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COOPERATION AMONG VIRTUAL ANTHROPOIDS IN A COMPLEX ENVIRONMENT

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ABSTRACT

This paper presents an agent based model of the evolution of cooperation in a complex environment. Anthropoid agents reproduce sexually, and live in a world where food is irregularly distributed in space and seasonally produced. They can share food, form hunting and migrating groups, and are able to build alliances to dispute territory. The agents memorize their interactions with others and their actions are mainly guided by emotions, modelled as propensities to react in specific ways to other agents' actions and environmental conditions. The results revealed that sexual reproduction is extremely relevant: in the proposed model cooperation was stronger between agents of opposite sex.

KEY WORDS

evolution of cooperation, computational model, anthropoids

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INTRODUCTION

Most agent based models of evolution of cooperation are built with simplicity in mind and the models are not intended to be realistic. However, I think that the goal of building realistic models of the evolution of cooperation *in the human species* would also be worthwhile. My goal in this paper is to offer a contribution to this approach by building a model of evolution of cooperation among virtual anthropoids with realistic assumptions about the agents' minds and their ecological environment. My emphasis in this model is on the agents' instinctive propensities to feel emotions, rather than on the evolution of cognitive abilities to make rational decisions.

The knowledge required to make realistic challenges came from many disciplines. Evolutionary psychology was the main source of ideas about evolutionary processes implemented in the model and primatology was the main source of information about real anthropoids.

Models of evolution of cooperation with emphasis on simplicity are not discussed in this paper. In the following sections, I briefly review the literature that most directly contributed to the development of this model[1]. I also discuss some advantages and disadvantages of simple and complex models. Then I present my model and the results of some simulations, followed by a brief conclusion.

KIN SELECTION AND RECIPROCITY

The basic natural selection mechanisms are the higher rates of survival and reproduction of the best adapted individuals. When one individual helps another, he is increasing the other's chances of surviving and reproducing. The problem is that, given the natural limitations of resources, as the other's chances increase, the helper's own chances decrease. So, how can we explain why individuals help one another? Biologists have basically found two explanations for the problem: *kin selection* and *reciprocal altruism*.

Dawkins says, metaphorically, that organisms are survival machines owned by their selfish genes [1]. The metaphor is meaningful because an organism which is well adapted to its environment will produce a larger progeny than a poorly adapted one. That is, the genes in its genetic code will yield more copies of themselves than the genes of other organisms, and, thus, their proportion in the genetic pool of the next generation will increase. Genes are simply molecules and, of course, they do not have either selfish or altruist sentiments. However, events take place as if genes were selfish agents manipulating their organisms to yield as many copies of themselves as possible. Metaphorically, we can say that a gene does not have any concern for the organism it lives in, and it will destroy the organism if, for any reason, this is the most efficacious way of producing copies of itself.

Each organism from a given species shares a high proportion of genes, but only close kin share an expressive quantity of some rare genes. Kin selection theory considers these facts while saying that genes will yield a larger number of copies of themselves if their organisms help their close kin to survive and reproduce, even if this help implies a cost for the organism itself. That is, a genuinely altruist organism that sacrifices itself to help close kin may be acting in a way that increases the chances of making copies of its own genes, including the genes of altruism. Returning to the metaphor, the selfish gene can produce an altruistic organism, but only with close kin. Hence, the use of the term *kin selection*.

Political scientists join biologists in the second theory that tries to explain the existence of cooperation. According to this theory, it will be adaptive to an individual to help other if, as a consequence of this action, the probability of receiving help in the future were significantly higher. In this case, we can say that we do not have a genuinely altruist individual, but a non-myopic selfish one. However, this may not be the complete truth. An individual may help another because his sentiments make him desire to help, without any intention of receiving something as payment. Of course, these sentiments have evolved under natural selection according to the egoistic reasoning explained above. Two individuals who establish a long-term altruistic relationship can be called friends.

The two mechanisms mentioned above may not be enough to explain the cooperation in large groups with hundreds of individuals. In large groups, the majority of individuals are neither close kin nor friends; they are merely strangers. However, some evolutionary psychologists argue that kin selection and reciprocal altruism evolved in the human species over a period of thousands of years when our ancestors lived in small groups. In these circumstances, to help a group member would probably be to help close kin or, at least, someone who would be around for long enough to have many opportunities to reciprocate the favour. Kin selection and reciprocal altruism would be enough to explain the evolution of altruism in these groups. Today, encounters among strangers are ubiquitous, but given that they were rare in our evolutionary past, human beings would have a strong inclination to cooperate and they would be cognitively ill prepared to discriminate between kin, friends or strangers when an opportunity to act altruistically appeared. Evolutionary psychologists argue that our psychological mechanisms lead us to act altruistically in circumstances where helping the other is no longer adaptive.

Henrich and Boyd [2] disagree. They argue that reciprocal altruism and kin selection are not enough to the evolution of cooperation in large groups. Henrich [3] enumerates several reasons that show the implausibility that the cooperation evolved from reciprocal altruism is still practised, despite it is no longer being adaptive. Reciprocity would be a good explanation only for small groups not threatened with extinction. That is, groups where the probability of future interactions is still sufficiently high.

Cooperation will be less difficult if individuals can refuse to have relationships with non-co-operators, that is, if free-riders are ostracised. If there were a permanently high probability of future encounters, ostracism would be enough to account for the evolution of cooperation. However, in our evolutionary past there were probably periods when there was no certainty of future interactions, and, hence, ostracism alone does not seem to have been sufficient to secure the evolution of cooperation [4].

Individuals must be take more action than simply ostracising free-riders and restricting their associations to trustworthy friends. Individuals must punish non-co-operators even if there is a cost to themselves, and even if there is no expected future gain [4]. Gintis called this more active attitude *strong reciprocity* [5].

