Evolution of Reciprocal Altruism in Animats

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I. Hypothesis

The hypothesis of this project is to see how a population of animats can evolve reciprocal altruism. To be altruistic means to put others' wellbeing above individual needs by taking actions that increase others' fitness at the cost of the individual's fitness. There have been various theories on how altruism can evolve. Inclusive fitness proposes that altruism can evolve when the benefits received by the individual's relatives outweigh the costs to the individual [1]. Group selection proposes that altruism can evolve because altruistic actions benefit the whole group's reproductive success despite the individual costs [2].

Reciprocal altruism is another theory that seeks to explain the evolution of altruism. In reciprocal altruism, an organism acts in a way that reduces its fitness in order to increase the fitness of another organism. The organism then expects the recipient organism to reciprocate by also doing the same in return at some later time [3]. In this project, an animat is altruistic rather than selfish if it has a very high probability of choosing the altruistic action when the option is given, as well as reciprocating after being a recipient of an altruistic action. A population of animats is more altruistic in this project if the number of altruistic interactions per animat increases. Altruistic actions increase the fitness of the recipient at the cost of the actor's fitness. In reciprocal altruism, the actor expects an altruistic act in return from the recipient.

II. Issues/Problems

One significant issue that came up in this project was how cheating animats should be punished. The goal of any punishment should be to deter cheaters from continuing to cheat. The solution was to have the initiator animat spit on the cheating animat, leaving a mark that indicates to all animats that the animat had cheated. With this knowledge, other animats will be less likely to choose the cheating animat as a receiver of an altruistic exchange or as a mating partner.

Another issue of this project was controlling the population size. If the population dipped too much, then the animats would not interact enough and mate enough to maintain a population. On the other hand, if the population started increasing, the increased population would mate even more, causing the population to keep increasing in an endless cycle. The decision was made to allow the population to grow rather than try to find the balance, but also to introduce restricting factors to prevent overpopulation. Every 5000 time ticks, all remaining animats of the oldest active generation die of old age, regardless of the state of each animat. Also, whenever the total population exceeds double that of the starting population, animats of the oldest active generation lose more fitness per time tick, slowly killing off that generation and limiting any further mating in that generation.

III. Methodology

For this project, the details of the environment and animats are focused around the choice of being altruistic or selfish. Altruism in this project takes the form of what will be referred to as altruistic exchanges. Animats have this choice in two different cases, as the initiator and as the receiver. An animat who is not hungry and sees another nearby animat that is hungry and not carrying food can choose to initiate an altruistic exchange with that animat and take on the role of the initiator, while the other animat takes on the role of the receiver. The initiator digs up food and brings it to the receiver. Once the initiator is adjacent to the receiver, the initiator passes the food to the receiver. The initiator will then expect to receive reciprocation from the receiver in the next time tick. If there is no response from the receiver, the initiator will know that the receiver cheated. Once the receiver gets the food from the initiator, it must choose in that time tick whether to be altruistic by reciprocating or be selfish and do nothing in response. The receiver can reciprocate by boosting the fitness of the initiator at the cost of its own fitness, and also lick the initiator's fur as gratitude for the initiator giving food to it. Animats enjoy being licked because it cleans the fur which makes the animat more visually appealing to other animats for mating. Licked fur indicates to other animats that the animat has done altruistic acts, whether as the initiator or as the receiver through reciprocation. If the receiver reciprocates, then the initiator will always end the exchange by licking the receiver back as an acknowledgement that the receiver reciprocated. If the receiver cheats, then the initiator will always respond by spitting on the receiver to mark it as punishment to indicate to other animats that the cheating receiver is more selfish. When the receiver cheats, the initiator does not receive a lick from the receiver.

The difference between the number of times an animat has been licked and the number of times the animat was spat on affects the probability that other animats of the opposite gender will choose the animat as a mating partner or as a receiver in an altruistic exchange. The more spit an animat has received, the dirtier and less visually attractive the animat will be, while the more licks an animat has received, the more visually attractive that animat will be.

For each animat, the difference between the number of licks received and the number of times being spat on has a small impact on the probability that other animats will initiate an altruistic exchange with that animat in the future. The function that is used to decide the probability is $(0.000064(x-y)^3+1)p$, where x represents the number of licks received, y the number of times being spat on, and p the deciding animat's altruistic probability. This is a less harsh punishment and mainly focuses on the animats that are the most selfish and cheat the most.

The difference between the number of licks received and the number of times being spat on also greatly influences the probability that an animat of the opposite gender decides to mate with that animat. If the difference is 0, the probability of an animat wanting to mate with another animat is 0.5. The probability is decided by the function $\frac{\mathrm{erf}\left(\frac{x-y}{20}\right)+1}{2}$, where erf() is the error function and x represents the number of licks received by the animat and y the number of times the animat was spat on for cheating. This function is used by both males and females. Males use the function to determine the probability of approaching the female animat in question, while females use the function after receiving a mating request from a male animat.

The project does not investigate how altruism emerges. Instead, the animats already have a system for altruistic exchanges and have a probability of choosing to be altruistic when given the chance. This project only tests whether a population of animats can evolve to the point that the average altruistic and reciprocal probabilities of an animat exceeds 50%, and more ideally approaches 100%. In Experiment Set 1, this evolution is tested without learning. The altruistic and reciprocal probabilities are treated as the same for this set. Experiment Set 2 adds in learning and tests how results differ with and without the assumption that the probability of choosing to initiate is the same as the probability of choosing to reciprocate for each animat. In the experiment results, the probability of choosing to initiate will be referred to as the altruistic probability, while the probability of choosing to reciprocate will be referred to as the reciprocal probability. In experiments where the two are considered to be the same, the single probability will be referred to as the altruistic probability. Experiment Set 3 modifies the altruistic exchange system so that the net benefits from the exchange are not symmetrical for the initiator and reciprocator and tests how this change affects the evolution of the animats. Finally, Experiment Set 4 examines how removing genders changes the results as opposed to the different genders in the previous experiments.

