1 Introduction

Fermi paradox is one fascinating topic elaborating contradiction between the lack of evidence for extraterrestrial civilizations and various estimates for their probability. One potential explanation brought by the fiction novel The Three-Body Problem is Dark Forest Theory.

In the novel, the argument is laid out on two main axioms: 1. Survival is the first need of civilization. 2. Civilization is growing and expanding, but the total amount of matter in the universe remains unchanged. Also, two important concepts follow: 1. Chain of suspicion: both sides can't judge whether the other side is civilization preferring goodwill. 2.Technology explosion: the speed and acceleration of technological levels for civilizations are not linear and necessarily the same, and the weak civilization is likely to surpass the strong civilization in a short time. From axioms and the nature of the chain of suspicion and technology explosion, it is concluded that if civilization A finds civilization B, A must strike B. In this way, the Dark Forest theory proposes one perspective for Fermi paradox: the civilization with a higher technological level tends to hide itself, which makes it difficult for other civilizations to explore. The civilization that exposed itself was destroyed in the attack of the dark forest. The result of this survival choice is that all civilizations become hard to find.

At the same time, other hypotheses also provide interesting views [1] :

1. Rare Earth hypothesis: How rare are planets like Earth in the universe in such magnificent time and space. The conditions for rising lives and intelligence is pretty tough, and our Earth and our human being are just a miracle with a really small probability. The origin of life is very rare as it took nearly a billion years for life on earth to emerge under such outstanding conditions. And lives are developing intelligence as we all know on Earth, this also took a long time. So basically, we are one miracle based on a series of events with small probabilities. Even if some place also has this miracle, either they are too far away from us, or we show in different periods.

2. Great Filter. The great filter theory holds that in the process from the appearance of life to the appearance of high-level civilization, there is a wall that almost all life will bump into. This wall is an extremely difficult or even impossible stage in the long evolutionary process. This stage is the great filter. And one terrifying fact is that have we gone across the great filter?

And what this great filter would be?

One possible explanation is that the intelligence would disappear at a certain period. In this perspective, our human being is lonely no matter we have crossed the Great Filter or not. Primarily, just as our appearance, the disaster with small probability could also happen and blot us out. Secondly, the great filter is just on the way. We would devastate ourselves due to a higher technology level or shortage of resources.

Other explanations reveal the fact that other high-level civilizations exist and there are some reasons that they have contacted us. Firstly, they have reached Earth, but intelligence has not appeared. Secondly, we are very alone in one corner and the technological level is so low that we do not know what is happening outside our small and isolated galaxy. Thirdly, there is only one of the greatest intelligent life - a super predator. They will destroy all civilizations that have developed to a certain level. It is inefficient and wasteful to eliminate all new civilizations as many new civilizations lead themselves to death, but when a civilization has passed a certain stage, the super civilization begins to act. This has some common with Dark Forest Theory as those dark forest attackers are playing this role.

So, based on those theories and hypotheses, I would like to do some simulation to find something fascinating out to give some feedback on those interesting thoughts. As our existence is one series of events with small probability and where intelligence or civilization goes is also the result of a load of probabilities, the simulation based on setting parameters is reasonable to some extent.

2 Research Targets and Methodology

2.1 Research Questions

So basically, we want to simulate those hypotheses on Fermi paradox. But let us admit, we could not answer the questions and what we are doing is also our human view. So firstly I would set parameters reasonable and see the original results. Then I will change the parameters and figure out which parameters could lead to the hypotheses. For a different set of parameters, the outcomes also vary so that we could know the conditions for each hypothesis. Finally,

basic machine learning could apply to see which features are important for the existence of civilizations. We could use softmax classification to test the effects of features on the outcomes (are they still exist or how they die out) of civilizations. Also, regression on living turns could conduct to see which dimensions are critical for the living of civilization.

In this way, this paper is more like a simulated experiment on cosmic sociology.

Firstly, we would see how this simulated universe goes by default parameters in human views.

Secondly, we would change the parameters to simulate the process as well as results for hypotheses and find out which parameters are vital.

Finally, supervised learning follows to test the importance of features for the existence of civilization. In my view, this would also provide us some information on what conditions a high-level civilization need.

2.2 Research Methodology

Simulation and supervised learning including multi-class classification and regression are the methods for this paper. For simulation, almost thirty parameters would be set to adjust the results of the simulation. A lot of events would be decided by random probabilities. For supervised learning, besides for train dataset and test dataset split to examine the validity of the model, we also explore the importance of features. And a lot of NaN values also influence our choices. In this context, Ensemble Decision Tree Model fits this task. So we would use the lightGBM model which matches the efficiency and strong capacity of feature selection.

3 Construction of Simulation

3.1 Initialing

There is no doubt that our main point is simulation. In the beginning, we simulate 100*100 (10,000) galaxies in a grid graph and also give them a certain level of natural resource (mostly little resource and much smaller probability for high level of natural resource). After initializing

our universe with a certain gift for different galaxies, we run a certain number of turns. As this is a simplified universe, we assume the interval between the galaxies is between 30 and 100 light-years. So for every turn, the time also lasts for this period.

Table 1: Probability for Gift of Galaxies

Gift	Probability
0	0.5
1	0.3
2	0.1
3	0.07
4	0.02
5	0.01

Then we will simulate the rise of lives with a certain probability (life born coefficient) based on the natural conditions of the galaxy. During the initializing of civilization, one certain type of civilization is also made.

As this simulation is mainly based on Dark Forest Rule (DFR), we assume that three types of civilization exist:

1. Communicative civilization with goodwill. These are ideal inhabitants in the universe. They prefer to communicate with other civilizations and what is more interesting, in a way with goodwill. They have not known the cruel fact of Dark Forest. Still, they will defend themselves once they are attacked. When they can report or radio their coordinate to show their existence to other civilizations, they will do that without hesitation.

2. Attacker civilization with malice. This is also the most aggressive and radical civilization. They will attack any civilization if their technology level is higher. And if they have the ability to launch dark forest attack (that is launch some weapon running at the speed of light), they will launch that once they get the radio coordinates.

