



Project Report: PH301

*Simulating an ecosystem and drawing
comparisons between population growth of
different species and a random walk*

Anurag Sanjay

200121007

anurag.kadam@iitg.ac.in

Btech Engineering Physics

Department of Physics

November 9, 2022

Abstract

In this project I have written a Python program simulating an ecosystem with various species mutually interacting through a food chain in order to study process of population growth/evolution through the tools of statistics.

A lot of these interactions happen seemingly randomly. This motivates the study of this system similar to a random walk, which is one of the most fundamental ideas in statistics.

I have run this simulation very many times and observed the resulting frequency distribution.

1 Motivation

I am fascinated with ecosystems and how the mutual interactions of all the organisms in a location control the trend of population growth of each species. With the sheer number of individual organisms and the various ways in which they interact, it seemed plausible to try to understand the evolution of population with a statistical description of this system.

With the knowledge of this complexity and randomness involved in all the interactions, I was motivated to code a miniature simulation with various species (eight) interacting and evolving following a food chain. I gave each species a set of genes which governs how and to what extent they reproduce, interact with other species etc. I also added in realistic factors such as natural death and random mutations.

With all the randomness involved, this model of evolution seems similar to a random walk problem, but in multiple dimensions. Hence, after running a large number of simulations (to get an ensemble), we should expect results similar to those of a random walk problem.

2 Expected Outcome

After plotting the final populations of each species after running a large number of simulations starting from the same starting point and for the same duration, we should get a plot approaching gaussian distribution.

3 Theory Involved

I Random Walk

In mathematics, a random walk is a random process that describes a path that consists of a succession of random steps on some mathematical space.

An elementary example of a random walk is the random walk on the integer number line which starts at 0, and at each step moves +1 or -1 with equal probability. Other examples include the path traced by a molecule as it travels in a liquid or a gas (see Brownian motion), the search path of a foraging animal, or the price of a fluctuating stock and the financial status of a gambler. Random walks have applications to engineering and many scientific fields including ecology, psychology, computer science, physics, chemistry, biology, economics, and sociology. The term random walk was first introduced by Karl Pearson in 1905.

The larger the number of times the random walk is performed, the more the frequency distribution of the final position approaches a gaussian distribution.

II Gaussian distribution

In statistics, a normal distribution or Gaussian distribution is a type of continuous probability distribution for a real-valued random variable. The general form of its probability density function is

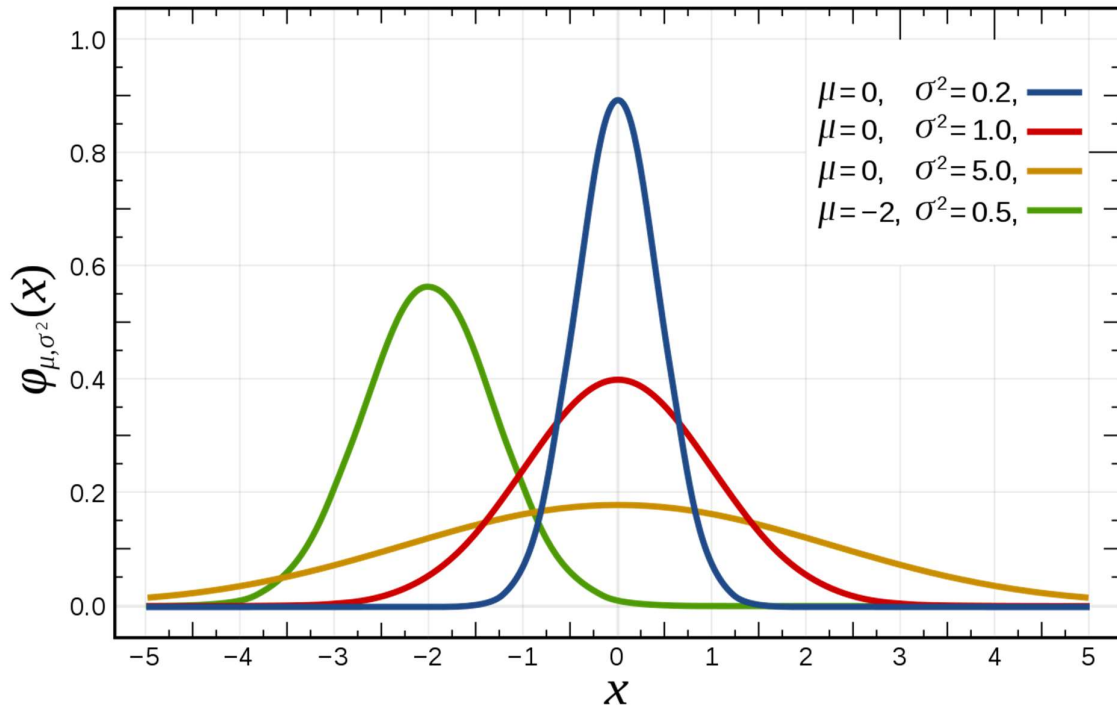
$$y = \frac{1}{\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma}$$

$$\mu = \text{Mean}$$
$$\sigma = \text{Standard Deviation}$$

The parameter μ is the mean or expectation of the distribution (and also its median and mode), while the parameter σ is its standard deviation. The variance of the distribution is σ^2 . A random variable with a Gaussian distribution is said to be normally distributed, and is called a normal deviate.