IV. Environment, Physics, and Food Types

The environment in the simulations is a 2.5D environment set up as a 40x40 grid. The edges of the grid are hard boundaries. Collisions are enabled so that only one animat can occupy one location at any given time. Animats can interact when they are vertically or horizontally adjacent on the grid. The environment is kept as simple as possible and only has food that animats can eat to stay alive. Each location on the grid has a food spawn timer of 40 time ticks. At the beginning of the simulation the timer starting value for each location is randomized between 0 and 40. After food has been dug up by an animat from one location, the timer at that location resets to 40 time ticks. Digging for food costs 15 fitness for males, 25 for females, and eating the food gives 50 fitness units. The additional digging cost for females is because female animats are weaker and have a harder time digging up food. Animats are only allowed to move horizontally or vertically on the grid.

V. Animat

Body

The animat agent has an effector that allows it to dig up and hold one unit of food at a time. If the animat is hungry and senses food, then the animat uses the effector to instantaneously dig up and hold the food in one action at the cost of fitness units, 15 for the males and 25 for the females because females are weaker and require more effort to dig up the food.

Genders

The animat population by default consists of male and female animats. Males and females are similar but have some differences. In the mating process, males ask females to mate with them and the female gets to decide whether to accept or reject. Female animats are weaker than males and use up extra energy to dig up food. They give birth to the child animat when mating with a male and care for the child animat for a period of time by carrying the child animat and sharing food with the child. There is no direct birthing cost for females, but sharing food does mean the mother sacrifices fitness gain for the child. Experiment 4-1 will test the case where there are no genders in the population.

Sensing

The animat is able to smell whether there is food at its current location. To help with the interactions between animats, each animat is able to see nearby animats in front of it within a semicircle with a radius of 5 steps. For each animat that is sensed, the sensing animat will know what the sensed animat's gender is and whether or not it is hungry, but not whether the sensed animat is holding food. When animats are hungry they visibly look thinner, which allows other animats to see that they are hungry. Animats were not given the ability to sense if a hungry animat is holding food because a hungry animat could still be below 750 fitness units and thus still be hungry after eating the food that it is holding. Therefore, hungry animat that is holding food is still considered to be a candidate to be a receiver in an altruistic exchange. This knowledge allows the animat to know which animats it can initiate altruistic exchanges with. This also allows male animats to sense nearby female animats that are not hungry so they can find a mating partner.

Behavior

Animats are able to move around in the environment, dig for food, eat food, decide whether or not to initiate or reciprocate in an altruistic exchange, and mate with other animats. For simplicity, the only genes the animats have control the probability that the animat chooses to initiate an altruistic exchange and the probability the animat chooses to reciprocate when it is the receiver in an altruistic exchange. The specific actions depend on the state of the individual animats. If an animat becomes a participant in an altruistic exchange, the animat cannot carry out any other actions until the exchange concludes with either cheating and punishment or reciprocation. An animat's maximum fitness is 1000. If an animat's fitness is under 750, then that animat is hungry. A hungry animat will search for food to dig up and eat unless it is chosen by an initiator to be a receiver. If an animat is not hungry, it will not search for food. A male animat cannot search for a female to mate with if it is hungry. Females that are hungry are ignored by a male when it looks for a potential mate. If an animat not hungry, the number of fitness units the animat has does not factor into mating choices, only the outward appearance of the animat's fur which is determined by the animat's record in altruistic exchanges.

Mating

Each generation of animats has a set period of time that the members of that generation can live in the environment. For example, the first generation will live up to the first 5000 time ticks of the simulation. Animats of the first generation cannot mate until after the 2500th time tick, giving the generation 2500 time ticks to mate. Animats are prevented from mating earlier to give time for altruistic interactions to reveal which animats are more altruistic and which animats are more selfish. Animats of the second generation are inserted into the environment right after birth, but the mating period of all animats in the second generation is still from time tick 7500 to 10000 of the simulation, even though they are all born before the 5000th time tick. The simulations are set up like this so that at the most only 2 generations will be active at any time. This makes it so that the younger generation cannot mate until 2500 time steps after the end of the older generation.

After a male animat asks a female animat to mate with him, the male animat is disallowed from making another request to mate to any female animat for 5 time ticks, whether or not the request was granted. The main reason for this cooldown is to have the male and female pair separate so that a male does not keep asking the same female if he keeps getting rejected by that female. At the same time, a longer cooldown seemed unnecessary given the purpose of the cooldown. Mating generates a child animat that stays with the mother animat for 250 time ticks. During this time, the child animat does not take any actions of its own and is updated together with its mother at each time tick. The mother evenly shares food between herself and the child. While the child animat is with the mother, the mother cannot mate. The child's altruistic and reciprocal probabilities are both determined using normal distributions as a form of mutation. The averages of the distributions are determined by a weighted average. The parent with the same gender as the child has its altruistic and reciprocal probabilities are weighted at 80% while the other parent has its probabilities weighted at 20%. The standard deviation for the two distributions are both always set at 0.02.

For animats that are not hungry and are not currently allowed to mate, they either wander around randomly or attempt to initiate an altruistic exchange with a nearby hungry animat. If a male animat is not hungry and is allowed to mate, then the animat will prioritize finding a female animat to mate with over initiating altruistic exchanges.

Learning

When learning is enabled, animats readjust their altruistic probability based on their interactions with other animats. If an altruistic exchange completes successfully, the initiating animat is more likely to participate in the altruistic exchange system more often and increases both the probability of initiating and reciprocating, and the reciprocating animat increases its probability of reciprocating in the future. On the other hand, if the altruistic exchange ends with the receiving animat deciding the cheat, the initiating animat will decrease its altruistic and reciprocal probabilities because it is discouraged by the lack of reciprocation. Male animats will also increase their altruistic and reciprocal probabilities if a female animat rejects their request to mate. The increase in probabilities applies in general, not just for interactions with females because altruistic exchanges do not take into consideration each party's gender. Even though a female is rejecting a male, the male can become more appealing as a mate through altruistic exchanges with a male or a female, so gender is not used as a factor in learning from having a mating request rejected by a female. Lastly, animats also slightly decrease their reciprocal probability if they stay hungry for 10 turns without eating or receiving any food.

