Using Agent Based Modeling to Understand Social Cooperation

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Abstract

We explore the question of whether cooperation has better outcomes compared to no or lower levels of cooperation by using the Agent Based Simulation paradigm. We try to answer such questions by simulating a dynamic world, with various types of agents living within it and each striving to survive by obtaining energy from a limited number of natural energy sources. We study the effect of cooperation in various conditions and report our findings.

1. Motivation

Today's world is witness to unprecedented globalization, which has resulted in interaction of many groups of people from various cultures. Mostly, they strive for a common pursuit but sometimes their ideologies may be against each other. In such a scenario, one may wonder whether mutual cooperation is the key for harmonious development of each community. Co-operation is the process of groups of organisms working or acting together for common, mutual, or some underlying benefit, as opposed to working in competition for selfish benefit.

To understand whether cooperation has any impact upon the prosperity of an individual as well as the group at a theoretical level, we need to somehow model the various interactions that may take place among different citizens. However, these interactions can turn out to be extremely complex, even though we start by defining some very primitive kinds of interaction. Therefore, we model the agents using the paradigm of Agent Based Modelling. An agent-based model (ABM) is a class of computational models for simulating the actions and interactions of autonomous agents (both individual or collective entities such as organizations or groups) with a view to assessing their effects on the system as a whole.

2. The World and its Citizens

We first define the construction of the world where the simulations take place.

- The world is modelled as a 100×100 grid. There is no restriction on number of occupants of any cell, i.e., one cell may have more than 1 agents at the same time. We refer to such grids as Multigrids. Thus, 1 cell is the basic unit of distance in this world.

- The world has a fixed number of natural energy resources, each with a starting energy content and decay rate. The decay rate is randomly selected to be a small positive or negative number. This emulates the natural resources available in real world. A negative decay rate means to enrichment of energy sources. On the other hand, a positive decay rate points towards depletion of resources, reminiscent of present conditions in real world.

Now that the world has been created, we move on to populate this world with agents. These agents interact with the world and among themselves in complex manners and give rise to interesting patterns of behaviour.

The world has 2 types of agents, `EXPLOITERS` and `EXPLORERS`, details of whose behaviour patterns are described in the following subsections. However, both the Explorers and Exploiters share some common attributes, although of varying magnitude which are described below:

- **Living Cost**: Each agent starts off with some initial energy content randomly assigned to it. However, just like real life, their must be some quantity which should model the natural growth of the agent. We do it by defining a living cost for each agent, which refers to the amount of energy depleted whenever an agent makes a movement. For exploiters, we also define an additional cost, called static living cost which refers to the amount of energy depleted when the agent makes no movement.
- **Sense Range**: Each agent can sense the presence of an energy resource within a certain radius of its current location. This radius is referred to as sense range. The sense range is kept higher for explorers than exploiters, keeping in mind the idea that explorers are the primary source of information to extract the locations of energy resources.
- **Communication Range**: Similar to the sense range for sensing energy resources, each agent also has a communication range, which enables the agent to locate all other agents within its vicinity with whom this agent can communicate. Note that communication is 1-way, i.e., agent A communicating with agent B is not equivalent to agent B communicating with agent A.
- **Mining Rate**: Each agent also has a mining rate which determines how fast the agent can procure energy from energy resources.

2.1. Exploiters

Exploiters are representative of the static population in real world. For a majority of their lifetimes, exploiters remain idle, and search for energy actively only when their own energy levels goes below a certain threshold. However, the exploiters may also move randomly otherwise, although a with a very low probability. They are characterized by higher cost for movement, and lower ranges for communication and sensing other energy resources. The exploiters have higher mining rates.

2.2. Explorers

Explorers are representative of the dynamic population in real world, they travel across the world in search of new resources. The explorers initially start at the base station and a random drift direction is assigned to each explorer, like north or east. The explorers move with a higher probability in their drift direction, thus drifting them in that general direction. The explorers also follow a cyclic movement pattern. After a fixed number of timesteps, the explorers return to a random position in the base station to share their knowledge with other members. The explorers are characterized by low cost for movement to facilitate far sighted movements, and higher ranges for communication and sensing other energy resources. The explorers have lower mining rates.

3. Designing a Dynamic World

We have described the structure and build of the world, and the general characterstics of both types of agents. However, what truly makes this world exciting is the ever dynamic nature of interactions and the underlying complexity. We try to model the dynamic nature of world in following ways:

- All agents are spawned in a bounded area called the base position. The locations within the base are decided randomly.
- The energy resources are also spawned randomly and the locations of these energy sources are also changed every fixed number of steps with a low probability. The decay rates of the energy resources are also changed every fixed number of steps.
- The explorers drift in a general direction for some steps. They follow a cyclic pattern, after some steps, they return to the base position and again drift in (possibly) another direction. The exploiters move greedily towards an energy resource from their memory if their energy falls below a certain threshold.
- If the explorers find some exploiters within a certain range, they can borrow some energy with a low probability.
- The agents can reproduce to produce new agents. The mode of reproduction is similar to asexual reproduction where only 1 parent is required. To allow only fit individuals to grow, only the agents above a certain threshold energy level are able to reproduce. Since reproduction is an costly process, a large amount of energy is depleted from parent after reproducing.
- The offspring inherits all the memory of its parent. Further, the type of the offspring may differ from that of its parent with a small probability. This is to ensure some mutation in population. All other parameters like sense range, communication range, living cost, etc are decided randomly.
- Communication and sensing energy sources are carried out every fixed number of timesteps.
- Each agent maintains a memory buffer of all energy resources it has seen so far. Sensing energy resources is straight forward, once an agent finds any resource, it stores it in it's memoty buffer. The parameters associated with each energy source in memory are amount of energy, location, decay Rate and Time of Sight. Time of Sight is important for 2 reasons: it helps in calculating the expected energy content of any resource when deciding the optimal source from memory buffer, second, in case multiple energy resources are same in terms of expected energy content, Time of Sight enables an agent an agent to choose the most recently seen one as there is higher chance of that information being correct.
- There are 2 types of communication - `INTRA-AGENT` which takes place between agents of same type like exploiter-exploiter or explorer-explorer and `INTER-AGENT` which takes place between exploiter-explorer.
- For each block of information in memory, it is shared with another agent with a probability denoted by `share_probability`. Thus, communication consists of 2 steps: first the other party must be within communication range of the agent and should qualify as eligible for communication according to some probability distribution. Once a link has been established between 2 agents, communication takes place according to the share probability. Once the agent reaches its target, it mines energy until a certain upper bound is reached. This cycle keeps continuing.

4. Life of an Agent

This section describes the life of an agent in this simulation world. Firstly, the agent starts off with some random energy content. Then, depending on whether it is an explorer or exploiter, it either keeps moving or settles to a static life. Once the energy content goes below a threshold, the agent actively searches for an energy resource irrespective of its type. For finding the best energy resource to replenish itself, if first goes through its memory buffer and calculates the expected energy content of each resource at the time when it will reach that resource's location. Accordingly, it selects the best resource according to some policy, which is fixed to be ϵ-greedy in this work.

5. Results

Its quite a difficult task to give mathematical formulations for all types of interactions even in this simple world. Hence we use statistics of various important quantities to understand the effect of cooperation. All results described below have fixed parameters, the details of which can be found in `config.py` file in the codebase. All code pertaining to these experiments can be found at: https://github.com/Abhipanda4/Agent-Based-Modelling.

We begin the results section by showing the plot for mean ages of explorers, exploiters and the whole population under *normal* conditions. Normal conditions refer to the default values specified in `config.py` file.

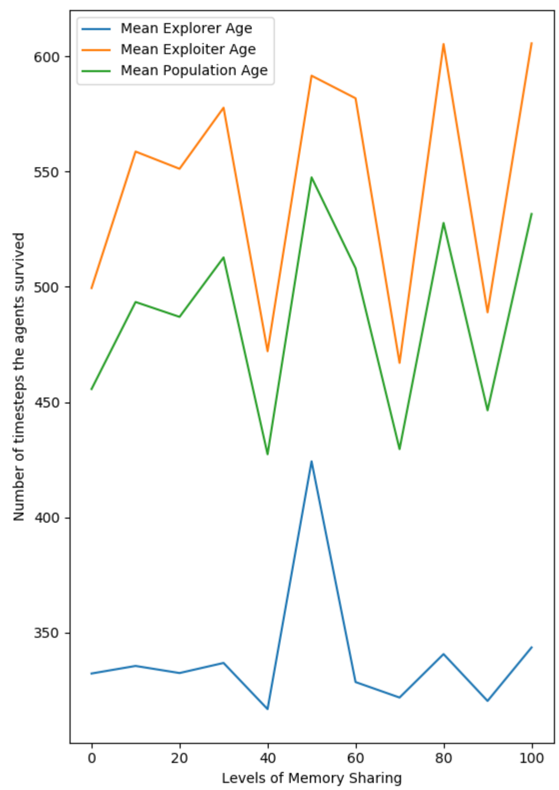

Figure 1: Plot of mean ages for exploiters and explorers under normal conditions

It can be clearly observed that there is no clear trend in the dependence of memory sharing and mean age of population although we get some peaks in the plot.

5.1. Communication Dependence in Increasing Energy conditions

The amount of energy in the world is a very influential factor which affects the overall age distribution. The world can either be energy poor, energy rich or energy balanced. Further, the variation of energy with time also affects the behaviour of agents. In this subsection, we deal with the scenario when energy of the world was slightly increasing over time as shown in 2.

