Urban Architects

A Bak-Sneppen and Cellular Automata Model of urban expansion under climate constraints

github.com/pmchrist/Urban-Architects

Background

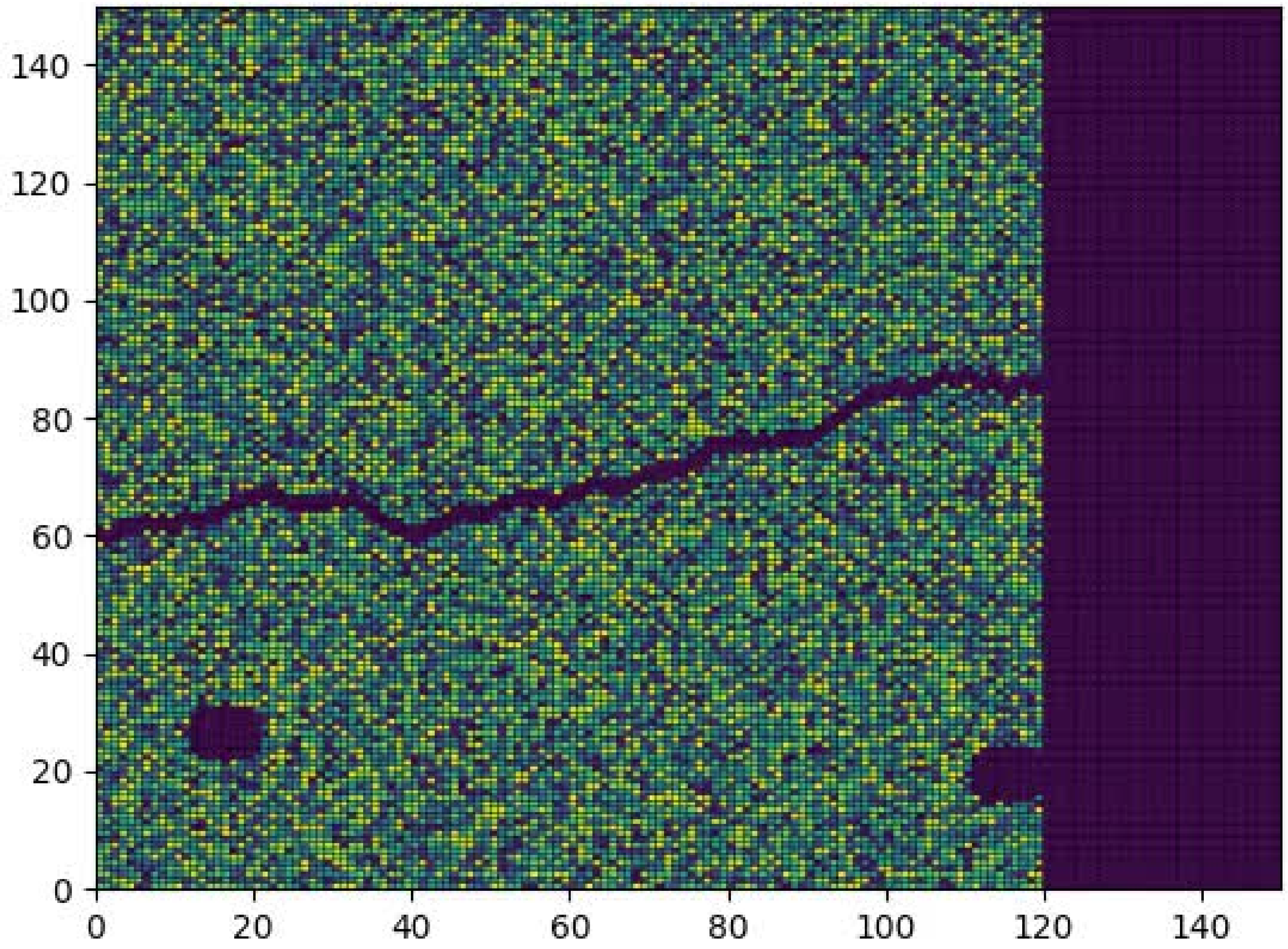
Population Growth + Climate Change

Urban Expansion

What drives people to move?

- Water?
- Population Density?
- Energy?

Siqin Wang, Yan Liu, Yongjiu Feng & Zhenkun Lei (2021) **To move or stay? A cellular automata model to predict urban growth in coastal regions amidst rising sea levels**, International Journal of Digital Earth



0
20
40
60
80
100
120
140
0
20
40
60
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100
120
140

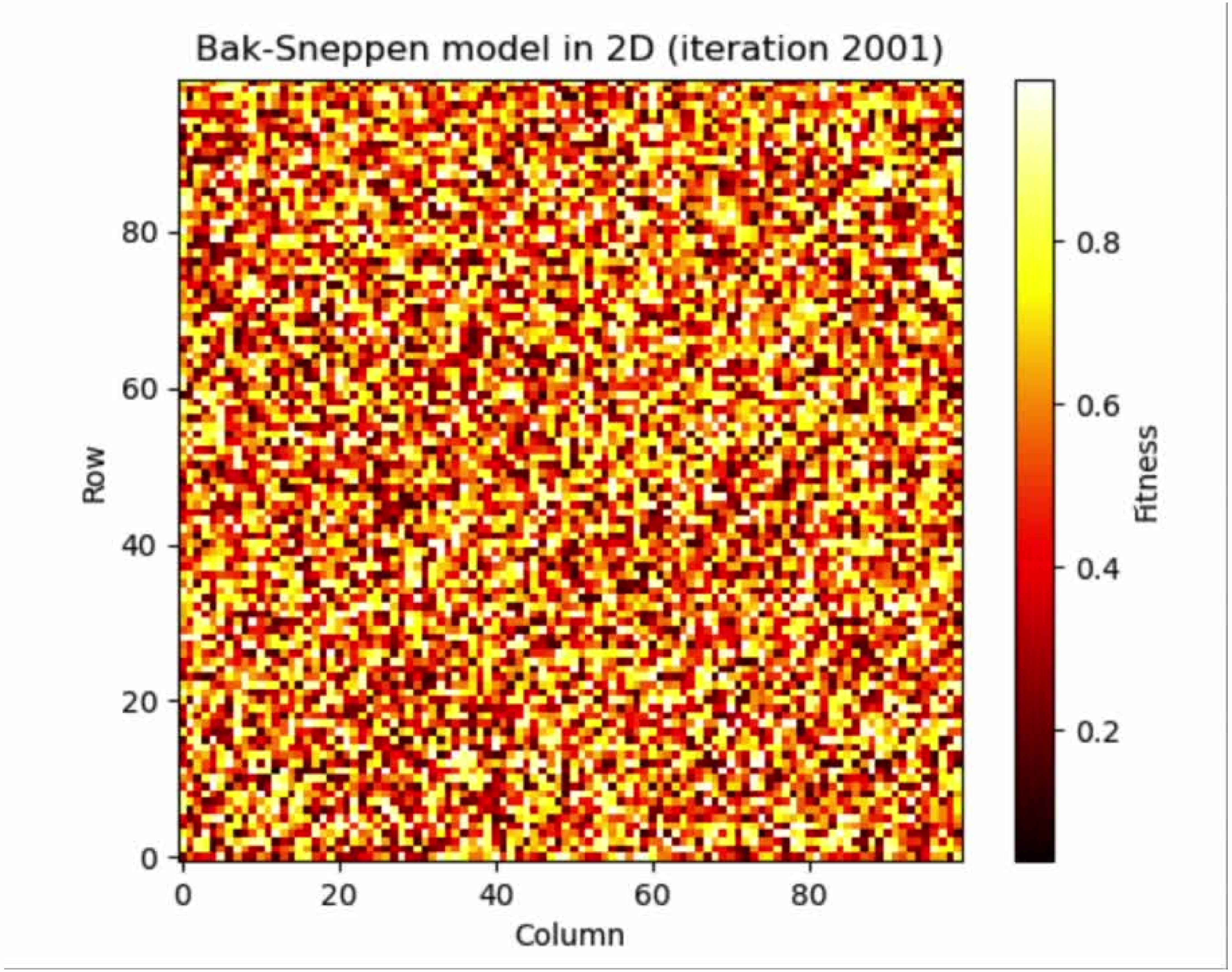
About the Bak-Sneppen Model

- Simple Evolutionary Model, Per Bak and Kim Sneppen, 1993
- Biological Evolution
- Self Organised Criticality