The learning algorithm is used to adjust the animat's probabilities of initiating or reciprocating in an altruistic exchange. The algorithm is simply $p_{n+1} = p_n(1 - r) + lr$, where p_{n+1} is the new probability, p_n is the old probability, r is the learning rate, and l is the learned value. For these experiments, r is always set as 0.02. The learned values used in these experiments are based on the old value. For instance, if the receiver cheated in the altruistic exchange, the initiator's learned value for both the altruistic and reciprocal probabilities are half of the original values.

VI. Instrumentation

The following data was collected in the experiments:

- Each animat's probability of choosing to initiate an altruistic exchange when it is healthy and detects a nearby hungry animat that isn't carrying food.
- Each animat's probability of choosing to reciprocate when it is the receiver in an altruistic exchange.
- Number of times each animat initiated an altruistic exchange and was reciprocated
- Number of times each animat reciprocated in an altruistic exchange
- Number of times each animat cheated instead of reciprocating in an altruistic exchange

VII. Algorithms / System Architecture

The environment and the animats use a global time tick. During each tick, the environment and each animat update their states and take actions. The order in which the animats update remains the same to ensure that the receiver gets a chance to respond to the initiator in an altruistic exchange. When a new animat is added to the environment post-childhood, that animat is placed at the end of the list. The environment spawns food at a location on the grid if the respawn timer for that location drops to zero, and resets the timer for locations where food has just been dug up by an animat. Each animat evaluates its current fitness level and whether it has received any interaction from another animat. Based on those factors and the animat's previous action, the animat is either given an action to carry out for that time tick or has to choose between two possible actions. Each animat's data is collected once the animat dies.

VIII. Experiments

Experiment Set 1: No Learning

These experiments compare how quickly reciprocal altruism evolves in the cases where animats cannot increase their altruistic probability through learning, and in the case that they can learn to increase their altruistic probability. These experiments check if there is a limit on how much the average altruistic probabilities increase for the evolution-only case. In this case the altruistic probability does not change throughout the lifetime of the animat, and change is fueled by mutation from generation to generation. In this experiment set, the altruistic and reciprocal probabilities are treated as the same probability. Male and female genders are present in this experiment, and altruistic exchanges are symmetric, meaning that both the initiator and the reciprocator gain the same net benefits from an altruistic exchange.

Experiment 1-1

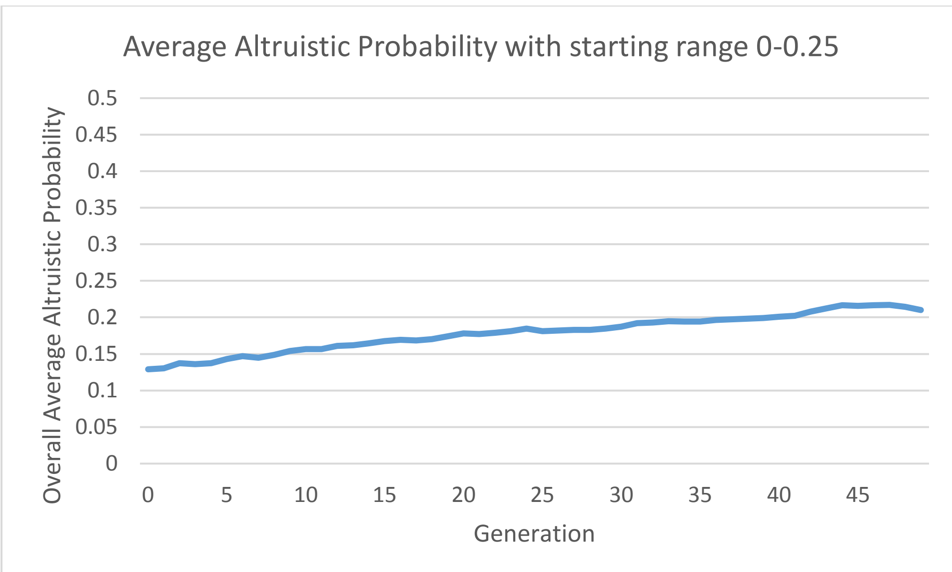

Figure 1. Average altruistic probability without learning. First generation animats assigned altruistic probabilities randomly chosen between 0 and 0.25.

In the first experiment, the first generation of animats were given an altruistic probability between 0 and 0.25 chosen at random, meaning that the starting average was around 0.125. The probability of initiating an altruistic exchange and the probability of reciprocating as a receiver in the altruistic exchange are treated as one and the same probability. After 50 generations, the average had increased to approximately 0.21, as shown in Figure 1 above. The pace of the increase was gradual and slowed down even more in later generations.

Figure 2 shows the breakdown of the results of the altruistic exchanges by showing on average per animat how many altruistic exchanges had the receiver reciprocating and how many had the receiver cheating. The increase in the altruistic probability means that more altruistic exchanges are initiated, but since the probability did not increase that much, the number of instances of cheating almost doubles even as the number of reciprocated altruistic exchanges increases.

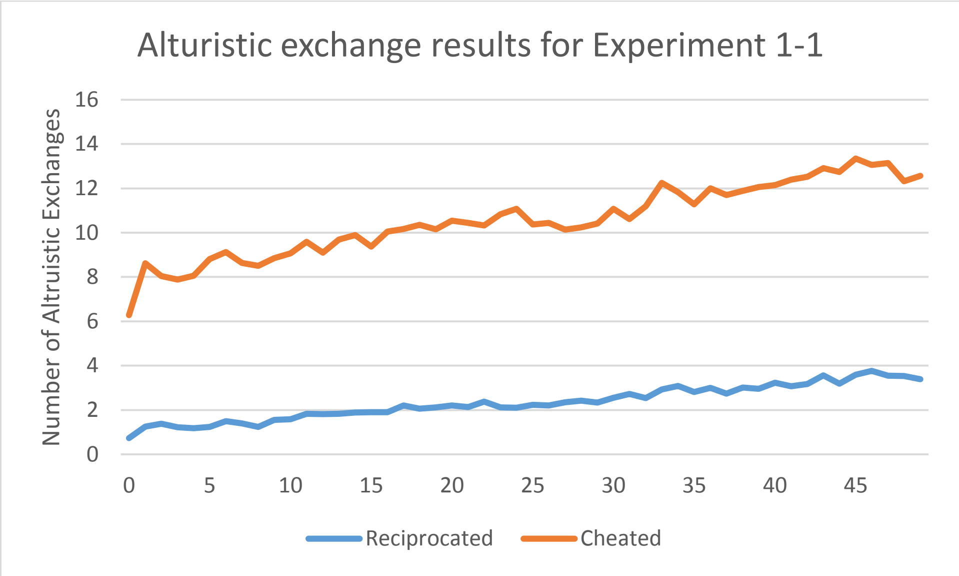

Figure 2. Altruistic exchange results for each generation averaged per animat without learning.