Normal distributions are important in statistics and are often used in the natural and social sciences to represent real-valued random variables whose distributions are not known. Their importance is partly due to the central limit theorem. It states that,

under some conditions, the average of many samples (observations) of a random variable with finite mean and variance is itself a random variable—whose distribution converges to a normal distribution as the number of samples increases. Therefore, physical quantities that are expected to be the sum of many independent processes, such as measurement errors, often have distributions that are nearly normal. Consequently, the observations of a large number of random walks also follow a Gaussian distribution.



III Factors controlling population evolution

- **Reproduction** – Reproduction in organisms is responsible for rise in population size
- **Mutation** – If species happen to get favorable mutations, their population grows
- **Death** – Death, either by natural causes, or being eaten by a predator cause the population rise to slow down

4 Methodology

I.Programing Language used

Python 3

II.Species programmed

1. Grass
2. Trees
3. Birds
4. Bugs
5. Tigers
6. Bears
7. Chickens
8. Buffalos

III. Genetic code for each species

	grass	trees	birds	bugs	tigers	bears	chicken	buffaloes
taste	32	32	40	48	-1	-1	32	48
speed	-1	-1	48	24	68	56	32	40
visibility	-1	-1	56	64	36	52	40	52
luminosity	-1	-1	-1	0	-1	-1	-1	-1
strength	-1	-1	-1	-1	72	60	-1	48
neck_length	-1	-1	-1	-1	-1	-1	-1	24
no_of_offsprings	40	16	8	64	8	8	12	8
reproduction_frequency	60	25	28	68	14	14	52	14
growth_rate	50	30	-1	-1	-1	-1	-1	-1
size	10	60	8	2	25	25	10	20
permanent_attributes								
plant	1	1	0	0	0	0	0	0
time_since_reproduced	30	30	30	30	30	30	30	30
hunger	-1	-1	40	40	40	40	40	40
sexual_reproduction	0	0	1	1	1	1	1	1
lifespan	12	70	16	5	50	50	13	30
index	0	1	2	3	4	5	6	7
age	0	0	0	0	0	0	0	0
initial_population	200	15	40	100	3	3	20	15

IV.Reproduction

There are two types of reproduction used - asexual and sexual.

In this simulation, grass and trees reproduces asexually whereas the animals reproduce sexually.

The difference is, in asexual reproduction identical copies of one parent are created, but in sexual reproduction, offsprings are created by taking the mean of genes of both the parents.

V.Mutation

After every instance of reproduction, an individual of the offspring generation is given some random mutation to their genetic code with a probability equal to the mutation probability (MUTATION_PROB).

This happens regardless of the type of reproduction.

VI.Nutrition

All animals (no grass and trees) are fed based on the implemented food chain. This step also depends on specific genes of the individual, speed (to catch the prey, or escaping from the predators).

VII.Natural Death

If an individual is hungry beyond a certain threshold, or if it crosses its species' life expectancy, it dies.

