1. Research Aim

Sugarscape model consists of cellular automaton (the world), resources (sugar), individuals (turtles) and rules. Resources and individuals are randomly distributed in the world, and individuals survive by seeking and utilizing resources. When resource (sugar) is acquired by individuals, it becomes the wealth. In this process, wealth changes at different rates and wealth inequality arise as a result.

The investigation takes wealth as the study object to explore its acquired behaviour and inequality. Part I of the experiment focuses on the most basic wealth behaviour, that is, "how much wealth can be acquired by turtles in a period of time". Exploring "the acquired wealth behaviour" in different models can reveal the principles both of wealth and sugarscape models. Experiment part II further explores the more complex behaviour of wealth - wealth inequality under varied parameters in order to explore how wealth inequality be affected by population and individual viability (metabolism and vision).

2. Research Method

The whole experiment is divided into part I and part II, whose experimental designs are independent of each other but their results may be mutually interpretable. In part I, none of original parameters are changed (i.e. variables outside the models are controlled), and only adds the reporter "average-wealth" to three original sugarscape models. The three models then repeatedly run over the same period and output the results. In part II, Gini index is added to models 1 and 2, and the values of initial population and individual viability (metabolism and vision) are varied in certain range to explore how wealth inequality is affected. The parameter variation of the three models is simultaneous and identical. (The experimental period for part I and part II are both 1000 ticks)

2.1 Part I of Experiment

Experiment part I sets up with the original parameter values of the three models (Table 1), and creates a new reporter named "average-wealth", which reports the mean sugar of turtles. This new reporter is then added to the interface as a 'plot', where the x and y axes are ticks and average wealth respectively.

Table 1 The major initial parameters set up for model 1, 2 and 3 in Experiment Part I

	Parameters	Range Values
World	Initial Population	400
	Height * Width	50 * 50
Agent	Initial Sugar	[5, 25]
	Metabolism	[1, 4]
	Vision	[1, 6]
	Minimum-sugar-endowment	5
	Maximum-sugar-endowment	25
Sugar	Regrow rate	Gradual / Instantaneous
	Distribution	Random as "sugar-map.txt"
	Max−psugar	Set up as "sugar-map.txt"

Creating new BehaviourSpace for model 1, 2 and 3 to start the experiments. In dialog of BehaviourSpace: set "Repetitions" 10, add "average-wealth" to "Measure runs using these reporters" and uncheck the "Measure runs at every step". Then the experiment would repeat 10 times for each model in 1000-tick period, the average value of 10 times would be used to explore.

2.2 Part II of Experiment

The major parameters set up in experiment part II are shown on the table 2. In this part, Gini indexes are added to model 1 and 2, which can achieve the observation of wealth inequality across models. The exploration of wealth inequality is divided into two main sub-experiments, the first of which varies initial population from 200 to 1600 in increments of 200, the second one varies metabolism and vision conjunctively to explore individual viability. The number of replications is still 10, which means that each model will perform 250 runs of per experiment, and the average value of 10 times would be used to explore.

Table 2 The major initial parameters set up for model 1, 2 and 3 in Experiment Part II

	Parameters	Range Values For "Population"Experiment	Range Values For "Individual Viability (metabolism and vision)"Experiment
World	Initial Population	**[0 200 1600]**	400
	Height * Width	50 * 50	50 * 50
Agent	Initial Sugar	[5, 25]	[5, 25]
	Metabolism	[1, 4]	**"max-metabolism" [2 2 10]**
	Vision	[1, 6]	**"max-vision" [4 2 12]**
	Minimum-sugar-endowment	5	5
	Maximum-sugar-endowment	25	25
Sugar	Regrow rate	Gradual / Instantaneous	Gradual / Instantaneous
	Distribution	Random as "sugar-map.txt"	Random as "sugar-map.txt"
	Max-psugar	Set up as "sugar-map.txt"	Set up as "sugar-map.txt"

3. Result and discussion

3.1 Part I (Basic): How wealth behaves under different models?

After 10 repeated experiments with 1000-tick period, the final average wealth of turtles for model 1, model 2 and model 3 are 1045, 1141 and 44 respectively (Figure 1), which all increase compared to initial value. In conjunction with figures 1 and figure 2, model 1 and model 2 grow rapidly over 1000-tick period, reaching a value well above the initial state at the end of the experiment, and this status will continue. However, in contrast to model 3, it peaks at about 76 ticks and starts to stabilize with the average wealth between 40 and 50 after 114 ticks, and remaining in this range. The figures show that the wealth behaviour vary greatly among the three models due to the different rules and attributes, especially between model 1, 2 and model 3.