Experiment 1-2

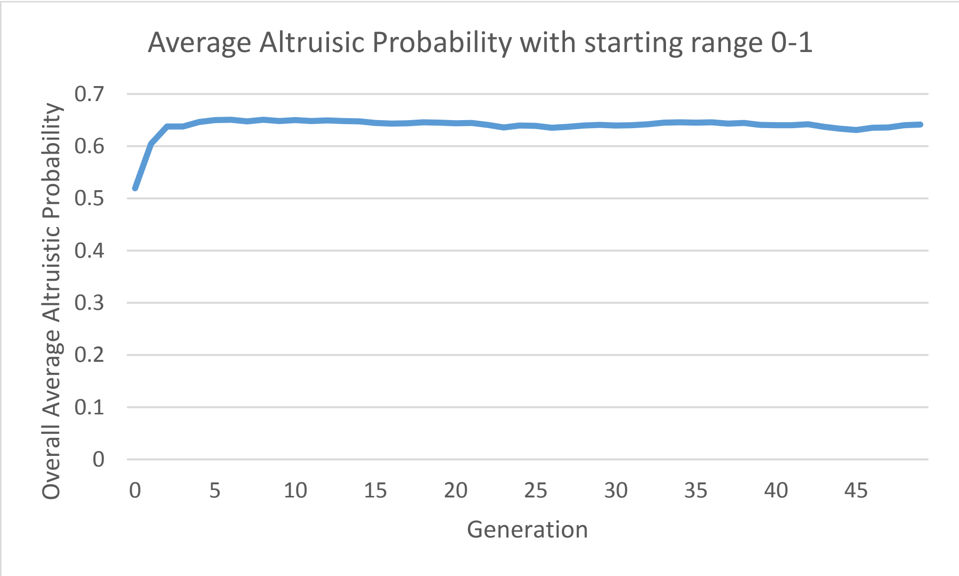

Figure 3. Average altruistic probability in each generation relying only on evolution and mutation. First generation of animats given altruistic probability without limitations.

For the second experiment of this set, the randomly assigned altruistic probability values given to the first generation of animats were anywhere between 0 and 1. Once again, there is only one altruistic probability that accounts for both the probability of initiating and the probability of reciprocating. The results show in Figure 3 that the average probability increases rapidly in the first few generations and then does not significantly change afterwards. The increases in the early generations clearly shows that the animats that are more altruistic have better success in mating during those generations. After the early generations, the average no longer increases, but actually slightly decreases from 0.65 to 0.64 by the end of the 50th generation. This seems to indicate that animats who are very altruistic do not find more mating success than animats that are only somewhat altruistic.

In conclusion, evolution and mutation does lead to the animat population slowly becoming more and more altruistic. However, there appears to be a limit at which animats do not gain enough for being more altruistic to offset the costs they incur for doing so. After that point it becomes disadvantageous to be even more altruistic.

Experiment Set 2: Learning

From this experiment set on, animats are able to adjust their altruistic and reciprocal probabilities based on their experiences in interacting with each other through altruistic exchanges. This experiment set also examines the difference between having just one probability for initiating and reciprocating versus having two separate variables, one for each. For both experiments in this set, the range of initial altruistic and reciprocal probability values is between 0 and 0.25. Male and female genders are present in these experiments and altruistic exchanges are symmetric for the initiator and the receiver that chooses to reciprocate.

Experiment 2-1

Table 1. Learning values for Experiment 2-1, where p is the current value of the animat's altruistic probability.

	Initiator after being reciprocated	Initiator after being cheated	Receiver after reciprocating and receiving lick	Male animat after mating request rejected
Male	$p + (\frac{1-p}{2})$	$p/2$	$p + (\frac{1-p}{4})$	$p + 3(\frac{1-p}{4})$
Female			$p + 3(\frac{1-p}{8})$	N/A

For the first experiment of this set, the altruistic and reciprocal probabilities are still assumed to be the same, as it was in Experiment Set 1. Table 1 above shows the learning values used to modify an animat's altruistic probability after being involved in certain events. For example, in the last column, a male animat increases his altruistic probability after having a mate request rejected by a female animat because being more altruistic makes an animat more likely to be chosen or accepted as a mate. Females have some different learning values based on their differences with males.

The learning value equations of Table 1 were chosen based on how an animat's altruistic probability should be affected by the events in which learning occurs. An animat that is more selfish should be more affected by an event that teaches it to be more altruistic than an animat that is already somewhat altruistic. At the same time, the animat that is already somewhat altruistic should still have a higher learning value than the more selfish animat. For example, given the equation $p + (\frac{1-p}{2})$ in Table 1, an initiating animat with altruistic probability 0.2 would get a learning value of 0.6 while an initiating animat with altruistic probability 0.5 would get a learning value of 0.75. The first animat got a lower learning value, but that learning value increases the first animat's altruistic probability more. The opposite applies when an animat learns to decrease its altruistic probability. An initiating animat that is more altruistic is more negatively affected by being cheated, but a more selfish animat would still have the lower learning value. The learning value equations differ for each of the different events in Table 1 based on the importance of each event. The learning value for a male animat being rejected by a female is higher because mating success is considered as more important to the animats. The learning values in an altruistic exchange are higher for the initiator than the reciprocator because initiators are the ones who give up the food to start the exchange and have more at stake, while the receivers never lose anything from an exchange, whether or not they choose to reciprocate. This makes a reciprocated altruistic exchange much more meaningful to the initiator. Lastly, a female receiver that reciprocates gets a higher learning value than a male receiver because female animats are weaker and use up more fitness units digging up food, so the benefits received as a receiver is more significant to females.

