# Random Numbers
## AI1110: Probability and Random Variables

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AI21BTECH11014

CONTENTS

*Abstract*—**This manual provides a simple introduction to the generation of random numbers**

### 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 files and execute the C program.

```
wget https://github.com/HARI−donk−EY/
    Rand_nums/blob/main/codes/1/unigen.c
wget https://github.com/HARI−donk−EY/
    Rand_nums/blob/main/codes/coeffs.h
```

Use the below command in the terminal to run code.

```
gcc unigen.c −lm −o unigen.out
./unigen.out
```

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

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

**Solution:** The following code plots Fig. 1.2

```
wget https://github.com/HARI−donk−EY/
    Rand_nums/blob/main/codes/1/
    cdf_plot_uni.py
```

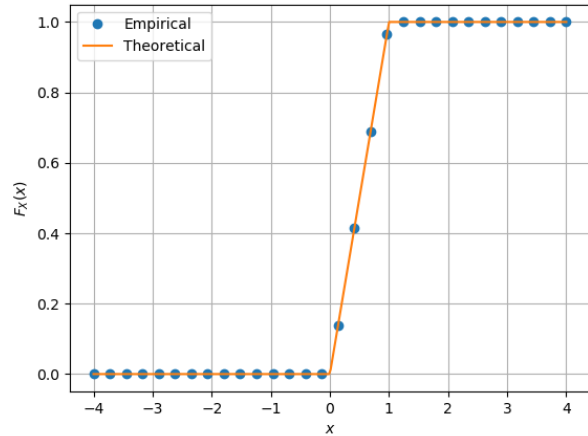Use the below command in the terminal to run code.



Fig. 1.2: The CDF of $U$

```
python3 cdf_plot_uni.py
```

1.3 Find a theoretical expression for $F_U(x)$.
**Solution:** $U$ is a Uniform Random Variable Distribution.
the PDF of the the distribution can be given as:

$$p_U(x) = \begin{cases} 1 & x \in [0, 1] \\ 0 & \text{otherwise} \end{cases} \quad (1.2)$$

The CDF of $U$ is given by

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

Therefore, we obtain the CDF of $U$ as

$$F_U(x) = \begin{cases} 0 & x < 0 \\ x & 0 \le x \le 1 \\ 1 & x > 1 \end{cases} \quad (1.4)$$

1.4 The mean of $U$ is defined as

$$E[U] = \frac{1}{N} \sum_{i=1}^{N} U_i \qquad (1.5)$$

and its variance as

$$\text{var}[U] = E[U - E[U]]^2 \qquad (1.6)$$

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

**Solution:** Download the C source code by executing the following commands

```
wget https://github.com/HARI−donk−EY/
    Rand_nums/blob/main/codes/1/
    mean_var_cal.c
wget https://github.com/HARI−donk−EY/
    Rand_nums/blob/main/codes/coeffs.h
```

Use the below command in the terminal to run code.

```
gcc mean_var_cal.c −lm −o mean_var_cal.
    out
./mean_var_cal.out
```

From the code we get the output of the Mean as 0.500007, and Variance as 0.083301.

1.5 Verify your result theoretically given that

$$E\left[U^k\right] = \int_{-\infty}^{\infty} x^k dF_U(x) \qquad (1.7)$$

**Solution:** We know that,

$$E[U] = \int_{-\infty}^{\infty} x dF_U(x) \qquad (1.8)$$

On differentiation thr CDF obtained above, we get,

$$dF_U(x) = \begin{cases} 0 & x < 0 \\ dx & 0 \le x \le 1 \\ 0 & x > 1 \end{cases} \qquad (1.9)$$

From this, we get,

$$E[U] = \int_{0}^{1} x dx = \frac{1}{2} = 0.5 \qquad (1.10)$$

Similarly,

$$E\left[U^2\right] = \int_{0}^{1} x^2 dx = \frac{1}{3} \qquad (1.11)$$

From varience,

$$\text{var}[U] = E\left[U^2\right] - (E[U])^2 \qquad (1.12)$$

By substituting,

$$= \frac{1}{3} - \left(\frac{1}{2}\right)^2 \qquad (1.13)$$

$$= \frac{1}{12} \approx 0.083333 \qquad (1.14)$$

## 2 CENTRAL LIMIT THEOREM

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

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

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

**Solution:** Download the C source code by executing the following commands

```
wget https://github.com/HARI−donk−EY/
    Rand_nums/blob/main/codes/2/gaugen.c
wget https://github.com/HARI−donk−EY/
    Rand_nums/blob/main/codes/coeffs.h
```

