TJHSST Senior Research Project
Simulating the Tragedy of the Commons Using Agent Based Modeling
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Abstract

The "Tragedy of the Commons" is an experimental economics social scenario, wherein a community of autonomous individuals share a pool of resources. Conventional economic wisdom dictates that each member of the community should act selfishly, for his/her own benefit. However, the Tragedy demonstrates this to lead to unforeseen negative consequences - in some cases, the collapse of the entire community. Agent Based Modeling Simulations (ABMS) can be programmed to model the Tragedy of the Commons. This research aims to create an ABMS model of the Tragedy using the programming language NetLogo, and then demonstrate how individual agent behavior and environmental conditions may be altered to find a more optimal solution to the scenario.

Keywords: agent based modeling simulation, ABMS, experimental economics, tragedy of the commons

1 Problem Statement and Purpose

1.1 Rational

The Tragedy of the Commons is a real life problem, instances of which may be observed throughout the world. For example, one way the American government chooses to deal with waste is to dump it in designated spaces. However, space being a finite resource, the cumulative effect of individual groups contributing to the nation's land use will over time mount into an exponentially more significant issue. The Tragedy of the Commons exists in any scenario consisting of autonomous individuals who stand to benefit by selfishly taking from a shared resource pool. Finding a potential solution to the Tragedy would have far reaching benefits.

1.2 Purpose and Goal

This research involved the programming of a Tragedy of the Commons model, engineered such that the model would possess those qualities key to a Tragedy of the Commons situation. These qualities include a characteristic instability in the population pools involved in the model, and how they may become more or less stable over time. This particular model consisted of grass, cattle, and people, in imitation of one the original ABMS Tragedy of the Commons models. Cattle consume grass to gain energy, and people consumed cattle for energy. Movement incurred an energy cost.

This, incidentally, is not the most basic representation of the Tragedy of the Commons. If it were, it would consist only of cattle and grass, or some other two-tier hierarchy. The additional layer (of people) in this model renders it more complex and unwieldy, but also more realistic.

If the model's parameters are correctly configured, the model should exhibit certain patterns. The grass, cattle, and people populations are graphed, so their trends may be visually tracked. In the original Tragedy model, the programmed cattle and people behavior resulted in their populations following the "overshoot-and-collapse" pattern. That is, they would grow exponentially, reach a peak, and then suddenly drop off. After falling to a certain level, the cycle would repeat, and the population would begin to rise exponentially again.

The original model demonstrating the overshoot-and-collapse pattern was put together using systems dynamics. My model differs in that it focuses not on macro trends, but on the trends produced by changes to individual agent behavior patterns, which exist on a smaller scale. With systems dynamics, it is easier to manage overall group trends than with ABMS. However, the advantage of using ABMS in this research is the ability to incorporate realistic, dynamic human behavior. Consequently, it will be easier to refine individual behavior and have agents respond to each other in a natural way.

The purpose of this research was to find a potential solution for the Tragedy of the Commons. The Tragedy of the Sahel is marked by its instability. Consequences of minor system perturbations may quickly escalate in magnitude. The exaggerated condition changes seen in the Tragedy generally lead to large fractions of populations suddenly starving/dying out. A solution to the Tragedy would stabilize conditions and population counts, so that populations do not grow and shrink so dramatically. However, consistent population sizes are difficult to reconcile with the inherent nature for people to better themselves, by raising population productivity and growth to as high a level as possible. Greater productivity leads to greater wealth, but also greater instability. Herein lies the difficulty of the Tragedy of the Commons.

2 Background

2.1 Similar Projects

"Understanding the Tragedy of the Sahel" provides the foundation for this project. It documents the original modeling of the Tragedy of the Commons using ABMS. This research aims to use that model as a foundation and then extend it through the incorporation of more advanced, dynamic human behavior.

"The Tragedy of the Commons as a Result of Root Competition" used ABMS to model root competition - that is, plants competing for space and nutrients. This resulted in a Tragedy of the Commons.

"Modeling the 'El Farol Bar Problem' in

NetLogo" models - not the Tragedy of the Commons, but a somewhat similar Experimental Economics scenario - using NetLogo. The scenario it models involves a resource shared by a group of autonomous individuals. Their ability to utilize the resource depends on there being a low number of other individuals using the resource. The model programs the individuals so that they base their decisions, on whether to attempt to take from the resource pool , on whether they expect others to do so.

2.2 Relevant Theory

1. "Understanding the Tragedy of the Sahel," Corey L. Lofdahl

   The Sahel is an arid region in Africa. During the 1980's, its inhabitants (people and animals) suffered from drought, which subsequently led to desertification and famine. The limited nature of these communal resources is a characteristic of the Tragedy of the Commons.

   This research examined the Tragedy of the Sahel through a systems dynamics based model. The goal was to study the situation using a model featuring unprecedented levels of realism and detail. Ultimately, the hope was to identify potential solutions for the problems in the scenario. The final model consisted of three types of agents: people, cattle, and grass. Cattle consumed grass to obtain life-sustaining energy, and people did likewise to cattle.