VIII.Putting it all together

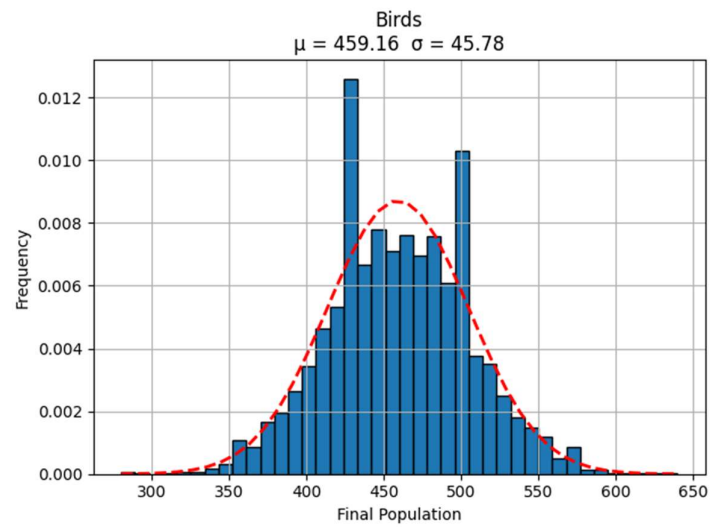
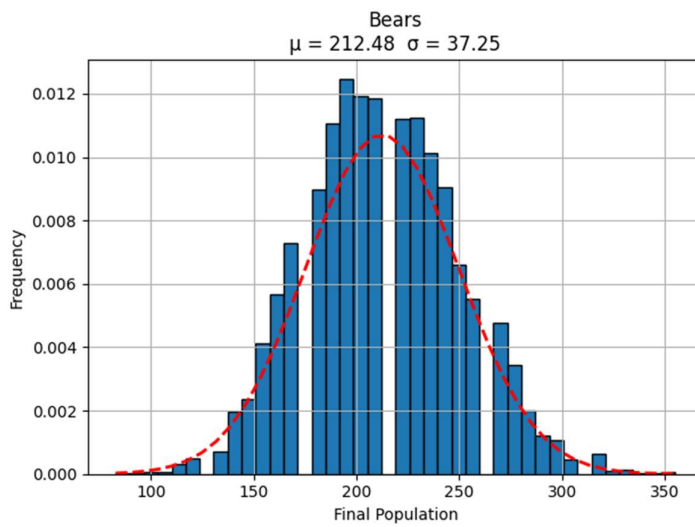
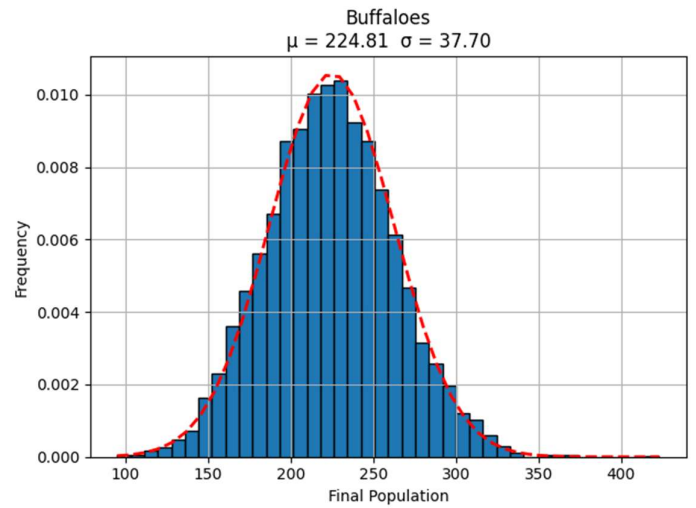
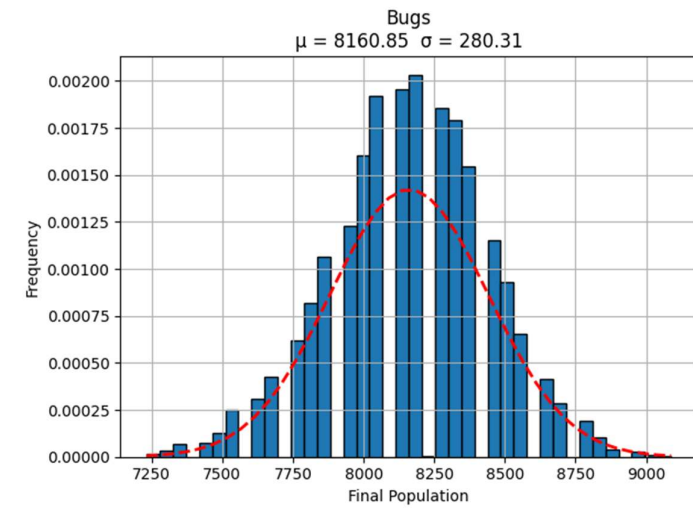
In this simulation, discrete time is implemented. After every step of time, above mentioned actions (reproduction, mutation, natural death) get sequentially implemented for all species.