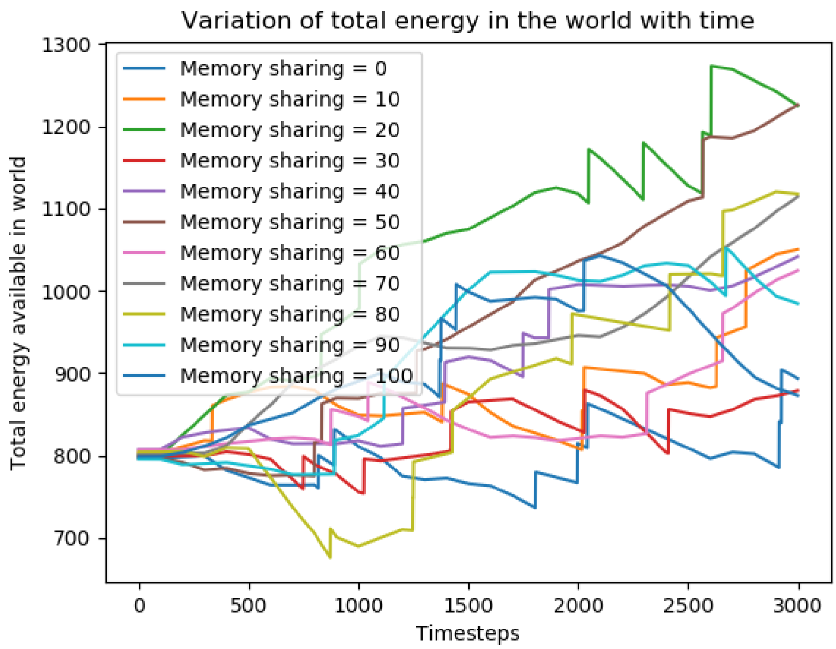

Figure 2: Energy Levels variation with time

With this energy profile, we experiment with varying levels of energy content and cooperation among agents in the world. Particularly, we consider 3 cases, when the world is either energy rich, energy poor or energy balanced. At each energy level, we simulate 4 scenarios arising due to varying the magnitude of intra and inter agent communication probabilities, which were: high-high, high-low, low-high and low-low respectively. High corresponds to a probability of 0.8 whereas low corresponds to a probability of 0.2 in contrast to the default probability of 0.5.

Figures 3, 4, 5, 6 show the dependence of mean ages with communication probability for various settings of intra and inter agent communication probabilities in the case when the world had high energy.

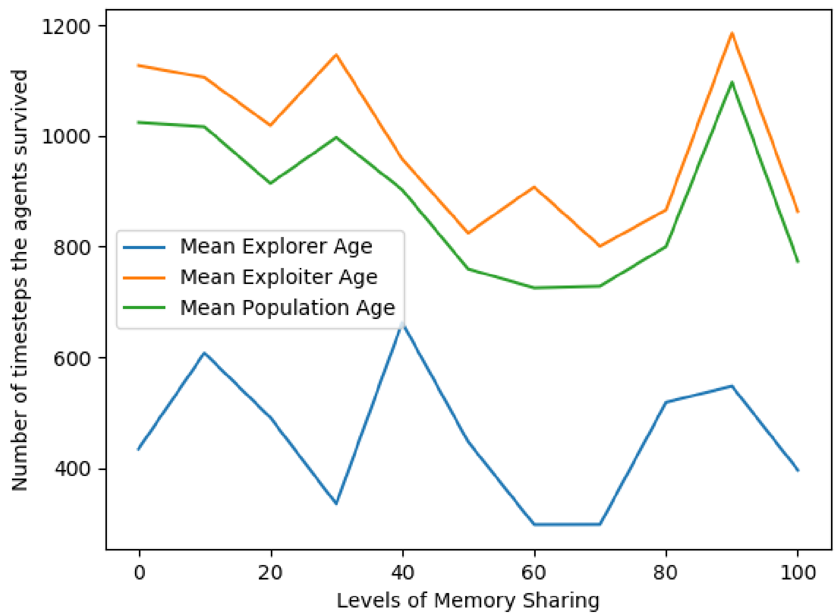

Figure 3: `high_high-high.png` - Mean Ages w.r.t memory sharing probabilities for High energy world with high-high cooperation