Comparing model 3 with models 1 and 2, the biggest difference is whether there is the replacement rule. The average wealth is decided by the sum of “sugar” and the count of all turtles. For model 1 and model 2, the experimental process is like a closed space of meritocracy, which means that turtles with low viability (low vision and high metabolism) will be eliminated, while those with high viability will reach the highest sugar patches in their vision range and eventually stay put. According to the equation “sugar = (sugar - metabolism + psugar)”, the “survival” turtles must be overall smaller than the regrow rate of sugar, thus the amount of sugar possessed by all turtles will grow infinitely over time. And due to the non-renewable rule, the population in model 1 and model 2 would finally stabilize. For model 3, the turtles would never stabilize due to the replacement rule, which means that it is always dynamic and the total amount of sugar cannot grow steadily. Also, because of the invariance of the population in model 3, the average wealth follows the fluctuation of the total amount of sugar, where each peak indicates an optimum reached.

Comparing model 1 and model 2, although they are quite similar, there are still minor differences because of the difference of sugar regrow rule. Compared to model 1, model 2 has a slightly higher value of final average wealth, and a slightly lower final count turtle and final sum sugar. This is because sugar grows to maximum at each tick in model 1 and the “resource” (sugar) of world is constantly saturated, which gives turtles more and better chances to survive. And due to the patches with high sugar are limited but more turtles survive, the slight difference between model 1 and model 2 occurs.