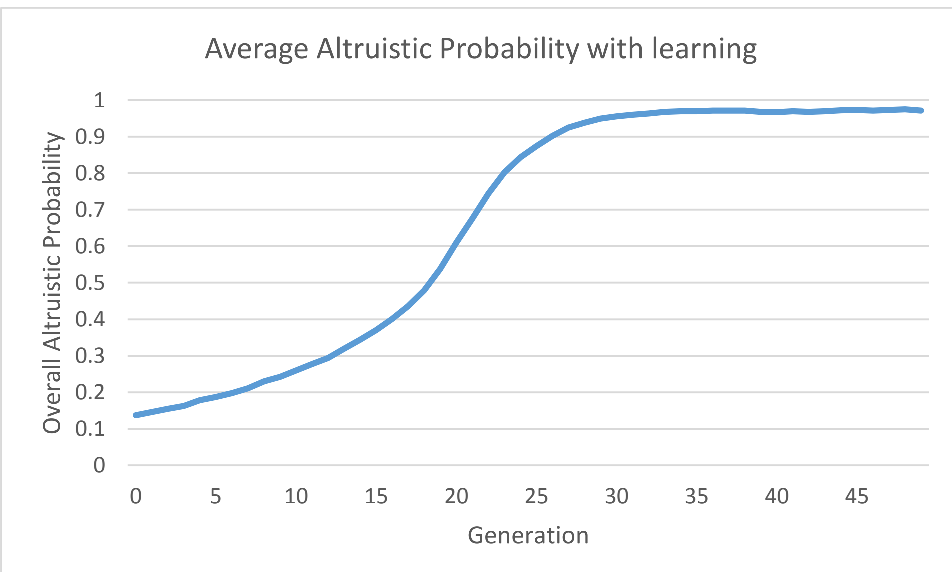

Figure 4. Average altruistic probability in each generation with learning enabled with the assumption that altruistic and reciprocal probabilities are identical.

From this experiment on, the animats of the first generation are given initial probability values between 0 and 0.25, just like in Experiment 1-1. At first, the probability average increases at a slow pace of roughly 0.01 per generation. However, as the average goes higher, the rate that the average altruistic probability increases gets faster. As animats become more altruistic, they are more willing to initiate and reciprocate, and are being cheated by other animats less and less. This leads to the rapid pace at which the average altruistic probability increases. The rapid increase in the average is only slowed down as the average starts approaching 1.

Experiment 2-2

Table 2. Learning values for Experiment 2-2, where a is the current altruistic probability and r is the current reciprocal probability

<table>
<tr><th rowspan="2"></th><th colspan="2">Initiator after being reciprocated</th><th colspan="2">Initiator after being cheated</th><th>Receiver after reciprocating and receiving lick</th><th colspan="2">Male animat after mating request rejected</th></tr>
<tr><th>Altruistic</th><th>Reciprocal</th><th>Alt</th><th>Rec</th><th>Reciprocal</th><th>Altruist</th><th>Reciprocal</th></tr>
<tr><td>Male</td><td rowspan="2">$a + (\frac{1-a}{2})$</td><td rowspan="2">$r + 3(\frac{1-r}{8})$</td><td rowspan="2">$a/2$</td><td rowspan="2">$r/2$</td><td>$r + 3(\frac{1-r}{8})$</td><td>$a + 3(\frac{1-a}{4})$</td><td>$r + 3(\frac{1-r}{4})$</td></tr>
<tr><td>Female</td><td>$r + (\frac{1-r}{2})$</td><td>N/A</td><td>N/A</td></tr>
</table>

In the previous experiments, the probability of choosing to initiate an altruistic exchange and the probability of reciprocating in an altruistic exchange were treated as one single probability. From this experiment on, those two probabilities are treated as different probabilities; an altruistic probability and a reciprocal probability. The initial values for both probabilities are selected independent of each other.

Table 2 shows the new learning value equations for the two probabilities in this experiment. These equations are mainly adapted versions of the equations from Table 1. An initiator increases its altruistic probability the same amount after the receiver reciprocates. The initiator also increases its reciprocal probability because the experience from receiving reciprocation strengthens the expectation that initiation must be responded to with reciprocation. The learning values for the receivers after the completion of an altruistic exchange are increased as an adjustment to having two variables rather than just one. The remaining equations stay the same and are used for both the altruistic probability and the reciprocal probability.

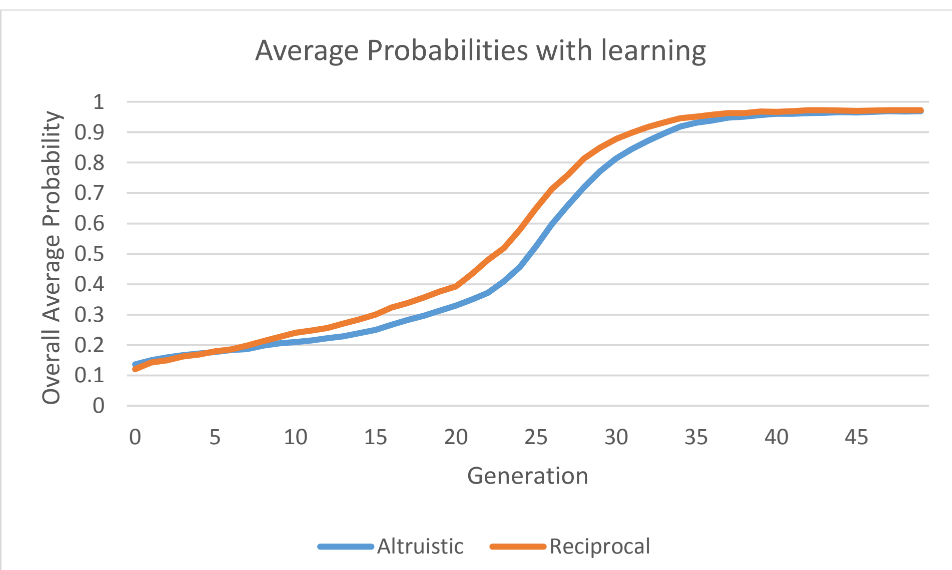

Figure 5. Average altruistic and reciprocal probabilities with learning enabled.