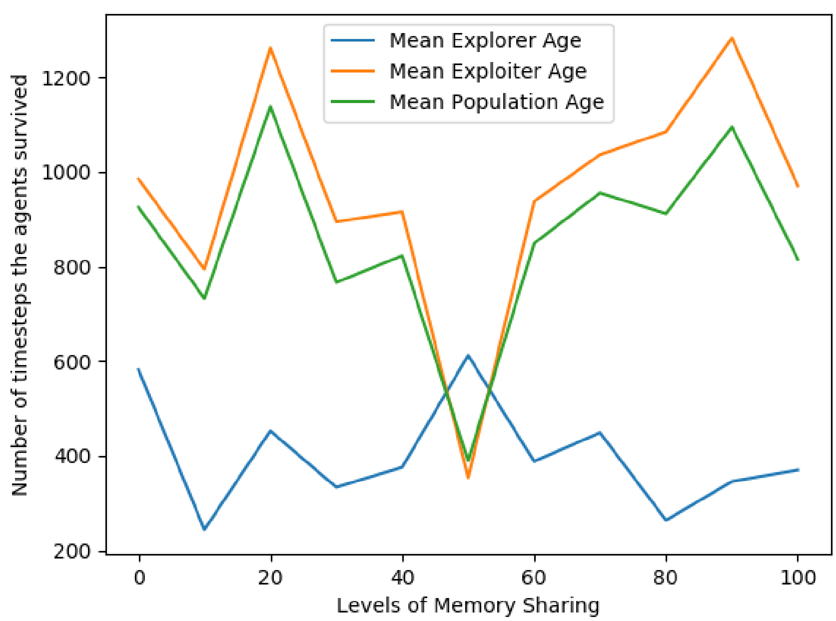

Figure 4: `high_high-low.png` - Mean Ages w.r.t memory sharing probabilities for High energy world with high-low cooperation

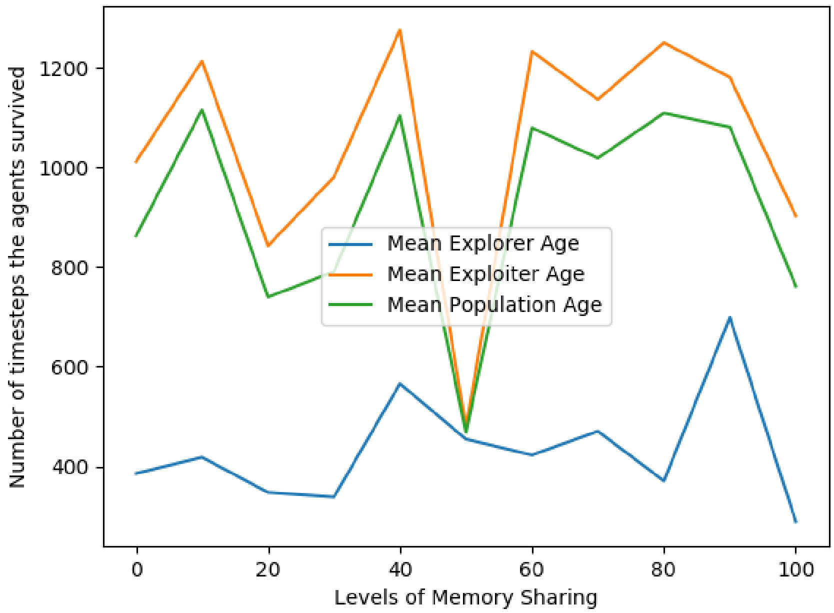

Figure 5: `high_low-high.png` - Mean Ages w.r.t memory sharing probabilities for High energy world with low-high cooperation

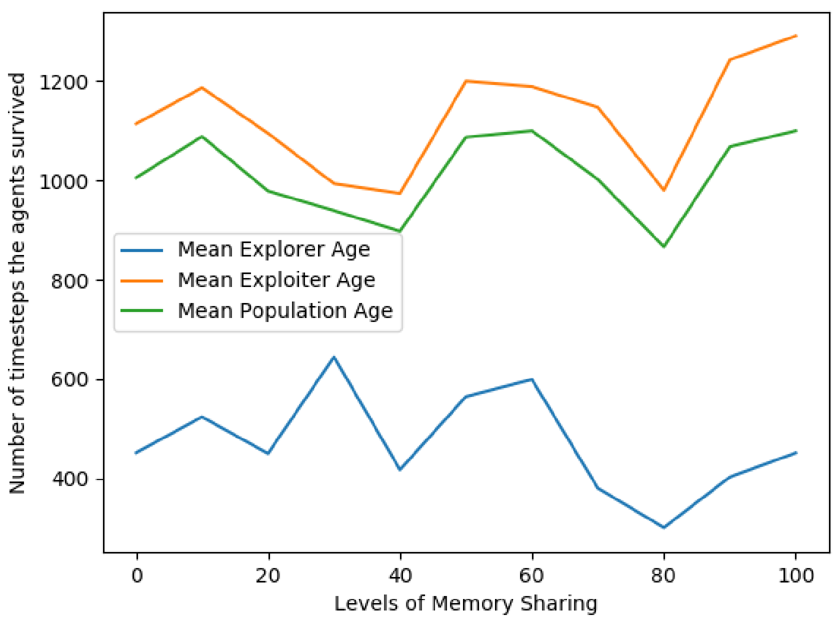

Figure 6: `high_low-low.png` - Mean Ages w.r.t memory sharing probabilities for High energy world with low-low cooperation

We obtain similar graphs in cases when energy content is medium or low, and for the sake of completeness, provide the obtained plots in case when cooperation was high-high.

