

# Guide1\_Ahilan\_Kumaresan

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Interactive Plot

```
[2]: %matplotlib widget
```

```
[3]: import matplotlib.pyplot as plt
plt.style.use('dark_background')
import numpy as np
```

## 0.0.1 Task 1: Simple random number generator

One of the simplest random number generators is the linear congruential generator that generates a new number  $x_{n+1}$  from the previous one  $x_n$  using

$$x_{n+1} = (ax_n + c) \bmod m$$

where  $a$  and  $c$  are integers and  $m$  is typically a large prime (and mod means modulo arithmetic—done in Python with the % sign). By dividing the resulting number by  $m$ , you get a real number between 0 and 1. Through a judicious choice of  $a$ ,  $c$ , and  $m$ , this sequence can have a relatively long period and show few correlations. Correlations can be seen by plotting  $x_{n+1}$  versus  $x_n$ . Poor random number generators will show correlated bands and do not uniformly cover the plane of  $(x_n, x_{n+1})$  (though sometimes you must look in 3D—i.e.,  $(x_n, x_{n+1}, x_{n+2})$ —and plot three consecutive points to see banding). Let's look at how the linear congruential generator performs.

```
[4]: # 2.

x0 = 1 # Seed
# Generate the next 12 numbers
a,c,m = 12,0,143

x =[x0]

# Pseudo:
# Take the seed or the previous Number
# Apply the equation
# Go to next formula

for i in range(12):
    x.append( (a*x[-1]+c) % m)
```

```
print(x)
```

```
[1, 12, 1, 12, 1, 12, 1, 12, 1, 12, 1, 12, 1]
```

3. The pattern repeats ever 2 elements.

First our seed is 1 so Variable is 1, - we do  $(12*1 + 0) \bmod 143$ , the remainder is 12 (Appended to list)

So our second element is, 12 now - Again we do,  $(12*12 + 0) \bmod 143$  that is 1 So we again get the seed 1. So this keep on going in a loop

```
[5]: # 4.
```

```
def linCon(xi,a,c,m):  
    return ((a*xi) +c) % m
```

In the 1970's and 80's, a popular choice for parameters was  $a = 65,539$ ,  $c = 0$ , and  $m = 2^{31}$ . This generator was called "Randu" and was frequently used in research.

```
[6]: # 5. Make 1000 Pseudo Random numbers using Randu
```

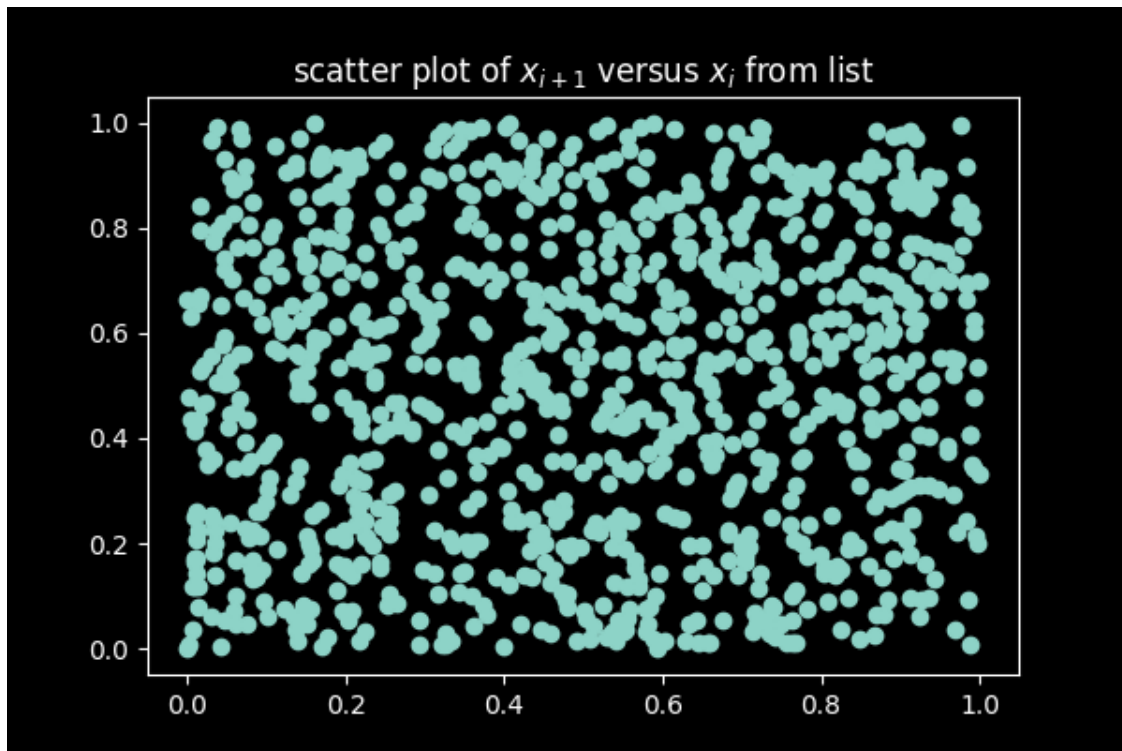
```
x0 = 42 # Seed  
x = [x0]  
  
m = 2**31  
for i in range(1000-1): # 1000-1 because the instructions said,  
    # Make a list of 1000 numbers starting with the seed. So including seed  
    ↪there must be 1000 numbers  
    x.append(linCon(xi=x[-1],a=65539, c=0,m=m))  
x = np.array(x)/m  
print(x[:50])  
  
len(x)
```

```
[1.95577741e-08 1.28179695e-03 7.69060571e-03 3.46074617e-02  
1.38429319e-01 5.19108756e-01 8.68788672e-01 5.40753222e-01  
4.25421287e-01 6.85748725e-01 2.85700765e-01 5.42466066e-01  
6.83489506e-01 2.18742444e-01 1.61049110e-01 9.97612662e-01  
5.36233981e-01 2.38889932e-01 6.07233760e-01 4.93393174e-01  
4.95255207e-01 5.30992671e-01 7.28659165e-01 5.93020952e-01  
1.93228014e-04 6.63970797e-01 9.82085732e-01 9.16777215e-01  
6.61891703e-01 7.20355286e-01 3.65106386e-01 7.07440740e-01  
9.58686967e-01 3.85155140e-01 6.82748136e-01 6.30092553e-01  
6.35822092e-01 1.44099577e-01 1.42198634e-01 5.56295610e-01  
5.79859512e-02 3.41255217e-01 5.25657740e-01 8.26494908e-02  
7.64977281e-01 8.46018269e-01 1.91314084e-01 5.33720083e-01  
4.80493744e-01 7.94817200e-02]
```

```
[6]: 1000
```

[7]: # 6.

```
plt.figure(figsize=(6,4))
plt.scatter(x[:-1],x[1:])
plt.title("scatter plot of  $x_{i+1}$  versus  $x_i$  from list")
plt.show()
```



[8]: `len(x[:])`  
`len(x[1:])`

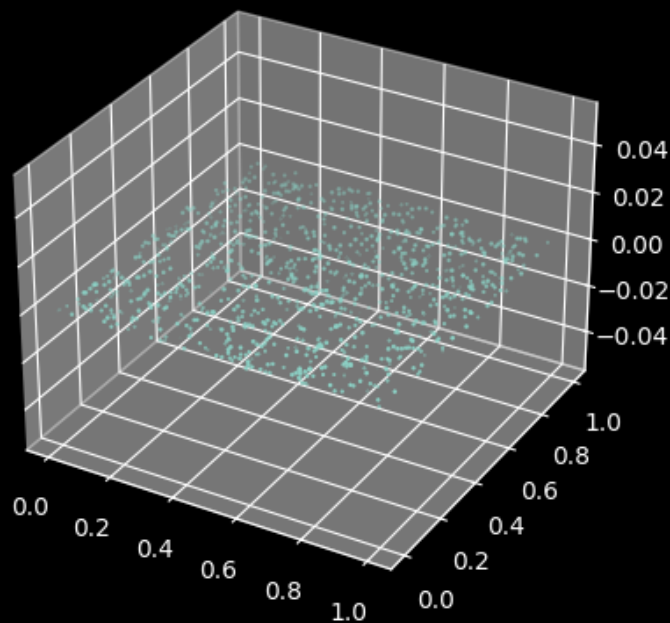
[8]: 999

ANS: Yes they do Look random, there are no visible bands and they seem to uniformly cover the plane

[9]: # 8. 3D plot

```
plt.figure() # Argues that this is a new plot
plt.subplot(projection="3d")
plt.scatter(x[:-2],x[1:-1],x[2:])
plt.title("3D plot by starting your cell, $x_{i+2}$ , $x_{i+1}$  versus  $x_i$  from list")
plt.show()
```

3D plot by starting your cell,  $x_{i+2}, x_{i+1}$  versus  $x_i$  from list



RANDU shows that all the values line on a thin plane at  $z = 0$ , Hence no, the values are not all Random in 3D. They are high predictable

Points collapse onto a small number of parallel planes in 3D, not volume-filling!

```
[10]: # To turn off the interactive widget
      %matplotlib inline
```