The results in Figure 5 show that the average altruistic and reciprocal probabilities grows slower as separate probabilities than as one probability. Both probabilities initially grow at a relatively flat rate, but once they exceed 0.4, the probabilities increase very quickly. The average reciprocal probability increases faster than the average altruistic probability, which lags behind before catching up as both probabilities approach 1. This suggests that the increase in the average altruistic probability could be limited by the average reciprocal probability.

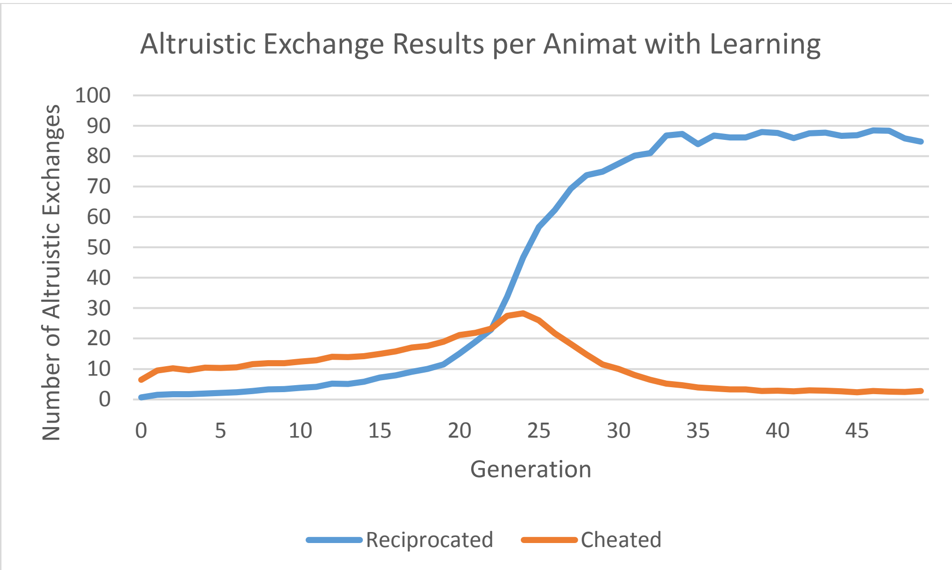

Figure 6. Altruistic exchange results for each generation averaged per animat with learning.

Figure 6 shows how altruistic exchanges increases over the course of the experiment. Initially an animat on average is only involved in 10 altruistic exchanges, most of which end up with the receiver choosing to cheat. As the reciprocal and altruistic probabilities reach 0.5 and beyond, the total number of altruistic exchanges increases rapidly. The number of altruistic exchanges in which the receiver reciprocates spikes very quickly and far surpasses the number of altruistic exchanges in which the receiver cheats. Meanwhile, the number of altruistic exchanges with the receiver cheating peaks and then drops off rapidly until cheating in an altruistic exchange becomes a rare occurrence.

Experiment Set 3: Asymmetric cases

In the previous experiment sets, both the initiator and the receiver receive the same net gains from a completed altruistic exchange including reciprocation. For this experiment set, I looked at how removing this symmetry affects the results. This is done by adjusting the amount of food and health exchanged and the health costs incurred during the exchange. These adjustments also mean that the learned values from interactions also change accordingly. In this experiment set, the altruistic and reciprocal probabilities are treated as two separate probabilities, learning is enabled, and there are male and females in the animat population.

Experiment 3-1

Table 3. Modified learning values for Experiment 3-1.

	Initiator after being reciprocated	
	Altruistic	Reciprocal
Male	$a + 3(\frac{1-a}{4})$	$r + (\frac{1-r}{4})$
Female		

In this experiment, the altruistic exchange is altered so that the initiator benefits more than the receiver. The initiating portion of the exchange is still the same with the initiator digging up food worth 50 health at the cost of 15 health and giving the food to the receiver. In the reciprocation phase, the cost the receiver incurs is increased to 30 health from 15 while the amount of health the initiator gains increases to 60 health from 50 health. The values that initiators learn in an altruistic exchange are also adjusted to reflect the changes in the benefits and costs as shown in Table 3. Since the initiator gains much more than the receiver, the altruistic probability learning values increase much more while the reciprocal probability learning values are adjusted downwards. All other learning value formulas previously listed in Experiment 2-2 remain the same.

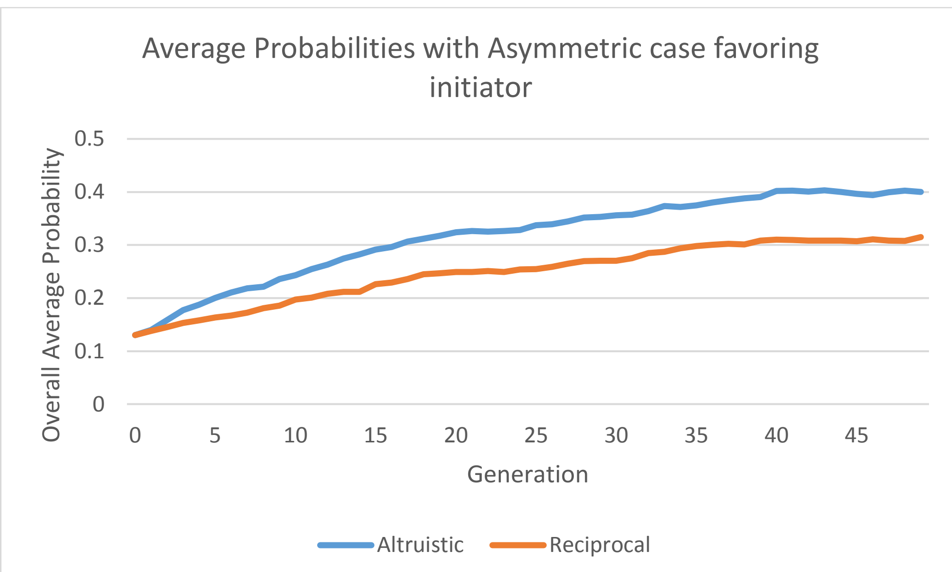

Figure 7. Average altruistic and reciprocal probabilities in the asymmetric case in favor of the initiator.