3. Hider civilization. This is one rational civilization as they know and take advantage of the DFR. They will be less inclined to explore the galaxies nearby and they will not give any feedback on communication and radios from other civilizations. However, as they know the truth of DFR, they also will attack other civilizations if they could assure their security. They will attack other civilizations during the exploration if the technology gap is larger than the threshold. They will also launch the dark forest attack if the distance between it and the radio

coordinate is larger than the threshold. Hiding, doing the cleaning is their true portrayal.

3.2 Technology development and consumption

After lives rising, we will enter into a new developmental stage as intelligence could develop their technology (for the evolution of cultures, we also consider it as some kind of technological progress). And of course, the technology explosion is of small probability, so basic the technology will develop at a slow rate. The technology development is based on their current technology level with a growth rate from 10**(-m) to 10**(n). If the latter technology level doubles the former technology level, we would call this turn this civilization happens technological explosion. The probability of disaster is also set to simulate the great disaster that would destroy civilizations only if they have gained enough level of technology. But this is also set a probability, as more advanced technology they have, the bigger probability they will avoid that.

And if the technology has made enough improvement, the volume of resources would also increase. This thought comes from our own experience. Our human being has gone through agricultural revolution (the grain crops become new resource), industrial revolution (coal and fossil fuels become new resource), etc. One day, we could even use stellar energy. At the same time, for each civilization, there is a consumption rate of resources and with the improvement of technology, the consumption rate would also increase. So when the technology level has entered into a new phase, the stock of every owned galaxy would increase. With technology advancing, the consumption rate also doubles.

Some important concepts are also introduced. If the stock of resource of one civilization is less than one threshold, the type of this civilization would transfer to the attacker unless it goes back above the threshold. The next threshold is for Malthusian Trap. Below this standard, the civilization would suffer from inner disaster and wars due to the shortage of resources, which is known as the Malthusian Trap. The technology level will be half to ease this emergency as the consumption rate would also decrease a lot. However, if the volume of resources comes to 0, this galaxy would run out of resources and the civilization would transfer if they can. And of course, they would die out for resource runs out.

3.3 Exploration on other galaxies and Galaxy War

If the civilizations have attained a new technology level of threshold, they would enter into a new phase where they could explore the surrounding galaxy. The starting point and travel direction are set randomly. If they travel to a new galaxy without the owner or the lives have not entered into the threshold of intelligence (this originates from the PC game Spore), they will take the galaxy. However, if this galaxy has intelligence, depending on their culture type, the interaction varies.

Table 2: Threshold for Different Actions

Action	Threshold on Technology Level
intelligence	2
radio (radio waves)	5
defend great disaster	10
galaxy travel (at least 10 percent of speed of light)	10
dark forest attack	15

If the explorer is a communicative civilization, they would communicate with other communicative civilizations. If they run into a hider civilization, the latter one will ignore their messages. And if the explorer or touched civilization is an attacker, they will launch a direct war if they have a higher technology level, or they will radio the coordinate of this galaxy and hope that a higher level of civilization will purge it. When it comes to hider as an explorer, they will avoid galaxy with intelligence and only launch direct war when their technology is much more advanced than the inhabitants.

The result of galaxy war is based on the gap of technology level of both civilizations and also random probability (this means weak civilization has a small probability to turn the tide). The random probability is advantageous for the host of this galaxy as we know they are more familiar with the environment and the other side has traveled for a long time and consumed a lot of resources.

3.4 Radio, Communication and Dark Forest Attack

This part is based on the framework of DFR. As we mentioned before, the attacker will report the coordinate of the galaxy if their technology level is lower. Hider does not intend to report

the coordinate as they have concerns about the risk of exposing their galaxy and the galaxies are so close.

Once the coordinate of one galaxy has been radioing, the message will travel in square shape. In the four edges of this square, if one civilization has the technology to get this message, they will have more interactions.

If the civilization is communicative, they will be happy to receive messages from the outside world and they will radio feedback with its coordinate. This would make them communicate with each other and this process is represented with value as communication degree which is based on their discount technology gap (the spatial mismatch would make this communication not efficient) as well. If the degree has reached a certain level, the two civilizations will merge and the weaker one will be extinct (but not in a direct way, just be part of another civilization).

If this civilization is the attacker and it enters into the threshold of launching Dark Forest Attack (DFA), it would launch on no condition. For hiders, if the coordinate is far away enough, they would also launch DFA if they have the capacity.

The DFA will run at the speed of light and attack the coordinate once arrives. The attacked civilization could defend it if they have more highly developed than the attacker. This would be decided on the technology level of the attacker when it sends the DFA and the defender when the DFA reaches.

4 Results of Simulation

4.1 Original Parameters

Table 3: Parameters of Simulation

Critical Parameter	Value
life born probability	0.001
technological increase coefficient	1+[10**(-4),10**(0.2)]
probability of disaster	0.001
consume coefficient	0.1
resource value for change type of civilization	2
resource value for malthusian trap	1
resource travel coefficient (exchange with resource and galaxy travel)	0.01
discount for galaxy travel by hider	0.5
radio times discount (the probability to radio itself)	0.1
combining coefficient by radio (affect the communication degree)	0.1
combining coefficient (affect the communication degree)	5
war coefficient (affect the probability of war)	5
safe distance for hider to radio	10
safe technology difference for hider to attack	5

As we set one turn could take a long time, we increase some basic values such as life born probability. In the beginning turns, it is obvious that sporadic civilizations rise. The green nodes mean friendly and communicative civilizations, blue for hider and red points represent attackers. Then attackers and communicative civilizations grow fast. And in the graph of the 30th turn, the gray nodes show as those galaxies have run out of resources.

