Natural Selection Simulation
Computer-Aided Simulations - Mini Lab G6

I. Problem overview

Our goal here is to develop a basic simulator for natural selection. It is possible to ask ourselves:

- how the reproduction rate of the population and the chance of mutation affect either the survival or the extinction of the species?
- what it takes for a population to be stable?
- how the resources availability affect the population?

II. Proposed approach

Our model consider a single species, where the reproduction rate of each individual is λ. We start with a population with P individuals (generation 0), with lifespan following a normal distribution $N(L_0, 1)$, where L_0 is a input parameter. For the following generations, the lifespan $LF(k)$ of a individual k whose parent is $d(k)$ is

$$LF(k) = \begin{cases} U[0, LF(d(k))] & \text{if no mutation} \\ U[LF(d(k)), (1+\alpha)LF(d(k))] & \text{if mutation} \end{cases}$$

where the probability of having a mutation is p_{imp} and $\alpha \geq 0$ is the improvement factor.

For this distribution, we can obtain the inverse of the c.d.f. so that we are able to generate the lifespan of a individual with the inverse-transform method, which is presented in Figure 1.

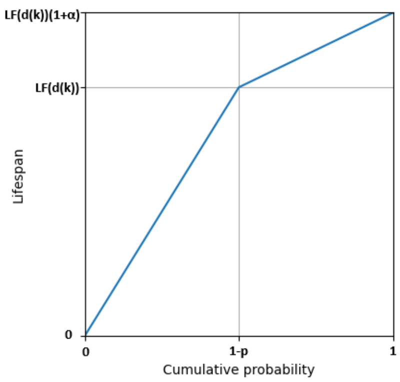

Fig. 1: Inverse CDF for individual k lifetime

For the reproduction of the individuals, we consider it to be asexual, i.e. one single individual produces it own offspring, according to a Poison process with rate λ. Another input parameter is the maturity age of the species. After this age, the individual produces its offspring, where the time between births is exponentially distributed also with rate λ, until its death.

Finally, in order to control the population, preventing it of growing exponentially, we have to consider the resources availability. It is represented by the population size threshold parameter. When the population grows bigger than this value, the lifetime of the newborn individuals will be penalized by a factor $pen \in [0, 1]$, which depends on how much the current population cp exceeds the threshold th. If we define the penalty as below, we do not penalize individuals born while the population size is lower than the threshold. Moreover, we define the maximum population size to be twice as the threshold, and individuals cannot be born when the population reaches this value.

$$pen = \begin{cases} 0 & \text{for } cp \in [0, th) \\ \frac{cp - th}{th} & \text{for } cp \in [th, 2th] \\ 1 & \text{for } cp \in (2th, +\infty) \end{cases}$$

A. Output measures

As output of the simulation, we have the population size over time, where we evaluate if it was extinct or reached a balance. We can also evaluate the final population size, after the pre-defined total simulation time, and the probability of extinction.

III. Experiments and results

We can now run the simulation for different input parameters and analyze how the population behaves.

A. First scenario

- Initial population size: $P = 10$
- Initial population average lifetime: $L_0 = 7.5$ years
- Reproduction rate: $\lambda = 0.5$
- Reproduction maturity: 2.5
- Probability of improvement: $p_{imp} = 5\%$
- Improvement factor: $\alpha = 0.5$
- Population size threshold: $th = 1000$

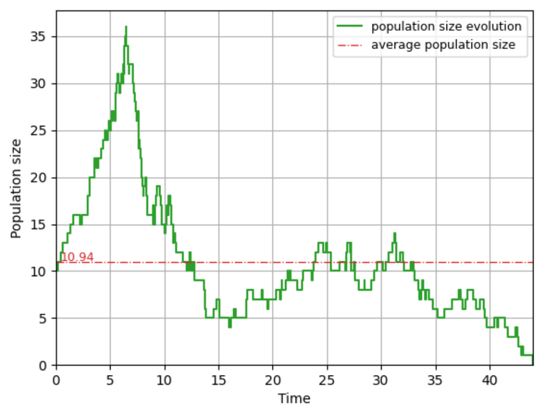

Fig. 2: Example of population size evolution for scenario 1

We run the simulation with these parameters for 50 years 2000 times and obtain the following results:

- Average population size: 22.28 ± 0.83
- Final population size: 25.41 ± 3.34

- Extinction probability: 0.554 ± 0.026

One example of the evolution of the population's size in shown in Figure 2

B. Second scenario

- Initial population size: $P = 10$
- Initial population average lifetime: $L_0 = 7.5$ years
- Reproduction rate: $\lambda = 0.5$
- Reproduction maturity: 2.5
- Probability of improvement: $p_{imp} = 15\%$
- Improvement factor: $\alpha = 0.25$
- Population size threshold: $th = 1000$

Again we run the simulation with these parameters 2000 times and obtain the results below and a example of the population evolution is presented in Figure 3

- Average population size: 57.05 ± 2.32
- Final population size: 156.48 ± 10.07
- Extinction probability: 0.106 ± 0.016

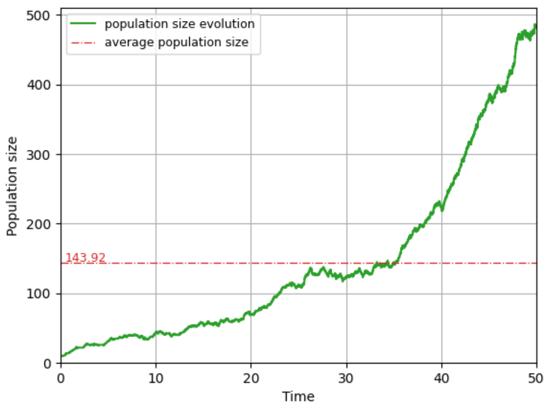

Fig. 3: Example of population size evolution for scenario 2

We see that for this second scenario, the extinction rate was lower. We can then rerun the simulation for a longer period (e.g. 300 years) only once, and analyze how the population behaves, which is shown in Figure 4. In this case, it is possible to evaluate how the resource limitation affects the species, resulting in a kind of balance around 1200 individuals.

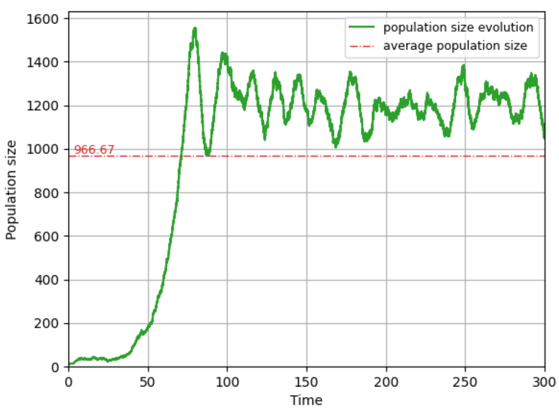

Fig. 4: Population size evolution for scenario 2 for 300 years

In conclusion, our model demonstrates to be able to simulate natural selection based on the defined rules. But there is still room for improvement, for example:

- Natural selection has more to do with genes than individuals and species. We should at least compare two different conflicting genes and see which one is the fittest and therefore, survives.
- It would be interesting also to consider the sexual reproduction, where two different individuals generate a new one, which has a certain probability of carrying the genes of the either its father or mother.

Those improvements will be explored during the next activity on Lab G7.