## 0.0.2 Task 2

```
[11]: from timeit import default_timer as timer
      import functools

      # I always wanted to use decorators, so here is my attempt
      # Explanation for how this works, "allows a function (the decorator) to
      # wrap and modify or extend the behavior of another function or method without
      # changing its source code"

      # Example here, I was able to have a wrapper function that calculates how long
      # a particular
```

```

# function takes, and I can input an entire functions into it

def time_taken(func):
    @functools.wraps(func)
    def wrapper(*args):
        start = timer() # Stat here

        result = func(*args) # My Process I want to time

        end = timer() # Ending with this
        time_taken = end - start # seconds
        return time_taken,result

    return wrapper

@time_taken
def lst_random(nos):
    return [np.random.random() for i in range(nos)]

calling_it_10000_time,calling_it_10000_data = lst_random(10_000)

print(f"it took {calling_it_10000_time}seconds when called 10,000 times")

```

it took 0.03188369993586093seconds when called 10,000 times

```

[35]: # 2.
# Healthy Replacement for ? np.random.random

print(np.random.random.__doc__)

```

```

random(size=None)

```

Return random floats in the half-open interval [0.0, 1.0). Alias for  
`random\_sample` to ease forward-porting to the new random API.

```

[13]: # 2. Cont...

random_lst = np.random.random(10_000)
len(random_lst)

@time_taken
def single_call_random_number(nos):
    return np.random.random(nos)

```

```
calling_it_once_time,calling_it_once_data = single_call_random_number(10_000)

print(f"it took {calling_it_once_time}seconds when called once")
```

it took 8.779997006058693e-05seconds when called once

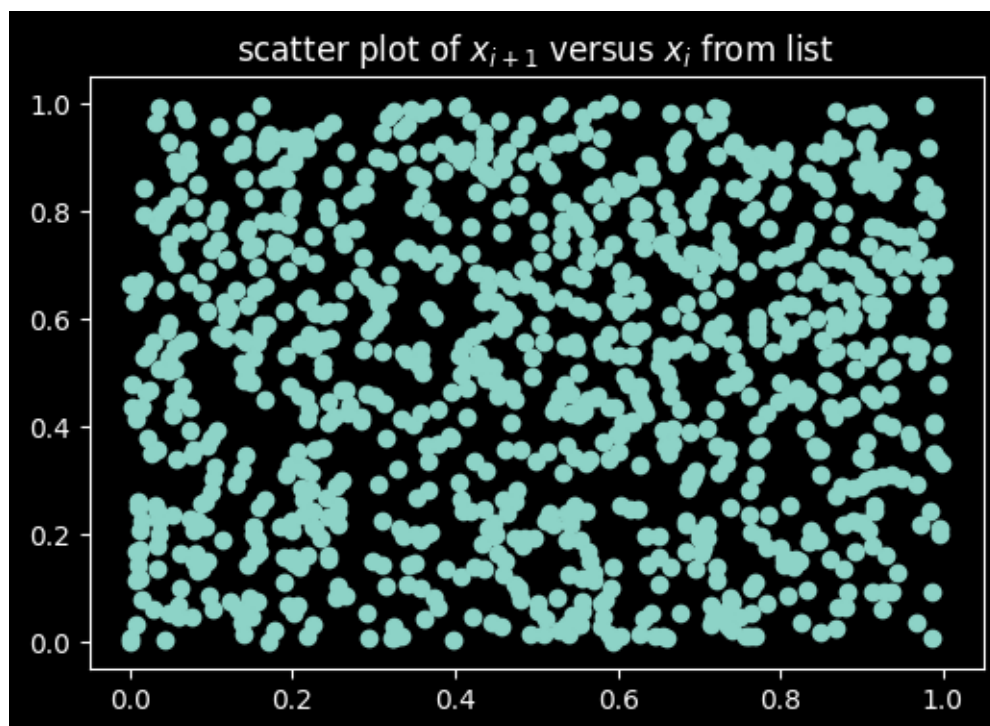
[14]: # 3.

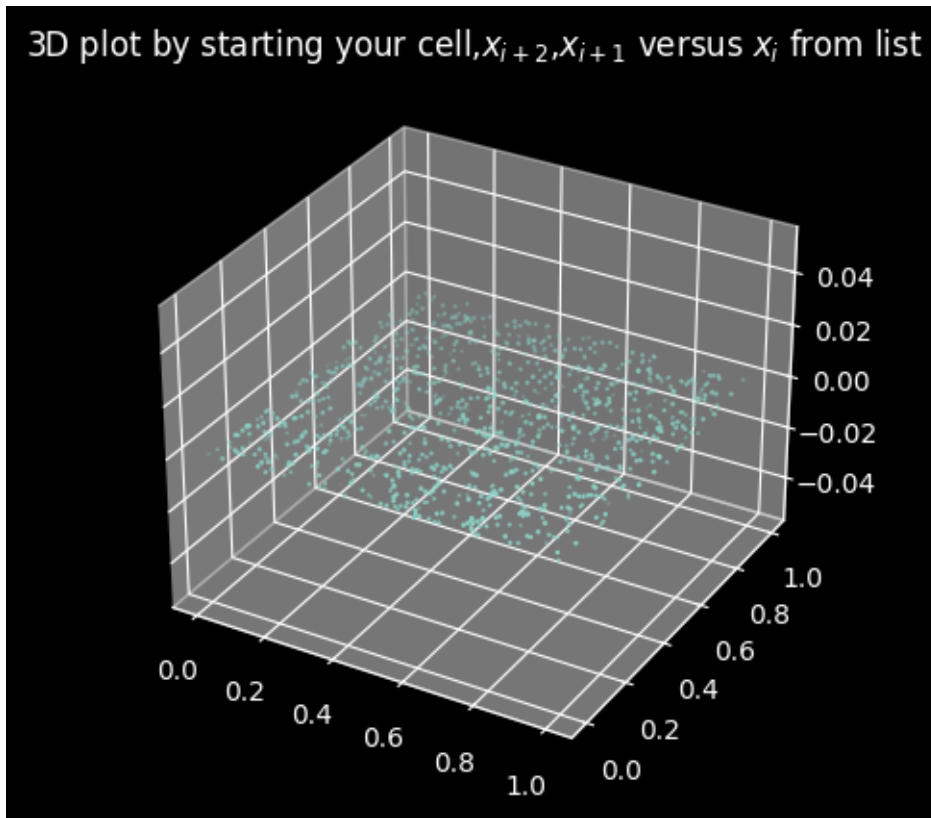
```
print(f"Calling it once is {calling_it_10000_time/calling_it_once_time} times_
↪faster")
```

Calling it once is 363.1402142148725 times faster

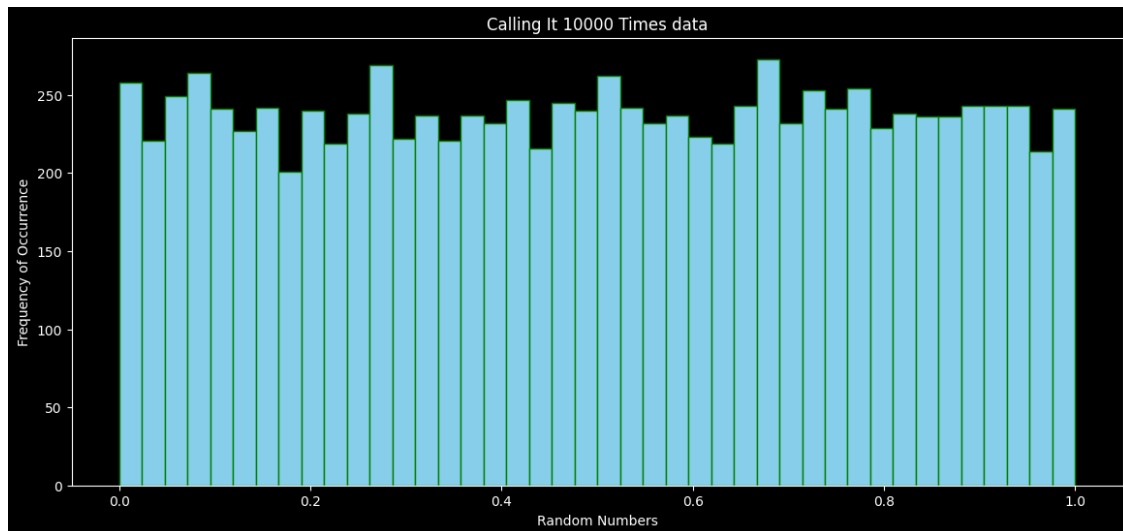
[15]: # 4.

```
plt.figure()
plt.figure(figsize=(14,6))
plt.hist(calling_it_10000_data, bins=42,color="skyblue",edgecolor='green')
plt.ylabel("Frequency of Occurrence")
plt.xlabel("Random Numbers")
plt.title("Calling It 10000 Times data")
plt.show()
```





<Figure size 640x480 with 0 Axes>



5.

Starting with too many binds, we just see all the numbers and none of the are grouped.

It looks as expected, there is not any accumulation of values in any bin, there is no “preferred” number the software chooses, so it does largely look random.

6.

Using Poisson counting statistics, the relative bin-to-bin fluctuation for a histogram bin with  $n$  counts is approximately

$$\frac{1}{\sqrt{n}}.$$

Requiring the relative fluctuation to be less than or equal to 5%,

$$\frac{1}{\sqrt{n}} \leq 0.05,$$

gives

$$n \geq 400$$

counts per bin.