Another type of reciprocity that might be particularly important for the evolution of cooperation among human beings is *indirect reciprocity* [6]. In models that include indirect reciprocity, cooperation and defections are observed by many agents not directly involved in interactions. These observers either add or subtract scores from the images that they have of other agents. In these models individuals cooperate not only in the expectation of direct reciprocation, but to build a good reputation that will increase their chances of benefiting in the future. The flow of information about who usually cooperates and who usually defects will increase if individuals are capable of exchanging information easily, as in the case of human beings.

METANORMS

Axelrod [7] has built in computer a model with 20 agents who could choose to contribute or not towards the production of a collective good. The costs of contributing were smaller than the benefits received, but for a selfish agent the rational action would be to consume the good without contributing towards its production. However, the agents were not rational; they were led by emotions, modelled as genetically inherited probabilities of behaviour.

BETWEEN SIMPLICITY AND COMPLEXITY

On the one hand, sociologists and political scientists often use statistical tools to analyse data, but, for a long time, attempts outside of economics to use mathematics to formalize social theory have not been very successful. Only in the last decades, a branch of theoretical research in social sciences-game theory-has started to build formal explanations of social phenomena. However, the social world is too complex to be easily translated into mathematical formulas.

To be able to elaborate formal explanations, game theorists generally adopt various simplifying assumptions about human behaviour. The two most important of these are that human beings are strictly rational and that they have complete information about their social interactions [8]. Rarely, if ever, is the world as simple as game theory descriptions, and this lack of reality frequently makes the interpretation of the game a difficult task. That is, we frequently cannot say if the way the game evolves adequately resembles what happens in the real world. This is a limitation of any model, but it is particularly visible in traditional game theory models.

On the other hand, the promise of multi-agent models is to build models of complex social phenomena from the actions of multiple and heterogeneous agents [9].

Agent-based models can simulate many phenomena, but we cannot say that they have the same level of formal rigour as equation based models. For example, Taylor’s analysis of reiterated the prisoner’s dilemma is mathematically rigorous; he *proved* that certain conclusions can be extracted from his model, what is more satisfying than *simulating* the same phenomena. The results found by Axelrod [10] simulating the reiterated prisoner’s dilemma were similar to Taylor’s conclusions, what is indicative that results reached through simulations are valid, although more difficult to analyse formally. If simulation’s sole utility were to replicate results found by equation models, it would be meaningless to do them. However, a simulation can be made with far more complex objects than the reiterated prisoner’s dilemma, and as a problem becomes more complex, any attempt to translate it into a mathematical formula becomes impracticable. It is thus expected that multi-agent models are an alternative way of finding explanations to social phenomena [9].

The simulation can be repeated if something apparently strange happens. The events will all be exactly replicated, and it will be possible to examine the minutiae of facts leading up to the phenomenon in question. At least partially, this can compensate for the frequent impossibility of making a rigorous formal analysis of a computer simulated agent-based model.

The basic rule that models must be a simplification of reality is still followed in multi-agent models. A frequently found recommendation is that the model must be kept simple to facilitate the analysis of its results. If the model has a large number of parameters, the numerous variables can interact in a complex way and the role of each parameter can be unclear to the researcher [8].

While a model is kept simple, it is possible to identify the effect of a given agent rule of behaviour. When many strategies are added to a single model, complex results can emerge, and, for instance, a strategy that was previously leading to cooperation, in the presence of other strategies, can begin to inhibit the cooperation [8].

The use of simple models, however, has its own disadvantages. The main one is the risk of building overly unrealistic and empirically irrelevant models. At first, when the basic techniques are being developed, there is no alternative but to build simple models, even if they are too unrealistic. Thus, even recognizing the great usefulness of the above recommendations regarding simplicity, I believe that the opposite approach can also be useful. That is, it is also valid to try to model complex situations, including more than the minimum amount of elements to test a specific kind of relation between variables; also including elements that allow modelling of other social phenomena that one believes are in some way significantly related to the main phenomenon studied.

Usually, multi-agent models are simple, and they are tested by running many simulations with varying values for the different parameters. A model is considered robust when it produces similar results in a broad range of values for its variables [11]. However, a better challenge to the robustness and empirical relevance of a model would be to put it to work in a more realistic environment. The results produced by a complex model can be equivalent to a simpler one. In this case, one strategy would predominate and the variables and other phenomena modelled simultaneously would be only making the result produced by the model more probabilistic.

EMPIRICAL CHALLENGES TO AGENT BASED MODELS

It is advantageous for individuals to solve their problems fast and efficiently. If our ancestors have been confronted with a problem repeatedly over the last million years, it is to be expected that we have the right biological propensities to unconsciously solve the problem (if this is possible). This is advantageous for the individual because he remains free to concentrate his attention in new problems, which can be solved only through improvisation. The identification of commonalities between human beings and apes (bonobos, chimpanzees, gorillas, and orangutans) allows us to create hypotheses regarding our current biological propensities and the biological propensities of our common ancestor with apes. We suppose that our ancestors probably had the cognitive and emotive capabilities currently common among apes and humans. Thus, these abilities should be recognizable in the initial agent characteristics in a model of the evolution of cooperation.

The ability to memorize results of recent interactions with other individuals, for instance, is a pre-requisite for the existence of what Brosnan and de Waal [12] call *calculated reciprocity*, which can also be interpreted as *gratitude*.

Other important ability is the capacity to have a notion of self, that is, the capacity to recognize oneself as an individual distinct from others or, in other words, the capacity to imagine oneself as an object in the world. The notion of self is important to understand the role of other individuals in a cooperative task and, thus, for coordinated action and teamwork. Among primates, macaques (*Capuchin monkeys*) have not shown clear evidence of having a notion of self, but apes have [13].