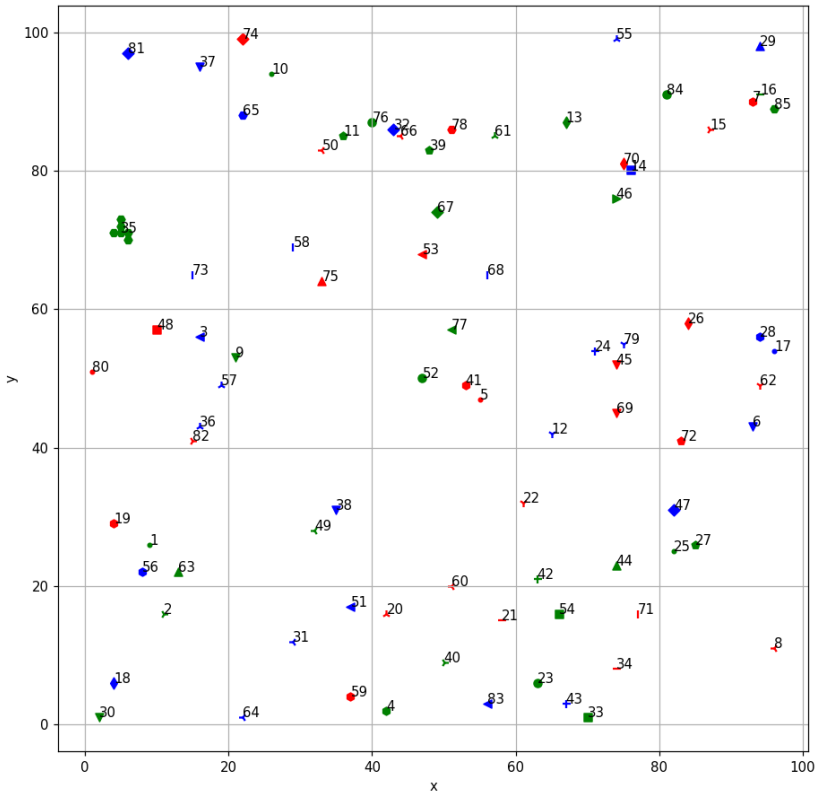

Figure 1: The 10th turn

In the 40th turn, we could see the galaxies that expansion of civilizations are on the rise and all three types of civilizations are booming and also fighting for survival.

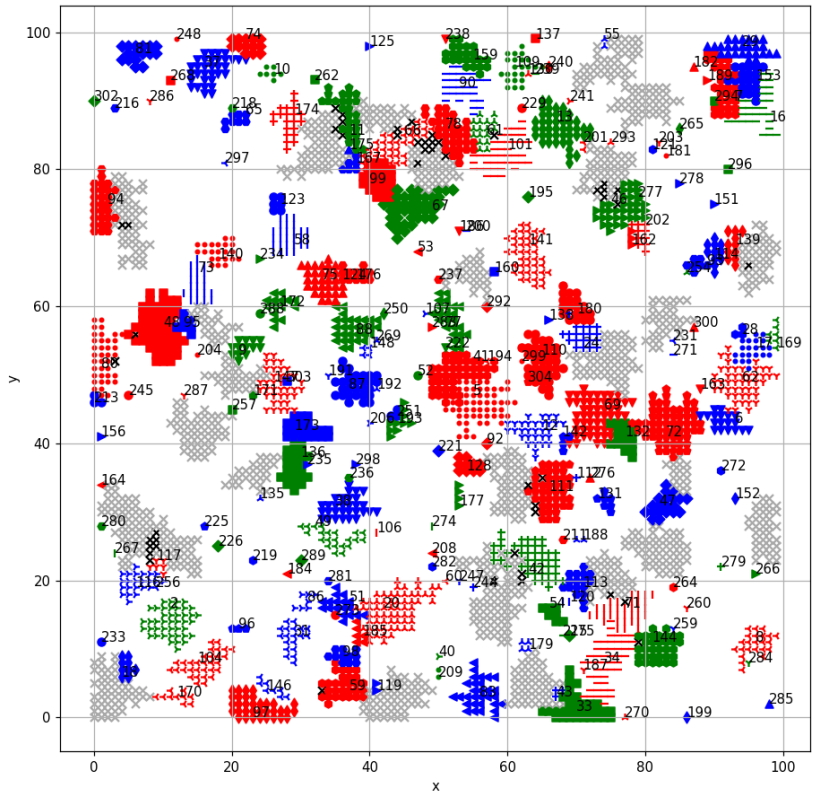

Figure 2: The 40th turn

Also, the black points appear showing the galaxy having suffered from DFA. And after that, we see some civilizations die out of a shortage of resources and this huge universe is more and more sparse.

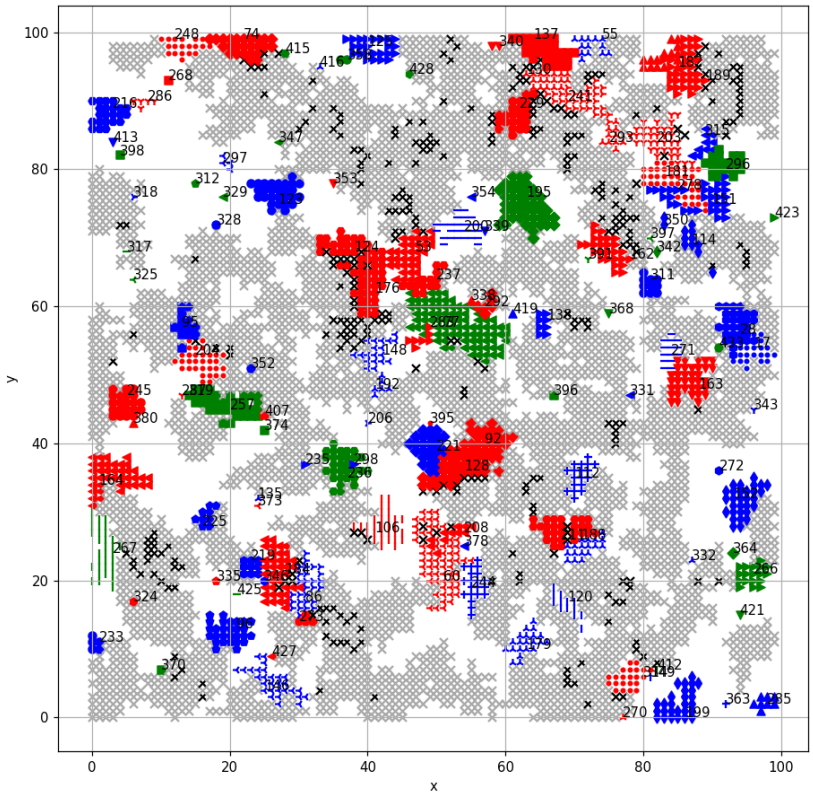

Figure 3: The 60th turn

The 60th turn is the final moment for a huge civilization. DFA prevails and in the center, 28737 friendly and communicative civilization is surrounded by attackers. Though the number of survival attackers is not small, they could extend to a larger scope. Then civilization 28737 and another high-level communicative civilization dies out for DFA and resource shortage.