With a total of  $N = 10,000$  uniformly distributed samples and  $B$  histogram bins, the expected number of counts per bin is

$$n \approx \frac{N}{B}.$$

Requiring  $n \geq 400$  therefore gives

$$\frac{N}{B} \geq 400 \quad \Rightarrow \quad B \leq \frac{10,000}{400} = 25.$$

Hence, the maximum number of bins that keeps relative bin-to-bin fluctuations below 5% is

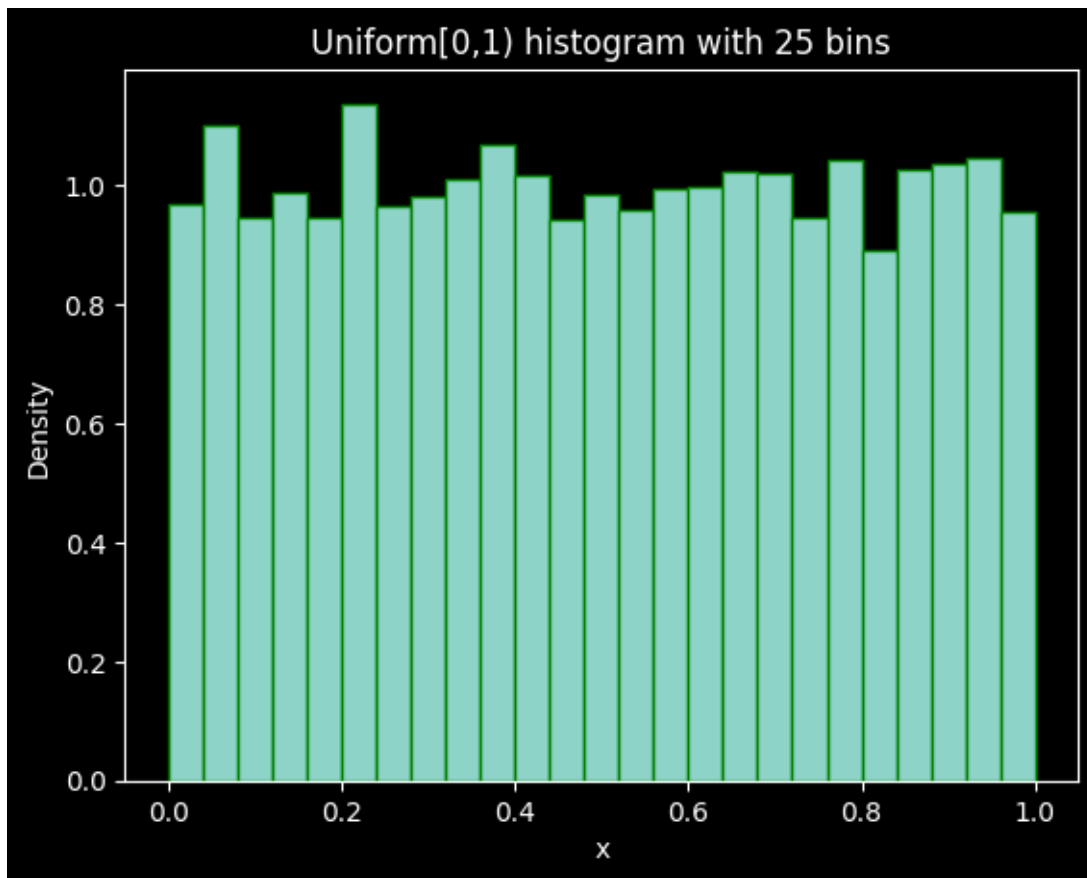
$$B_{\max} = 25.$$

**Source:** (Bevington & Robinson, *Data Reduction and Error Analysis for the Physical Sciences*).

```
[16]: # 6. cont...

plt.figure()
plt.hist(calling_it_once_data, bins=25, density=True, edgecolor='green')
plt.xlabel("x")
plt.ylabel("Density")
plt.title("Uniform[0,1) histogram with 25 bins")
plt.show()
```






---

### 0.0.3 Task 3

Going to simulate a stochastic process and show that a histogram of a sample of randomly generated data matches the known statistical distribution for the process.

Use Python to generate random numbers that are sampled from a variety of known distributions.

**Radioactive decay** An unstable nucleus has a probability  $r$  per unit time for turning into a different isotope. If one watches such a first-order decay process (a death process) and records how long it took for each decay to happen, one has a list of decay times.

**1. Derivation of the decay probability distribution** Let  $P_{\text{not yet}}(t)$  be the probability that a radioactive decay has **not occurred** up to time  $t$ .

We are given that  $r \Delta t$  is the probability that a decay occurs in a small time interval  $\Delta t$ .

**Probability of *not* decaying in a small interval**

If the probability that a decay occurs in  $\Delta t$  is  $r \Delta t$ , then the probability that a decay **does not** occur in  $\Delta t$  is  $1 - r \Delta t$ .

### Survival to $t + \Delta t$

For the nucleus to survive until time  $t + \Delta t$ :

- it must not have decayed up to time  $t$ , and
- it must not decay in the interval  $\Delta t$ .

Therefore,

$$P_{\text{not yet}}(t + \Delta t) = P_{\text{not yet}}(t) (1 - r \Delta t).$$

### Forming the differential equation

Subtract  $P_{\text{not yet}}(t)$  from both sides:

$$P_{\text{not yet}}(t + \Delta t) - P_{\text{not yet}}(t) = -r \Delta t P_{\text{not yet}}(t).$$

Divide by  $\Delta t$ :

$$\frac{P_{\text{not yet}}(t + \Delta t) - P_{\text{not yet}}(t)}{\Delta t} = -r P_{\text{not yet}}(t).$$

Notice this is the forward difference, i.e., a numerical approximation to the first derivative.

Taking the limit  $\Delta t \rightarrow 0$  gives

$$\frac{dP_{\text{not yet}}}{dt} = -r P_{\text{not yet}}(t).$$

### Solving for $P_{\text{not yet}}(t)$

Separating variables:

$$\frac{dP_{\text{not yet}}}{P_{\text{not yet}}} = -r dt.$$

Integrating and exponentiating:

$$P_{\text{not yet}}(t) = C e^{-rt}.$$

Using the condition that the decay has not occurred at  $t = 0$  ( $P_{\text{not yet}}(0) = 1$ ) gives  $C = 1$ , so

$$P_{\text{not yet}}(t) = e^{-rt}.$$

### Relating $P_{\text{not yet}}(t)$ to $p_{\text{now}}(t)$

The probability that the decay occurs **at time**  $t$  is the probability that it has not yet occurred by time  $t$ , but does occur immediately after. Thus the probability density is

$$p_{\text{now}}(t) = -\frac{d}{dt} P_{\text{not yet}}(t) = r e^{-rt}.$$

### Final result

$$p_{\text{now}}(t) = r e^{-rt}.$$

[17]: # 2.

r = 1

```

dt = 0.1 # Delta t

print(f"r * dt= {r*dt}")

@time_taken
def decay_simulation(nos):
    decay_times = []
    for i in range(nos):
        t = 0
        while True:
            if np.random.random() < r * dt:
                decay_times.append(t)
                break
            t += dt

    return decay_times

decay_time_taken, decay_times = decay_simulation(10_000)
print(f"Simulation Took: {decay_time_taken:3f} seconds ")

print(decay_times)

```

r \* dt= 0.1

Simulation Took: 0.034343 seconds

[1.6000000000000003, 0.6, 1.8000000000000005, 1.7000000000000004,  
1.7000000000000004, 0.2, 0.4, 0.5, 0.9999999999999999, 0.2, 0,  
2.6000000000000001, 0.30000000000000004, 0.6, 0, 0.4, 0.2, 2.5000000000000001, 0,  
0.4, 0.2, 0.7, 0.1, 0.30000000000000004, 0.5, 1.7000000000000004, 1.3, 0,  
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0.9999999999999999, 0.7999999999999999, 0.4, 0.7, 0.8999999999999999,  
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```

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0.7999999999999999, 0.4, 0.1, 1.2, 0.2, 0.7, 0, 0.6, 0.4, 0.5,
1.5000000000000002, 0.2]

```

[18]: # 3.

```

plt.figure()
# density=True for normalized probability density
plt.hist(decay_times, density=True, bins=50, label="Simulated")

t = np.linspace(0, max(decay_times), 100)
p_analytic = r * np.exp(-r * t)