It is interesting to note that even macaques have an emotional reaction resembling that of individuals who practice strong reciprocity. These monkeys often share food in their natural habitat and, when captive, show what seems to be a certain kind of sense of fairness. They become angry when a mate receives a bigger reward for the same effort from their caretakers [14].

MODEL DESCRIPTION

I was guided by some principles while developing the model presented in this paper. The environment should be interpretable as empirically relevant to the evolution of cooperation among our ancestors and agents should have the potential to evolve and not fixed patterns of behaviour. Global phenomena, like groups and communities should not be directly modelled. Instead, I expected the emergence of these phenomena through the interaction between individuals. These are the reasons why agents have so many genetic features subject to mutation and evolution through "natural" selection.

The model was initially developed using Swarm libraries [15] but latter I translated it into C++, and used GTK and GTKMM to build the graphical user interface[2]. Some ideas were borrowed from the models written by Pepper and Smuts and by Premo, notably the distribution of plants in patches, the possibility of food sharing, predation risk, and territoriality [16, 17]. The agents' genetic propensities to feel emotions resemble many of the emotions discussed by Trivers [18].

The world is a rectangular grid whose dimensions are defined at the beginning of the simulations. In many agent based models, the world is a torus to avoid edge effects on agents' behaviour. However, since real anthropoids live in places with borders made by rivers and mountains, I opted for not using a torus world.

In this model time runs in discrete steps, called hours. A day has 4 hours and a year has 50 days.

PREY

The simplest agents in the simulation are the prey hunted by anthropoids. They simply get older and, when reach their maximum age, go back to age zero. At this point, if the number of prey in the world is below the maximum defined before the start of the simulation, the prey gives birth to an offspring. Their behaviour consists in making random movements in the world. When a quarry is hunted, it is not replaced until another one reaches the maximum age. Preys are protected against extinction by over predation: if all of them are hunted, the model creates a new one in a random place. When hunted, prey is converted into an amount of meat proportional to their age.

VEGETATION

Each cell in the grid has either a tree or terrestrial herbaceous vegetation (THV). The THV, as the plants in Pepper and Smutts Pepper [16], grows continuously during the entire year, according to a logistic curve: growth is slower when the plant is near the minimum and maximum values of energy.

The model does not allow the complete consumption of a THV. The plant always remains with an energy level at least equal to its logistic growth rate. The maximum energy of a THV is 1,1 and the logistic growth rate is 0,01.

Trees are capable of producing fruits and the anthropoid agents try to pick as much fruit as is necessary to reach the maximum level of energy. There are three species of trees. The period of fruit production, the number of fruits produced a day, the amount of energy each fruit has, and the time a fruit remains edible are species specific, and all trees of a species share the same features. The fruits are produced once a day, but each anthropoid agent tries to eat either fruits or THV once every hour. In a real tropical forest, anthropoids prefer ripe fruits. Analogously, in this model the first fruits to be eaten are the older ones. The trees are distributed in patches containing only one tree species. The purpose of creating different tree species and distributing them in patches is to emulate the seasonality and irregularity of fruit distribution in real tropical forests.

Trees and THV do not die, and none of their parameters evolve. Of course prey, trees, THV, and cells are agents, but in this article I will reserve the expression *agent* for anthropoid agents. The Figure 1 shows the world in a simulation before and after the presence of anthropoids, which are only created one year after the vegetation. Thus, when anthropoids are created, the world already has enough vegetation to support them. A single cell may have any number of agents. In the graphical representation of the world, different tree species can be distinguished by the different colours of their borders. The greater the amount of fruit, the more yellowish is the center of the tree. The THV's colour goes from light green (maximum energy level) to almost yellow (minimum energy level). Cells containing agents have their central region coloured with a colour between red (when all agents are female) and blue (when all agents are male).

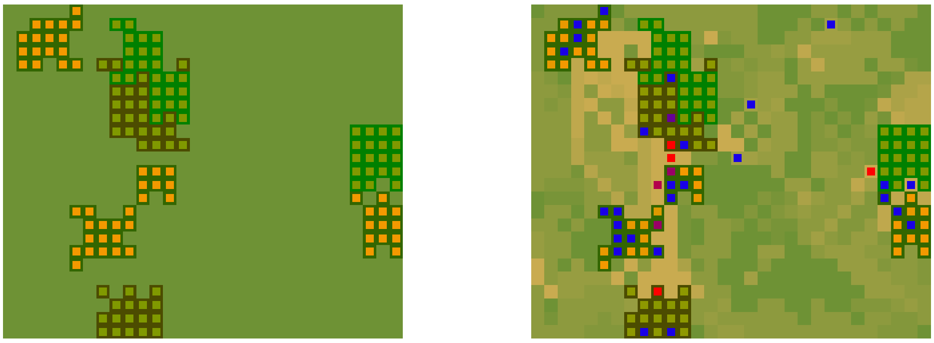

Figure 1. The world before and after the creation of agents.

THE ANTHROPOIDS

Anthropoids are born, grow up, reproduce sexually, and die. A newborn agent receives a name consisting of seven random characters. This name is used during the agent's interactions to identify relatives, friends, and enemies.

Newborn behaviour consists simply of receiving energy from its mother and of following her continuously.

The maximum amount of energy an agent can accumulate, the amount of energy spent hourly (metabolic rate), and the maximum age are fixed for the entire simulation, but the duration of childhood is subject to evolution.