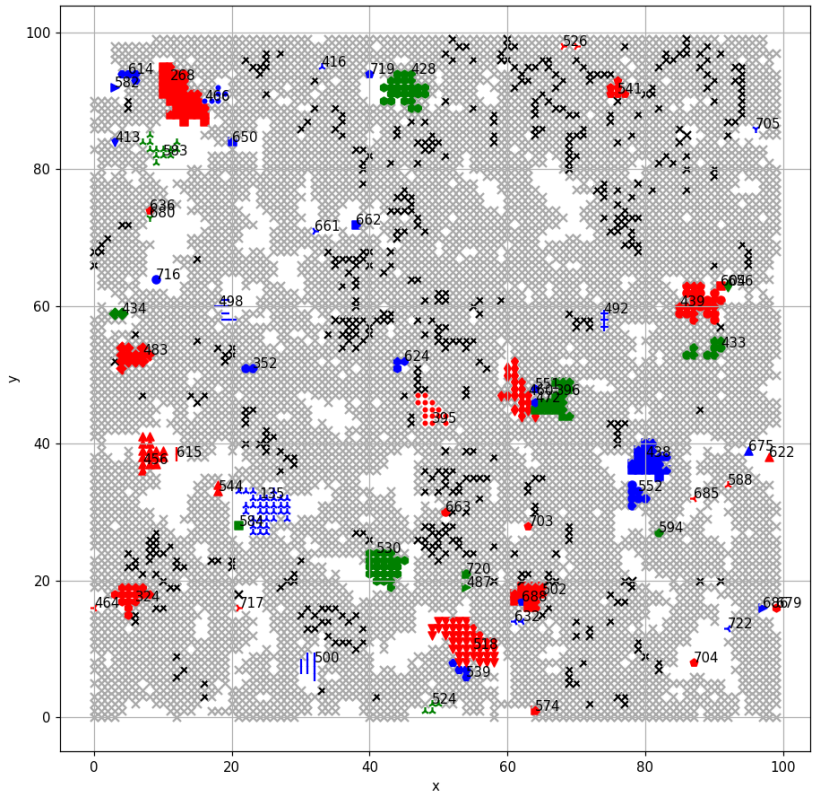

Figure 4: The 100th turn

In the 100th turn, some new civilizations appear but also die out quickly. Here we could see communicative civilizations almost disappear and this universe is full of ruins by DFA and resource depletion (this could arise from slow technological development).

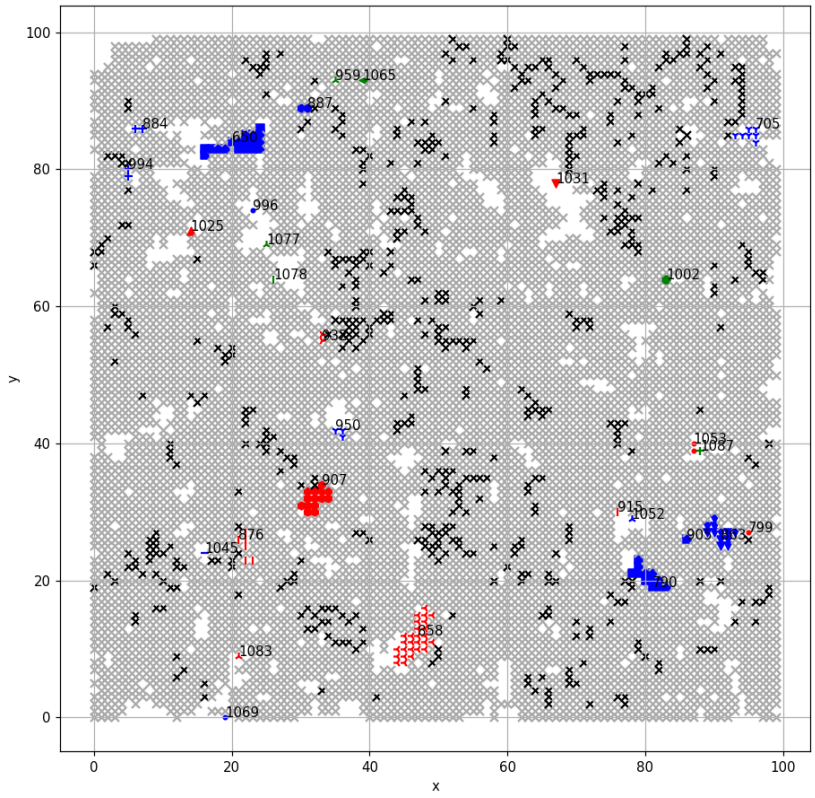

Figure 5: The 150th turn

In the final 150th turn, mostly hiders and smaller attackers survived, and also new friendly civilization 1002 breeds new life in one isolated corner.