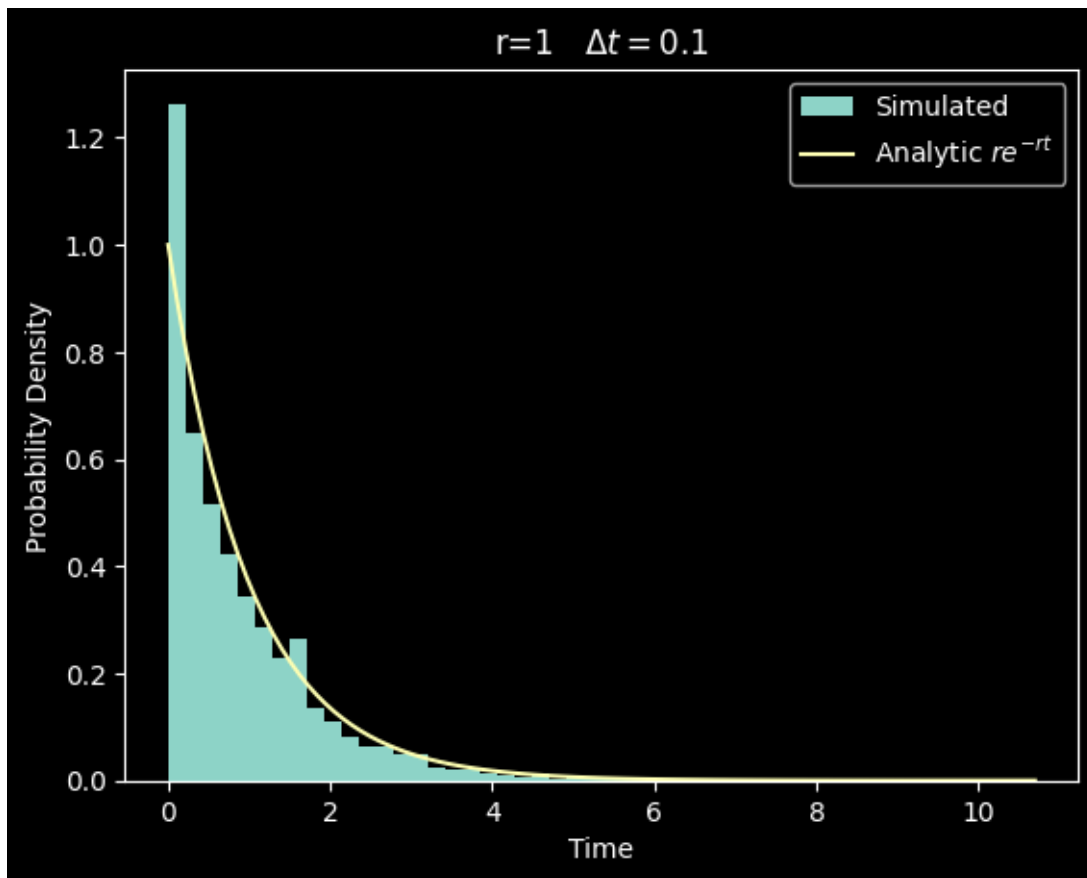
plt.plot(t, p_analytic, '-', label="Analytic  $re^{-rt}$ ")
plt.xlabel("Time")
plt.ylabel("Probability Density")
plt.title(f"r={r}     $\Delta t={dt}$ ")
plt.legend()
plt.show()

```

```

<>:14: SyntaxWarning: invalid escape sequence '\D'
<>:14: SyntaxWarning: invalid escape sequence '\D'
C:\Users\ahila\AppData\Local\Temp\ipykernel_27892\2429032632.py:14:
SyntaxWarning: invalid escape sequence '\D'
    plt.title(f"r={r}     $\Delta t={dt}$ ")

```



ANS: They Mostly Agree, Except a few places, like at time 0, where they largely diverge, usually the analytical line is able to predict the trend.

```
[19]: # 4.

r = 1
dt = 0.01 # Delta t

print(f"r * dt= {r*dt}")

@time_taken
def decay_simulation(nos):
    decay_times = []
    for i in range(nos):
        t = 0
        while True:
            if np.random.random() < r * dt:
                decay_times.append(t)
                break
```

```

        t += dt

    return decay_times

decay_time_taken, decay_times = decay_simulation(1000)
print(f"Simulation Took: {decay_time_taken} seconds ")

plt.figure()
# density=True for normalized probability density
plt.hist(decay_times, density=True, bins=50, label="Simulated")

t = np.linspace(0, max(decay_times), 100)
p_analytic = r * np.exp(-r * t)

plt.plot(t, p_analytic, '-', label="Analytic  $re^{-rt}$ ")
plt.xlabel("Time")
plt.ylabel("Probability Density")
plt.title(f"r={r}     $\Delta t$ ={dt}")
plt.legend()
plt.show()


r = 1
dt = 0.001 # Delta t

print(f"r * dt= {r*dt}")

@time_taken
def decay_simulation(nos):
    decay_times = []
    for i in range(nos):
        t = 0
        while True:
            if np.random.random() < r * dt:
                decay_times.append(t)
                break
            t += dt

    return decay_times

decay_time_taken = decay_simulation(1000)[0]
decay_times = decay_simulation(1000)[1]
print(f"Simulation Took: {decay_time_taken} seconds ")

```

```

plt.figure()
# density=True for normalized probability density
plt.hist(decay_times, density=True, bins=50, label="Simulated")

t = np.linspace(0, max(decay_times), 100)
p_analytic = r * np.exp(-r * t)

plt.plot(t, p_analytic, '-', label="Analytic  $re^{-rt}$ ")
plt.xlabel("Time")
plt.ylabel("Probability Density")
plt.title(f"r={r}     $\Delta t={dt}$ ")
plt.legend()
plt.show()

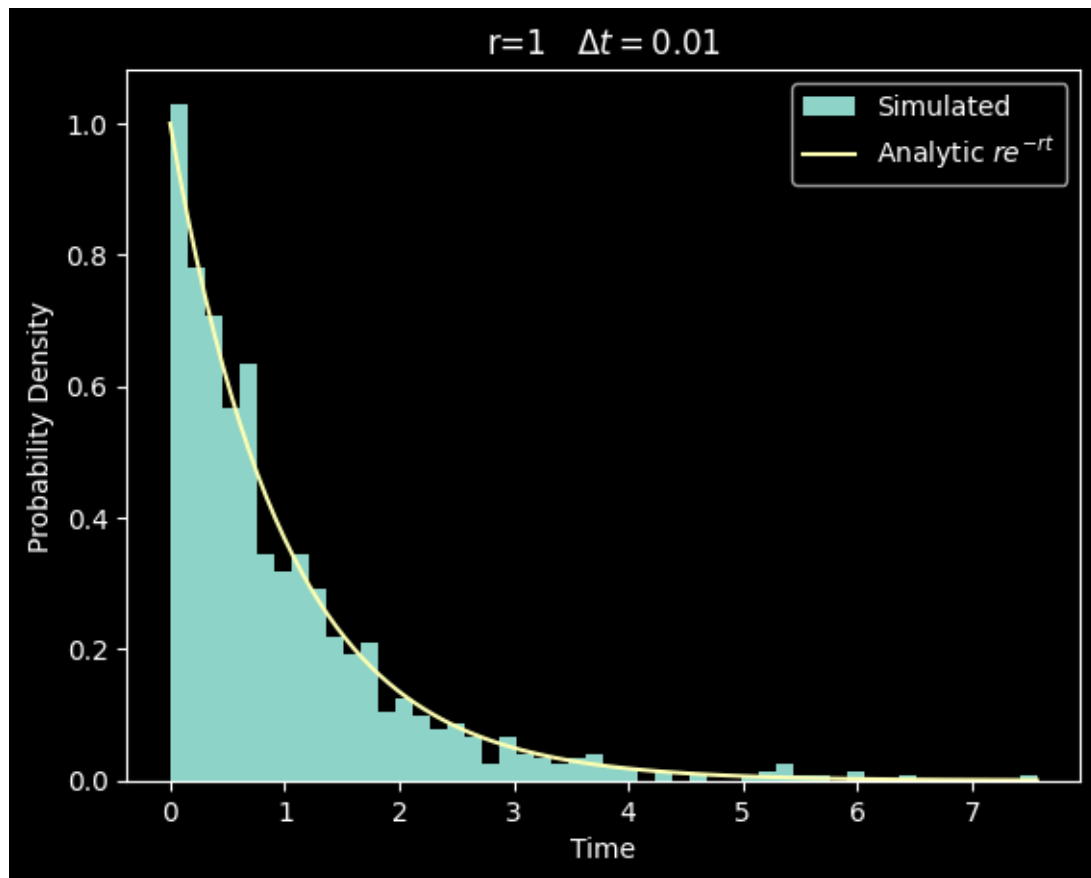
```

```

<>:36: SyntaxWarning: invalid escape sequence '\D'
<>:76: SyntaxWarning: invalid escape sequence '\D'
<>:36: SyntaxWarning: invalid escape sequence '\D'
<>:76: SyntaxWarning: invalid escape sequence '\D'
C:\Users\ahila\AppData\Local\Temp\ipykernel_27892\481941872.py:36:
SyntaxWarning: invalid escape sequence '\D'
    plt.title(f"r={r}     $\Delta t={dt}$ ")
C:\Users\ahila\AppData\Local\Temp\ipykernel_27892\481941872.py:76:
SyntaxWarning: invalid escape sequence '\D'
    plt.title(f"r={r}     $\Delta t={dt}$ ")