The metabolic rate of adults has a fixed value, 1, but it is possible to define the maximum energy level at the beginning of simulations. These values are used to calculate the duration of childhood for the first population of agents. The duration of childhood has the same value (in hours) as the maximum energy level (in units of energy). The maximum age will be approximately 16 times longer than the initial value for childhood.

Children's metabolic rate is half that of adults and a child receives two times what it spends from its mother. Thus, the childhood duration defined with the above calculation is enough for the first population of children to reach adult age with 50 % of the maximum energy level. An adult dies if its energy falls below 30 % of the maximum. The agents cannot eat more than is required to reach the maximum energy level, and they can consume at the most two times the value of their metabolic rate. The minimum level of energy to stay alive during childhood increases continuously, reaching the adult level when the agent becomes adult.

Most of the agents' actions are guided by emotions, and not by rational calculations. Emotion is here defined as the propensity to behave in specific ways according to the circumstances.

The propensity to feel emotion is genetically inherited, and, in most cases, is represented by real numbers. During reproduction, the propensities are subject to mutation, that is, small increases and decreases in their values.

In this model, almost all of each agent's genetic features is stored in two variables. Both variables are subject to mutation, but during the agent's life only the variable corresponding to its sex is active. During reproduction, for each genetic feature, the agent inherits both variables from either its father or its mother. The aim of this duplication of variables is to give agents the possibility of having different behaviours from the same genetic code. Real animals do not have separate genetic codes for males and females, but a reasonably comparable process exists: many important genes have a different manifestation depending on the presence of masculine or feminine hormones.

MEMORY

Agents can have both positive and negative memories of other agents, and, in many circumstances, they have to elaborate a feeling about another agent from their memories. This feeling will be neutral, positive or negative. There are different ways of calculating this feeling according to the circumstances. If the agent does not have any remembrance of the other agent, the feeling will be neutral. The result will also be neutral if the sum of everything given and the sum of everything received are zero.

When an agent becomes adult, it starts to interact with other agents, including its mother. At this point, it stores in its memory that its mother has given it energy equivalent to motherValue, and its mother remembers that has given her child childValue.

Agents may follow different strategies to remember others: (a) The most vengeful ones will be vengeful when the last value given is higher than the last value received, (b) the moderately vengeful ones will be vengeful if the last value given is higher than zero and the last value received is below zero, (c) the least vengeful agents will only be vengeful if the sum of all that the agent has given is higher than zero, the sum of all it has received is equal to or below zero, the last time it has received is more recent than the last time it has given, and the last value received is below or equal to zero. When being vengeful, the value recalled is calculated according to the expression:

$$\text{feeling} = (-1) \cdot \text{vengefulness} \cdot (\text{given} \cdot \text{received}), \tag{1}$$

where, depending on its vengefulness strategy given and received will refer either to all that was given and received or only to the last event of each kind. The strategy employed is a genetic characteristic of agents.

If not being vengeful, an agent uses gratitude to recall the other, and, there are two ways of remembering with gratitude. In one strategy, only the total value received is remembered, and in the other the calculus considers the difference between given and received, as shown by the expressions:

$$\text{f1} = \text{gratitude} \cdot \text{received}, \tag{2}$$

$$\text{f2} = \text{gratitude} \cdot (\text{received} - \text{given}). \tag{3}$$

In the model, recent facts may be considered more valuable than old ones. Hence, the calculation of given and received is not a simple sum of everything given and received, respectively. The age of the event, t, and a factor, f, between 0 and 1, are used to calculate the value of past events. The recall value of each event is defined by the expression:

$$v' = v \cdot f^t, \tag{4}$$

where v' is the recalled value and v is the stored value.

Agents can only store 4 events per known agent, and a new event replaces the least valued one in the agent's memory. If an agent encounters a stranger it will ask its neighbouring friends whether they remember the stranger. To some extent, this is representative of the process of image score discussed by Nowak and Sigmund [6].

Each agent, in almost all circumstances, gives a specific value to unremembered agents. The value differs for female and male strangers and is genetically defined. These values are not used in territory defence, in which the fact of the agent being xenophobic or not prevails.

Agents also memorize the location and the tree species of visited patches as well as whether they were expelled (or not) from the patch in a dispute for territory.

Immediately after being created, the first population of each simulation memorizes the nearby patches of trees as visited and peaceful. They also memorize receiving a small positive value (0,01) from their same cell neighbours. The goal of these memorizations is to deal with the unrealistic fact of all agents being born simultaneously as adults and without social relations or a record of migrations.

BASIC ACTIONS OF AGENTS

Once every hour the agents are activated sequentially and behave according to the algorithm sketched in Figure 2.

Every hour the agent becomes older, has its energy level reduced according to its metabolic rate, and runs a risk of being victim of predation. If the agent has meat, it will eat a bit of it at this time. The probability of being a victim of predation may be defined at the start of simulations, but it will be six times higher in grassland than in a tree patch. The risk will also decrease as the number of agents in a cell increases. If the agent is an infant, it simply follows its mother.

Most of the time the agent either stays put or moves to the best of the eight adjacent cells. If a cell is unoccupied, its value will simply be its energy level. Otherwise, the agent evaluates the adjacent cells using the expression

$$\begin{aligned} V = &\frac{e \cdot e_2}{N} \cdot (1 + m) \cdot (1 + s \cdot N_s) \cdot (1 + o \cdot N_o) \cdot \\ &(1 + x \cdot N_x) \cdot (1 + c \cdot N_c) \cdot \left(1 + f \cdot \sum l_i\right), \end{aligned} \tag{5}$$

where e_c is the cell energy and e the value that the agent attributes to this energy; N is the total number of agents in the cell, including the future occupant, and N^* is the number of agents of a given type; The types are m, mother; s, siblings; o, opposite sex agents; x, same sex agent; c, son or daughter for females and oestrous females for males. The cell's friendship will also be considered. The agent will multiply its propensity, f, to go to a cell where its friends are by the sum of recalled values of occupants.