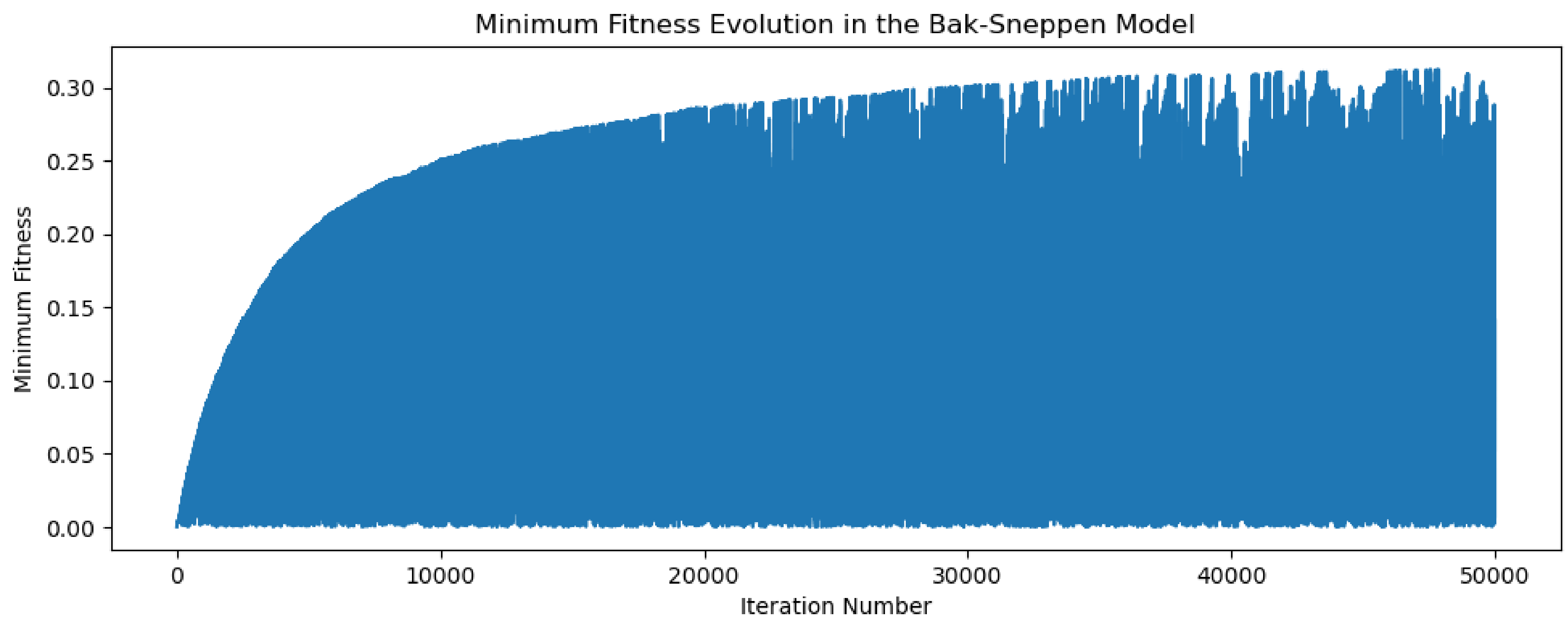
2D Model - Initial Setup

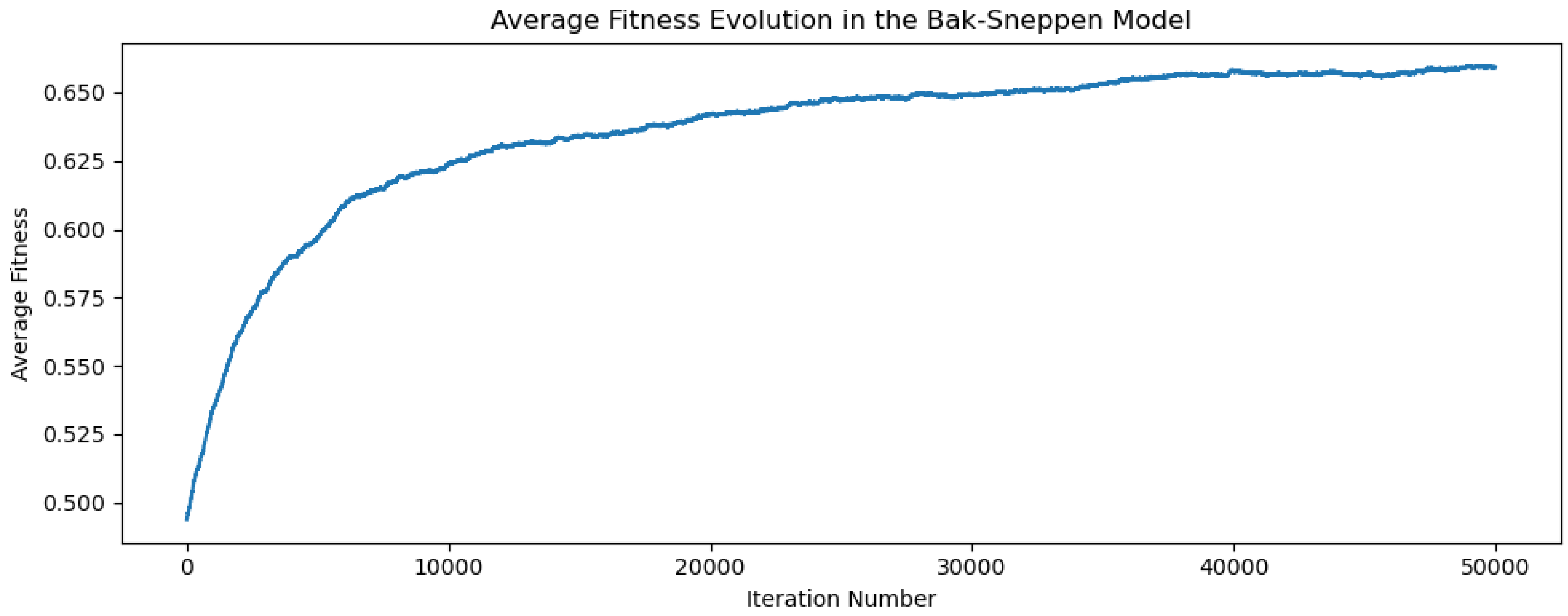
- Grid: 100x100
- Each cell has random fitness (uniform)
- Lowest fitness and its neighbours gets replaced with random fitness
- Avalanche starts when min fitness increases and ends when the min fitness stops increasing