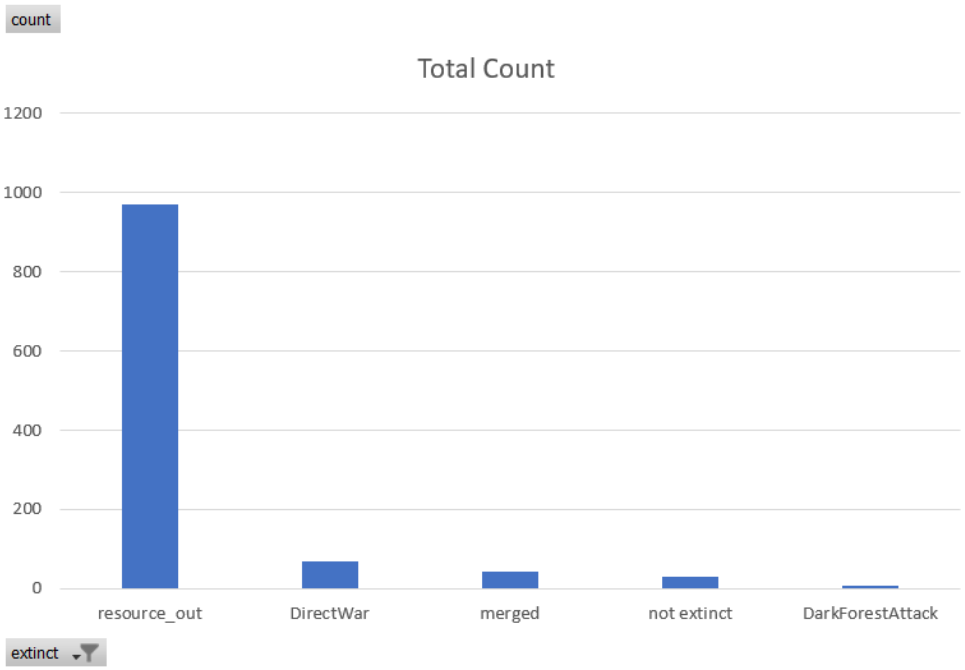

Figure 6: Total count for civilizations concerning the extinct reasons

In this simulation, most civilizations die out due to resource depletion, accounting for about 86.76 percent. 6.26 percent of them are for direct war and 3.76 percent for being merged. Only 0.63 percent are extinct due to DFA. Surprisingly, 2.59 percent of civilizations survive.

In this way, we could see that the Malthusian trap happens in the universe. 86.76 percent of civilizations have to meet the Malthusian trap once. Civilizations lose more than 13 galaxies due to resources running out in this galaxy. And what's more astounding is that slowing down the technology state would not help the shortage of resources though I set the technology level would be half to slow down the consumption rate.

So basically, in this framework with those parameters. It not only proves the DFR (as communicative civilizations are all extinct and hiders own the highest technology level) but also provides the perspective on the Great Filter. That is, with the technology development and need for consumption, the technology revolution as a small probability event has not come, and civilizations are so easily prone to fall into the Malthusian trap and die out eventually. In this situation, the technology level, as well as technological explosion, is critical for one civilization but it is also a small probability event. If the civilization could not make it and also have explored all the near galaxies, it is hard for it to meet the increasing need followed by technology development and population growth. This could be the Great Filter, the big

probability end, Malthusian trap. The civilization will disappear by itself.

The strong civilizations fell into the Malthusian trap when they failed to make a technological breakthrough enough to reach new galaxies to gain new resources. Then they would be pinned to owned galaxy forever or could not meet the need and disappear. The remaining parts of the world would be out of the attention and have nothing to do with them. Those small civilizations with only one or two galaxies, like us, will look up at the stars and ask: where are they? This would also reveal the fact that Reduction of Entropy plays a vital role as lives may appear in various galaxies but eventually they would go back to be silent.

4.2 Rare Earth hypothesis

To examine the Rare Earth hypothesis, we would decrease the probability of breeding the lives and slow down the technological development. The probability of a Great Disaster would increase.

Table 4: Parameters of Simulation on Rare Earth hypothesis

Critical Parameter	Value
life born probability	0.0001
technological increase coefficient	1+[10**(-5),10**(0.2)]
probability of disaster	0.01

After controlling those parameters to simulate Rare Earth, the first observation is that the showing of civilization slows down. There are only 7 civilizations in the first 10 turns. And it is hard for one civilization to last due to resource depletion.

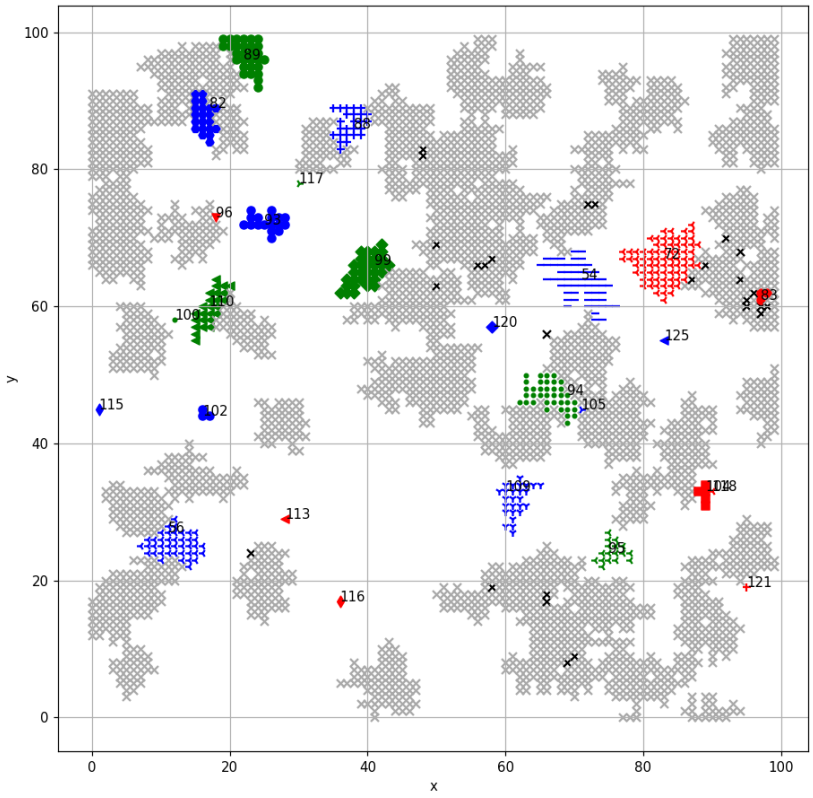

Figure 7: the 150th turn for Rare Earth hypothesis

In this way, we could think the Rare Earth hypothesis also has a point as other civilizations are existing that are too far away from us. If we decrease the probability much more (life born probability as 1e ** -5), this isolated state will be more obvious and civilization remains spotted distribution. Once civilization becomes bigger, it would suffer from a shortage of resources. And, the DFA still exists.