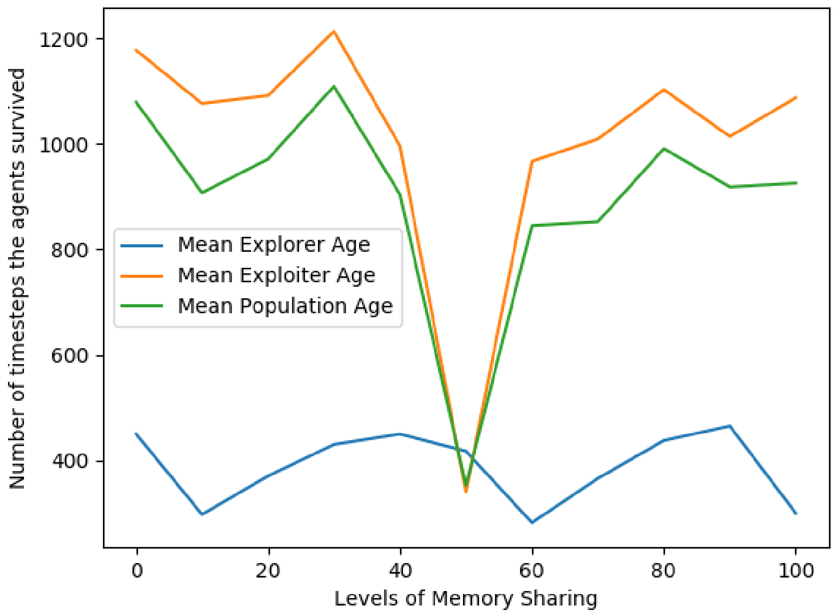

Figure 7: `medium_high-high.png` - Mean Ages w.r.t memory sharing probabilities for Medium energy world with high-high cooperation

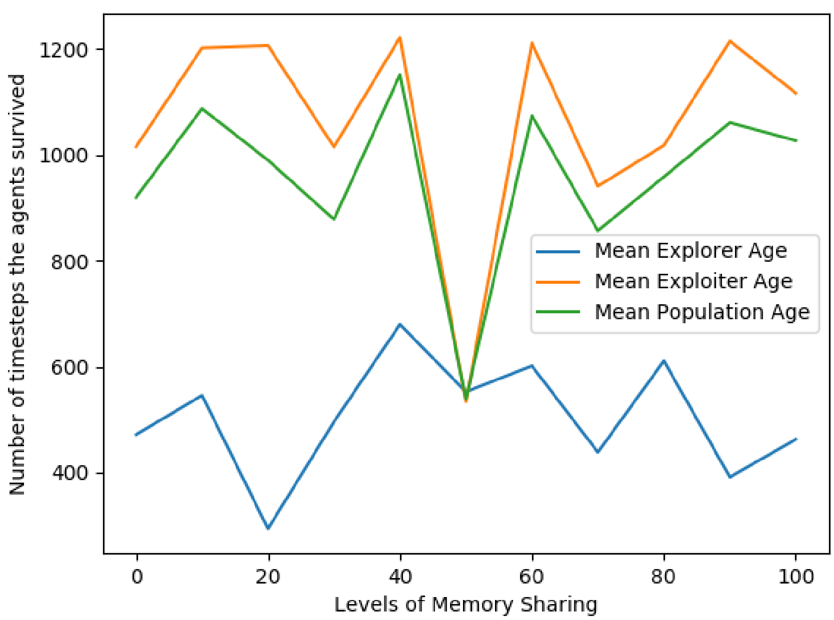

Figure 8: `low_high-high.png` - Mean Ages w.r.t memory sharing probabilities for High energy world with high-high cooperation

5.1.1. Observations

An extremely interesting observation is a prominent dip in the average age of population at memory sharing levels of around 50% in several scenarios. We observed such dips in many of the plots for medium and low energy cases as well. Note that the dip is caused due to a sudden decrease in life expectancy of exploiters whereas explorers approximately maintain the same mean ages. Since number of exploiters is quite higher than number of explorers, the mean age of population also goes down. We are not sure about the root cause of such unexpected behaviour, our hypothesis being the setting of (many) other hyperparameters of the world dynamics somehow combine mathematically and make 0.5 memory sharing ratio an unfavourable factor for exploiters.

5.2. Variations in proportions of Explorer-Exploiter

In most of our experiments, the initial population consisted of 10% explorers and remaining 90% were exploiters. In this subsection, we investigate how varying this initial ratio affected the population distribution on the long run.

We experiment with 3 cases, one being the case described above. Then we consider the extreme cases, 1% explorers and 99% exploiters vs 90% explorers and 10% exploiters. We focus on the number of agents of each type over time and report our observations in figures 9, 10, 11. In each of these plots, memory sharing level was fixed to 0.5 and the communication probability between 2 agents was also fixed to 0.5 irrespective of their types.