Simulation & Visualisation

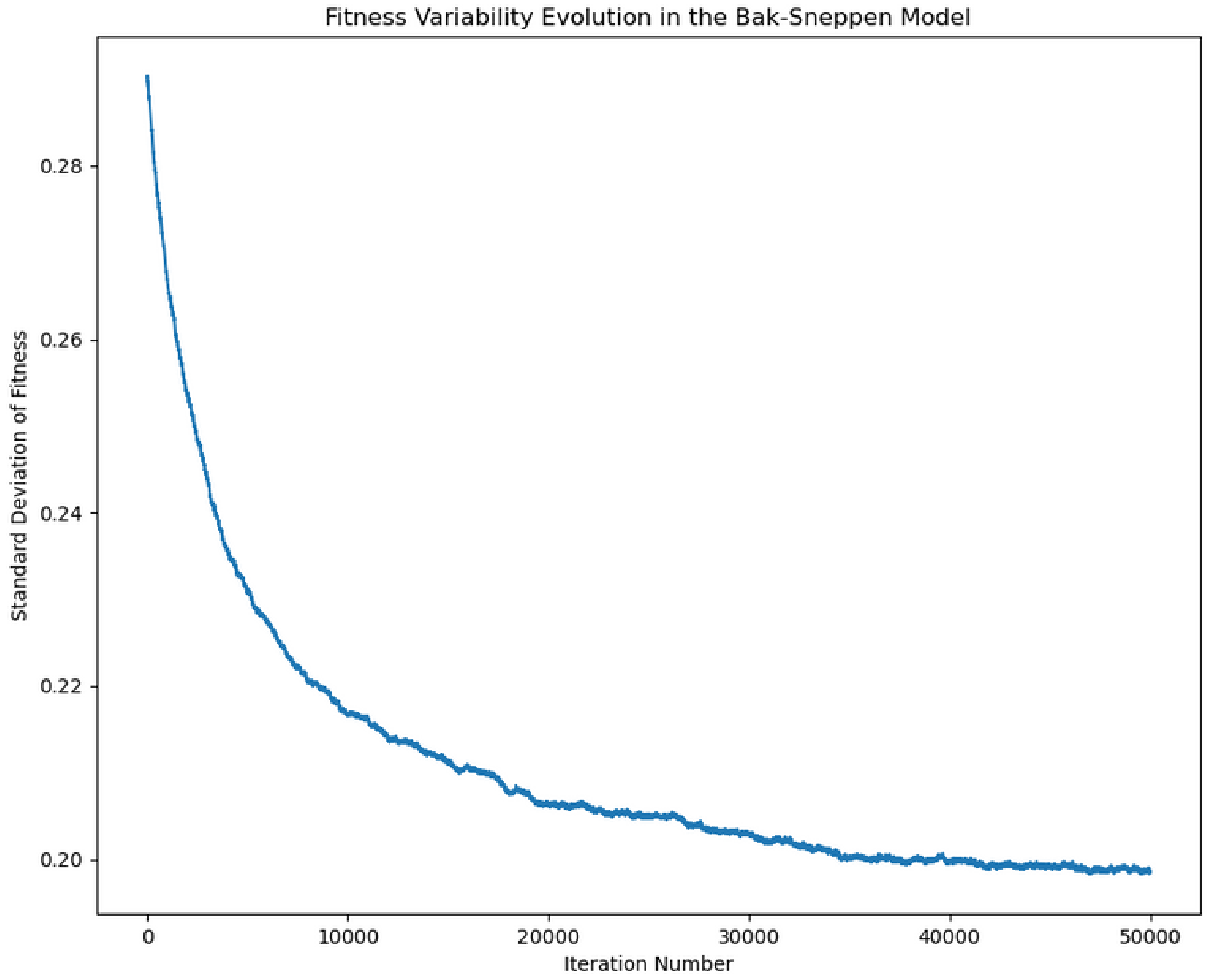


Behaviour & Properties

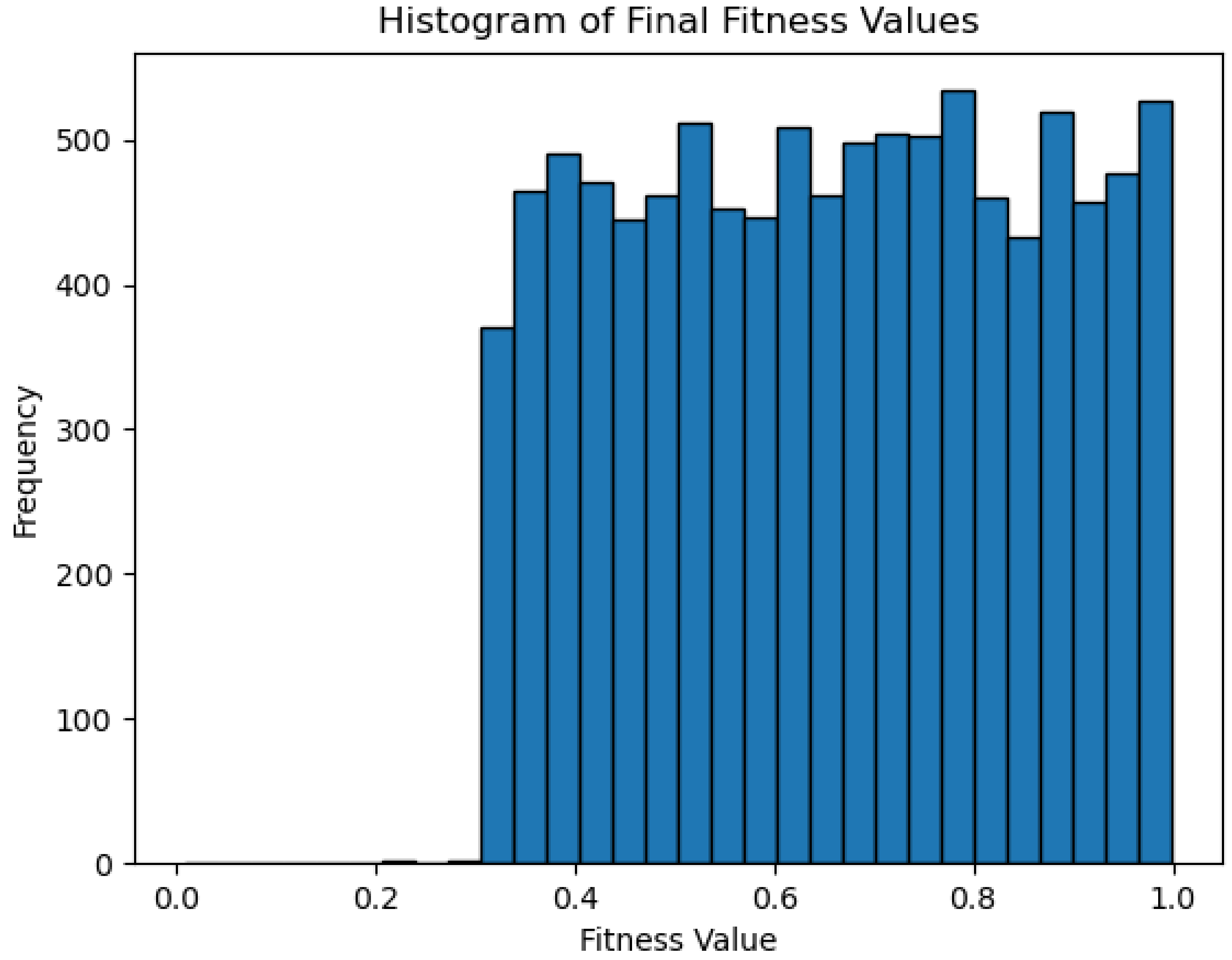




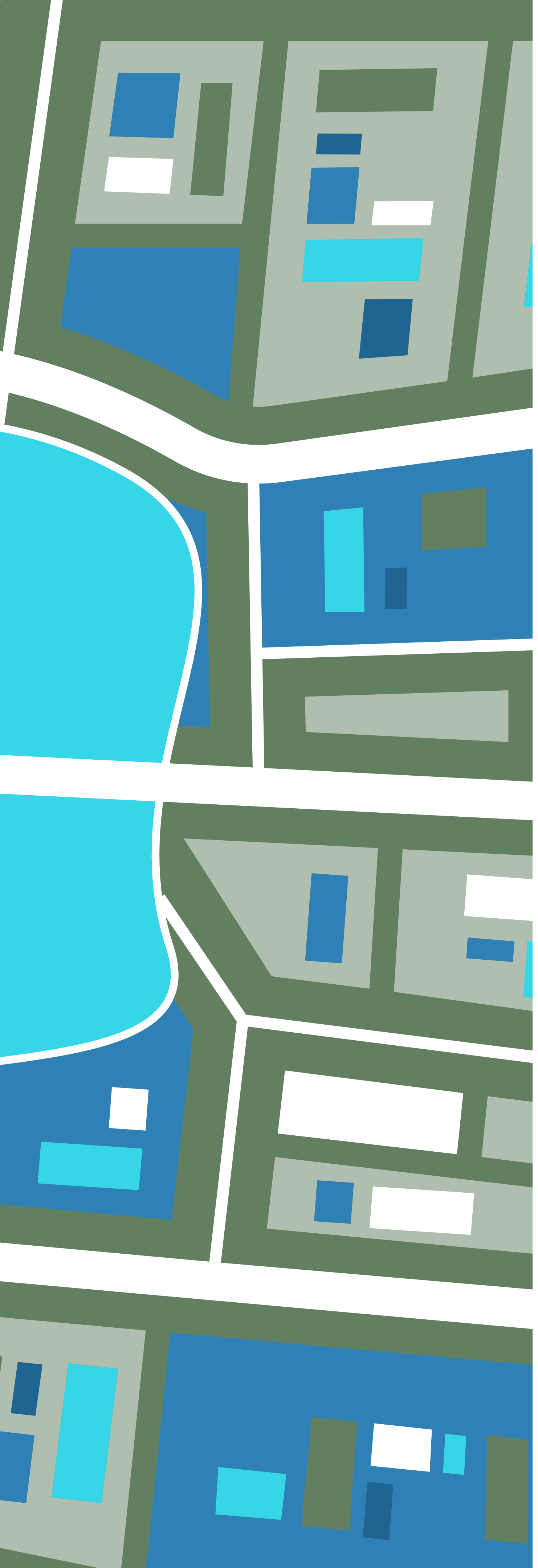
Behaviour & Properties



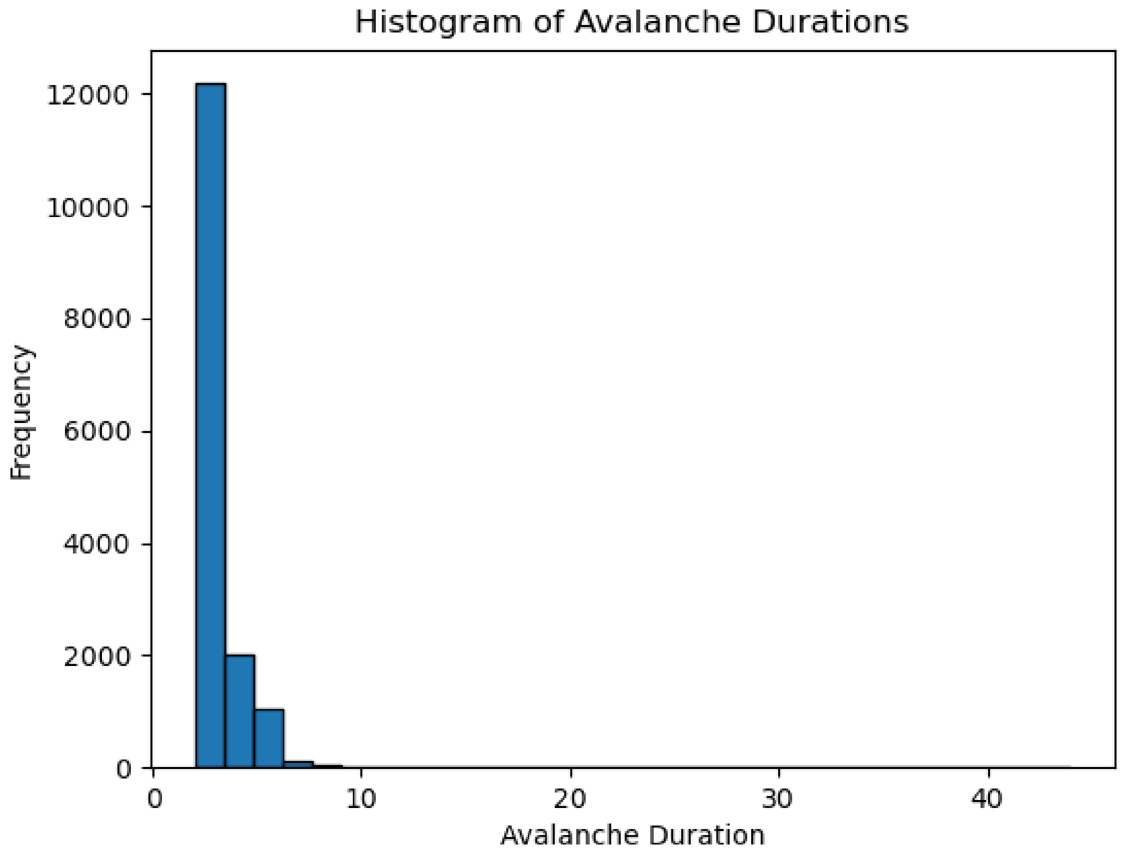
Diversity decreasing
Self optimise to higher overall fitness

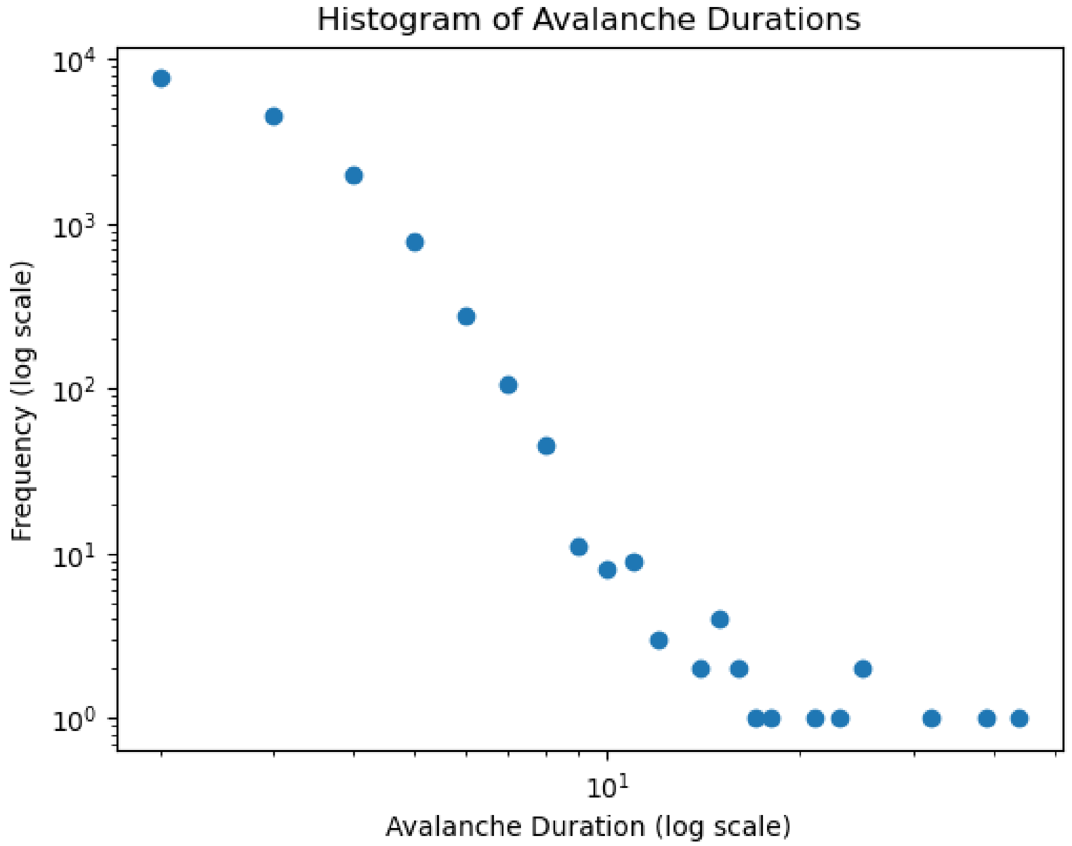


Critical threshold:around 0.3
Evidence of SOC



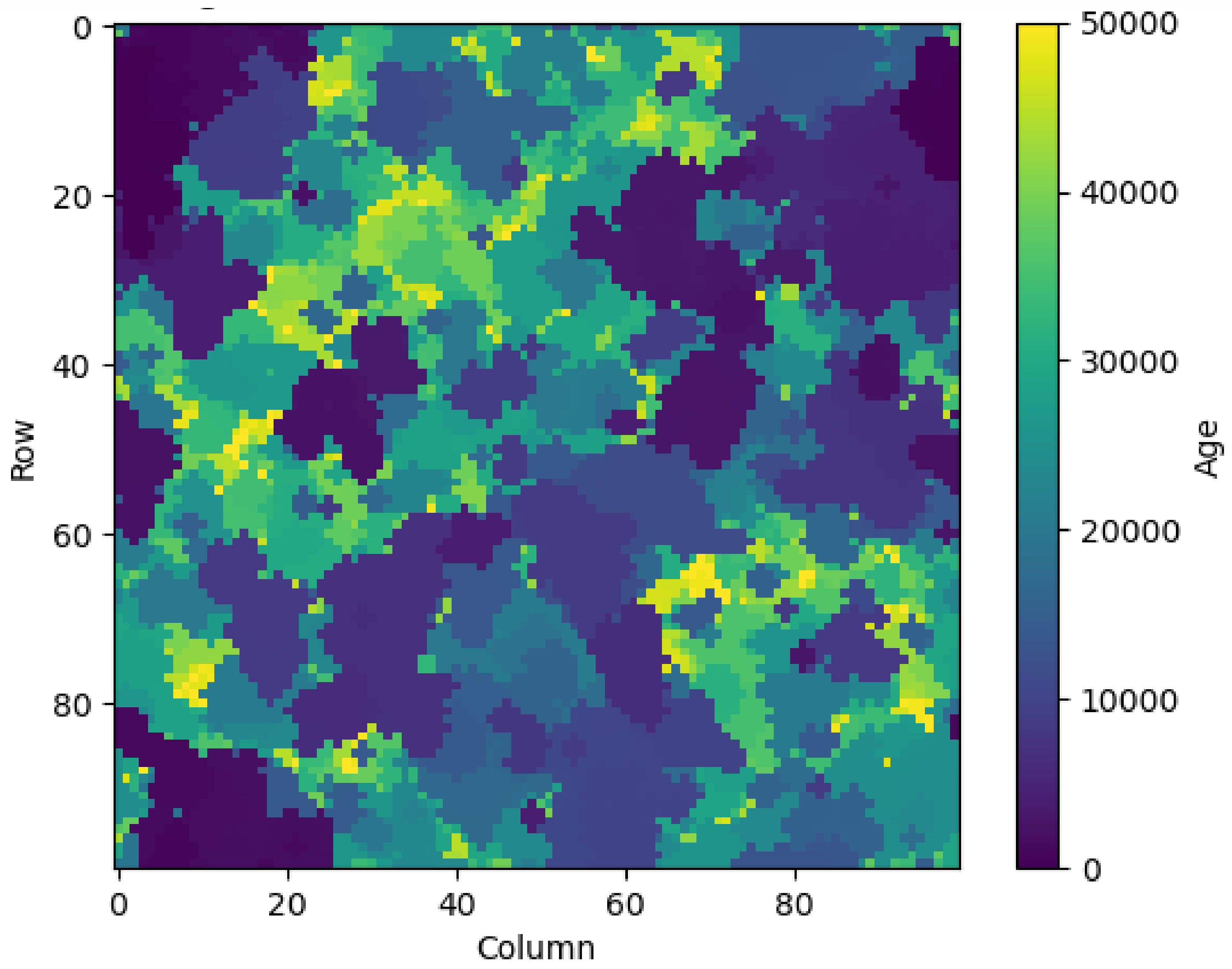
Avalanches





Minor shifts occur frequently
Major shifts less frequently
Typical of Power law
Slightly negative R Value:
Log normal distribution

Age: number of iterations a node has gone through without being replaced



Why is this useful

Balance of stability & instability
Always evolving

Population dynamics

Changes to the simple BS model:

- Population densities
- Choose lowest non-zero density
- Propose new densities based on current cell and neighbors