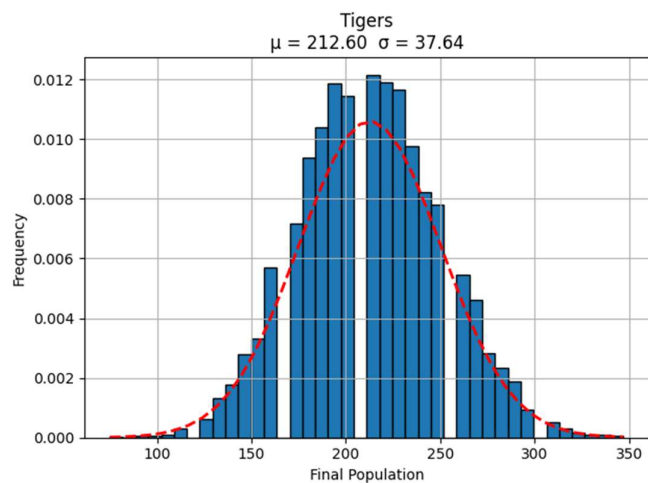
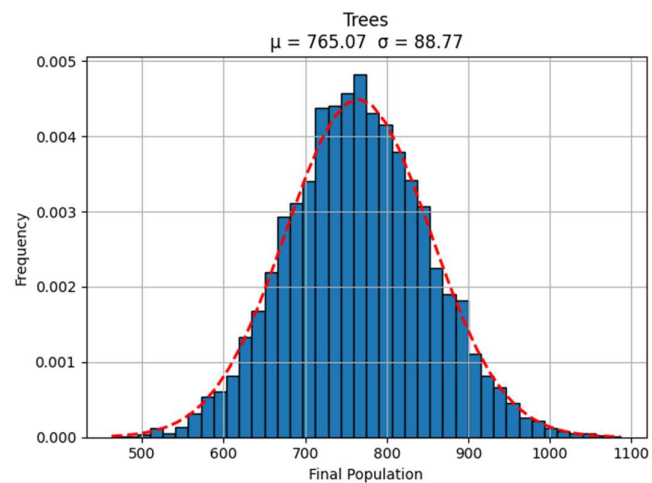
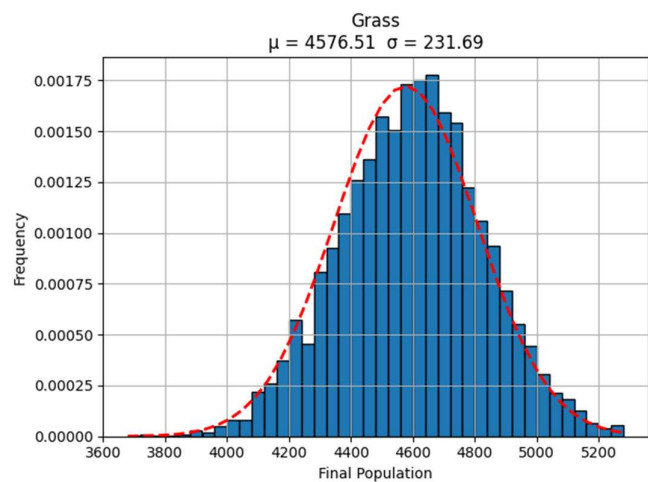
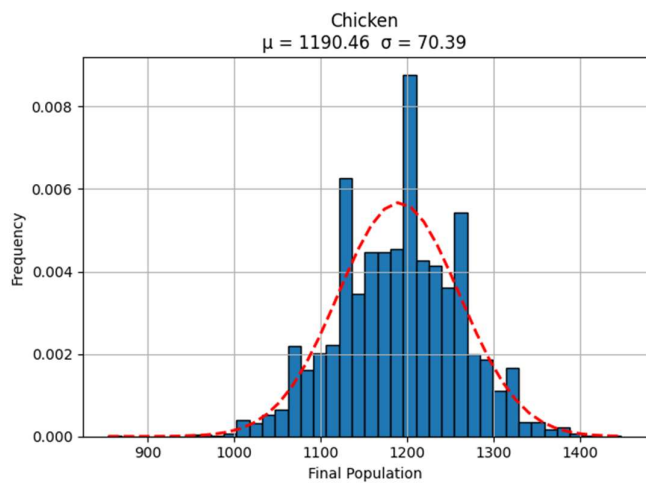
IX.Ensemble

The simulation is run many times with identical durations and initial conditions in order to get an ensemble of systems. This ensemble is used to plot the data at the end to get the frequency distribution.

5 Plots

Probability density plots (histograms) after 6000 simulations.





6 Parameter values in the code

Number of time steps in each simulation run = 30

Number of simulations run = 6000

Mutation probability = 1/10

Code Github Link - [anuragskadam/evolution-simulation \(github.com\)](https://github.com/anuragskadam/evolution-simulation)

7 Result

The final populations of each species approaches a Gaussian distribution showing that population evolution does follow this property of a Random Walk.

8 Summary

We created a computer simulation of model the changes in population in an ecosystem. We created 8 species with unique features and ran the simulation 6000 times to get an ensemble of this system.

We introduced randomness through randomly performing actions such as nutrition and mutation following a specific probability.

With this simulation we found that population growth of different species in an ecosystem acts like a random walk in the sense that the plot of the population of each species follows a gaussian distribution.

9 Further Research Scope

Due to computational restrictions, this simulation could not be run over a longer time duration. If one does solve this problem, we might be able to observe a significant evolution of species through natural selection.

If this happens then we might check for a similar Gaussian distribution of each gene.

10 References

- www.wikipedia.org