r * dt= 0.01
Simulation Took: 0.03156240005046129 seconds

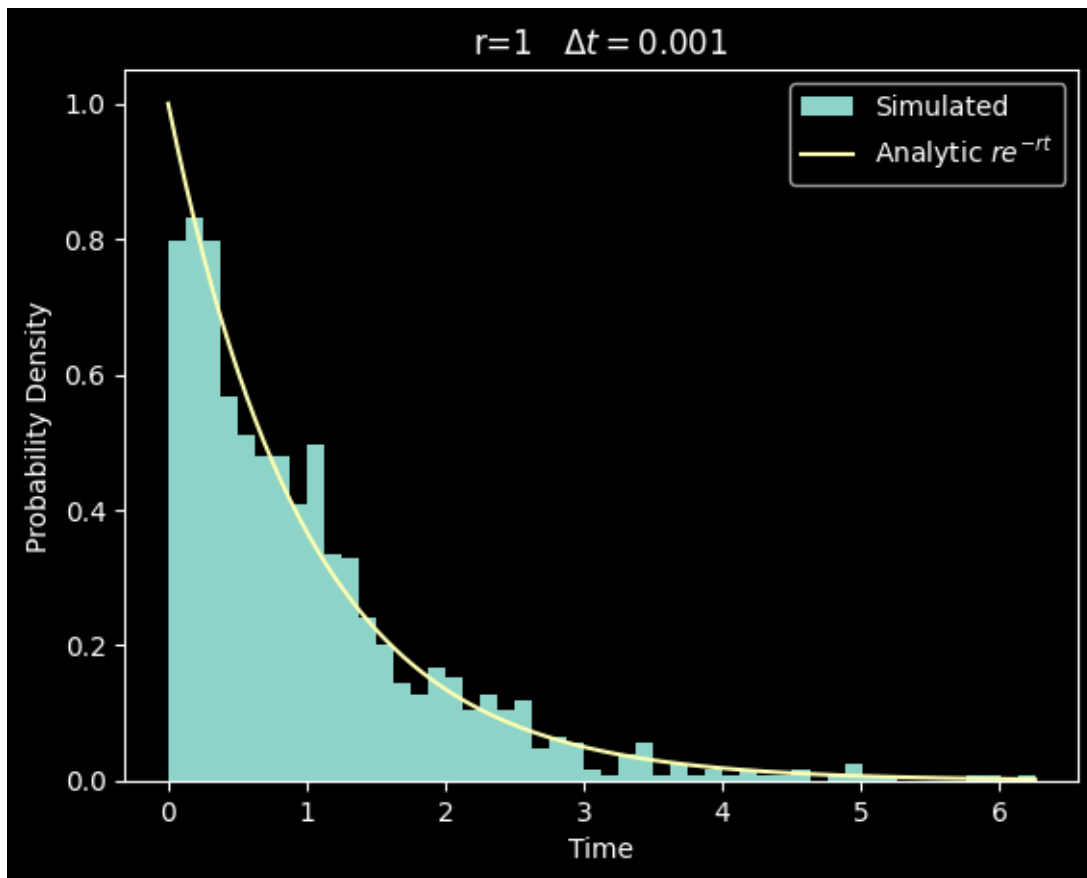
```



$r * dt = 0.001$

Simulation Took: 0.33641630003694445 seconds





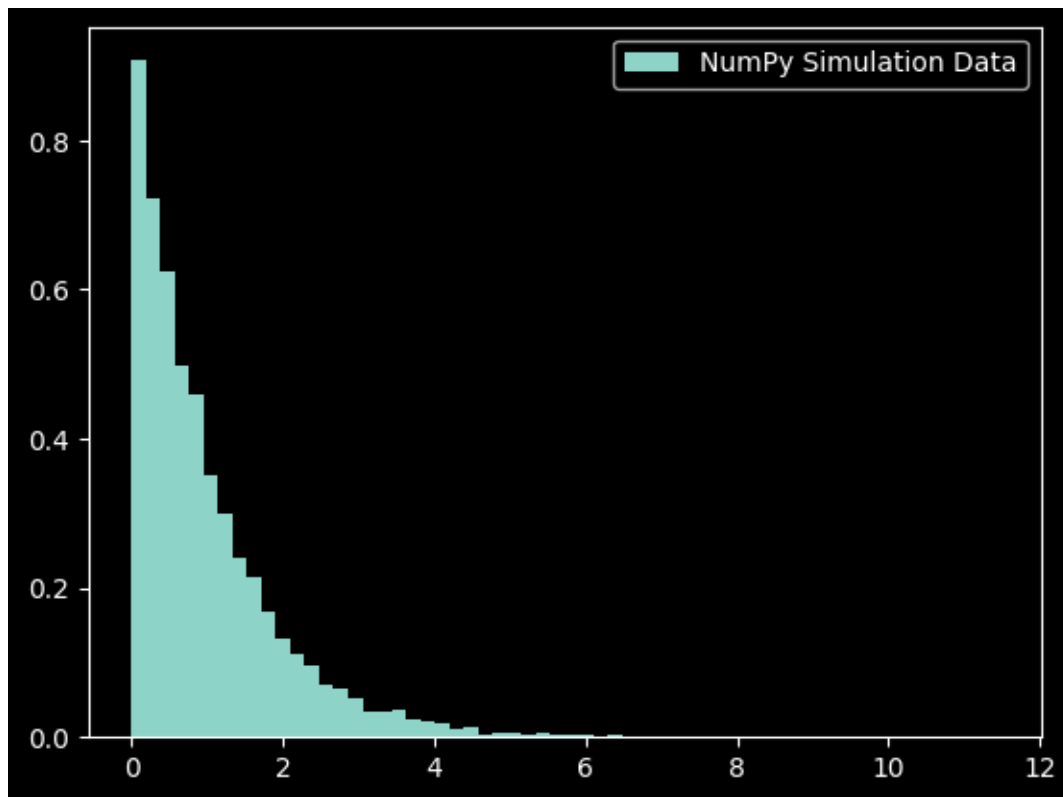
ANS: As the  $\Delta t$  got smaller, the curve and the Histogram aligned more. Note: I know I could have altered the function I made to do this more efficient but, I thought it is ok to just copy paste the same code.

```
[20]: #5.

@time_taken
def np_generator():
    numpy_function_times = np.random.exponential(scale=1/r,size=10000)
    return numpy_function_times

time,numpy_function_times= np_generator()

plt.figure()
plt.hist(numpy_function_times,bins=60,density=True,label="NumPy Simulation_
↳Data")
plt.legend()
plt.show()
```

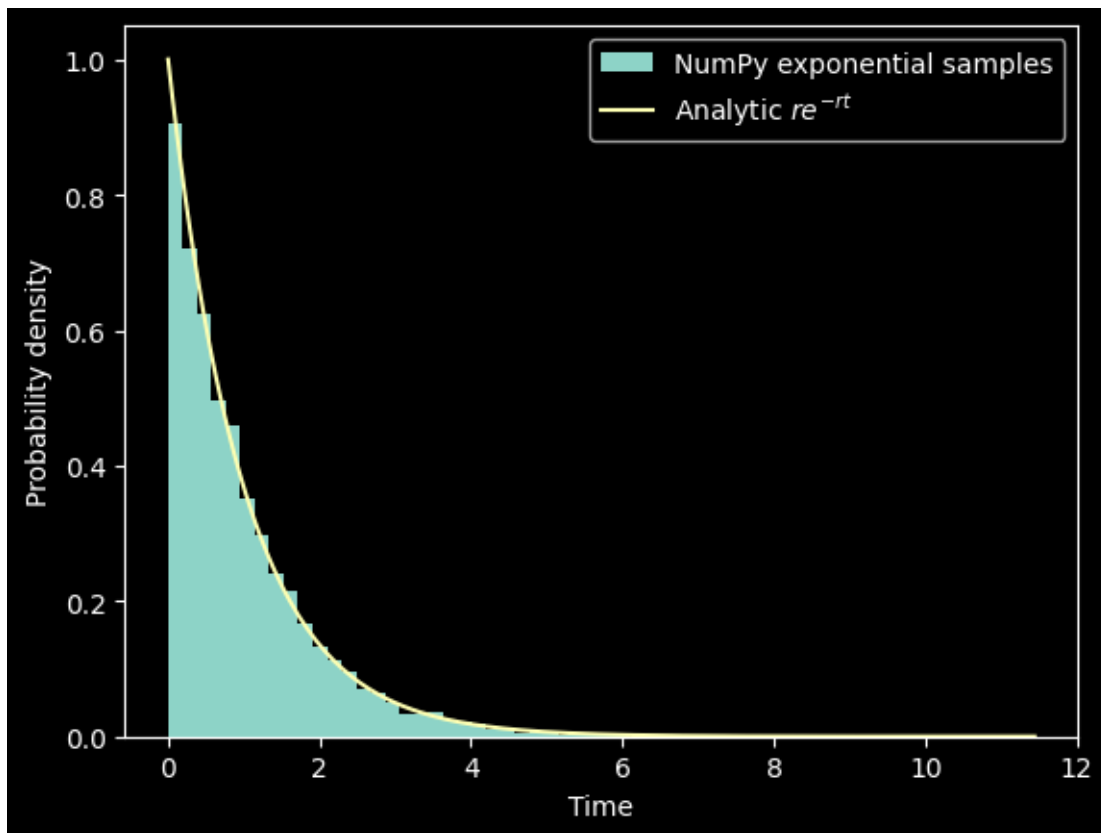


```
[21]: #6.

plt.figure()
plt.hist(numpy_function_times, bins=60, density=True, label="NumPy exponential_
↳samples")

t_np = np.linspace(0, max(numpy_function_times), 200)
p_analytic_np = r * np.exp(-r * t_np)

plt.plot(t_np, p_analytic_np, label="Analytic $r e^{-rt}$")
plt.xlabel("Time")
plt.ylabel("Probability density")
plt.legend()
plt.show()
```



ANS: Yes it does match with the NumPy's Histogram really well. NumPy behaves as in theory.

Note: `scipy.stats` has the Poisson distribution, that you can generate random samples from

[22]: # 7.

```
import scipy.stats as stats
```

[23]: # 8.