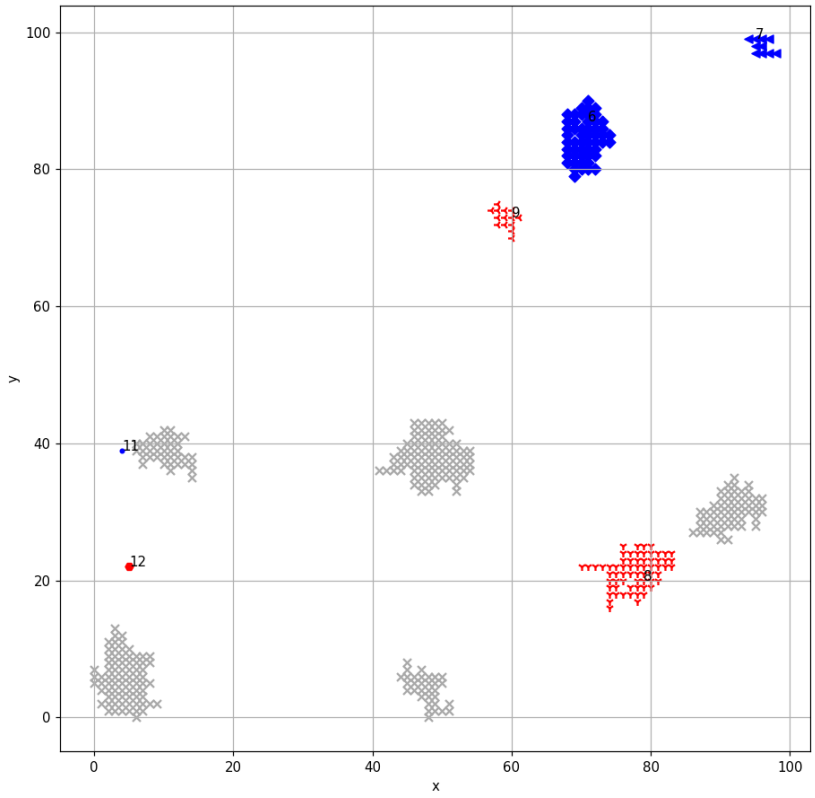

Figure 8: the 150th turn for Rare Earth hypothesis (life born probability = 1e $^{-5}$)

4.3 the Great Filter

As we have shown in the sections before, the default parameters have revealed us the Malthusian trap as the Great Filter. Once the civilization enters into high-level technology, the need would also grow according. Once they could not realize a new technological explosion or find a new galaxy with rich resources, they would probably vanish someday due to resource depletion.

One possible reason could be the consumption coefficient is too high.

Table 5: Parameters of Simulation on the Great Filter

Critical Parameter	Value
consume coefficient	0.01

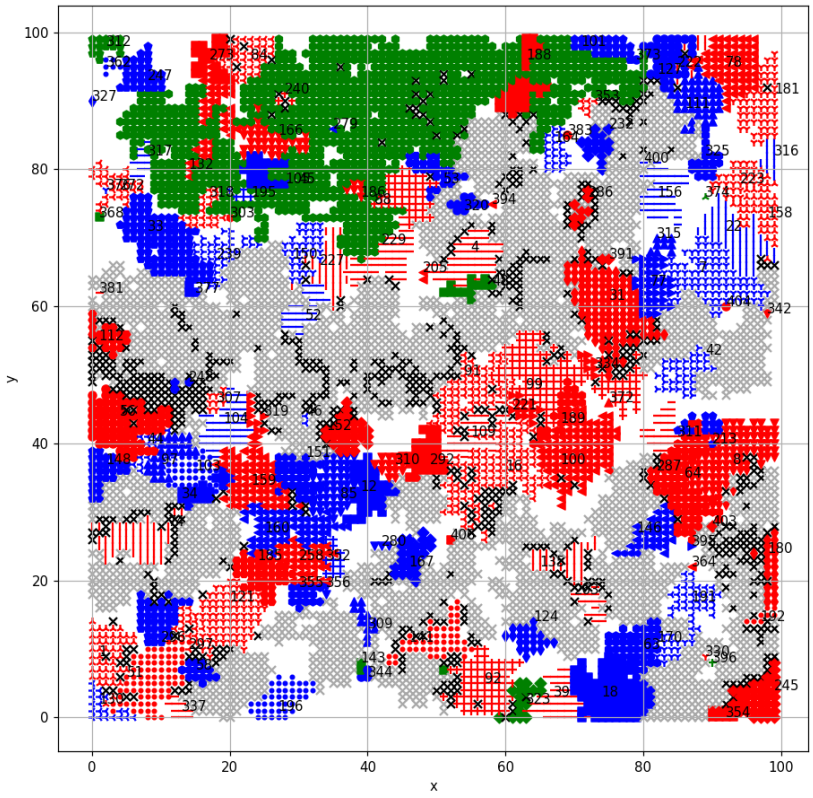

Figure 9: 70th turn for smaller consume coefficient

As in the 60th turn, we could see the consumption rate is much slower and civilization would not disappear that fast. And soon we see one giant friendly civilization in the upper bound. But after 70 rounds with a lot of DFA, these communicative civilization clusters are purged.