The results in Figure 7 were significantly different from the previous learning experiments. The average reciprocal probability did not increase by much over 50 generations, which was expected from the changes made for the experiment. However, the average altruistic probability also increased less than in Experiment 2-2. Although the average altruistic probability did end up greater than the average reciprocal probability as expected, if the two probabilities were independent of each other, then the expected outcome would have been for the average altruistic probability to increase faster rather than slower. This gives further indication that the reciprocal probability can limit how much the altruistic probability increases, making the reciprocation part of the altruistic exchange much more important than the initiating part.

Experiment 3-2

Table 4. Modified learning values for Experiment 3-2.

<table>
<tr><td rowspan="2"></td><td colspan="2">Initiator after being reciprocated</td></tr>
<tr><td>Altruistic</td><td>Reciprocal</td></tr>
<tr><td>Male</td><td rowspan="2">$a + 3(\frac{1-a}{8})$</td><td rowspan="2">$r + (\frac{1-r}{2})$</td></tr>
<tr><td>Female</td></tr>
</table>

In this experiment, the altruistic exchange is altered so that the receiver benefits more than the initiator. Once again, the initiating phase remains unchanged from previous experiments. In the reciprocation phase, the cost the receiver incurs is reduced to 5 health from 15 while the amount of health the initiator gains decreases to 35 health from 50 health. Again, the values learned by initiators for the reciprocal and altruistic probabilities are adjusted accordingly as shown in Table 4. This time, since the reciprocators benefit much more in an altruistic exchange than the initiators, the altruistic probability learning values are lowered while the reciprocal probability learning values are increased. Once again, the learning value formulas not listed in Table 4 are assumed to be the same as what was listed in Table 2 for Experiment 2-2.

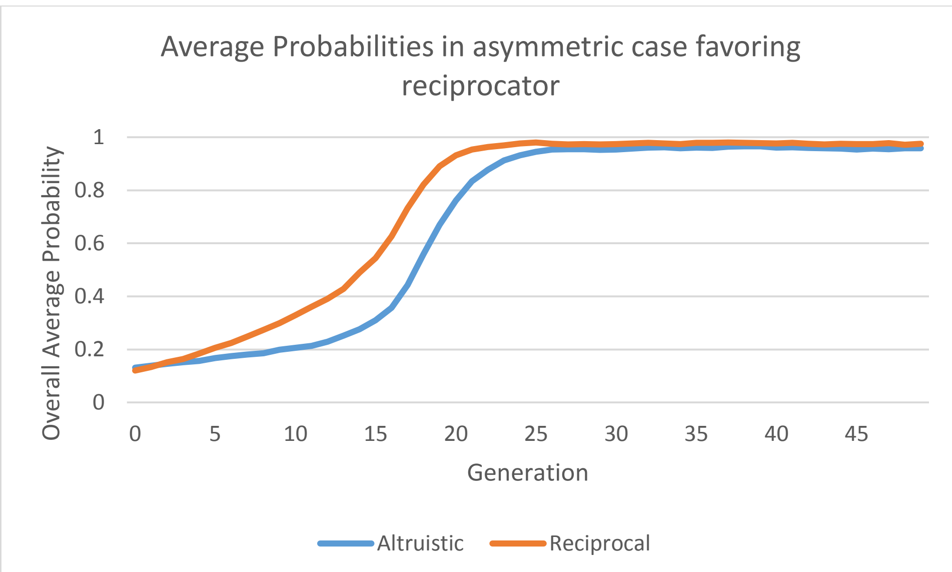

Figure 8. Average altruistic and reciprocal probabilities in the asymmetric case in favor of the receiver.

This time, the results were the opposite of the previous experiment, as Figure 8 illustrates. The average reciprocal probability increased faster than in Experiment 2-2, as expected, but the average altruistic probability also increases faster even though the learning values for the altruistic probability were decreased. After these experiments it is quite clear that whether or not the animats learn to reciprocate more often largely determines whether or not reciprocal altruism can evolve in the population.

Experiment Set 4: Gender differences

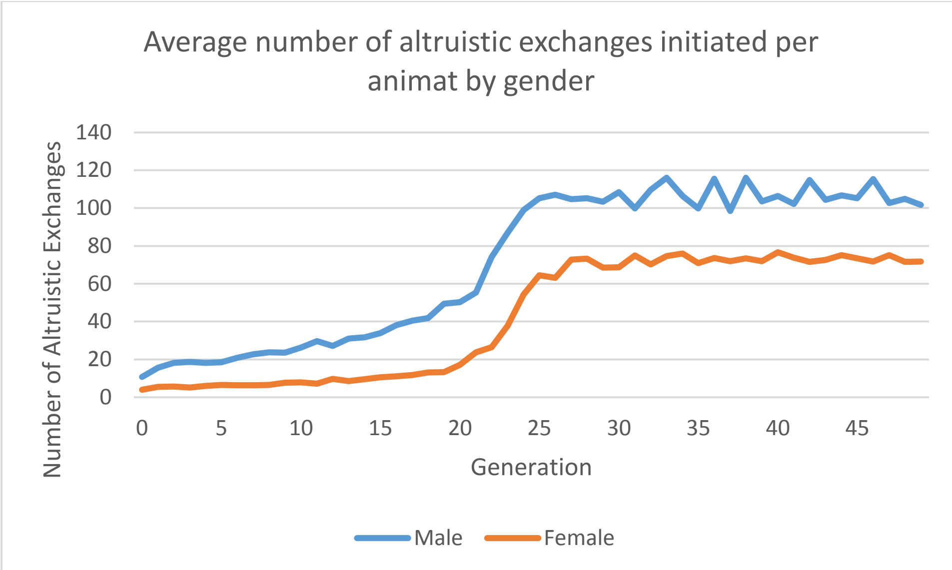

Figure 9. Average number of altruistic exchanges initiated per animat by gender in Experiment 2-2.