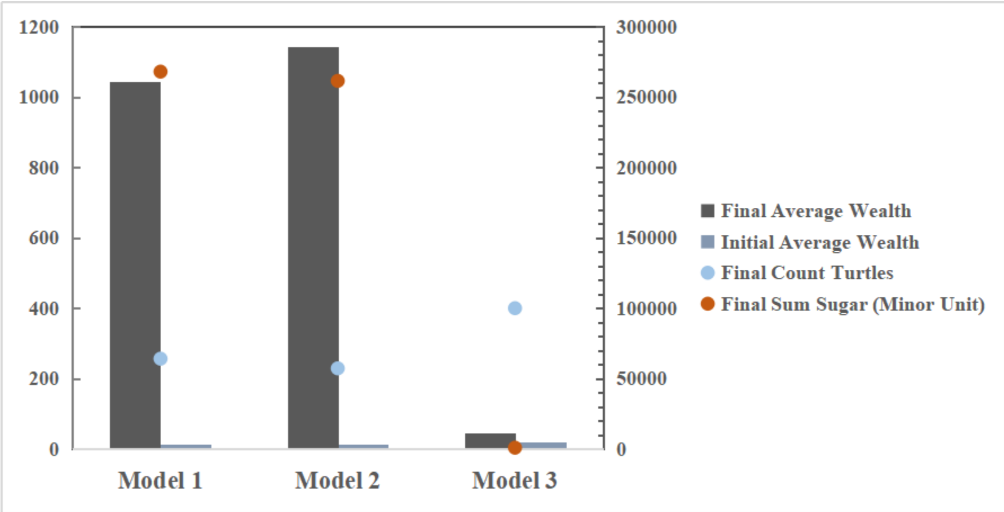

Figure 1 Average wealth before and after the 1000-tick experiment

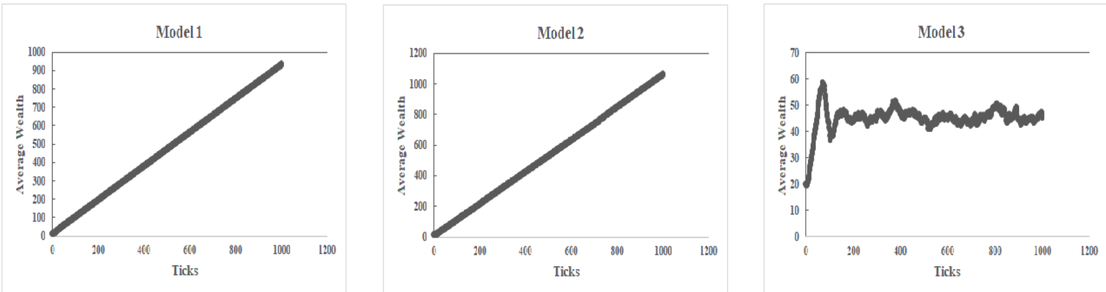

Figure 2 Average wealth trend over 1000-tick experiment

3.2 Part II (Complex): How wealth inequality be affected by parameters?

Wealth inequality can be described quantitatively by the Gini index, which ranges from 0 to 1, with values closer to 0 indicating a more equal distribution. Although there is no international standard defining what is the best Gini index, it is generally accepted that a Gini index between 0.2 and 0.4 is reasonable and that either too large or too small is not conducive to social development (n.d., StudySmarter) .

3.2.1 Population

Varying initial population from 200 to 1600 in increments of 200, the Gini indexes of three models are shown in Figure 3. Overall, Gini index dose not increase exactly in line with the population growth; instead, it mostly has some poles. The Gini index remains relatively stable within a certain population range, but may rise or fall significantly once it is outside this range. In model 2, for example, the Gini index could be effectively reduced if the population is kept in the range of 400 to 800, but it would continue to rise once the population exceeds 800. Therefore, 600 (with the Gini index of 0.25) may be the optimal population value for model 2, and similarly 400 and 800 for model 1 and model 3 respectively.

Assimilating three different models to societies, some conclusions can be drawn. Model 1 is like an unrealistic society with inexhaustible resources, and its wealth inequality depends entirely on individual capabilities, which creates extremes of inequality. Model 3 has a society much like China and India, with adequate resources but with high competition, resulting in greater wealth disparities. While the society in model 2 much like developed country, adequate resources and low competition making it less unequal in terms of wealth.

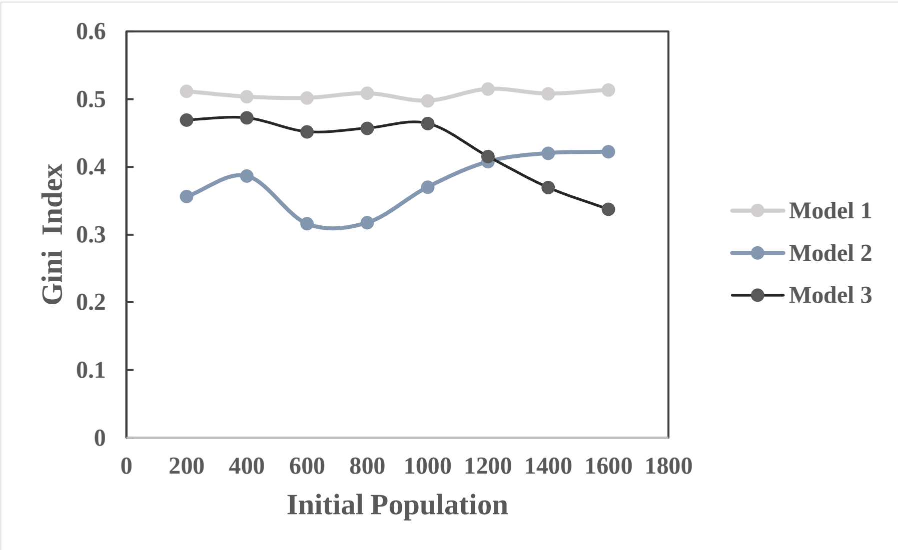

Figure 3 The Impact of Initial Population on the Gini Index

3.2.2 Individual viability (Metabolism and Vision)

Varying metabolism and vision in certain range, the Gini index of three models are shown in Figure 4. In this experiment, vision can be seen as the individual's ability, and metabolism can be seen as the competence in handling money. In all three models, the lowest point or lower area of the Gini index (the darker yellow part) appears in the lower right-hand corner of the matrix, suggesting that the wealth inequality would be reduced in any society if the overall earning power and financial management of individuals is good. Comparing the three models, the matrix colours of models 1 and 3 are more uniform than model 2, which suggesting that the society of model 2 are more influenced by individual viability and have more resilience for social development.