When an agent leaves a tree patch, it memorizes information about the patch: localization, tree species, and current time.

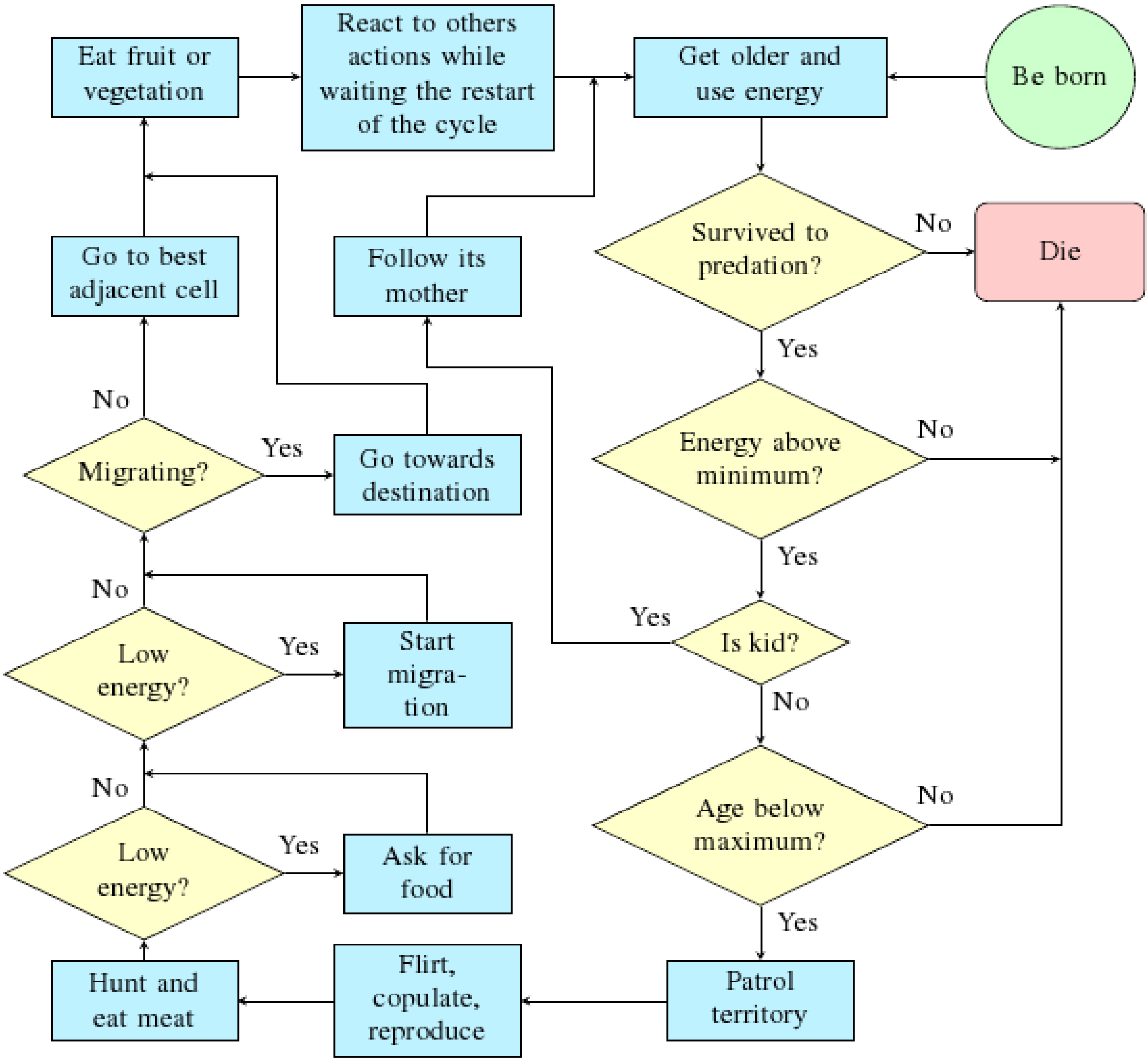

Figure 2. Basic algorithm of the proposed model.

FOOD SHARE

An agent will ask another agent for food if its energy level falls more than lowDeficit since the last step and it will migrate if its energy level drops more than highDeficit.

The agent checks which of its neighbours generates the most positive memories in order to choose the potential donor. However, the agent must evaluate its neighbours with incomplete information. It knows what events involving it the other remembers because all interactions are memorized by all agents involved, but it does not know the other's propensity to be vengeful or grateful, nor does it know the other's recall strategy. Thus, the agent calculates what the other's feeling for it would be using its own propensities and strategy. This equates to saying that the agent is capable of empathy. Because males and females follow different behaviour patterns, agents may also opt to remember past events using average values for vengefulness, gratitude, and the timeFactor that defines the value of old events.

Initially, the probability *p* of donation is equal to the agent's recall value. To this basic value, it adds its benevolence towards its mother, children, siblings, and, also, its benevolence towards agents of opposite sex or of the same sex. Of course, these benevolence values are only added if the supplicant agent can be classified in such categories. These different propensities of benevolence are defined by the agent's genetic code. The agent will also add to p the value of its pity if the begging agent has less energy than it has, and subtract from it the value of its envy if the opposite is the case. The program generates a random number between 0 and 1 and, if the number is smaller than p, the agent makes the donation. The donation value depends on two kinds of agent generosity. One refers to the agent's energy level, and the other to the amount of meat that it has. If the agent is carrying any meat and its meatGenerosity is higher than zero, it will donate a piece of his meat proportional to its meatGenerosity, but always lower than 1,5. If either the agent does not have meat or its meat donation is lower than its metabolism, it will add the value of generosity to the donation, with the donation limited to the value of metabolism. In this second case, the agent's energy level will decrease by the value of donation.