```
# For a single single random number
r = 4; T = 5

mu = r*T

poisson_random_number = stats.poisson.rvs(mu=mu, size=1)
print(poisson_random_number)
print(f"mu = {mu}")
```

[25]

```
mu = 20
```

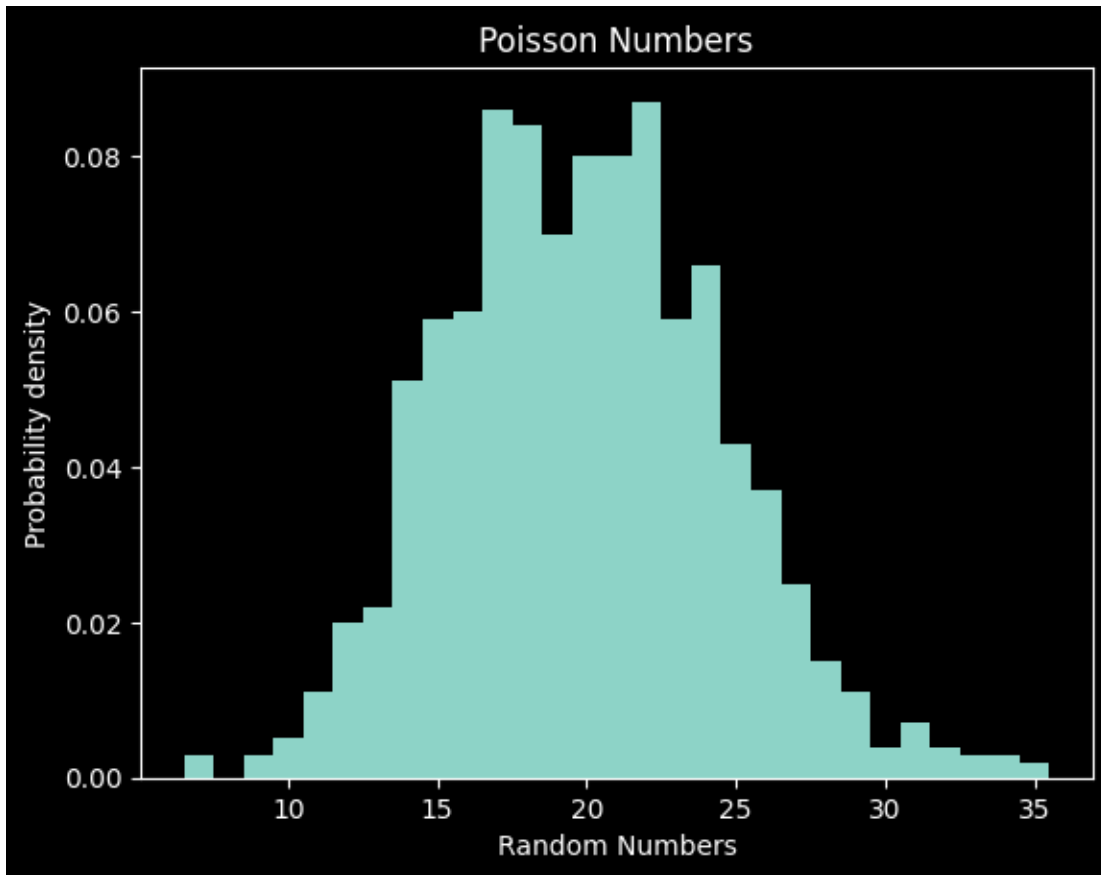
```
[24]: # 9.

plt.figure()
poisson_random_numbers = stats.poisson.rvs(mu=mu,size=1_000)

# Discrete distribution, so bins should be integers
bins = np.arange(min(poisson_random_numbers), max(poisson_random_numbers) + 2)
    ↪ - 0.5
plt.hist(poisson_random_numbers,bins=bins,density=True,label="Poisson Random
    ↪ Numbers")

plt.xlabel("Random Numbers")

plt.ylabel("Probability density")
plt.title("Poisson Numbers")
plt.show()
```



ANS: For a Poisson process the mean and variance are both equal to  $\mu$ . With 1,000 samples, the sample mean and sample variance fluctuate around the true value  $\mu$ , but by the law of large numbers they are close to  $\mu$ , as seen in the output.

NOTE: I initially put the bins as 60, and on inspection I saw that the data naturally had only 8 discrete Values in x. This made me curious, so I searched online and found the above formula to use for discrete distribution. This is so I don't have to hard code things.

```
[25]: # 3.10 Mean and Variance
print(f"Mean: {np.mean(poisson_random_numbers):.2f} (Expected {mu})")
print(f"Var: {np.var(poisson_random_numbers):.2f} (Expected {mu})")
```

Mean: 19.93 (Expected 20)

Var: 20.93 (Expected 20)

ANS: They Match really well, why???

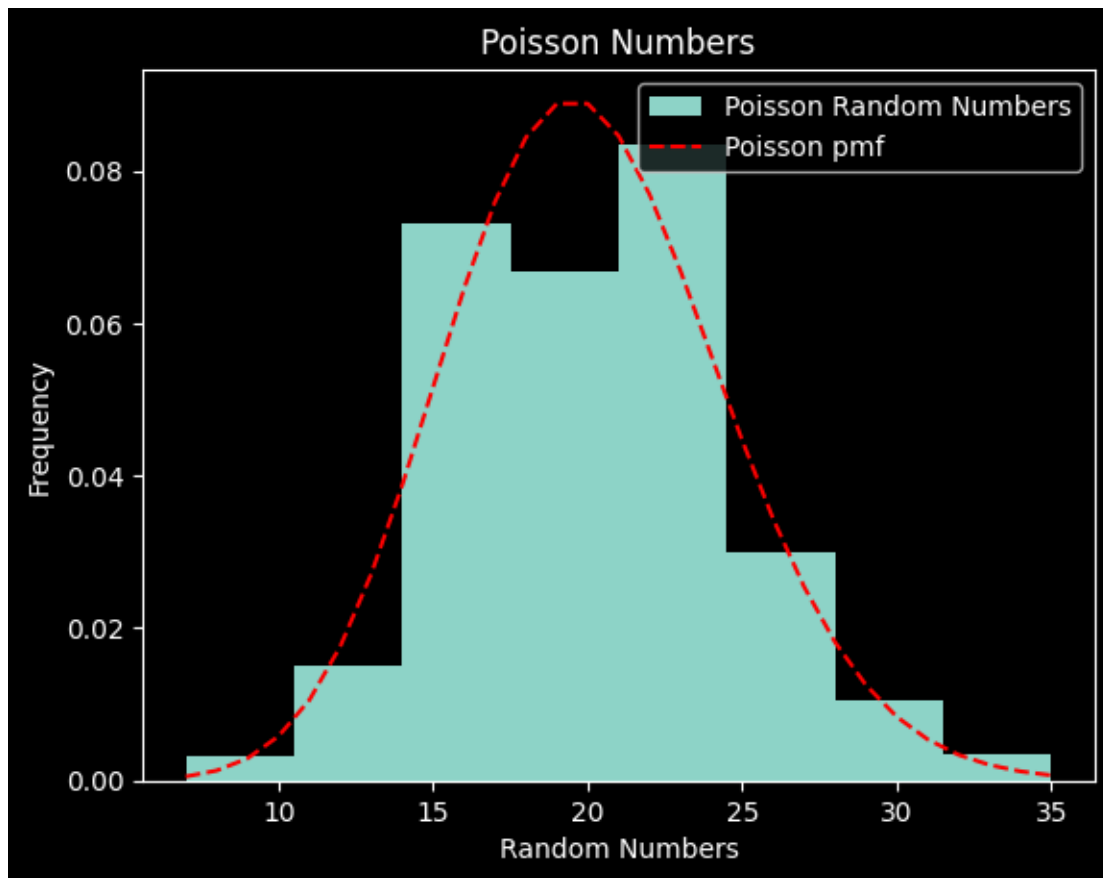
```
[26]: # 11.

plt.hist(poisson_random_numbers, bins=8, density=True, label="Poisson Random_
↪Numbers")
k = np.arange(min(poisson_random_numbers), max(poisson_random_numbers) + 1)

probability_mass_function = stats.poisson.pmf(k, mu)
plt.plot(k, probability_mass_function, 'r--', label="Poisson pmf")

plt.xlabel("Random Numbers")

plt.ylabel("Frequency")
plt.title("Poisson Numbers")
plt.legend()
plt.show()
```



Ans: They Mostly Match, the poisson random Numbers are slightly sqwed to the right but this is till a great match. I noticed that if I Increase the mu, the values are also move to the right. Which makes sense.

Ask: How do I make sure the legend and the graph do not interfere?

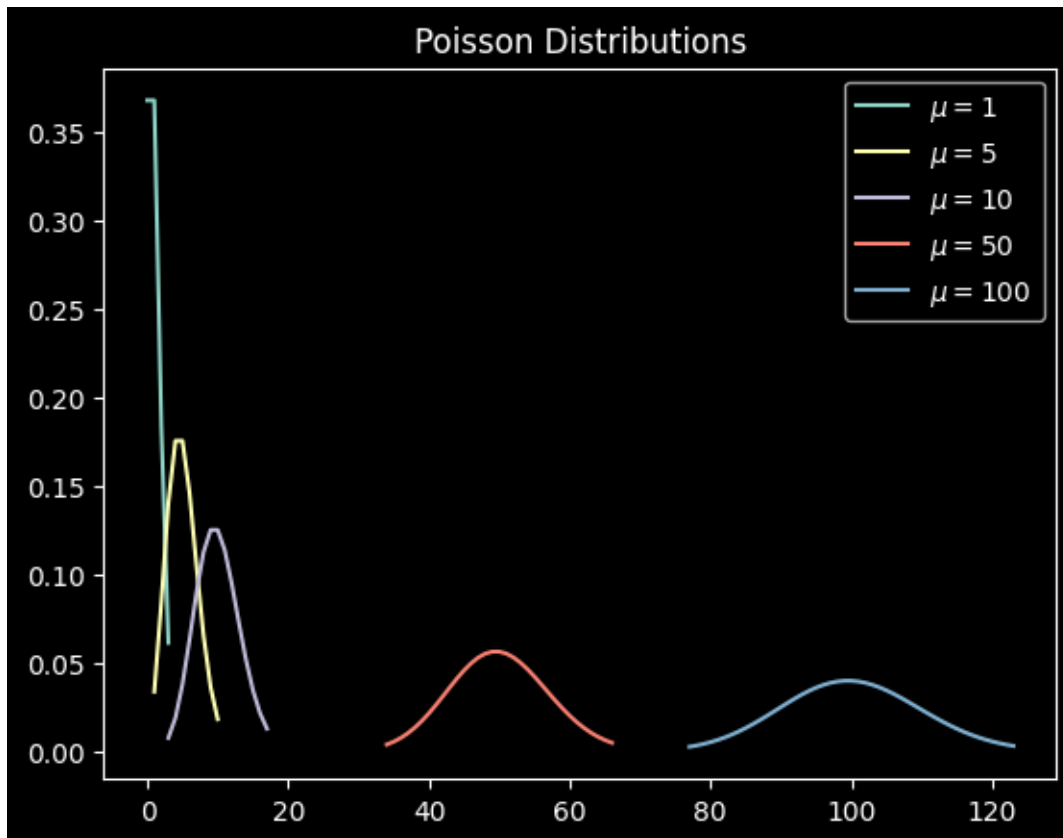
```
[27]: plt.figure()
mu_list = [1, 5, 10, 50,100]
for mu in mu_list:
    x = np.arange(stats.poisson.ppf(0.01, mu), stats.poisson.ppf(0.99, mu))
    plt.plot(x, stats.poisson.pmf(x, mu), '-', label=f"$\mu={mu}$")
plt.legend()
plt.title("Poisson Distributions")
plt.show()