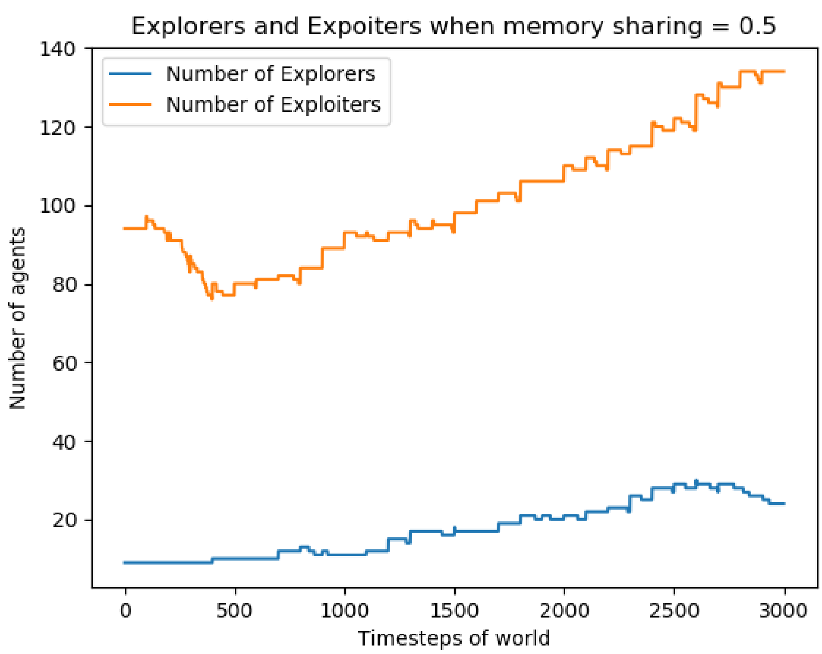

Figure 9: Normal Trend in population of exploiters and explorers when starting with 10% explorers

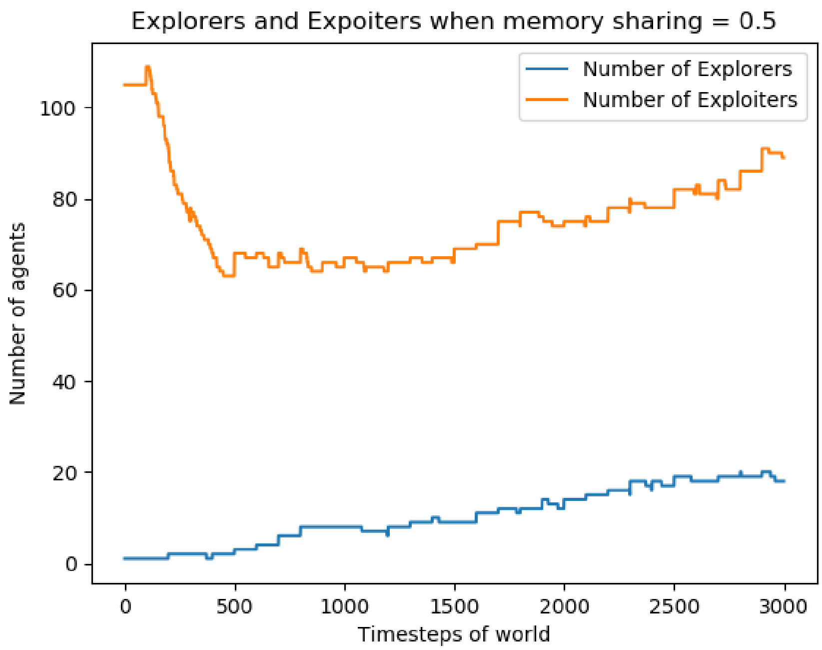

Figure 10: Trend in population of exploiters and explorers when starting with 1% explorers. The fall in number of exploiters at beginning is alarming

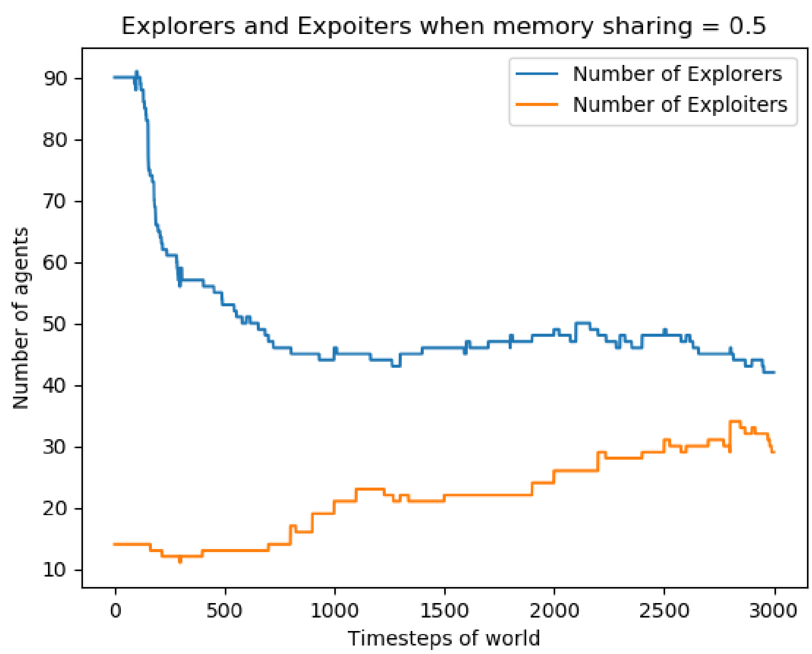

Figure 11: Trend in population of exploiters and explorers when starting with 90% explorers. Many explorers die within the first few time steps of the world.