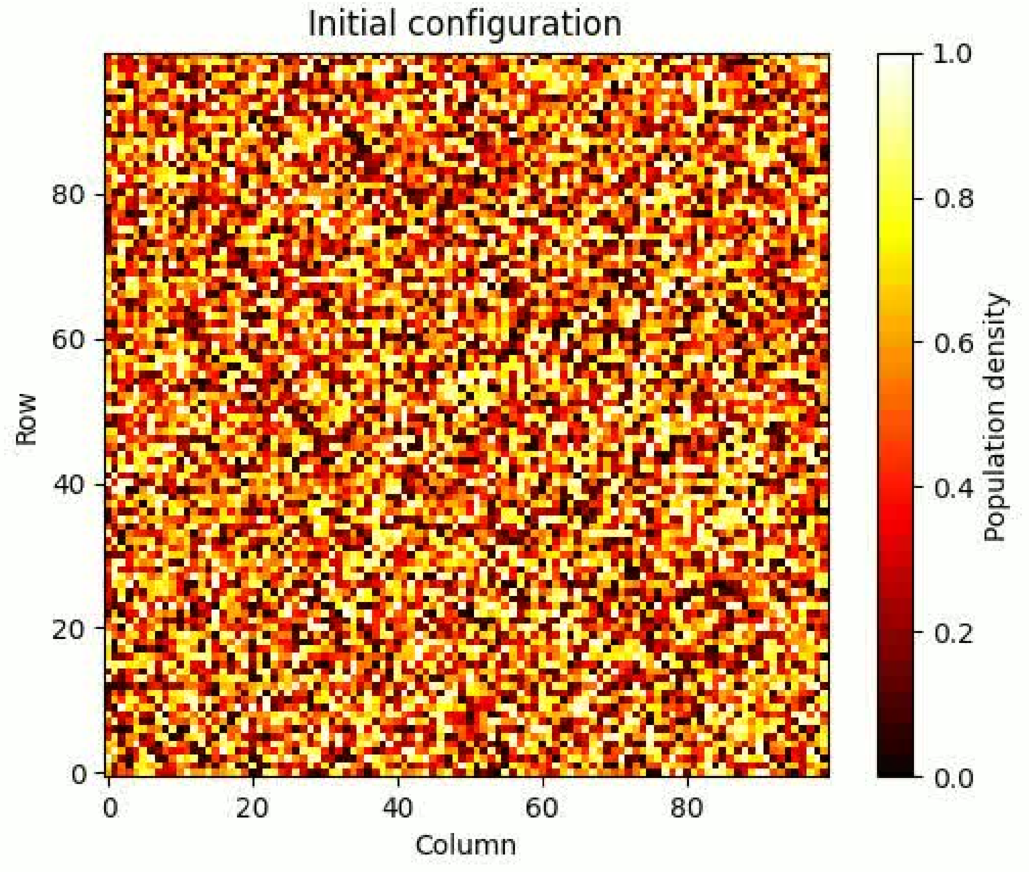
$$\text{new density} = \alpha \times \text{local density} + \beta \times \text{average density} + \gamma \times \text{fitness}$$

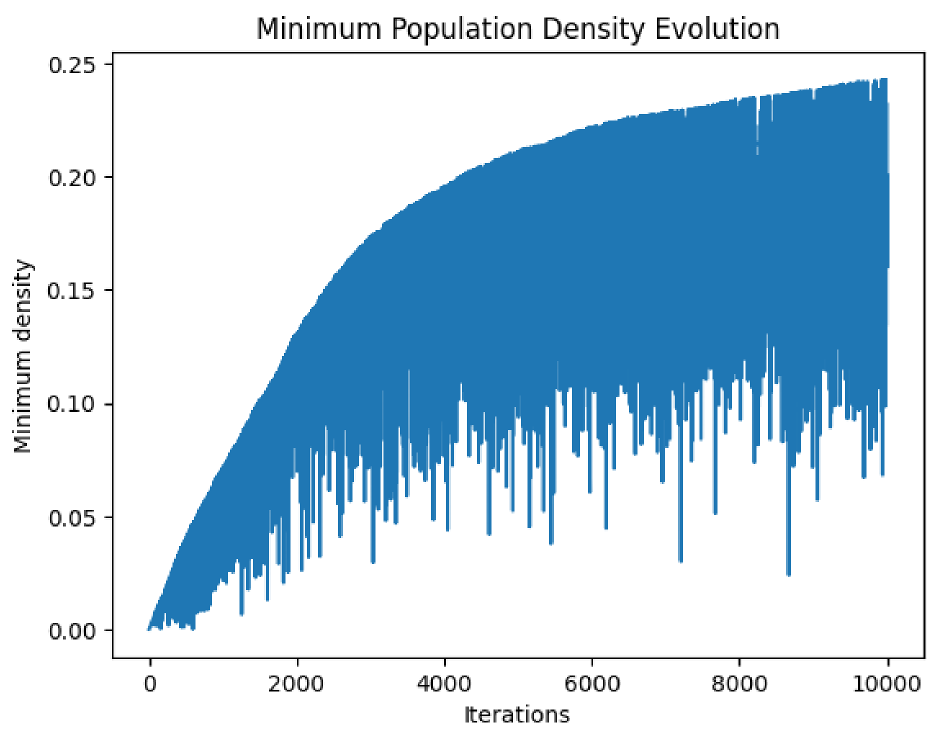
$$\text{fitness} = p \times \text{Gauss}(\text{local density}, \mu, \sigma) + (1-p) \times e^{-\lambda(\text{local density} - \text{average density})^2}$$

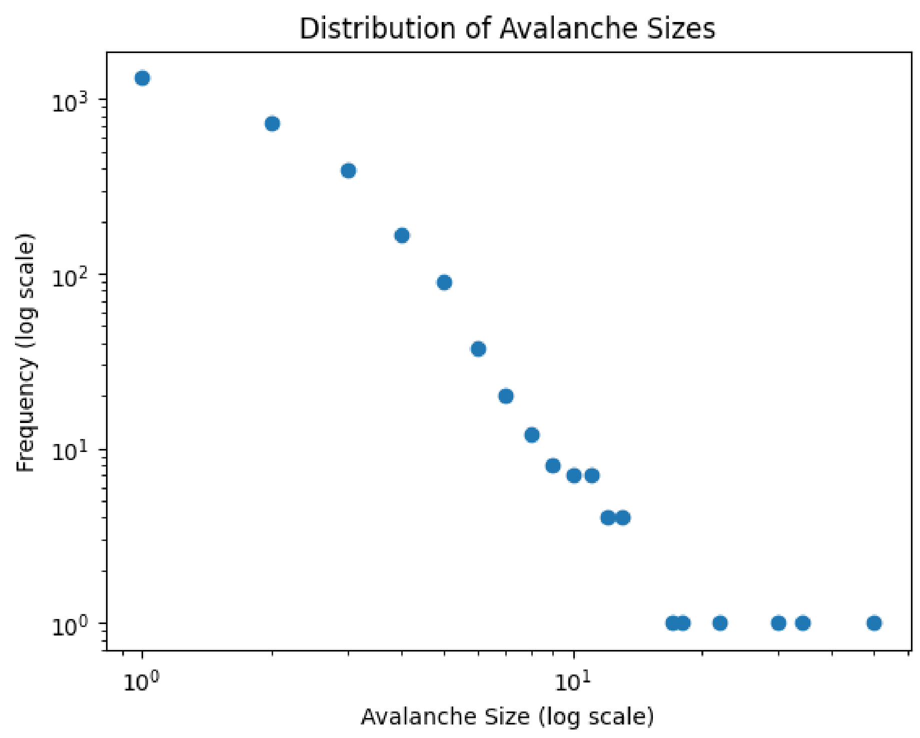
Last but not least: Migration!