When the process of energy or meat donation finishes, the agents memorize the event. If there was donation, donor and supplicant memorize the value given. If there was no donation, agents memorize the value that they attribute to negative answers to food requests. Each agent has different values for male and female refusals, and, if these values are positive, nothing is memorized.

MIGRATION

Migrations are dangerous because the risk of predation is higher in open land than in tree patches and because trees give much more food than terrestrial herbaceous vegetation. Furthermore, the agent does not know whether its destination will be overpopulated. In any case, the migrations are necessary because fruit production is seasonal. Thus agents may postpone, but cannot avoid migrations. After begging for food, the agent evaluates whether migration conditions are met or not.

The procedure to decide on the migration destination is complex. The agent makes three attempts to decide on a good place to go, and on each attempt it uses a different algorithm.

One of the algorithms consists of going to the best nearest cell, that is, to a cell whose distance is equal or shorter than MaxVision. The best cell is chosen using (5).

Another strategy is to remember known tree patches and check which patch is the best in terms of fruit production at the time the agent would be reaching it. More specifically, the patches are evaluated according to the expression:

$$V_{(\text{tree patch})} = N\, e_{\text{f}} \tag{6}$$

where N is the number of fruits that will be produced by all patch trees from the moment the agent arrives to the end of the tree fruit season, and e_{f}, is the energy value of each fruit.

The third strategy consists of following a nearby agent who has already begun to migrate. In this case, each neighbouring migrant is evaluated according to the expression:

$$V_{migrating} = remembrance \cdot V_f + \frac{V_a \cdot a'}{a}, \tag{7}$$

where remembrance is the recall value and may be positive, negative or neutral (as already explained), V_{f} is the value of friendship regarding migration decisions, V_{a} is the value of age (it may be better to follow an older agent than a younger one because the former probably has a better knowledge of the local geography), a is the agent age, and a' is the migrant's age. The values of V_{f} and V_{a} are specific for each individual and are subject to evolution.

The sequence of algorithm activation is genetically determined and subject to evolution. If the three attempts to find a good destination fail, the agent begins the migration to a random place within a distance between MaxVision and 2×MaxVision. In this case, once a day the agent tries to find a good place to go using the near good cell search algorithm.

Once the destination is chosen, the agent invites all friends that are nearby to form a migration group, and each agent who accepts the invitation also invites all its neighbouring friends. Each invited agent sums the recalled values of all agents that already joined the group and if the sum is positive, it accepts the invitation, unless its migration strategy is never accepting invitations. Invitations to migrate to random places are refused.

The migration algorithm proper is very simple: at each time step the agent moves one cell towards the destination.

TERRITORIALITY

Each agent has an enmityThreshold. If the recalled value of another agent is below this value, it is considered an enemy[3]. Agents may also be xenophobic towards different types of strangers: males, females and females carrying children.

Once an hour each agent in a tree patch checks whether there is either an enemy or a stranger in the cells as far as NearVision. A neighbour is considered an intruder either if it is a stranger from one of the categories towards which the agent is xenophobic or it is an enemy. If any intruder is found, and if the agent's own bravery is higher than a random number between 0 and 1 generated by the computer, it will try to expel the intruder by inviting all nearby friends to join the alliance against it. The intruder will also try to form an alliance. The Figure 3 shows a flow chart of the process.

An agent invites its best friends from its own cell and from the cells within the AllianceRadius, whose value is defined before the start of the simulation. Invited agents may follow two different strategies to decide accepting or not the invitation to join an alliance. They may accept invitations coming either from only positively remembered leaders or from strangers and neutrally remembered leaders. If this first condition is met, the agent will accept the invitation if its loyalty is higher than a randomly generated number between 0 and 1. The refusal of the invitation is remembered by both agents as valueOfNoCT (value of no in conflict for territory). A neighbour is considered an intruder if the value of the remembrance it triggers is below the enmityThreshold of the patrolling agent. The intruder will also try to form an alliance. When the two alliances are formed, agents vote to decide whether their alliance will fight and all agents involved in the conflict register in their memories that they received positive values from their allies and negative values from their enemies.

The agents may follow the norm of punishing others who refused to join the alliance. In this case, the punishment will mean a loss of energy for both groups: punished and punishing agents. Agents that follow the norm of punishing non co-operators may follow the metanorm of punishing those alliance members that did not punish non co-operators. In all cases, the cost c of the punishment process will be proportional to the number of punishing and punished agents, according to the expression:

$$c_1 = \frac{n_2}{2n_1}. \tag{8}$$

The punishment process is memorized by all agents. Punished agents will memorize either the evil that they committed or the penalty that they received, depending on the value of their shame.

The probability of an alliance winning the conflict is proportional to the total energy of its

Figure 3. Algorithm of territory patrolling.

allies, and each ally casts a vote favourable to the fight if its audacity is above the probability of its alliance winning the conflict. That is, the rational value for audacity is about 0.5. If the two alliances decide not to fight, nothing happens. If the two alliances decide to fight, the program will generate a random number that will decide the conflict outcome. All agents will lose energy due to conflict, but loss will be inversely proportional to the total energy of the alliance the agent is part of.

Agents of an alliance that voted for peace and agents of alliances that lost the fight will flee from the leader of the winner alliance, running a distance equivalent to NearVision.