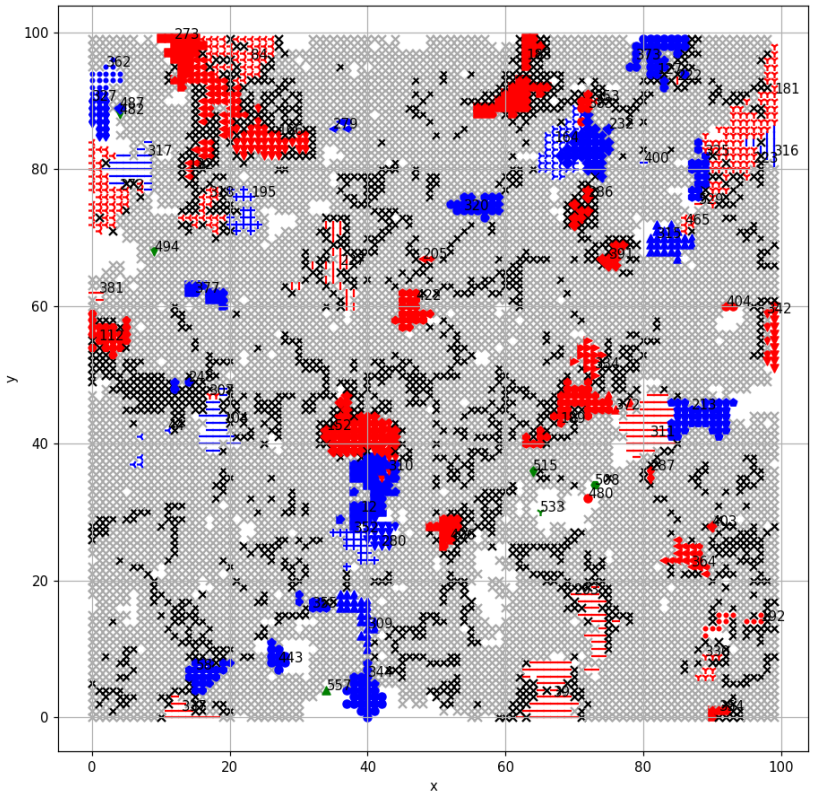

Figure 10: 100th turn for smaller consume coefficient

In the latter period, we could another great filter just as DFR and the Great Filter Hypothesis. Attackers and hiders take dominance in this universe and some spark new communicative civilizations rise on isolated galaxies. But once they have grown into a developed civilization with the ability to radio themselves and even galaxy travel. They are much easier to be hunted quickly.

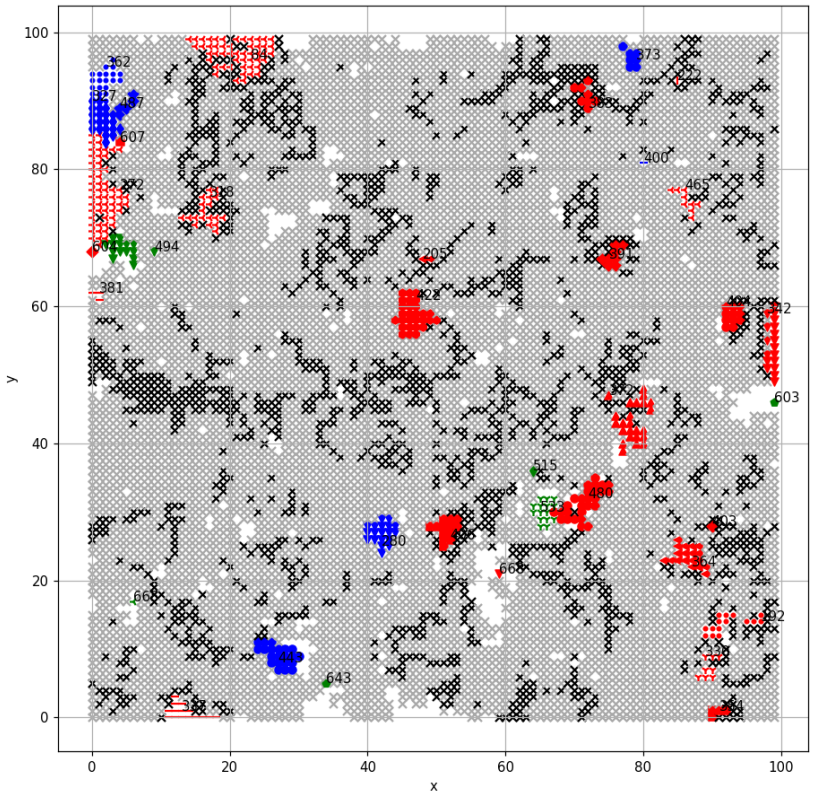

Figure 11: 120th turn for smaller consume coefficient

Between turn 120 and turn 130, we could see civilization 533 is attacked by civilization 480 and becomes colonies. Civilization 494 has been radioed times and gotten the DFA. Only civilization 603 and 643 expand their galaxies due to their isolated positions. However, it could be foreseen that with their radio spreading, they would suffer from DFA in time. In this way, those highly-developed attackers and hiders play the role of cleaners, which is another great filter. And what is more sarcastic, they are also faced with the major great filter, resource depletion. New civilizations may rise in the ruins where former civilizations run out of their resource and this loop continues.

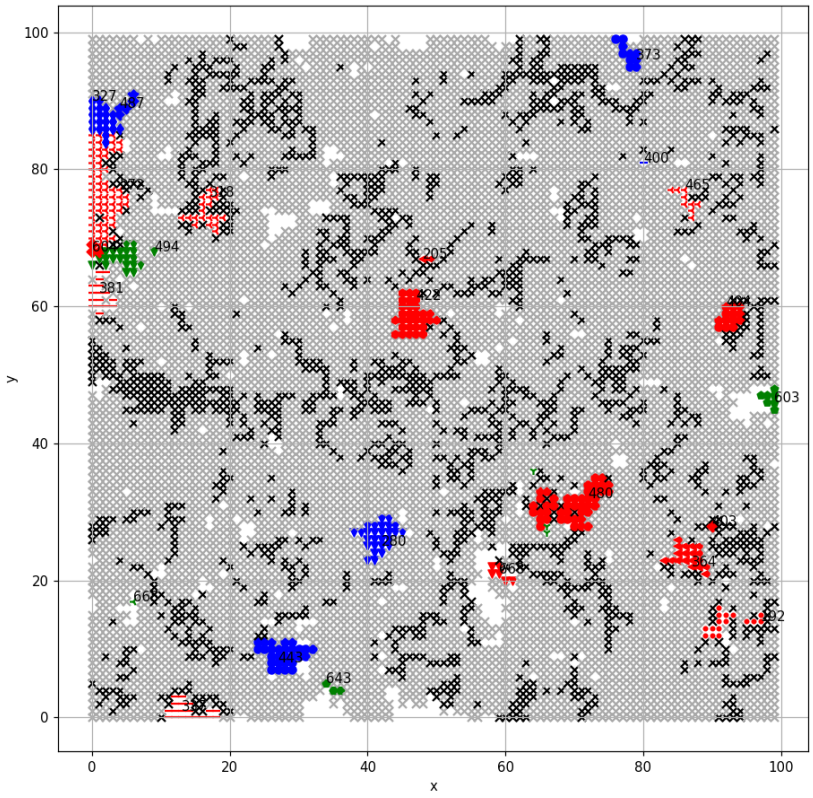

Figure 12: 130th turn for smaller consume coefficient

As we continue to decrease the consumption coefficient, this situation will prevail and we could see some civilizations are attacked both from direct war and DFA, left by black points.