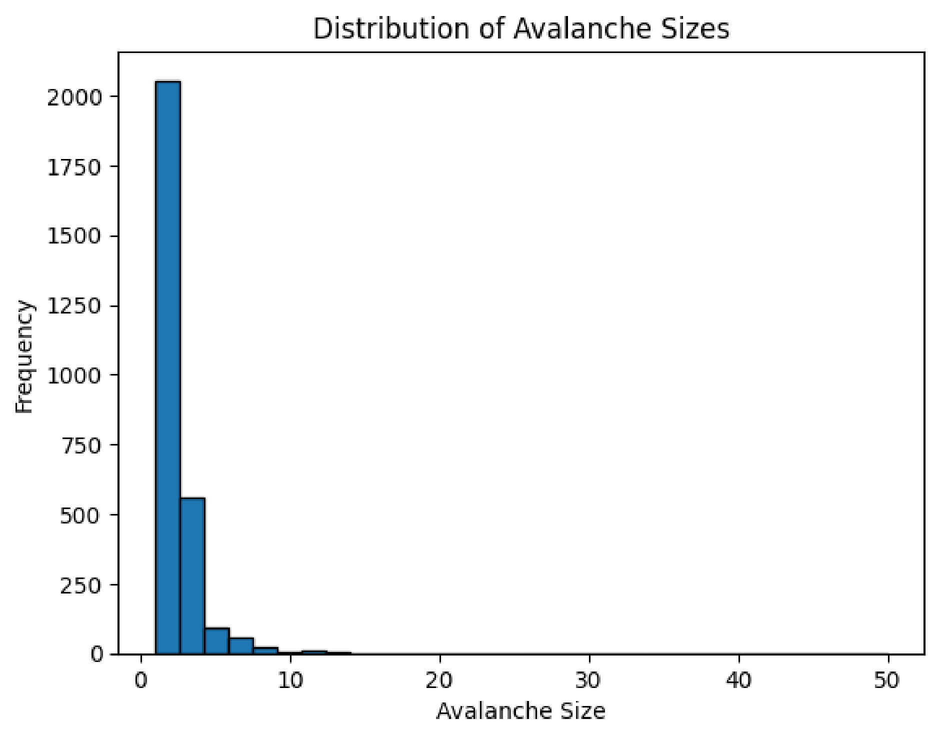
Only Gaussian fitness

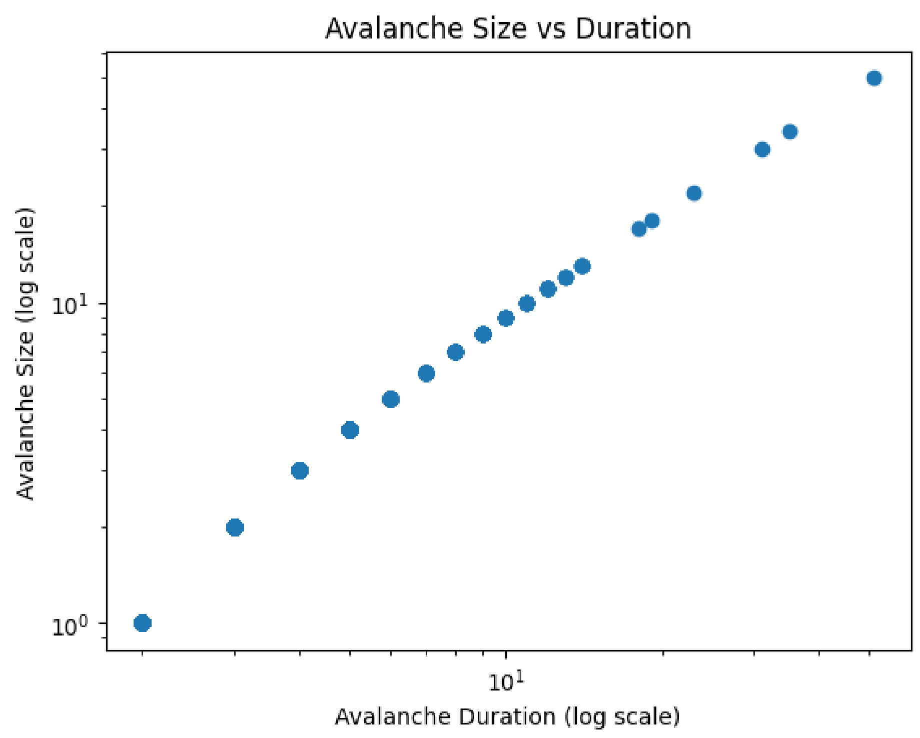
Mean = 0.5, Standard deviation = 0.3





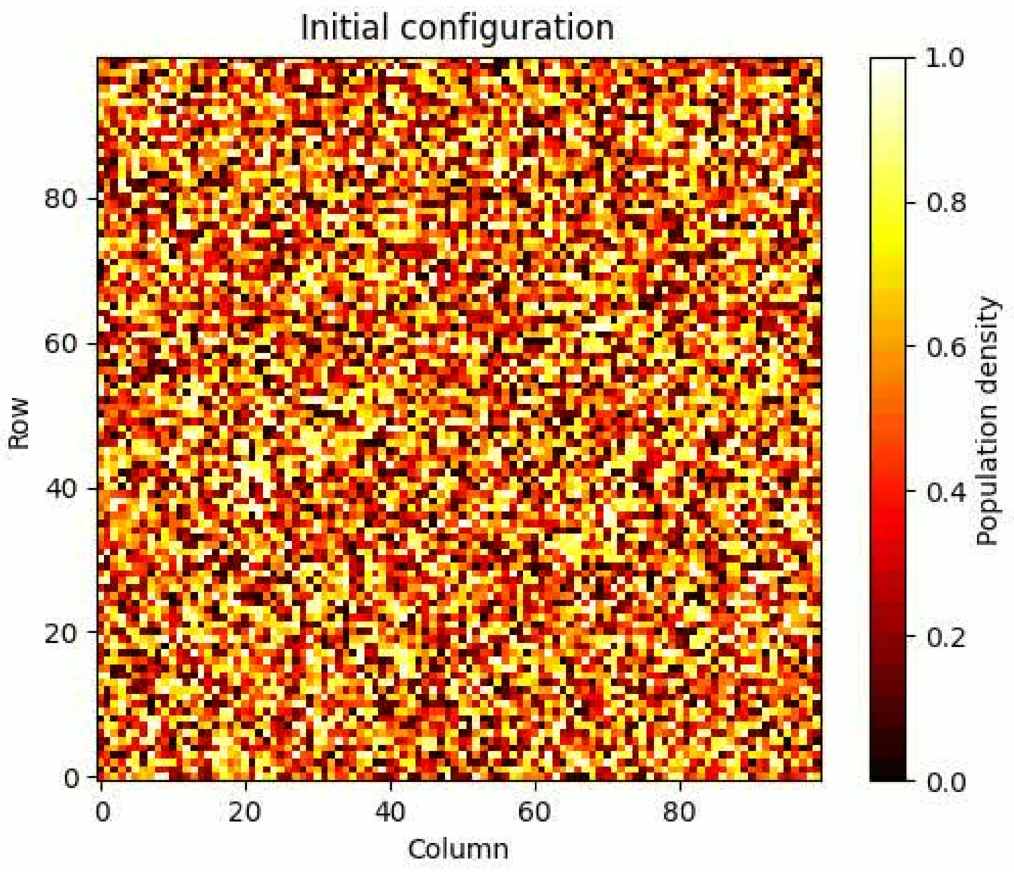


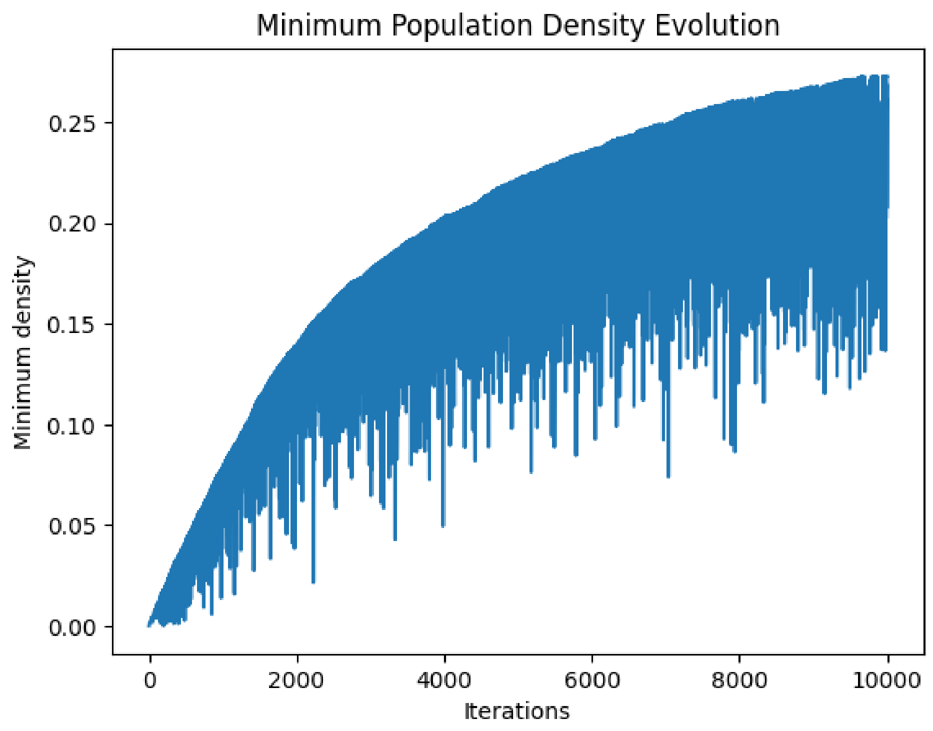


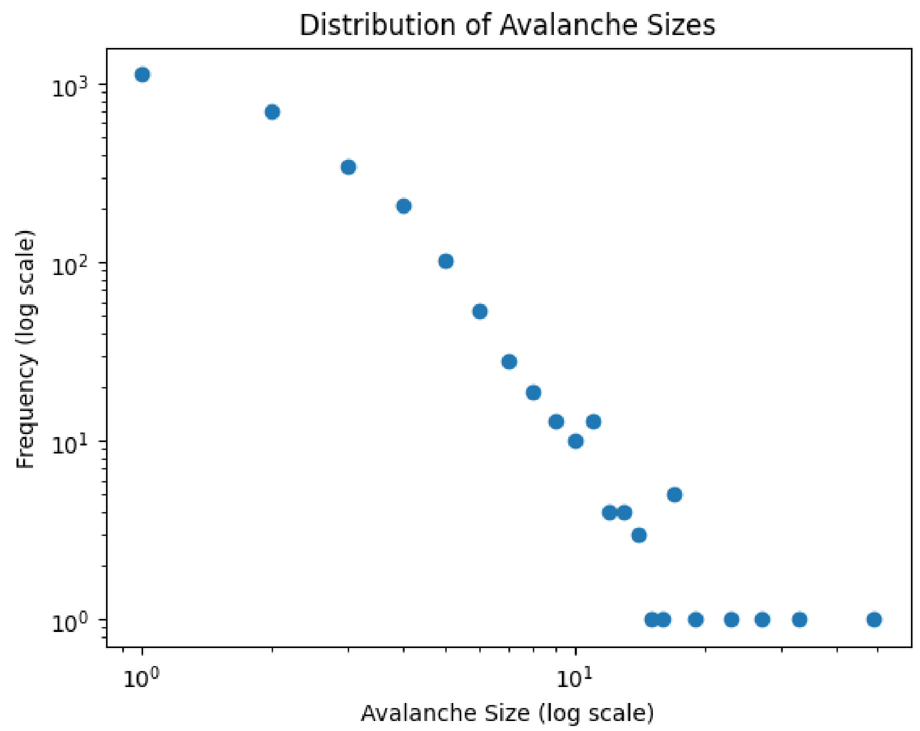


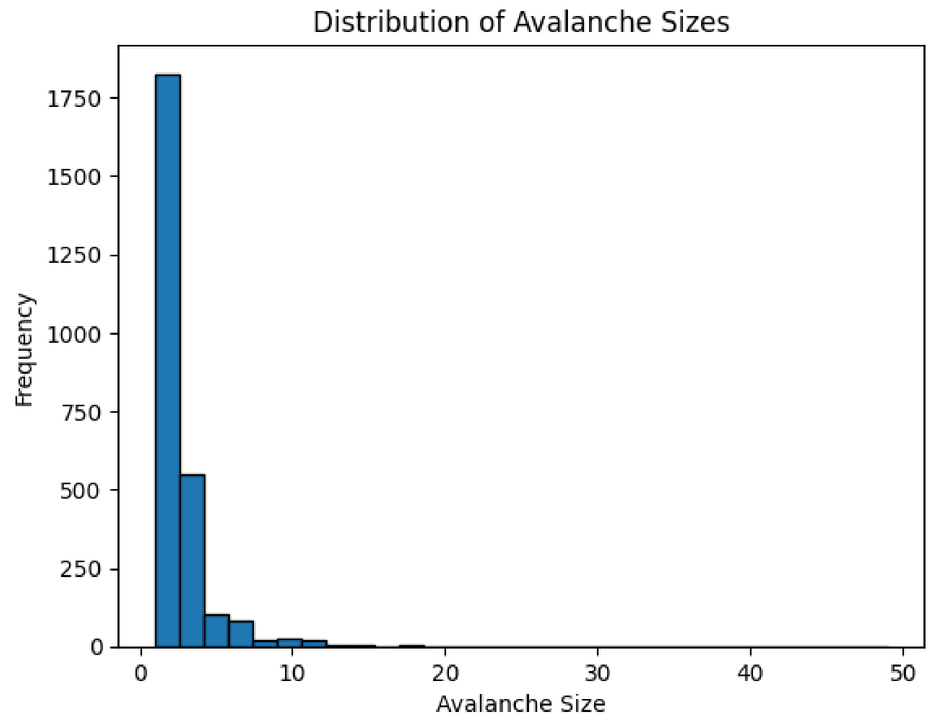
Add Exponential Fitness