HUNT

Once during each cycle of the basic algorithm, the agent decides whether it is time to hunt. The evolution of no-hunting agents is possible because they may follow three strategies: (1) never hunt, (2) hunt only during migrations, and (3) hunt periodically. The interval between hunts is not a genetic variable; it may be considered a cultural one. The agent decreases its interval whenever it participates in a successful hunt and increases it whenever the hunt is unsuccessful. The hunter also increases or decreases its hunt interval according to the average interval of its group members.

When it is an agent's hunting time it invites its best friends to form a group of hunters. The maximum number of invited hunters is defined genetically. A big group has more chances of capturing prey than a small group, but members of successful small groups receive more meat. Thus, the evolution of an optimum group size within some generations is expected.

An agent accepts the invitation to join a group of hunters if it does not follow the strategy of never hunting and if at least half of its hunt interval has elapsed.

The event of refusing the invitation to join a hunting group is remembered, and the members of a group of hunters have their energy level decreased by HuntCost each time they join a group.

Agents seek prey at NearView distance, which is defined at the beginning of the simulation. If prey is found, the probability, p, of it being caught is given by:

$$p = 1 - 2^{(-8n/e)} - \left(\frac{1 - 2^{(-8n/e)}}{3n}\right), \tag{9}$$

where n is the number of hunters and e is the prey's energy. Then, the expected amount of meat, m, that an agent expects is given by:

$$m = pe/n. \tag{10}$$

Figure 4 shows the amount of meat expected according to the number of hunters and the size of the prey.

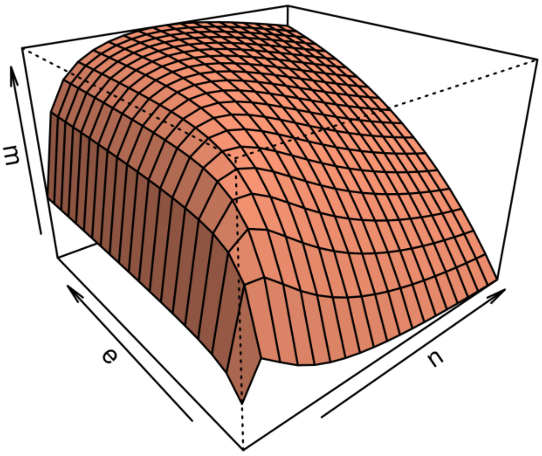

Figure 4. Expected meat reward.

The agent who made the invitation distributes the meat according to its fairness. If its fairness is 1, all agents in the group of hunters receive the same amount of meat. In addition to its own fairness, each agent also expects leaders of groups of hunters to have fairness above a certain threshold (expectedFairness). If the leader's fairness is below this value, the agent who received the meat remembers the event as if the leader has given it

$$\text{valueOfNotFair} \times \cdot (\text{expectedFairness} - \text{leaderFairness}).$$

Each agent expects different levels of fairness from male and females leaders.

Agents may carry their meat for some hours before it is spoiled and can consume a maximum of 2 units of the meat's energy at each hour.

REPRODUCTION

Females are solely responsible for nurturing offspring. An adult female enters a five hour oestrous period when her energy level is near the maximum. She then starts to receive mating proposals from nearby males. When the oestrous cycle finishes, the female sorts her suitors according to the memories that she has of them. The evaluation of a male is also influenced by his energy level and age. Females may consider males more worthwhile if they have high energy and are close to the age she considers ideal. The value of each suitor is defined by the expression

$$V_{suitor} = rememb \cdot \left(\frac{v_a \cdot |\Delta a|}{MaxAge}\right) \cdot \left(\frac{v_e \cdot e}{MaxEnergy}\right), \tag{11}$$

where v_a is the importance for the female of the difference between the male's age and the ideal age; Δ is the difference between the male age and the ideal age; v_e is the value of male energy; and e is the male energy. The necessary adjustments are made to the above expression when a male's value is negative. Another factor that contributes to female's evaluation of males is the distance between them. The more distant the male at the end of the oestrous period, the less worthy he is considered by the female.

With males sorted by values, the female decides how many of them she will copulate with, according to her promiscuity index, which is genetically determined and may be between 0 and 1. The number of sexual partners will be the rounded value of n^f, where n is the number of suitors.

The probability p of a male being the father of the future newborn is proportional to his value to the female in relation to the sum of values of all sexual partners. The males who have the opportunity to copulate, register in their memory $p \times$ childValue, where childValue is the value attributed by the male to sexual intercourse. The suitors not chosen as sexual partners memorize the event with the valueOfNoSex. The female also does the corresponding memorization of all these events, but using her own values for childValue and valueOfNoSex.

In the real world, many animals, guided by instincts, and humans, guided by instincts and cultural norms, avoid sexual relations with close kin. In this model, males do not have sexual interest in their own mothers.

SETUP OF SIMULATIONS

Due to the model's complexity and limited computational resources, even the simulation of a small world runs slowly. There were 32 different combinations of parameters, but some of them were run more than once and some and were not run (due to either hardware failure or collapse of the population). The total number of simulations was 39. The size of the patches of trees could be either small (just 1 tree) or big (between 4 and 10 trees), the density of trees could be low (0,005 or 0,007) or high (0,05), the maximum density of preys could be either low (0,01) or high (0,03), the world could be shaped as either a strip (20×300) or a square (100×100), and in some simulations there was a period of the year without fruit production (drought).

The average results of some previous simulations were used as initial values for the agent's genetic characteristics. At the beginning of the simulations each agent from the first population received values between 0,2 below and 0,2 above the values shown in Table 1 (all tables are listed in Appendix).

