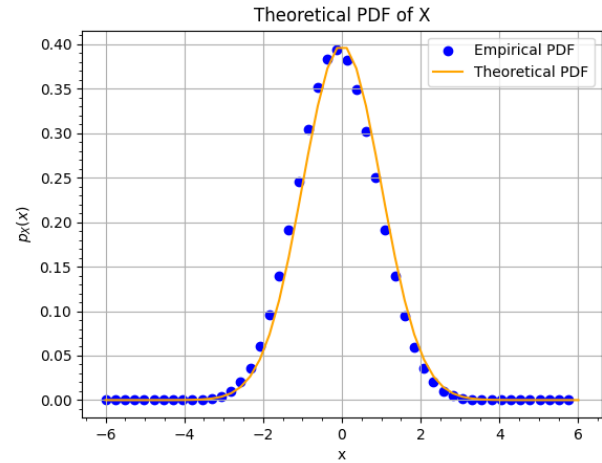
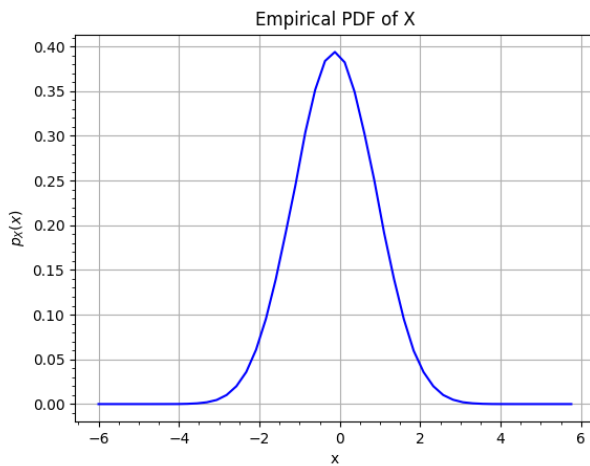
**Solution:** The empirical CDF of  $X$  is plotted in Fig. 2.2 using the code below

```
wget https://github.com/cs21btech11051Rajiv/
  AI1110_assignments/blob/main/manual1/
  q1/2p2.py
```

A CDF is a non-decreasing function. Its value varies from 0 to 1. It is continuous if PDF has finite values.

2.3 Load gau.dat in python and plot the empirical PDF of  $X$  using the samples in gau.dat. The PDF of  $X$  is defined as

$$p_X(x) = \frac{d}{dx} F_X(x) \quad (2.2)$$

Fig. 2.2. The CDF of  $X$ Fig. 2.5. The theoretical PDF of  $X$ Fig. 2.3. The PDF of  $X$ 

What properties does the PDF have?

**Solution:** The empirical PDF of  $X$  is plotted in Fig. 2.3 using the code below

```
wget https://github.com/cs21btech11051Rajiv/
AI1110_assignments/blob/main/manual1/
q2/2p3.c
```

Values taken by a PDF are non negative. The total area under a PDF is equal to 1.

2.4 Find the mean and variance of  $X$  by writing a C program.

**Solution:** Run the following C file

```
wget https://github.com/cs21btech11051Rajiv/
AI1110_assignments/blob/main/manual1/
q2/2p4.c
```

Results were,

$$E[X] = 0.000294 \quad (2.3)$$

$$\text{var}[X] = 0.999560 \quad (2.4)$$

2.5 Given that

$$p_X(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right), -\infty < x < \infty, \quad (2.5)$$

repeat the above exercise theoretically.

**Solution:** The theoretical PDF of  $X$  is plotted in Fig. 2.5 using the code below

```
wget https://github.com/cs21btech11051Rajiv/
AI1110_assignments/blob/main/manual1/
q2/2p5.c
```

Using given equation (1.10),

$$E[X^k] = \int_{-\infty}^{\infty} x^k dF_X(x) \quad (2.6)$$

$$E[X] = \int_{-\infty}^{\infty} x dF_X(x) \quad (2.7)$$

Using given equation (2.2),

$$E[X] = \int_{-\infty}^{\infty} x p_X(x) dx \quad (2.8)$$

$$E[X] = \int_{-\infty}^{\infty} x \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) dx \quad (2.9)$$

Taking  $t = \frac{x^2}{2}$

$$E[X] = \int_{\infty}^{\infty} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{t}{2}\right) dt \quad (2.10)$$

$$E[X] = 0 \quad (2.11)$$

To calculate variance we take  $k=2$

$$\text{var}[X] = E[(X - E[X])^2] \quad (2.12)$$

$$\text{var}[X] = E[X^2] \quad (2.13)$$

$$\text{var}[X] = \int_{-\infty}^{\infty} x^2 dF_X(x) \quad (2.14)$$

$$\text{var}[X] = \int_{-\infty}^{\infty} x^2 p_X(x) dx \quad (2.15)$$

$$\text{var}[X] = \int_{-\infty}^{\infty} x^2 \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) dx \quad (2.16)$$