5.2.1. Observations

When the initial number of explorers is too small, the number of exploiters goes down rapidly, as shown in Fig. 10. This can be attributed to the fact that that due to shortage of exploratory activities, there is a shortage of information regarding the location of energy resources. Hence, many exploiters die at the beginning due to unavailability of energy, akin to *famines* in real world.

On the other hand, when population primarily consists of explorers, many explorers die out at beginning as shown in Fig. 11. Although it may seem a bit odd, it was actually expected since exploration basically means going to some random place without any guarantees of payoff in future. As a result, most of the explorers who unfortunately went to some energy poor area died out quickly.

5.3. Memory Capacity as a measure of Cooperation

The experiments described so far do not give any concrete explanation to how cooperation determines the ages of various agents. But going back to the basics, what exactly is cooperation in the context of our world - it is about sharing the knowledge about energy resources. Ultimately, agents need energy to survive using these energy resources. Thus, it makes more sense to measure the effect of information content on the expected ages. We show the relevant figures in Fig. 12 and 13 for 0% and 100% memory sharing probabilities. These figures depict the mean ages of an agent w.r.t the average length of its memory buffer throughout its lifetime.

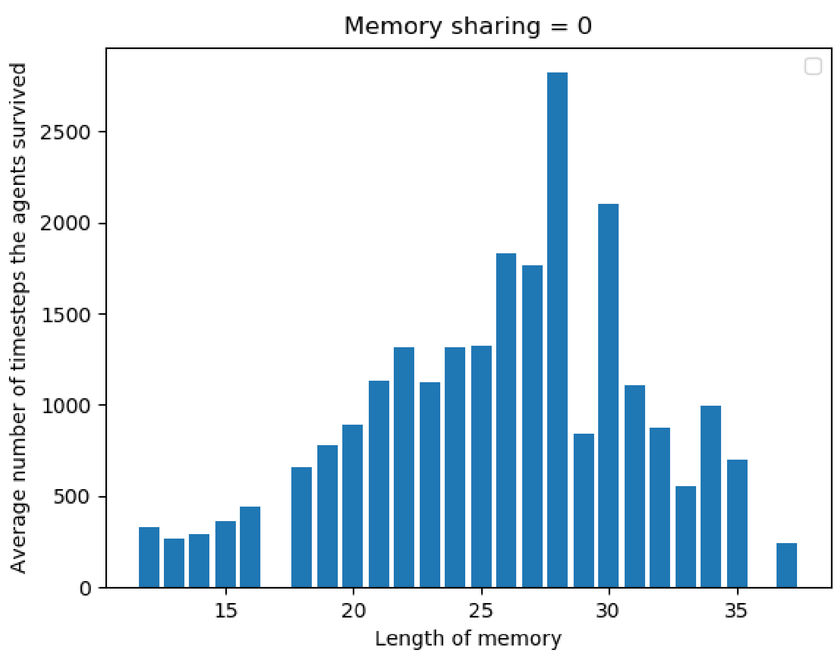

Figure 12: Average age of agents with varying levels of memory lengths when share probability was 0

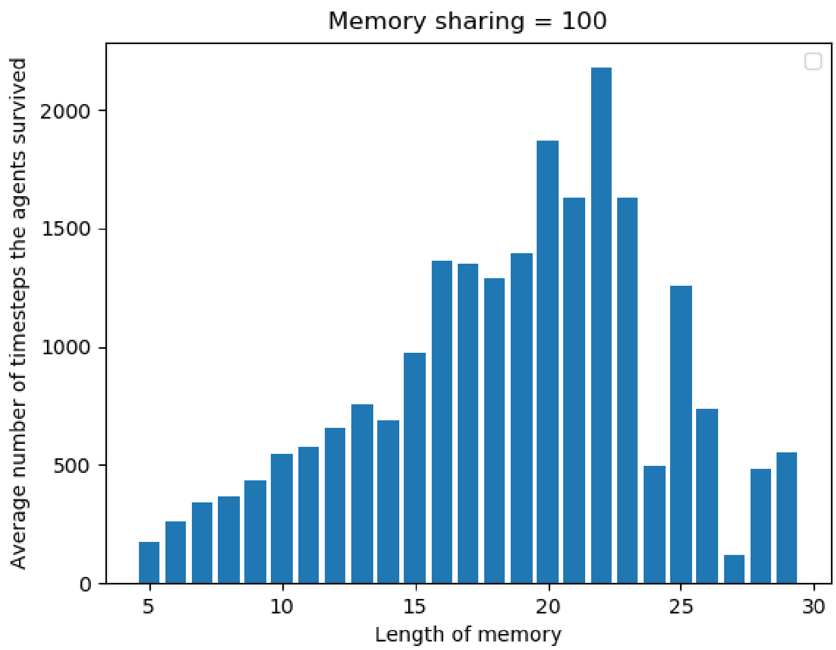

Figure 13: Average age of agents with varying levels of memory lengths when share probability was 100%