Compile and run the C program by executing the following

```
gcc gaugen.c −lm −o gaugen.out
./gaugen.out
```

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 following code plots Fig. 2.2
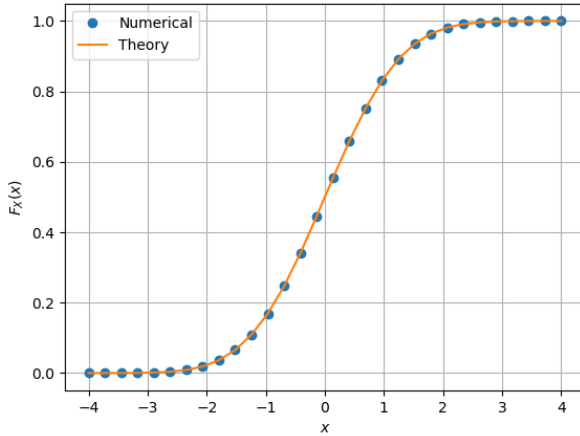
```
wget https://github.com/HARI−donk−EY/
    Rand_nums/blob/main/codes/2/
    cdf_plot_gau.py
```

Use the below command in the terminal to run code.

```
python3 cdf_plot_gau.py
```

Properties of this CDF are:
- $F_Z(x) = P(Z \le x) = 1 - Q(x)$

Fig. 2.2: The CDF of $X$



Fig. 2.3: The PDF of $X$

- $\lim_{x \to \infty} F_Z(x) = 1, \quad \lim_{x \to -\infty} F_Z(x) = 0$
- $F_Z(0) = \frac{1}{2}$
- $F_Z(-x) = 1 - F_Z(x)$

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

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

What properties does the PDF have?
**Solution:** Download the following Python code that plots Fig. 2.3

```
wget https://github.com/HARI−donk−EY/
    Rand_nums/blob/main/codes/2/pdf_plot.
    py
```
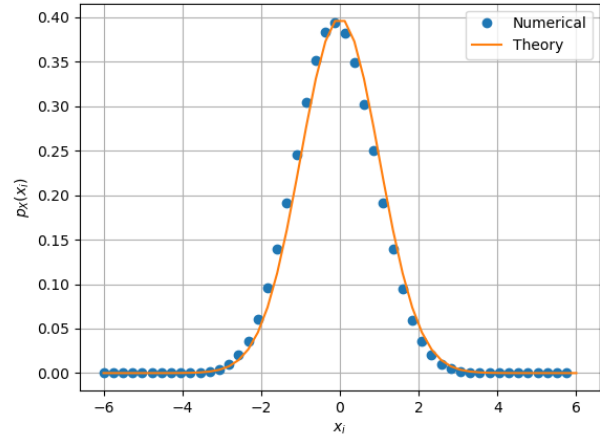
Run the code by executing

```
python pdf_plot.py
```

The PDF graph is symmetric about $x = 0$ and bell shaped. The mean of the graph is situated at the apex of the bell.

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

**Solution:** Download the C source code by executing the following commands

```
wget https://github.com/HARI−donk−EY/
    Rand_nums/blob/main/codes/2/
    mean_var_cal.c
```

```
wget https://github.com/HARI−donk−EY/
    Rand_nums/blob/main/codes/coeffs.h
```

Use the below command in the terminal to run code.

```
gcc mean_var_cal.c −lm −o mean_var_cal.
    out
./mean_var_cal.out
```

From the code we get the output of the Mean as 0.000294, and Variance as 0.999560.

2.5 Given that

$$p_X(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right), -\infty < x < \infty, \quad (2.3)$$

repeat the above exercise theoretically.
**Solution:** From above, the Mean will be given as,

$$E[X] = \int_{-\infty}^{\infty} x p_X(x) dx \qquad (2.4)$$

$$= \int_{-\infty}^{\infty} \frac{x}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) dx \qquad (2.5)$$

$$= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} x e^{-\frac{x^2}{2}} dx \qquad (2.6)$$