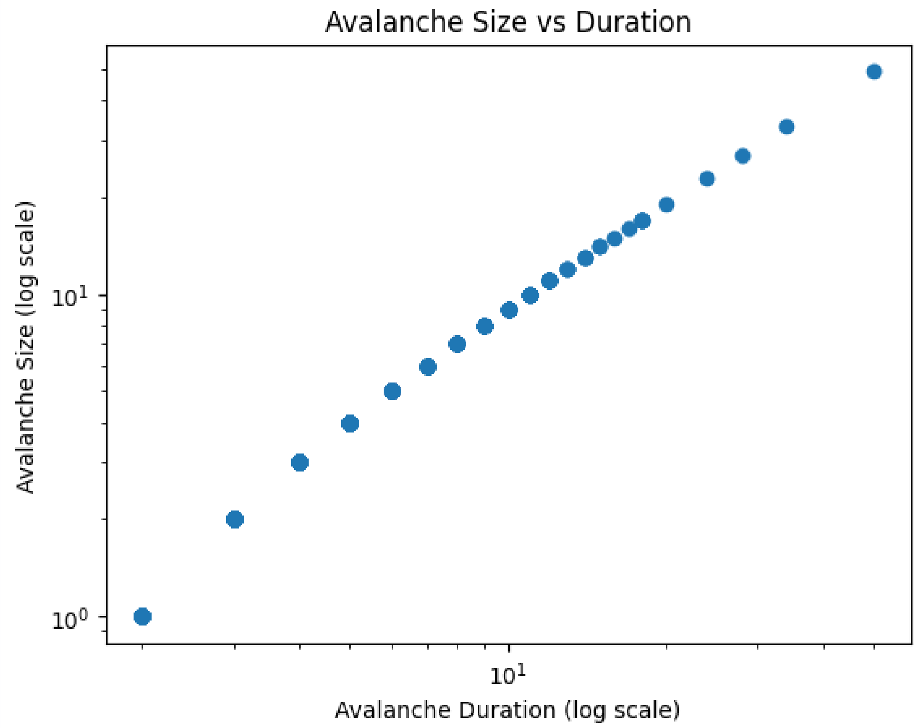
Lambda = 10



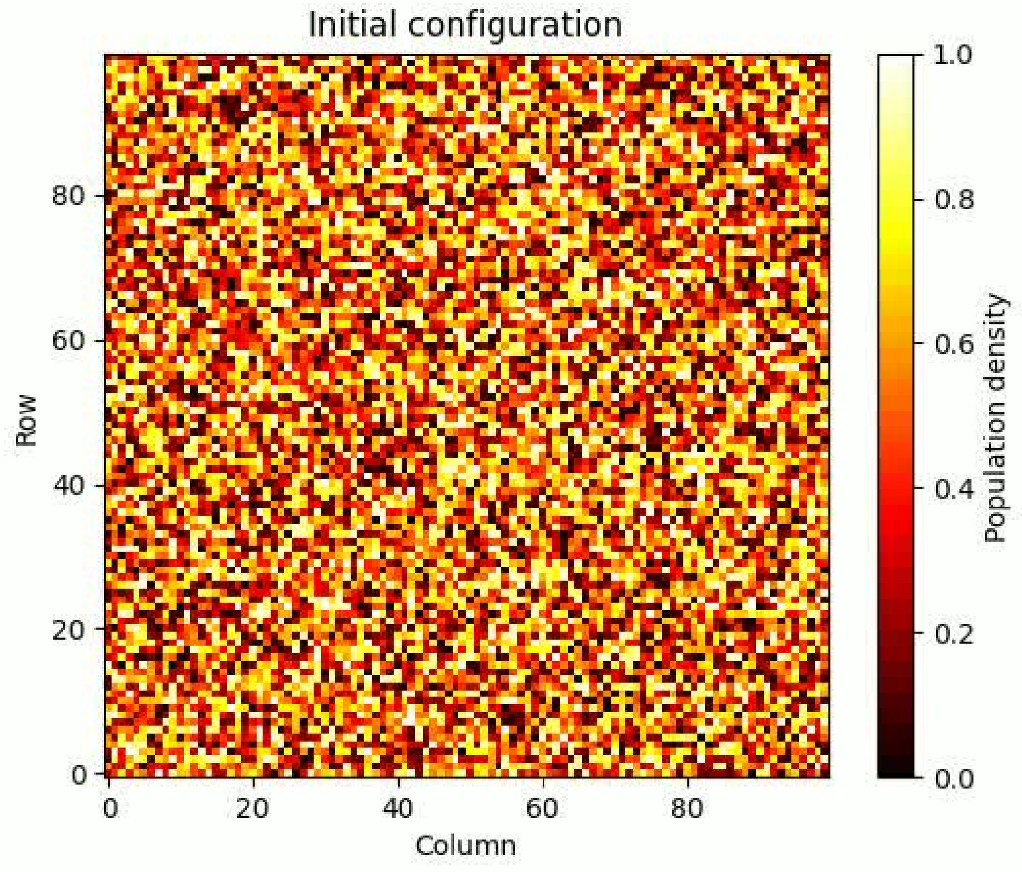


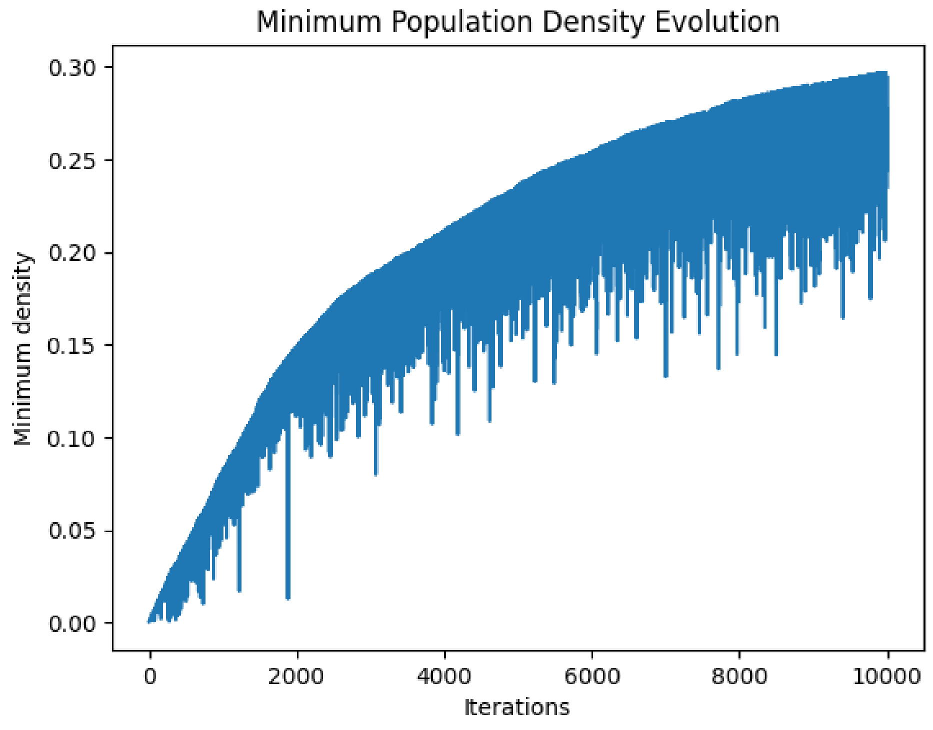


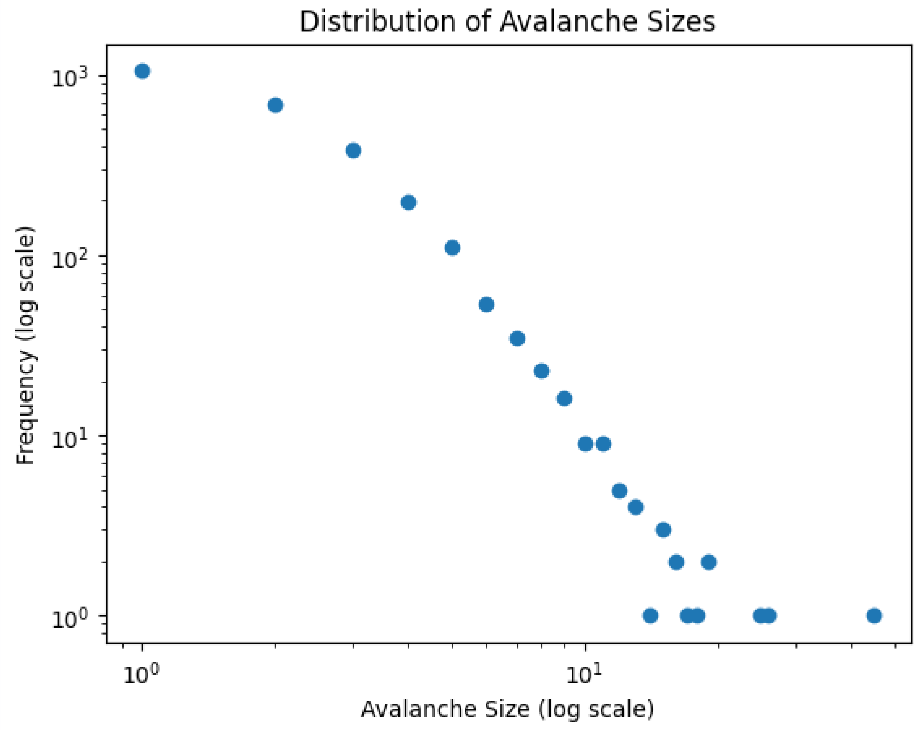


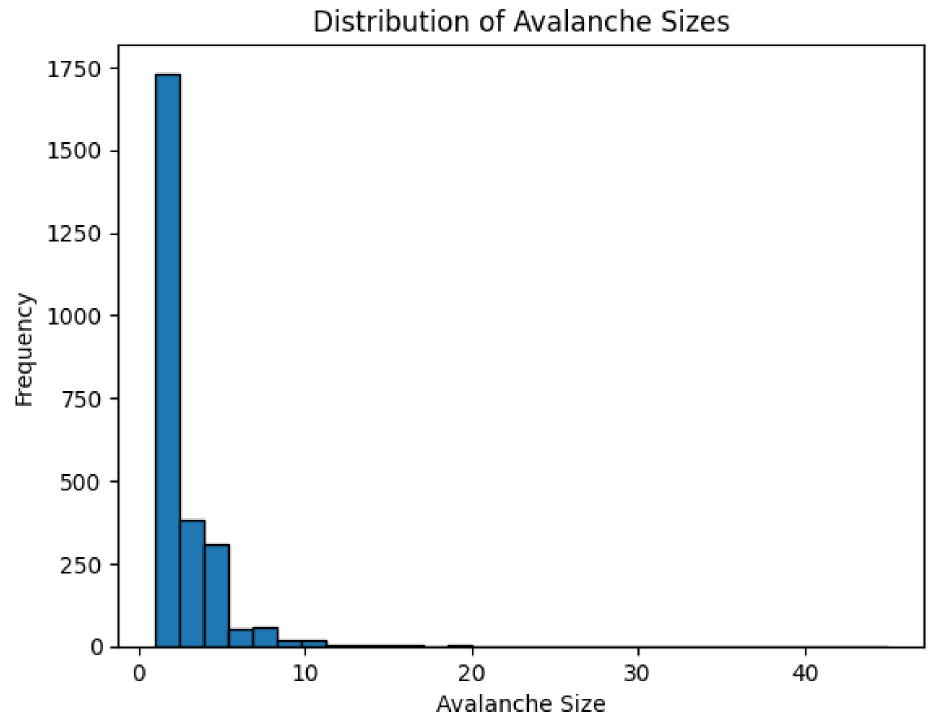


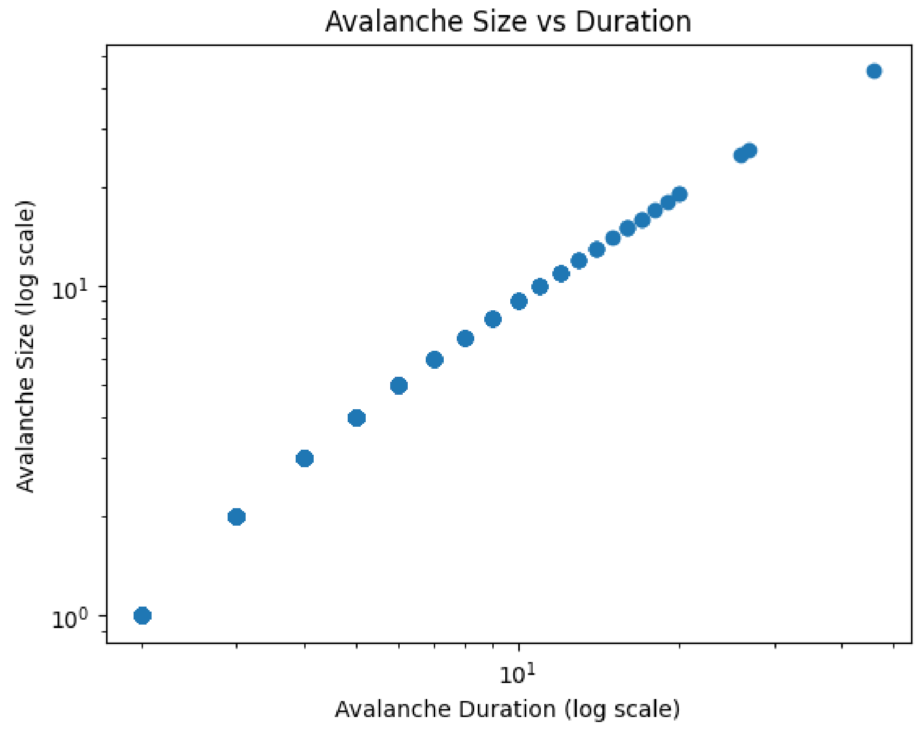
Include explicit cell dependencies











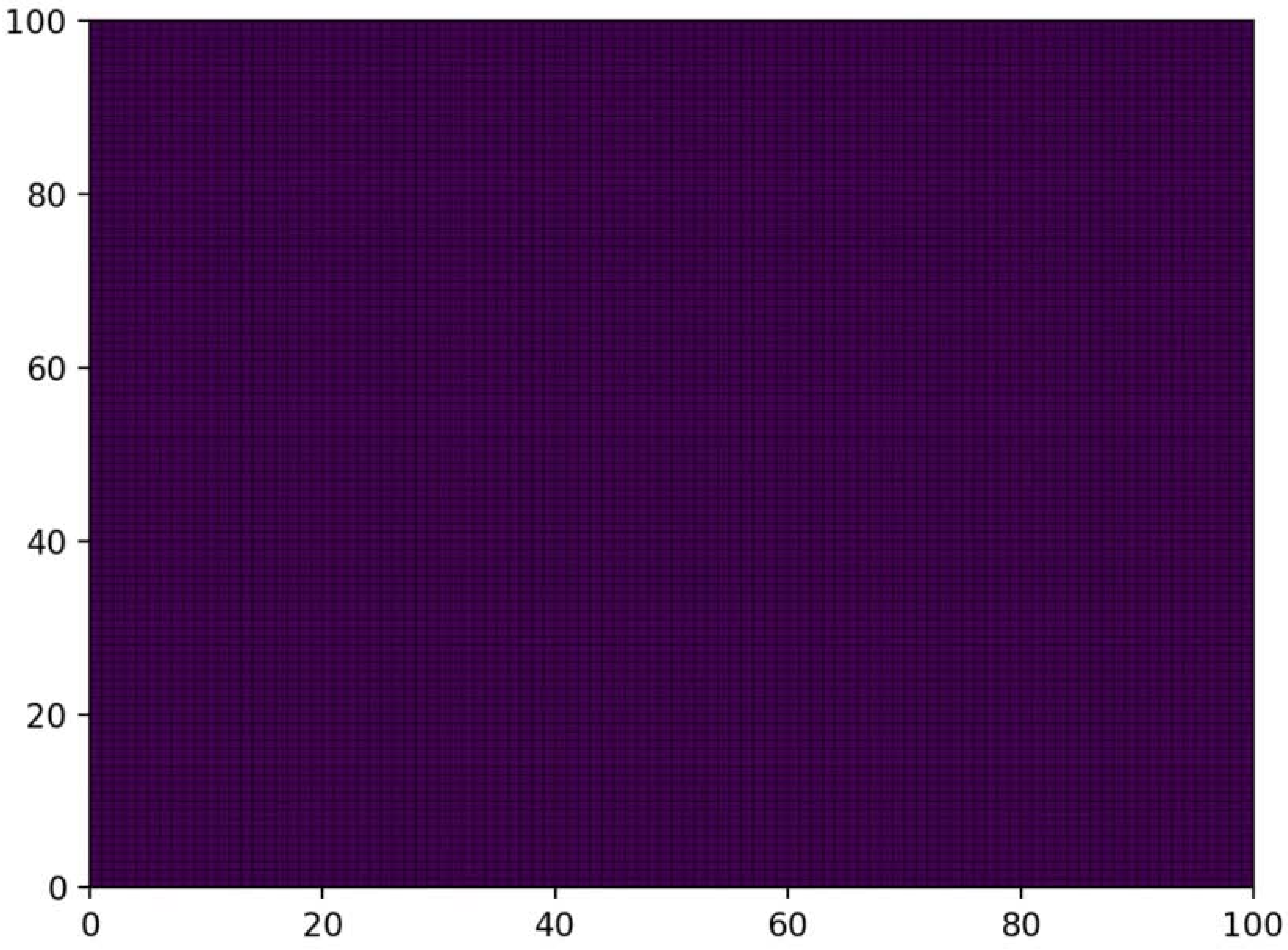
Now to our Spatial (CA) Model