5.3.1. Observations

The distribution of mean ages w.r.t memory lengths seems like a normal curve leaning slightly towards right. The left tail is quite intuitive, lesser information about energy resources automatically reduces the life expectancy of an agent. However, the right tail is somewhat counter-intuitive, after all more choices for determining a good energy resources should result in better decisions! However one caveat in this notion is the quality of energy resources in memory, most memory blocks in lengthy memory buffers contained information that was observed a long time ago. Since the world is dynamic, this information becomes incorrect after some timesteps and gives misleading directions to the agents due to which they travel to incorrect locations and eventually die out early.

5.4. Other Experiments

Apart from the figures given above, we have generated around 700 plots with various parameter settings and behaviour patterns. Further, we have also designed a graphical simulator using Projectmesa which enables us to observe the world in real time. A screen-shot of the simulation is given in Fig. 14.

All code and plots for this project can be found at https://github.com/Abhipanda4/Agent-Based-Modelling.

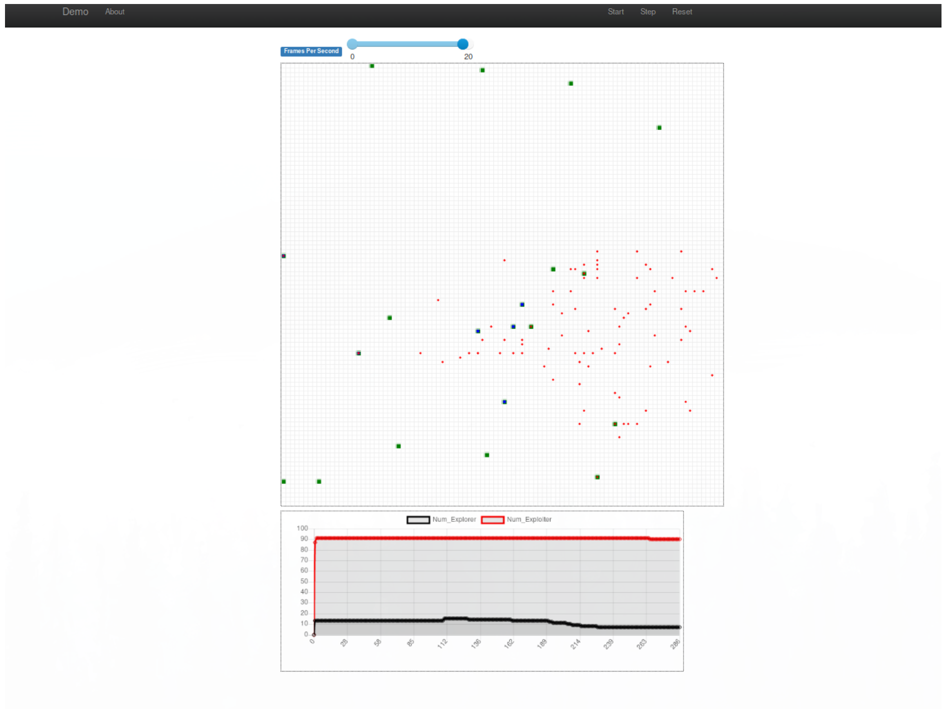

Figure 14: Average age of agents with varying levels of memory lengths when share probability was 100%

6. Conclusion

This work was an exploratory attempt to explain the advantage/disadvantage of social cooperation using the techniques of agent based modelling. Our basic premise was "Higher cooperation among agents will lead to higher benefits". We measured cooperation using the metric of memory sharing probability and benefits were in the form of longer lives. While our work does not give a definite answer of whether cooperation is useful or not, it certainly shows some interesting results with regards to how cooperation may affect the agents. We firmly believe that while cooperation is essential, it may not be the primary factor in deciding the fate of an agent - it only influences a latent factor and future works in this field should be focused towards finding this latent factor.

7. Future Work

The possibilities for incorporating new ideas into the world are endless. A very important idea to get closer to real world will be to include multiple species in the world, thus lifting the unrestricted access on any energy resource as was the case currently. This represents real world more appropriately since different groups have different policies as to how they allow people from other groups to use their resources. Another important work will be to introduce spatial variation in energy distribution, which will give rise to energy rich and energy deprived areas in the world. This is important since studies have revealed that civilizations generally flourished in an area that had abundant supply of natural resources. Other improvements can be to change the memory access to incorporate some importance to fresh information over old ones. Further, nomadic lifestyle may also be introduced among the citizens, where the agents periodically change their base locations to some other place that they think to be better in terms of energy availability.

References

Projectmesa. Mesa: Agent-based modeling in python 3+. https://github.com/projectmesa/mesa.