For this experiment set I examined the effect that genders or the lack thereof had on the evolution of reciprocal altruism. Gender-specific data was collected in Experiment 2-2 to use for comparison here. At first glance, there does not appear to be any difference between males and females based on the average altruistic and reciprocal probabilities. However, it turns out that male animats initiate more altruistic exchanges than females according to Figure 9, and female animats are the receivers in an altruistic exchange more often than males as shown in Figure 10. This is most likely because females use up more health digging up food to eat, and end up hungry more often which makes them less likely to initiate altruistic exchanges but more likely to be a receiver in an altruistic exchange.

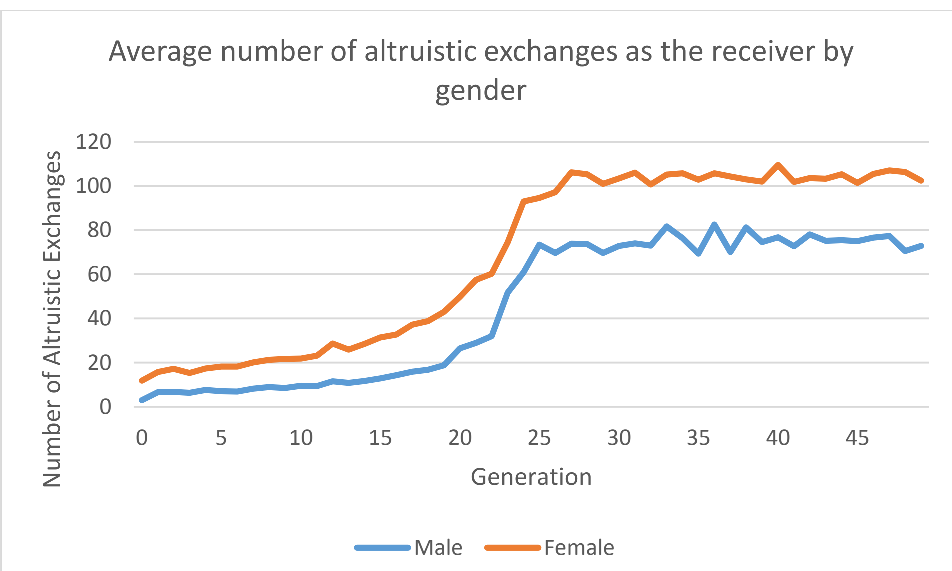

Figure 10. Average number of altruistic exchanges where the animat is the receiver by gender in Experiment 2-2.

Experiment 4-1

In previous experiments, the population consisted of male and female animats with differences between the two genders. For this experiment, there are no separate genders. Any animat can now mate with any other animat in the population. Mating now results in the child animat being released into the environment on its own immediately so that neither parent has to endure the burden of raising the child. All of the animats are like the males from the previous experiments, except that they can be asked to mate rather than only being the askers. Besides removing genders, all assumptions and parameters from Experiment 2-2 remain the same for this experiment. The animats of the first generation are each given an altruistic probability and a reciprocal probability with values between 0 and 0.25. The altruistic exchanges are symmetric once again, so that the initiator and the receiver equally benefit from an altruistic exchange where the receiver reciprocates.

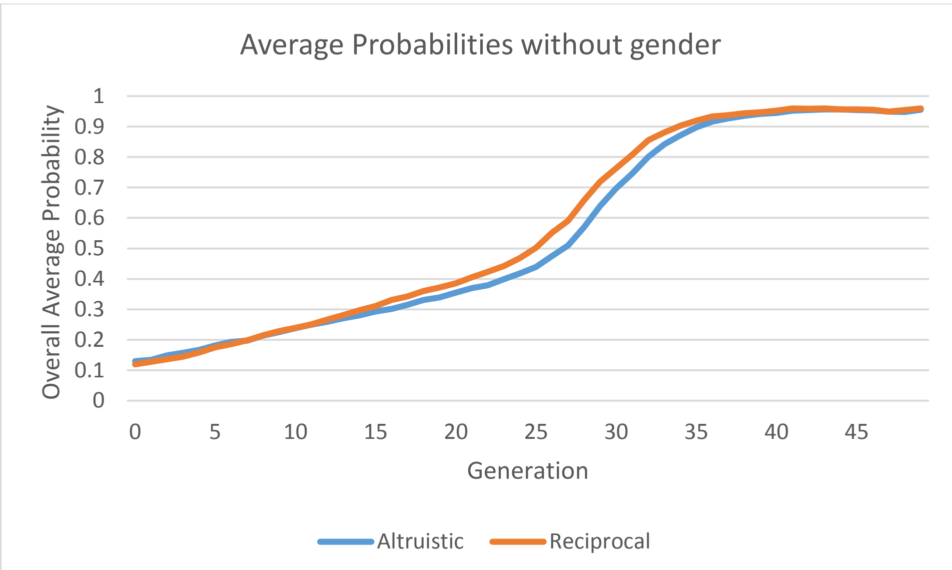

Figure 11. Average altruistic and reciprocal probabilities in a population without genders.

The results without the separate genders were not too different from Experiment 2-2, which had the same parameters besides the necessary changes to remove genders. It does appear that the evolution of reciprocal altruism took longer than in Experiment 2-2. This is most likely an effect of removing the female gender and making all animats like the male animats. Since female animats got hungry more often than males due to them being weaker, altruistic exchanges occur more often with more animats available to be receivers. More exchanges eventually means that the animats will learn quicker to increase their altruistic and reciprocal probabilities.

IX. Conclusion

Based on the experiments conducted, several conclusions about the evolution of reciprocal altruism can be made. First, reciprocal altruism can evolve without the aid of learning given enough time, but there seems to be a limit beyond which being more altruistic is not beneficial for the animat. Next, with the addition of learning, an animat population can quickly learn and evolve to the point that the average altruistic and reciprocal probabilities approach 1 with symmetric altruism. However, in cases of asymmetric altruism, the altruistic probability is limited by whether animats evolve and learn to reciprocate. Finally, an animat population without genders takes longer to evolve reciprocal altruism compared to an animat population with genders and having one of those genders being weaker.

X. References

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