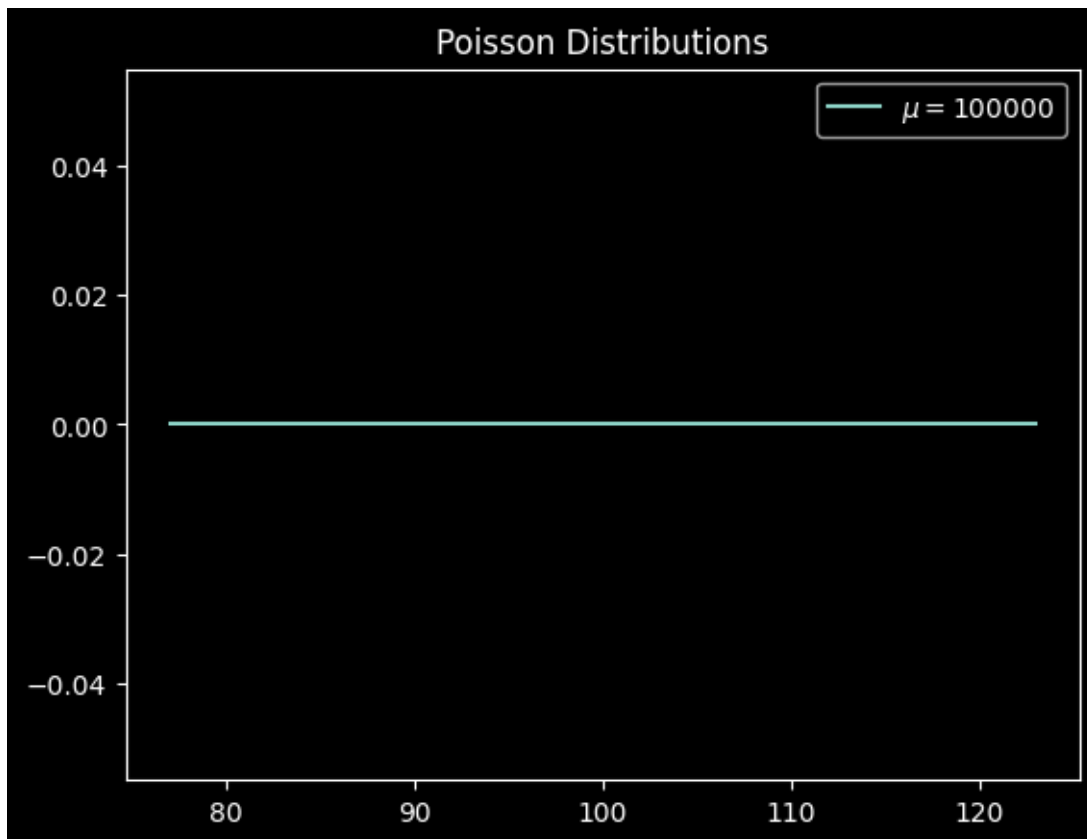
mu = 100000
plt.plot(x, stats.poisson.pmf(x, mu), '-', label=f"$\mu={mu}$")
plt.legend()
plt.title("Poisson Distributions")
plt.show()
```

```

<>:5: SyntaxWarning: invalid escape sequence '\m'
<>:11: SyntaxWarning: invalid escape sequence '\m'
<>:5: SyntaxWarning: invalid escape sequence '\m'
<>:11: SyntaxWarning: invalid escape sequence '\m'
C:\Users\ahila\AppData\Local\Temp\ipykernel_27892\3625135045.py:5:
SyntaxWarning: invalid escape sequence '\m'
    plt.plot(x, stats.poisson.pmf(x, mu), '-', label=f"$\mu={mu}$")
C:\Users\ahila\AppData\Local\Temp\ipykernel_27892\3625135045.py:11:
SyntaxWarning: invalid escape sequence '\m'
    plt.plot(x, stats.poisson.pmf(x, mu), '-', label=f"$\mu={mu}$")

```





Ans: I already answered this in 11., but again, as I increase mu (the mean) the distribution's FWHM increases, the peak height of the distribution decreases.

As we can see, for extremely small values of mu, the distribution is nearly a delta function, straight on the y axis, as we increase the value of mu, the distribution approaches a flat line on the x axis.

#### 0.0.4 Task 4.

```
[28]: #1.
a = 1
# Difference between a walk and a step is, in 1 walk, you do N steps
# so walks is no of repetition

# Pseudo COde. We want a generator to generate N(steps) numbers and repeat this
↳ walks number of times.
# This Generator must only choose randomly between -1 and + 1

walks_nos = 10_000
N_list = [10,20,30,40,50,100,1000]

# This above track could have worked but it would have been long.
```



```

# If we are already told we need random numbers with the size = (N,
↳ steps, walks_no),
# we can put this into the np.random.choice

def random1D_walk(N,a=1,walks_nos=walks_nos):
    steps = np.random.choice([-a,+a],size=(N,walks_nos))

    displacements = np.sum(steps, axis=0) ### ASKKKKKKKK
    return displacements

steps_10 = random1D_walk(10)
steps_20 = random1D_walk(20)
steps_30 = random1D_walk(30)
steps_40 = random1D_walk(40)
steps_50 = random1D_walk(50)
steps_100 = random1D_walk(100)
steps_1000 = random1D_walk(1_000)

```

```

[29]: # 2. Mean Displacement
displacement_list =
↳ [steps_10,steps_20,steps_30,steps_40,steps_50,steps_100,steps_1000]
N_list = [10,20,30,40,50,100,200]
i = -1

for displacemen,N in zip(displacement_list, N_list):
    i += 1
    mean_disp_endToend = (np.mean(displacemen))

    print(f"N={N_list[i]} ---- Mean End to End Displacement=
↳ {mean_disp_endToend:.3f} | Abs Distance {abs(mean_disp_endToend):.3f}")

#

```

```

N=10 ---- Mean End to End Displacement= 0.016 | Abs Distance 0.016
N=20 ---- Mean End to End Displacement= 0.015 | Abs Distance 0.015
N=30 ---- Mean End to End Displacement= 0.001 | Abs Distance 0.001
N=40 ---- Mean End to End Displacement= -0.041 | Abs Distance 0.041
N=50 ---- Mean End to End Displacement= 0.089 | Abs Distance 0.089
N=100 ---- Mean End to End Displacement= 0.027 | Abs Distance 0.027
N=200 ---- Mean End to End Displacement= -0.273 | Abs Distance 0.273

```

Not the most efficient but gets the job done

3. I expected the mean to approach zero as we take more Steps, but there is some reason why it goes near zero at  $N = 40$  and increases a little. Maybe just random fluctuations and some systematic noise? This is regardless of how many times I run the program

```
[30]: #4.