   The environment essentially regulated itself; for example, high populations of cattle would cause grass levels to fall, which would cause famine, which would cause many cattle to die, thus "correcting" the problem. To curb the inhumane nature of this situation, external forces introduced modern technology into the Sahel. This, unfortunately, had the unintended effect of overpopulating the Sahel. Without grass shortage present as a regulation force, populations were able to exceed their natural limits. Then, when drought occurred, populations suffered even greater losses than they had previously. In other words, after the introduction of technology, populations would still fluctuate as before, but their fluctuations would now be of a greater magnitude.

   This research illustrates the complexity of the Tragedy of the Commons. Many factors are generally at play.

2. "The Tragedy of the Commons," Garrett Hardin

   This research established the Tragedy of the Commons in basic, human-related terms: people do work to survive, and require energy to do work. An ideal environment would include the maximum amount of goods possible, for the maximum amount of people possible. However, these two qualities are at direct odds with one another. A perfectly efficient person would do only the work required to provide for survival and, thus, take in no more energy than absolutely necessary. Thus, a society with the maximum number of people - ie, one consisting only of perfectly efficient individuals - can not provide for the theoretical "maximum amount of goods" for each person. The ideal situation is an impossibility.

   A balance must be track within a Tragedy of the Commons. Determining the ideal balance is complicated;

whatever it may be, however, it will not include the maximum possible population. The ideal Tragedy scenario would involve a population whose size would grow until it reaches the ideal balance; thereafter, nobody within the population would work or consume any more or less than necessary to sustain the balanced population level. An individual taking a relatively greater cut could lead to a Tragedy of the Commons.

3. "Empirically Based, Agent-based Models," Marco Janssen and Elinor Ostrom

   This research outlined the recent growth Agent-Based Modeling Systems (ABMS) have seen, and some of the findings ABMS have produced in the field of economics. Also discussed was how these findings may be demonstrated empirically, suggesting that the next step, now that agent-based models have been proven to be a legitimately useful method of study, is to find methods by which ABMS findings may be generalized and made useful for further applications and research.

4. "Tragedy of the commons as a result of root competition,"Mordechai Gersani, Joel Brown, Erin O'Brien, Godfrey M. Maina and Zvika Abramsky

   This research dealt with different types of competition between plants and their effects on root proliferation and seed yield. Greater root proliferation leads to greater uptake of nutrients/resources. Greater seed yield leads to more productive plants. Two types of plant competition were studied: intraplant competition and interplant competition. Intraplant competition involves multiple plants sharing equal shares of a defined space, with each plant prohibited from accessing the resources in any other plant's space. Meanwhile, interplant competition involves plants freely sharing all of the total space and its resources.

   This research provided evidence for the importance for individuals in a tragedy of the commons to defend their personal shares of the resource pool. The paper goes on to suggest that the best way to defend one's resources is simply to acquire those resources before any competitors have the opportunity to do so.

5. "Modeling the 'El Farol Bar Problem' In NetLogo," Mark Garofalo

   The purpose of this research was to model the El Farol Bar Problem using NetLogo and an agent-based modeling system. The prepared model consisted of a number of autonomous agents who were to decide whether to take from a common resource pool, based on their expectation that competing agents might also be taking from the pool. A higher quantity of competing agents taking from the pool would dilute the personal benefit reaped from any one agent's taking from the pool. Consequently, agents were expected to adapt to one another's actions and, in a sense, work together (or, at least, with one another).

6. "Artificial Agents Learning Human Fairness," Steven de Jong, Karl Tuyls, and Katja Verbeeck

   The purpose of this research was to incorporate fairness into a computational, agent-based model. The programmed fairness was based on a combination of 'Continuous Action Learning Automata' and the 'Homo Equalis utility function.' This programmed behavior was meant to reflect the results being drawn in the field of behavioral economics. The Homo Egualis utility function involves a quantitative measurement of the effects of any agent's actions.

3 Development

3.1 Overview

The model employed in this research was written with the NetLogo programming language. NetLogo is ideal for this research because its models are designed to incorporate autonomous agents, who can then be programmed with unique behavior. NetLogo models are represented visually when run, and may also be programmed to graph specific aspects, such as agent/population counts.

This model includes certain parameters which may be altered to affect agent behavior and population trends. An example of such a parameter would be the amount of energy a human-type agent receives from eating a cattle-type agent. The parameters in the model have been refined specifically to mimic those trends produced by the original Tragedy of the Sahel. However, this original model was prepared with system dynamics, as opposed to the agent-based modeling approach this research utilizes. Therefore, certain trends - namely, the overshoot-and-collapse trend, might not accurately be reproduced.

The overshoot-and-collapse trend involves a population growing exponentially in size until it reaches the carrying capacity as dictated by the environment and its resources, at which point the population size drops off abruptly and steeply. However, while trends such as this may not be reproduced, the agent-based nature of the model used in this research does confer other benefits. Group behavior may not be easily modified, but behavior may instead be altered on an individual agent basis. Consequently, this model may incorporate unprecedented levels of realism in human behavior, and may provide for agents who react to one another/their surroundings and modify their individual behavior over time.