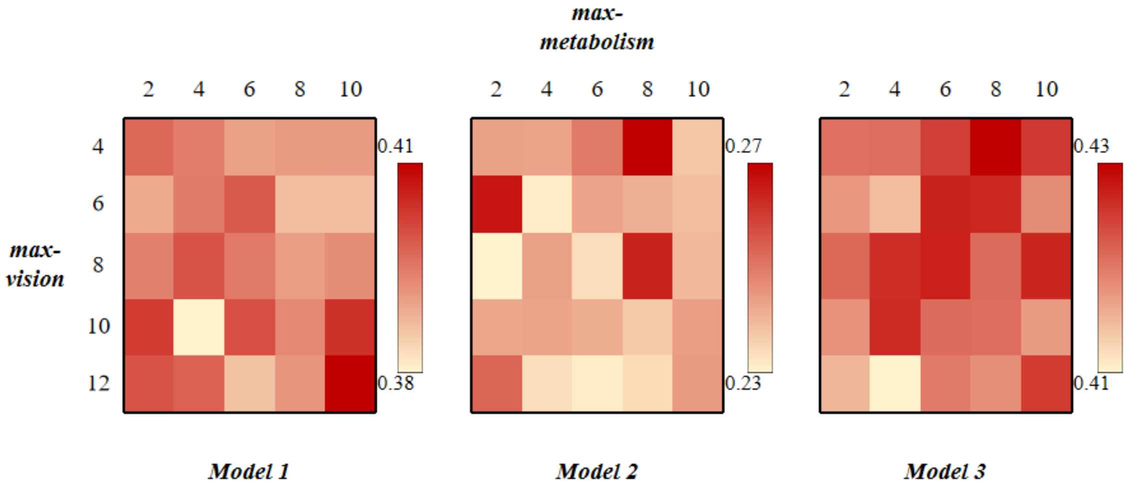

Figure 4 The Impact of Individual viability on the Gini Index

4. Conclusion

The wealth that individuals process and wealth inequality has always existed in the virtual and real world. Experiment Part I shows that the same individuals in different worlds can end up with vastly different behaviour of wealth. Experiment Part II shows that variation in population and individual viability within the same world could have different impact on wealth inequality, but these impacts are always not linear but with an optimum interval. What's more, the three models can represent the ideal society, the developed society and the developing society respectively, and the significance of models would become more apparent when they combine with the reality factors.

Reference:

StudySmarter, n.d. Gini Coefficient: Meaning, Examples & Theories [WWW Document]. StudySmarter UK. URL https://www.studysmarter.co.uk/explanations/microeconomics/poverty-and-inequality/gini-coefficient/ (accessed 2.24.23).

Appendix:

1. Adding new reporter of average wealth (Part 1)

```
to-report average-wealth
   report mean [sugar] of turtles
end
```

2. Adding ticks limit (Part I and Part II)

```
to setup
   set tick-limit 1000
end

to go
   if ticks > tick-limit [stop]
   tick
end
```

3. Adding Gini index to model 1 and model 2 (Part II)

```
globals [
   tick-limit
   gini-index-reserve
   lorenz-points
   max-metabolism
   max-vision
]

to update-lorenz-and-gini
   let num-people count turtles
   let sorted-wealths sort [sugar] of turtles
   let total-wealth sum sorted-wealths
   let wealth-sum-so-far 0
   let index 0
   set gini-index-reserve 0
   set lorenz-points []
```

```
  repeat num-people [
    set wealth-sum-so-far (wealth-sum-so-far + item index sorted-wealths)
    set lorenz-points lput ((wealth-sum-so-far / total-wealth) * 100) lorenz-points
    set index (index + 1)
    set gini-index-reserve
      gini-index-reserve +
      (index / num-people) -
      (wealth-sum-so-far / total-wealth)
  ]
end
```

4. Turning turtle variables to global variables (Part II)

```
globals [
  max-metabolism
  max-vision
]

to turtle-setup
  set metabolism random-in-range 1 max-metabolism
  set vision random-in-range 1 max-vision
end
```