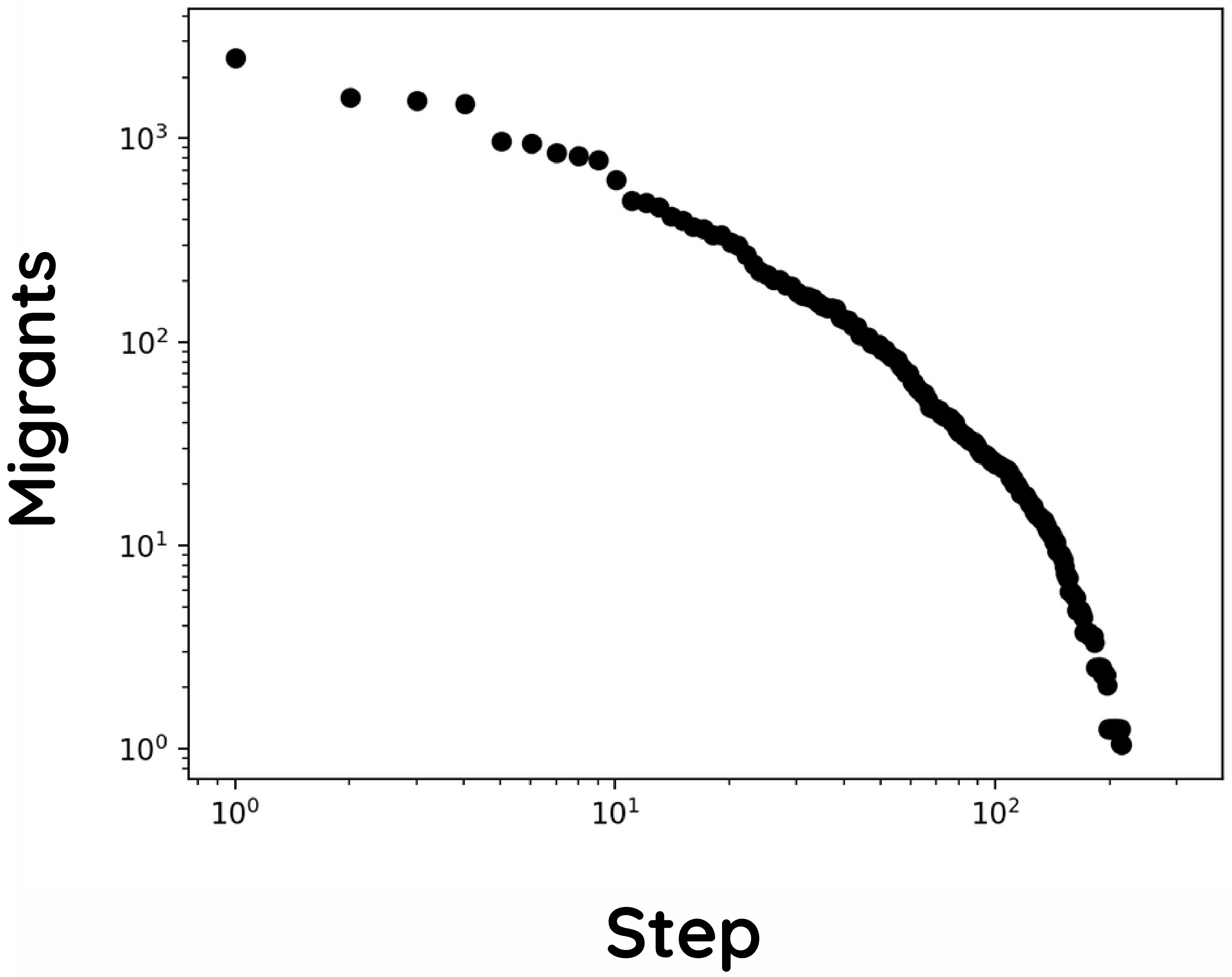
How does migration work and does terrain affect it? (It should change migration waves)

Set up:

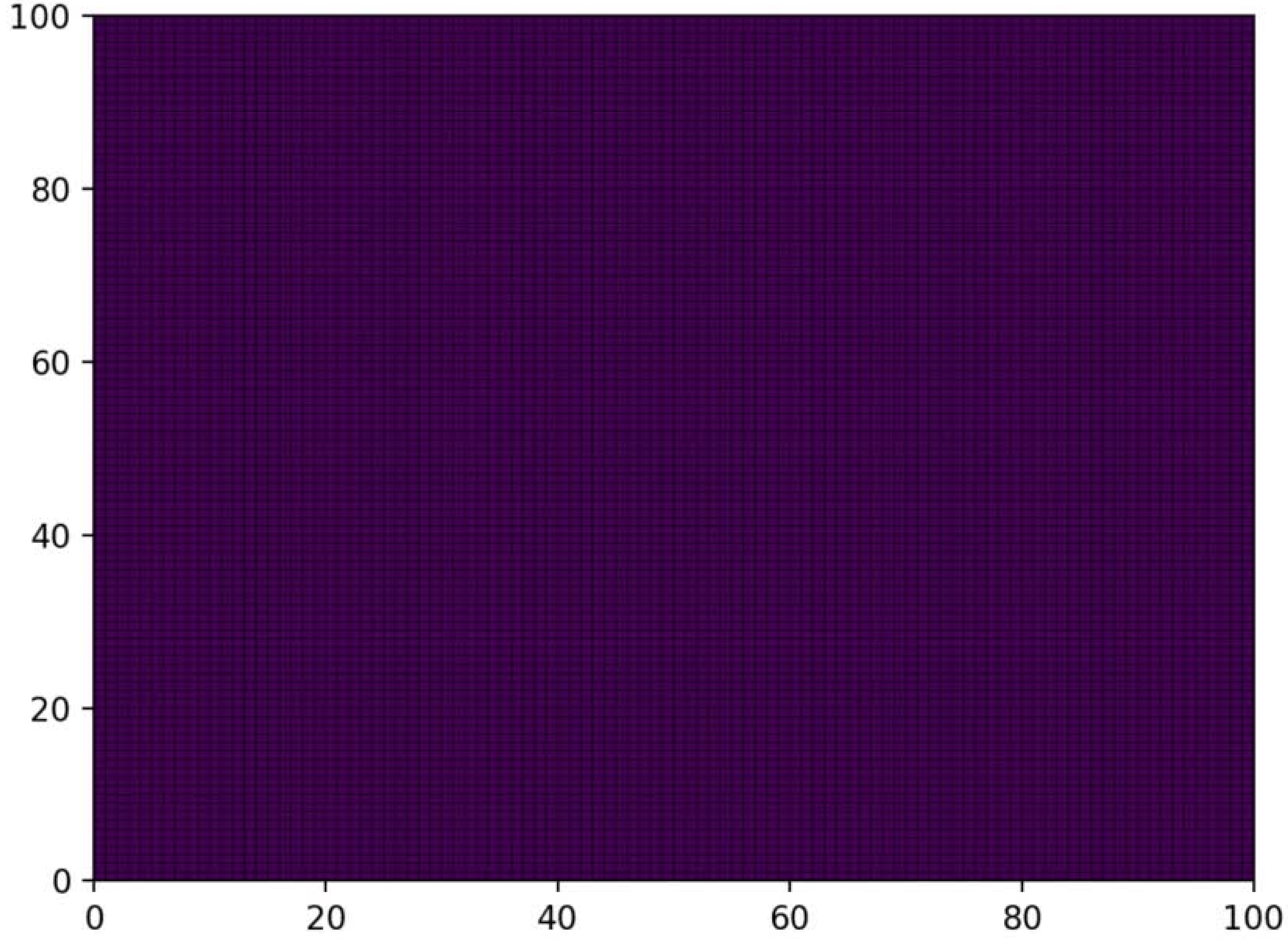
- Initialize an empty map
- Spawn people at random cells
- People disperse based on neighborhood's density (Gaussian)
- Calculate emissions and water level increase