The goal is to find a specific set of environmental conditions which elicits a stabilization in the overall populations.

3.2 Research Theory

The parameters for the model used in this research were set based on the intent to reproduce certain trends evident in a preexisting Tragedy of the Sahel model.

Grass is the foundation of the environment's energy cycle. New grass is grown with every time step. The environment's grass growth rate adheres to a predefined value. However, while the growth rate is preestablished, the location of each patch of grass created at each time step is random.

Cattle and people are created when the model is initialized. This is the only point at which agents are created manually. Thereafter, new agents may only be wrought through reproduction via existing agents. To this end, both cattle and people have a characteristic energy cost which must be satisfied before either can reproduce. This energy cost is met by consuming resources and accumulating the energy those resources provide. Cattle consume grass for energy, while people consume cattle. However, in addition to consuming and reproducing, cattle and people also both move with every time step. Their movement is completely random; each movement depletes the given agent's energy a predefined amount. If at any given time step, an agent does not possess the energy necessary to move, that agent dies.

3.3 Testing and Analysis

The model allows for real time alteration of a selection of crucial parameters. These crucial parameters are: the aforementioned grass growth rate, the amount of energy a patch of grass confers upon its consumption, and the amount of energy a cow agent provides upon its consumption. These parameters are crucial because they most directly affect the likelihood that any given cattle or people agent will find resources at each time step.

The likelihood of finding the requisite resources for sustenance is the most crucial factor in determining population survival rates. As an example, it is logical to expect that an increase in grass growth rates would cause an increase in cattle populations. However, a higher cattle population leads directly to two outcomes: one, grass supplies will logically be depleted; second, any given cattle agent will now have greater difficulty locating and securing grass, as there are now a greater number of agents with which it is competing. Now we see that, in the long term, raising grass growth rates actually diminishes cattle populations. Moreover, the greater cattle populations and subsequent greater population oscillations indicates that raising grass growth rates leads to the destabilization of population levels. If a population is unstable enough, it will be susceptible to extinction due to any minor perturbation to the system.

If the model used in this research is correctly configured, certain trends are expected to occur The grass, cattle, and human populations should demonstrate inverse correlations with one another.

One NetLogo feature which is extremely useful in testing models such as this is the BehaviorSpace feature. This feature can be configured so that NetLogo will run multiple iterations of the model, modifying a specific variable within a specific range with each successive iteration. For example, the BehaviorSpace feature can be configured to run five iterations of the model, incrementing the grass-growth-rate variable by one degree each time. NetLogo can also export specific types of data to an Excel spreadsheet at each timestep of each iteration of the model. This is particularly useful, because without this feature, the only easy way to observe trends in the population is to follow the onscreen graph and attempt to discern what underlying trends are occurring.

The BehaviorSpace feature was used to test the grass-growth-rate and cattle-threshold variables. Several observations were made. For one, the cattle and people populations became unstable after the grass-growth-rate reached a high enough level, and subsequently went extinct. This demonstrates the ability of the populations to sustain themselves and adjust to their surroundings only up to a point. It was also observed that the human populations are comparatively more unstable than the cattle populations. This makes sense, as the cattle are dependent only on the grass, whereas the people are dependent on the cattle and also by extension the grass. Minor changes in the environment have a more significant impact on the human population, in other words. Finally, testing the cattle-threshold variable yielded the observation that the higher the cattle-threshold, the more stable the cattle populations become.

Additionally, a curious anomaly was observed while testing and modifying the parameters of the model. It was observed that under the right circumstances, an emergent behavior was demonstrated. This behavior hinges on the grass growth rate being high enough. If it is, then the human, cattle, and grass populations will appear to form vertical columns and then sweep horizontally across the model.

4 Conclusions

After conducting several experiments with this model - particularly with the aid of the BehaviorSpace feature - and examining the resultant data, several conclusions may be made. First, given a multi-tiered economy, those tiers which depend on other tiers - in this case, the people tier, which depends on both the cattle and grass - are more unstable.

Secondly, stability within counterbalance allows for intuitive counterbalancing of perturbations within the system. For example, adding grass to the system will lead to greater numbers of cattle, which will lead to decreased levels of grass, thus creating balance. However, stability may only balance perturbations up to a point. If a perturbation leads to a population reaching a level too high or too low for the system to balance itself, that population may collapse, ie go extinct.

Thus, the key to stabilizing a Tragedy of the Commons is to minimize perturbations and maximize a population's ability to sustain itself at a steady level. Altering certain parameters within the model had clear impacts on the latter. Namely, raising the cattle-threshold and people-threshold variables raised stability. This makes sense, as raising either of these variables results in decreased resource competition within those two classes, thus increasing the likelihood of any given unit's chances for survival. Another key variable was grass-growth-rate, the raising of which would increase competition and decrease stability.

Ultimately, what conclusion this model yields is the fact that for any given level of resources within an environment, an appropriate balance of population size and reproduction rate must be struck, in order for there to be minimal competition and maximum stability within the environment.

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