Integrating by parts, we obtain

$$\begin{aligned} \text{var}[X] &= -x \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) \Big|_{-\infty}^{\infty} \\ &\quad + \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) dx \end{aligned} \quad (2.17)$$

The second term is the area under the PDF, which is 1

$$\text{var}[X] = 0 + \int_{-\infty}^{\infty} p_X(x) dx \quad (2.18)$$

$$\text{var}[X] = 1 \quad (2.19)$$

### 3 FROM UNIFORM TO OTHER

#### 3.1 Generate samples of

$$V = -2 \ln(1 - U) \quad (3.1)$$

and plot its CDF.

**Solution:** Run the following files to generate samples and CDF.

```
wget https://github.com/cs21btech11051Rajiv/
  AI1110_assignments/blob/main/manual1/
  q3/3p1.c
wget https://github.com/cs21btech11051Rajiv/
  AI1110_assignments/blob/main/manual1/
  q3/3p1b.py
```

#### 3.2 Find a theoretical expression for $F_V(x)$ .

**Solution:**

$$F_V(x) = \Pr(V \leq x) \quad (3.2)$$

$$F_V(x) = \Pr(-2 \ln(1 - U) \leq x) \quad (3.3)$$

$$F_V(x) = \Pr\left(\ln(1 - U) \geq -\frac{x}{2}\right) \quad (3.4)$$

$$F_V(x) = \Pr\left(1 - U \geq \exp\left(-\frac{x}{2}\right)\right) \quad (3.5)$$

$$F_V(x) = \Pr\left(U \leq 1 - \exp\left(-\frac{x}{2}\right)\right) \quad (3.6)$$

$$F_V(x) = F_U\left(1 - \exp\left(-\frac{x}{2}\right)\right) \quad (3.7)$$

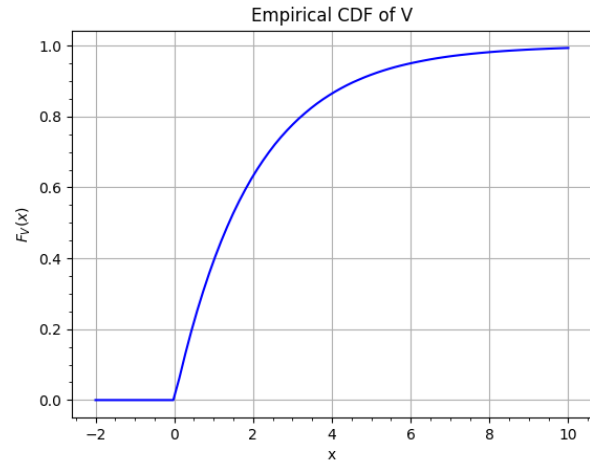


Fig. 3.1. The CDF of  $V$

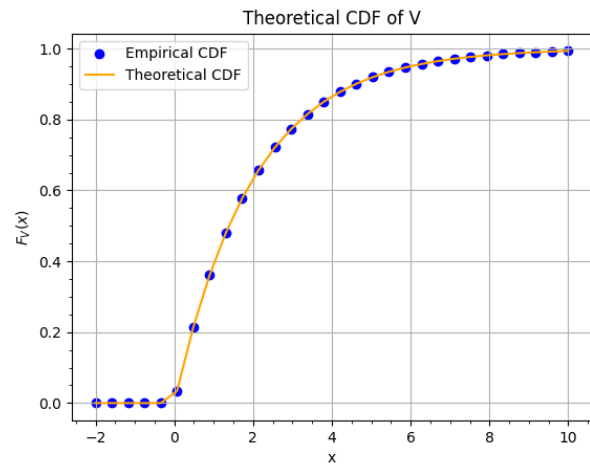


Fig. 3.2. The CDF of  $V$

$$F_V(x) = \begin{cases} 0 & 1 - \exp\left(-\frac{x}{2}\right) < 0 \\ 1 - \exp\left(-\frac{x}{2}\right) & 0 \leq 1 - \exp\left(-\frac{x}{2}\right) \leq 1 \\ 1 & 1 < 1 - \exp\left(-\frac{x}{2}\right) \end{cases} \quad (3.8)$$

This simplifies to

$$F_V(x) = \begin{cases} 0 & x < 0 \\ 1 - \exp\left(-\frac{x}{2}\right) & x \geq 0 \end{cases} \quad (3.9)$$

The following code plots the theoretical CDF.

```
wget https://github.com/cs21btech11051Rajiv/
  AI1110_assignments/blob/main/manual1/
  q3/3p2.py
```