Simple Grid Model

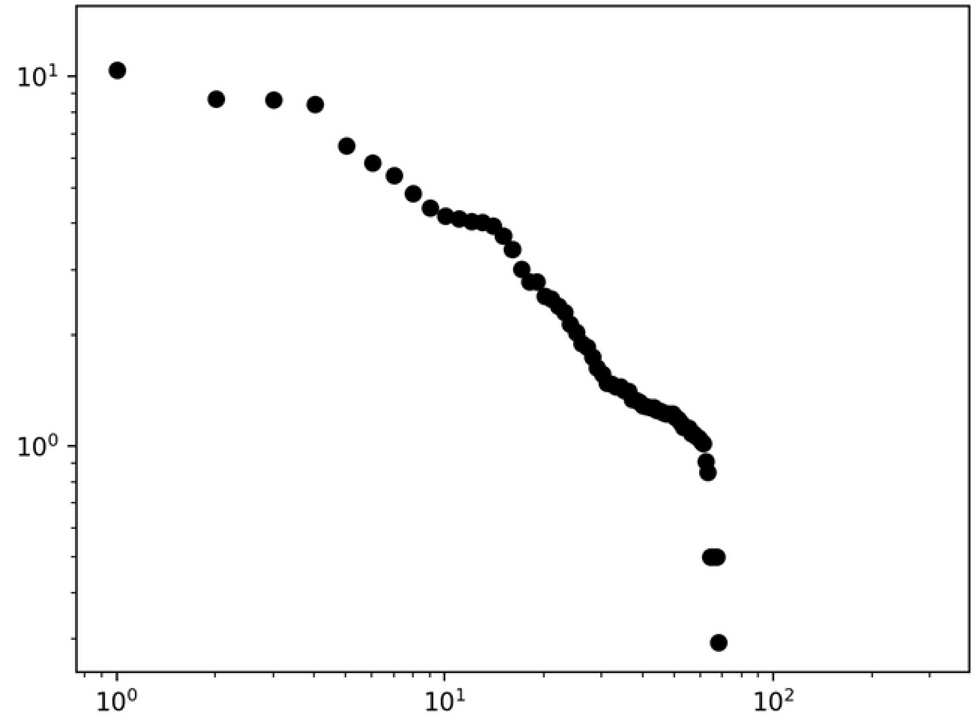




Grid Model with Topography

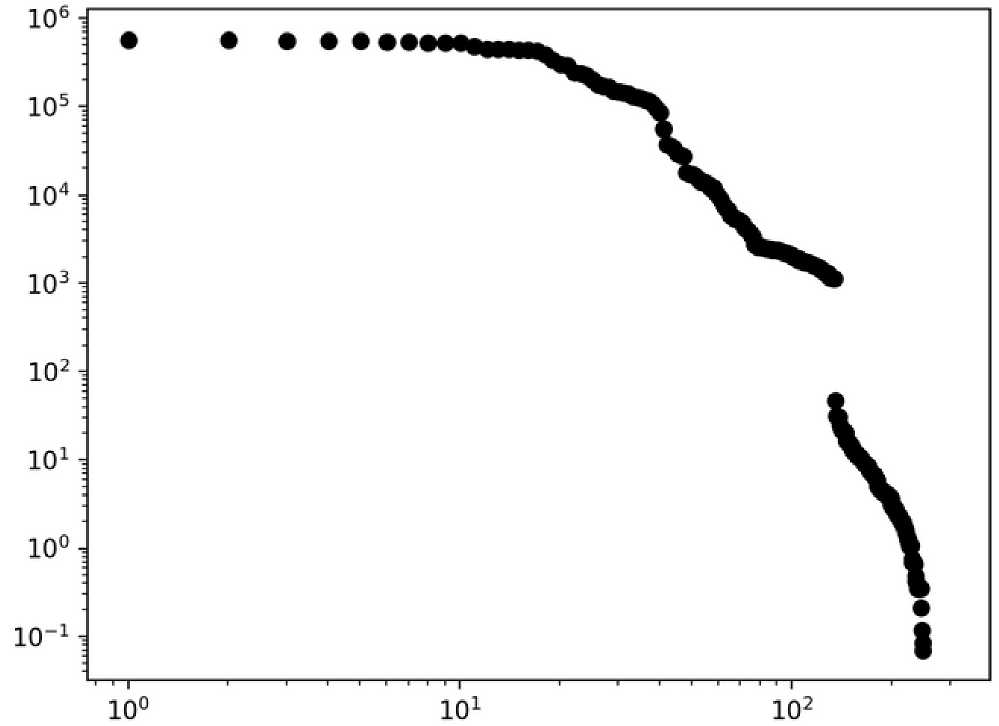


Migrants
Deceased



Step

Migrants
Survived



Step

Now to our Complicated Spatial (CA) Model

Set up:

- Initialize an empty map
- Initialize available Energy at random
- Calculate Fitness based on Neighborhood and Energy
- People try to migrate to the cells with the highest fitness
- Consume Energy and Grow proportionally
- Calculate Emissions and Water level increase

- Plot twist: It was supposed to be our first model and it did not work.
- By adding Fitness and Energy based Growth it became overcomplicated, and we could not count any statistics.
- Previous model - Spatial (CA) is us trying to rebuild this one step by step
- Complicated model played with us by showing SOC behavior and which disappered after a slight parameter change...

Findings:

- Using the Bak-Sneppen model:
  - successfully simulated population migration
  - avalanche sizes and durations to follow a log-normal distribution, indicates emergent behaviour
  - dynamic evolving behaviour based on climate change
- Using CA model:
  - found out and quantified size of migration waves
  - terrain affects migration and creates more chaotic avalanches
  - Even 2 parameters can get out of hands quickly

Limitations and future work (this weekend)

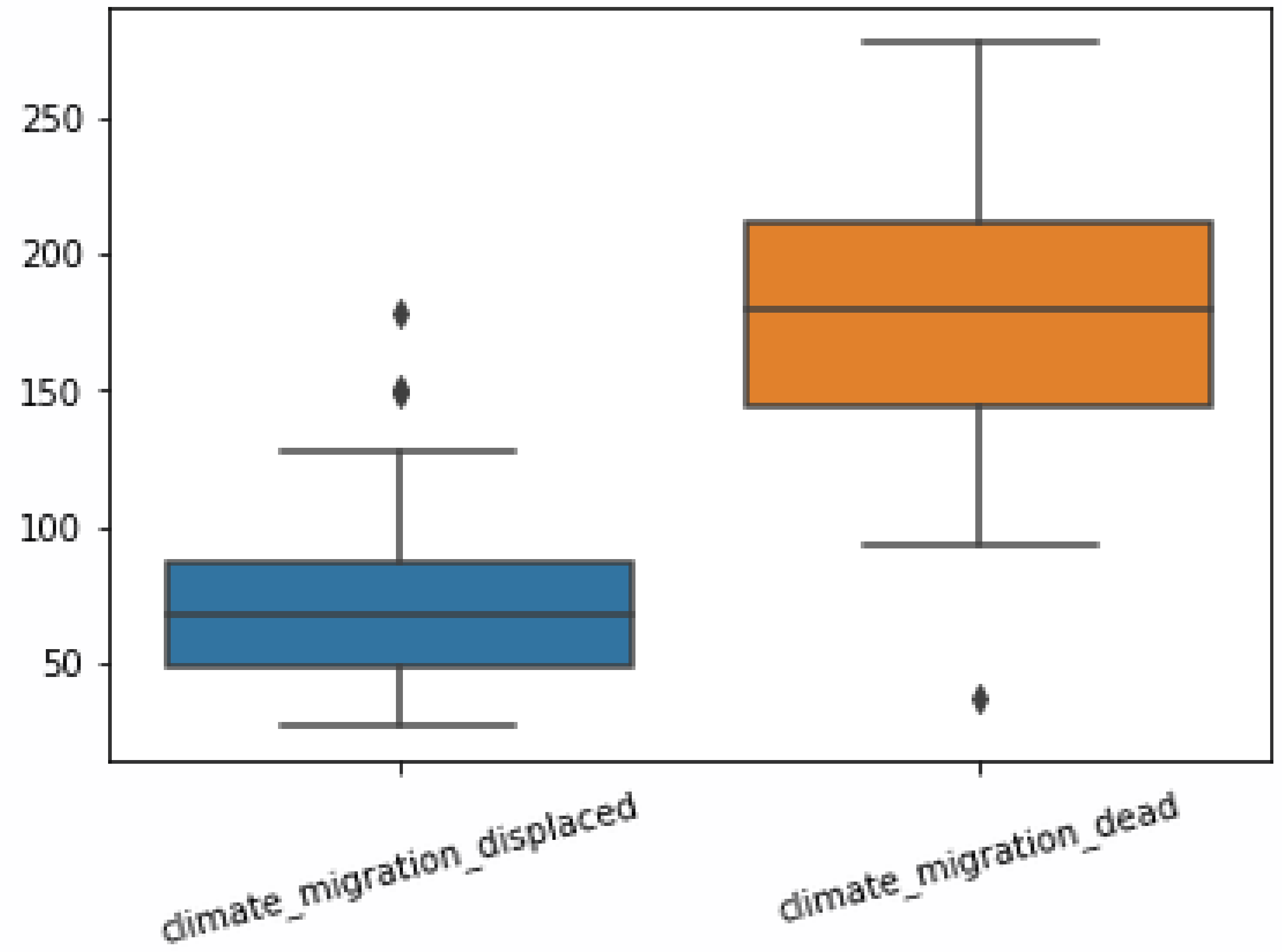
- Avalanches could have been defined differently
- Visualised clustering but need to quantify
- Also look into correlation
- Quantifting interdependence of growth speed and migration patterns

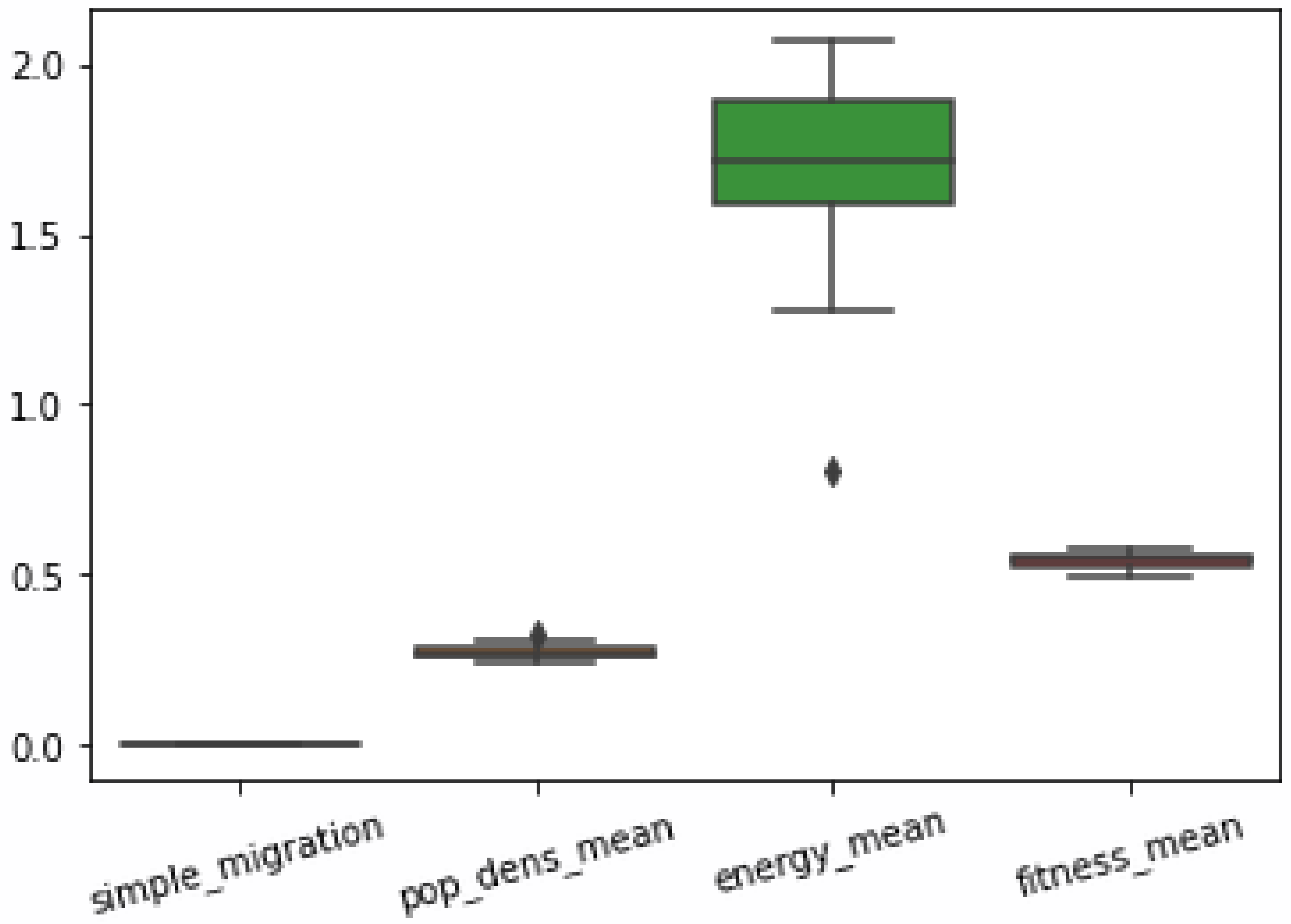
Thank you!

Any Questions?

Appendix:

Distributions of Complicated model Parameters through Time





After few more days, the model still only showed linear behavior. We assume adding a fitness function which is a derivative of some parameters kills the complex behavior by making migration patterns predictable.