i = -1
msd = [] # List to store Mean Squared Displacements

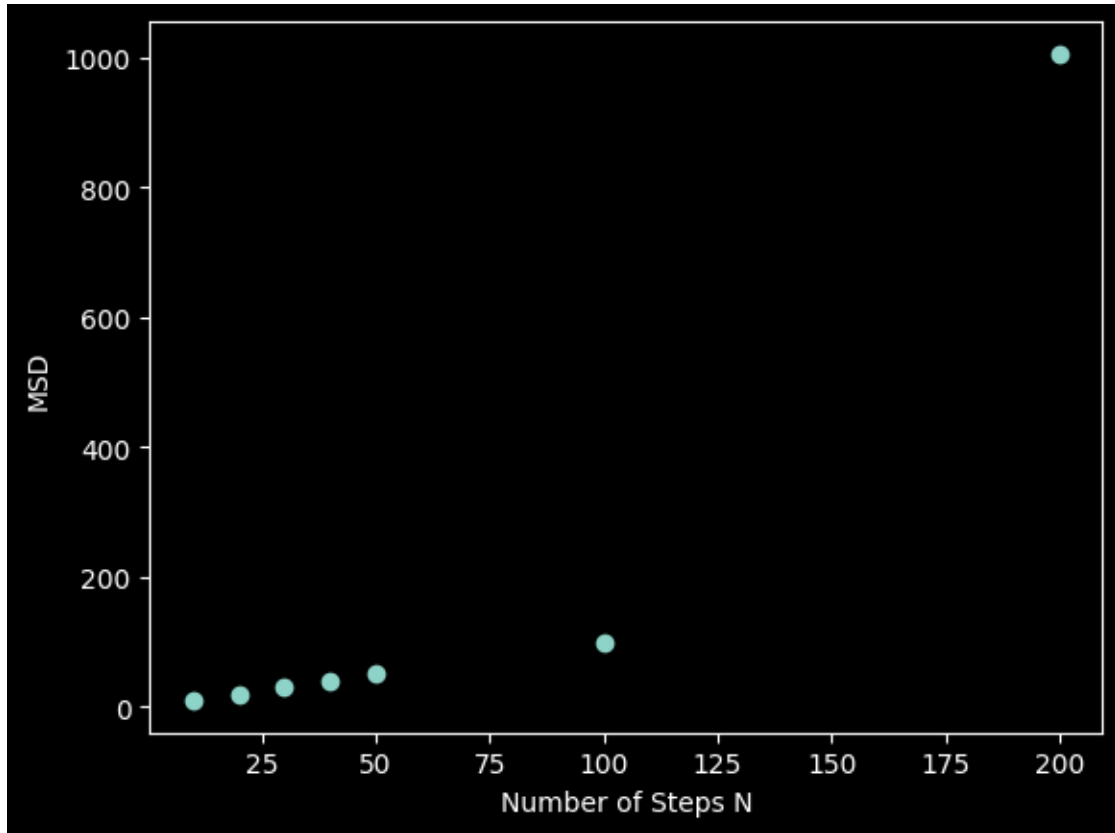
for displacemen,N in zip(displacement_list, N_list):
    i += 1
    mean_sqdisp_endToend = (np.mean(displacemen**2))
    msd.append(mean_sqdisp_endToend)

    print(f"N={N_list[i]} ---- Mean sqared End to End Displacement=  ␣
↪{mean_disp_endToend:.3f}")

# msd vs N
plt.scatter(N_list,msd)

plt.xlabel("Number of Steps N")
plt.ylabel("MSD")
plt.show()
```

```
N=10 ---- Mean sqared End to End Displacement= -0.273
N=20 ---- Mean sqared End to End Displacement= -0.273
N=30 ---- Mean sqared End to End Displacement= -0.273
N=40 ---- Mean sqared End to End Displacement= -0.273
N=50 ---- Mean sqared End to End Displacement= -0.273
N=100 ---- Mean sqared End to End Displacement= -0.273
N=200 ---- Mean sqared End to End Displacement= -0.273
```



## 5. Deviation Math

- a) Because each step has  $dx_i = \pm a$ , as  $N$  grows large the expected displacement must approach zero. We take almost equal numbers of steps left and right, so

$$\sum_{i=1}^N \langle dx_i \rangle = 0 = \langle r(N) \rangle.$$

- b) Since steps are uncorrelated, one step does not affect another, giving

$$\langle r(N)^2 \rangle = \sum_{i=1}^N \langle dx_i^2 \rangle + \sum_{i \neq j} \langle dx_i dx_j \rangle.$$

Using the facts that  $\langle dx_i \cdot dx_j \rangle = \langle dx_i \rangle \langle dx_j \rangle = 0$  and  $(\pm 1)^2 = 1$  so  $\langle dx_i^2 \rangle = 1$ , we obtain

$$\langle r(N)^2 \rangle = \sum_{i=1}^N 1 + \sum_{i \neq j} \langle dx_i dx_j \rangle = N.$$

**Finally,**  $\langle r(N)^2 \rangle = N$ .

```
[31]: # 6.

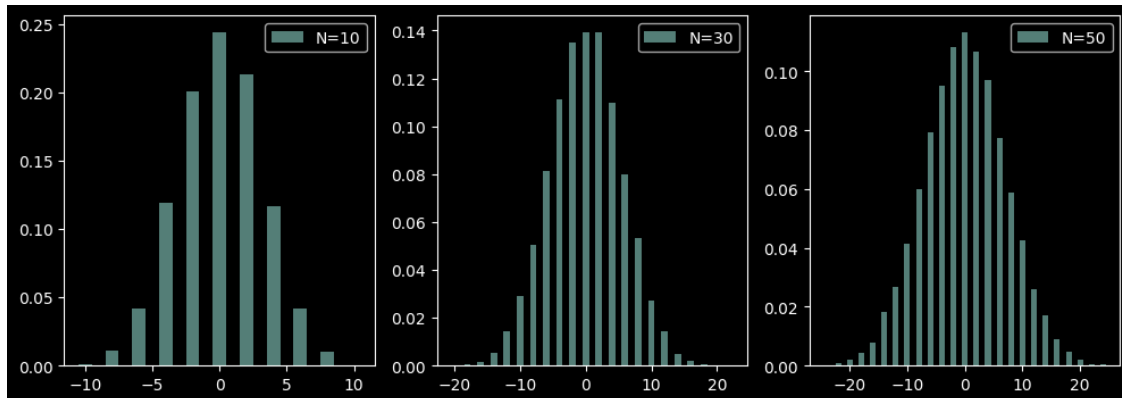
plt.figure(figsize=(12, 4))
N_plot = [10, 30, 50]

for i, N in enumerate(N_plot): # Gives a pair of index and the value as:
    # (0, N_plot[0]) ... (3, N_plot[3]) ...
    plt.subplot(1, 3, i+1)
    data = random1D_walk(N)

    # Histogram
    # Binning: ensure bins cover the range. Steps are integers, displacements
    # differ by 2
    bins = np.arange(min(data), max(data) + 2) - 0.5
    plt.hist(data, bins=bins, density=True, alpha=0.6, label=f"N={N}")

plt.legend()

#plt.tight_layout()
plt.show()
```



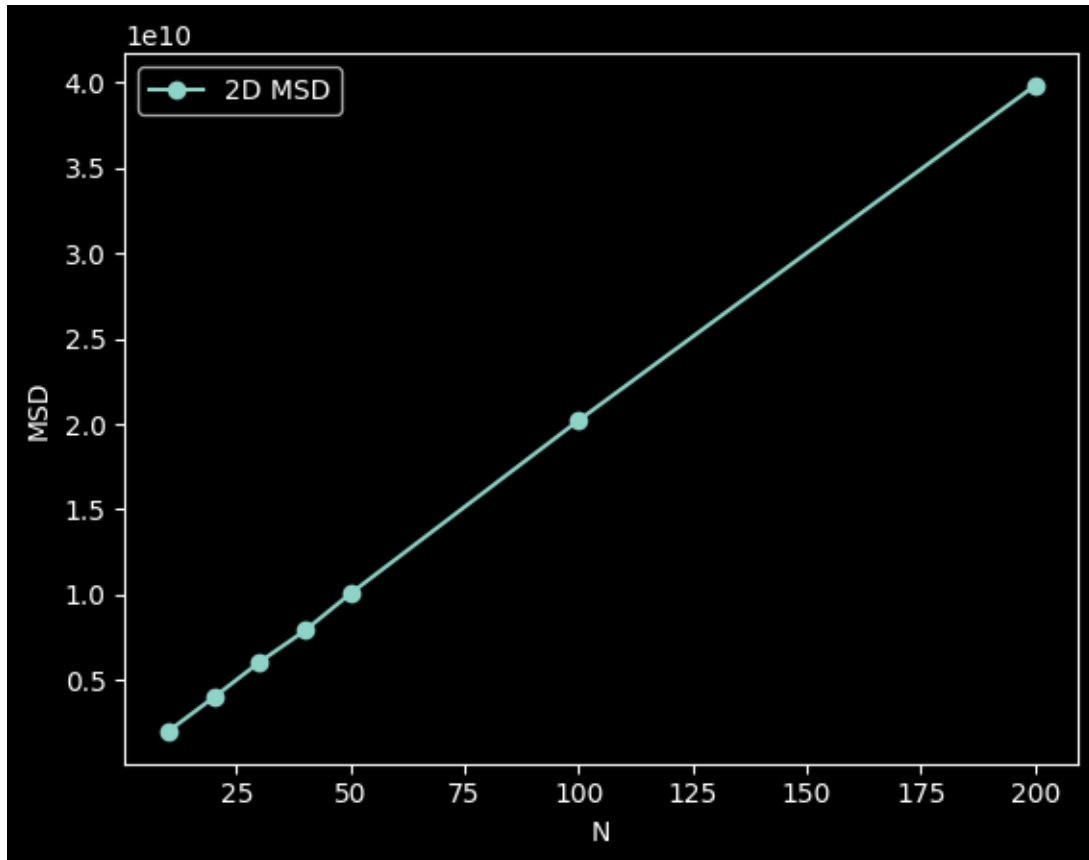
Ans: Yes, As the Values for N increaes, more and more the Graph resembles like a Gaussian

```
[32]: def simulate_2d_walks(N, num_walks=10000):
    # X steps and Y steps are independent 1D walks
    x_disp = random1D_walk(N, num_walks)
    y_disp = random1D_walk(N, num_walks)
    r2 = x_disp**2 + y_disp**2
    return r2

msd_2d = []
for N in N_list:
```

```
r2 = simulate_2d_walks(N)
msd_2d.append(np.mean(r2))

plt.figure()
plt.plot(N_list, msd_2d, 'o-', label="2D MSD")
plt.xlabel("N")
plt.ylabel("MSD")
plt.legend()
plt.show()
```



## Task 5: Wrap up 5.1 Confusing Questions

### 5.2 General Feedback