And another thought come into mind, what if civilization could obtain more resource with the development of technology. We would make the growth of resources not linearly decided by technology progress, but multiply it with their current technology level. However, resource depletion still happens.

5 Classification Analysis for the Results

Now we have figure out the decent parameters for each hypothesis and also tune our parameters in this process, but there is still doubt that what could decide the end of one civilization. We all know this is built on a series of probabilities, but are there more important factors affecting this

process? Here, we have 6 concepts of ends for extinct civilizations.

1. Not Extinct. This is the most fortune ending for one civilization as they survive.

2. Great Disaster. This could only be affected when intelligent cannot defend themselves from the great disaster that could cover the whole galaxy. So this means the technology level to protect them from that is not low.

3. Resource Depletion. This is the most common end as we have seen above. Once the civilization has run out of all the resources among their owned galaxy.

4. Culture Merging. This means they communicate with each other and finally, one civilization is merged into another and becomes part of it. This speed of progress of communication is based on their technological gap. And if they communicate by radio, there will be a discount on that due to long-distance messages compared to meeting on galaxy travel.

5. Direct Galaxy War. During exploration, there could be galaxy war.

6. DFA. Once the last galaxy of one civilization is attacked successfully by DFA. This could be categorized as DFA.

So the multi-class classification conducts to examine the importance of all the features. Due to the complex data types and NaN, we choose an efficient ensemble decision tree model, LightGBM. To choose the best parameters and for efficiency, we also adapt the Randomized Cross-Validation. All the indicators are based on a test dataset.

Table 6: Indicators of the classification

Indicators	Value
AUC OvO Macro (with original turn and extinct turn)	1.00
Accuracy (with original turn and extinct turn)	0.9925
F1 Score Macro (with original turn and extinct turn)	0.7818
AUC OvO Macro (without original turn and extinct turn)	0.9785
Accuracy (without original turn and extinct turn)	0.9925
F1 Score Macro (without original turn and extinct turn)	0.7710

In this way, we could observe that the model performs great. Without original turn and extinct turn, the performance does not change a lot. In this way, we could think of our model as acceptable.

Table 7: Importance of features with original turn and extinct turn

Major Features	Importance
malthusian trap times	264
technology level	186
original turn	186
extinct turn	186
consumption rate	149
number of owned galaxies	136
times of losing with lower technology level	117
communication times	117
type of civilization	55

According to the importance of features, we could see that factors relating to resources play a huge role in the classification model. Technology level decides on the demand and the number of owned galaxies sets the supply.

Table 8: Importance of features without original turn and extinct turn

Major Features	Importance
technology level	304
consumption rate	281
times of malthusian trap	267
number of owned galaxies	137
communication times	127
lose times with lower technology level	101
type of civilization	86

The importance of features without information of turn is similar to the former one. In this way, we would think that resource is the key for the existence of one civilization.

6 Regression Analysis for the Results

As we have known which factors influence the outcomes of civilizations more, I think that living turns (the difference of original turn and extinct turn) are also vital metrics to evaluate the success of one civilization. Maybe it does not survive, but its power and advanced development were still magnificent. And just as we describe above, the great filter exists and all civilizations would die out unless they could create material and energy by themselves. Thus, the living turns could also be analyzed by supervised learning to observe the importance of all dimensions.

Table 9: Indicators of the regression

Indicators	Value
MSE (with original turn)	0.1568
MSE (without original turn)	25.6008

Differs from classification, by removing the feature of the original turn, we could see the difference is pretty huge.

Table 10: Importance of features with original turn

Major Features	Importance
original turn	9918
technology level	8760
consumption rate	8465
original galaxy gift	1781
original type of civilization	1217
number of galaxies for resource depletion	1056
times of taking galaxies without intelligence	530
times of technology explosion	498

But at the same time, the order of importance of items is not that different.

Table 11: Importance of features without original turn

Major Features	Importance
consumption rate	428
technology level	420
original galaxy gift	162
times of winning with better technology level	56
times of suffering from DFA	55
original type of civilization	52
number of galaxies for resource depletion	51

The summary is pretty similar to classification. But we also see that the original galaxy gift and original type of civilization play a more critical part in regression. In this way, we may conclude that the living turns are decided by their gift to some extent in this simulation.

7 Conclusion

In conclusion, though we have almost 30 parameters and dynamic processes for this simulation where some frameworks are applied, it is pretty just an experiment to test some of our assumptions towards the Fermi paradox. And the interaction of civilizations is tough to predict but we could set some basic rules and introduce random probability for decisions. With a lot of probabilities, we could be closer to some mechanism and draw the pictures of cosmic sociology. The Rare Earth hypothesis and the Great Filter hypothesis (no matter we have crossed or not) are all persuasive and could be tested to some extent in simulation.

What is common is that all civilizations are faced with resource depletion. Once they could not have a breakthrough in the development of technology, the civilization will fall into the Malthusian trap which is a loop, and get stuck or even die out. The attackers and cleaners may exist, but they are also suffering from that. And this is also the reason why we are so rare as in such a magnificent time and space, colorful civilizations show and disappear, and this circle continues to run.

So whenever we ask: where are you? We could also ask where we are. We have made breakpoints in the emergence of Homo sapiens, the agricultural revolution, industrial revolution, and information revolution. Where is our next big breakthrough? Could we balance our demand and supply? Are we united and cooperative enough to go outside of Earth and the solar system? The sword of Damocles is always there and we need to advance bravely.

References

[1] James D Miller and Debbie Felton. The fermi paradox, bayes' rule, and existential risk management. *Futures*, 86:44–57, 2017.