$x e^{-\frac{x^2}{2}}$ is an odd function.
Hence, $E[X] = 0$

Similarly,

$$E\left[X^2\right] = \int_{-\infty}^{\infty} x^2 p_X(x)dx \qquad (2.7)$$

$$= \int_{-\infty}^{\infty} \frac{x^2}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right)dx \qquad (2.8)$$

$$= 2\int_{0}^{\infty} \frac{x^2}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right)dx \qquad (2.9)$$

$$= \sqrt{\frac{2}{\pi}} \int_{0}^{\infty} x\left(x.\exp\left(-\frac{x^2}{2}\right)\right)dx \qquad (2.10)$$

$$\qquad (2.11)$$

Using integration by parts, we get,

$$= \sqrt{\frac{2}{\pi}}\left(x\int x\exp\left(-\frac{x^2}{2}\right)dx\right)\Bigg|_{0}^{\infty}$$

$$- \sqrt{\frac{2}{\pi}}\int_{0}^{\infty} 1\cdot\int x\exp\left(-\frac{x^2}{2}\right)dx$$

$$\qquad (2.12)$$

$$= \sqrt{\frac{2}{\pi}}\left(\left[-x\exp-\frac{x^2}{2}\right]_{0}^{\infty} - \int_{0}^{\infty}-\exp\left(-\frac{x^2}{2}\right)\right)$$

Substituting $x$ with $t\sqrt{2}$,

And $dx$ with $dt\sqrt{2}$

$$= \sqrt{\frac{2}{\pi}}\left(0 - \left(-\sqrt{2}\int_{0}^{\infty}\exp(-t^2)\,dt\right)\right)$$

$$= \sqrt{\frac{2}{\pi}}\left(\sqrt{2}\int_{0}^{\infty}\exp(-t^2)\,dt\right)$$

$$= \sqrt{\frac{2}{\pi}}\left(\sqrt{2}\left(\frac{\sqrt{\pi}}{2}\right)\right)$$

$$= 1$$

Therefore, Variance of $X$ will be,

$$var(X) = E[X]^2 - E\left[X^2\right]$$
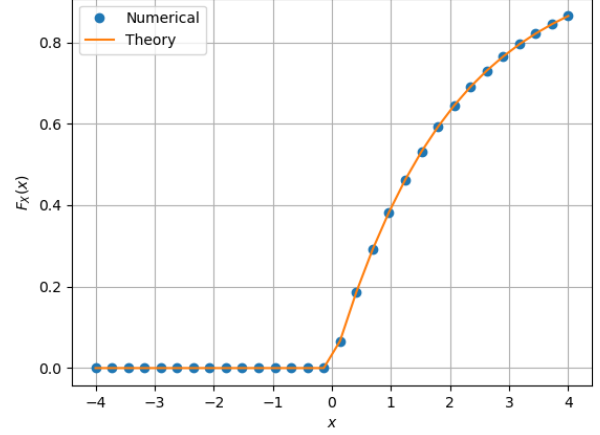
$$= 0 - 1 = 1$$



Fig. 3.1: The CDF of $V$

## 3  FROM UNIFORM TO OTHER

### 3.1  Generate samples of

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

and plot its CDF.
**Solution:** Download the C source code by executing the following commands

```
wget https://github.com/HARI−donk−EY/
    Rand_nums/blob/main/codes/3/vgen.c
wget https://github.com/HARI−donk−EY/
    Rand_nums/blob/main/codes/coeffs.h
```

Compile and run the C program by executing the following

```
gcc vgen.c −lm −o vgen.out
./vgen.out
```

The following code plots Fig. 3.1

```
wget https://github.com/HARI−donk−EY/
    Rand_nums/blob/main/codes/3/
    cdf_plot_vdat.py
```

Use the below command in the terminal to run code.

```
python3 cdf_plot_vdat.py
```

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

**Solution:** We have

$$F_V(x) = \Pr(V \le x) \tag{3.2}$$

$$= \Pr(-2\ln(1-U) \le x) \tag{3.3}$$

$$= \Pr\left(\ln(1-U) \ge -\frac{x}{2}\right) \tag{3.4}$$

$$= \Pr\left(1-U \ge \exp\left(-\frac{x}{2}\right)\right) \tag{3.5}$$

$$= \Pr\left(U \le 1 - \exp\left(-\frac{x}{2}\right)\right) \tag{3.6}$$

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

Now,

$$0 \le 1 - \exp\left(-\frac{x}{2}\right) < 1 \qquad \text{if } x \ge 0 \tag{3.8}$$

$$1 - \exp\left(-\frac{x}{2}\right) < 0 \qquad \text{if } x < 0 \tag{3.9}$$

Therefore,

$$F_V(x) = \begin{cases} 1 - \exp\left(-\frac{x}{2}\right) & x \ge 0 \\ 0 & x < 0 \end{cases} \tag{3.10}$$