RESULTS

In many simulations, females, males or both developed negative propensities to feel vengefulness, gratitude or both. In only eight simulations, on average, both females and males developed positive propensities to feel both vengefulness and gratitude. The development of negative values for this propensity to feel emotions was unexpected and we can consider the agents in these eight simulations the normal ones. However, the comparison of the mean values of some other variables reveals that the others may not really be masochistic and ungrateful; it seems that they have developed negative values for vengefulness and gratitude as an adaptation to other unusual values. For example, an abnormal female stores a positive value in memory (on average, 0,33) when other female is not fair to her. In this case, it is adaptive to have an inverted propensity to feel vengefulness. Hence, it was the lack of determination of the model that allowed these unexpected equilibriums between vengefulness and gratitude and other genetic propensities.

I considered as indicators of evolution of cooperation the size of patrol alliances, the size of hunt groups, and the proportion of food shared to food requested. Table 2 in Appendix presents average values of cooperation during the last 1 % of the simulation's steps as well as the average number of generations elapsed. In this table, *N. Hunters* is the average number of agents who formed groups of hunters; *NA 1* is the average number of agents who joined an alliance to defend a patch of trees from an intruder; *NA 2* is the average number of agents who joined the second alliance, formed by the intruder to avoid being expelled. *Food Share* is the proportion of requests for food which were granted; a capital *M* means Male, and *F* means Female. *N. Gen.* is the average generation number of agents. When an agent is born, it receives two generation numbers, a masculine one and a feminine one, which correspond to its parents numbers +1.

Food sharing is highly biased by sex. Females adapted to the exigencies of motherhood by developing the propensity to almost never share food. Males, who need to be positively remembered by females, developed the propensity to be generous towards females in about 60 % of requests, but they also shared food with other males in about 20 % of occasions. As we can see in Table 3, females developed negative values for generosity; an agent with negative generosity never shares food, regardless of who is requesting. Males developed positive generosity when carrying meat, and were generous with females, specially their mothers.

The preference to move and migrate are similar in males and females. Table 4 shows that both sexes prefer to go to cells with agents of opposite sex, but males are more prone to do so, particularly if the cell has an oestrous female. As expected, cells rich in energy are more positively evaluated by females than by males.

On average, the size of alliances to defend territory was not remarkable. The presence of many values below 1 indicates that on many occasions agents not only formed small alliances but also frequently voted for their dissolution. That is, impelled by low audacity, they acted as they would if consciously following a conflict avoidance strategy. It seems that there was no pressure towards or against the evolution of xenophobia or fear of hostile patches as can be seen in Table 5: the values near 0.5 indicate that these variables were changing randomly. The other variables show signs of evolution. Females bravely initiate alliances, rationally decide whether to fight or not and refuse to join alliances initiated by others. Males have a lower propensity to start alliances, but once part of one they are irrationally audacious. They also are more prone to accept an invitation to join alliances than females are. On average, both males and females have the same propensity to follow the norm of punishing agents who refuse to join an alliance, and neither has the propensity to follow the metanorm of punishing the non-punisher agents.

There are some differences between females and males in memorization and recall of events. Both males and females store more negative values when a male refuses to share food than when a female does the same (Table 6). This is equivalent to recognition that females cannot share food because they always need it more than males. Males are less vengeful than females.

Females do not consider it a great favour if an agent joins their alliance to expel an intruder. A male becomes more upset when a female refuses to have sex with him than a female imagines.

Table 7 shows some results related to agents' reproduction. Females developed a propensity to prefer young males. A male's age is more important than his energy because males memorize a high value for the event of being one of the probable fathers of a child. That is, this event makes the male remember a female as his friend for a long time, increasing the chances of food share. Female low promiscuity is correlated with male vengefulness strategy. In simulations with males following more vengeful recall strategies, females are less promiscuous because a male following the most vengeful strategy will consider another agent his friend only if the last value given is higher than the last value received. If a female is promiscuous, the *child value for male* will be divided by many males and, thus, will soon be remembered as a small value. That is, depending on male vengefulness it may be better for females to be either more promiscuous, and, thus, make many male friends and avoid male enemies or less promiscuous and make at least a few male friends.

The burden of children rearing made starvation the most frequent cause of death for females, even in simulation number 27, which had the smallest difference between the number of female and male generations. In no simulation females lived longer than males. The ratio of the number of male generations to the number of female generations, which I have called *fLife* varied from 0,45 to 0,87. Unexpectedly, Table 8 shows that *females clearly fare better when males are vengeful*, particularly when they use the last values given and received while being vengeful. In simulation number 27, females had a low promiscuity (min. 0, mean 0,11, max. 0,22) and males had a high vengefulness (min. 1,10, mean 1,31, max. 1,45). The other most significant variables do not have surprising effects. Females will live less if they join alliances, because conflicts mean loss of energy, and they will live more if males have a high meat generosity.

The abundance of food is the most significant ecological factor in the evolution of cooperation. As shown in Table 9 in Appendix, the summaries of stepwise regression analyses including *patch size*, *tree density*, *prey density*, *world shape*, and the existence of *drought* as independent variables reveal that high tree density is favourable to the formation of larger groups of hunters, and to food share by males. Big patches of trees are favourable to food share from male to females and drought is unfavourable to food share from females to females. High prey density is favourable to food share by females.

One desirable result would be the emergence of fission-fusion societies, similar to real anthropoid societies. The seasonality of fruit production obligates agents to migrate frequently from one patch to another and is responsible for the trend of continuous reshuffling of the population. Although in some of the sociograms of Figure 5 we can identify the existence of big groups of agents who have friendly relations, we cannot distinguish the formation of communities of small interconnected groups. Each sociogram represents the network of friends and was built from the memories of those agents who were alive when the simulation ended; the arrows point to agents remembered with positive values. The sociograms are not sufficient to know which process has caused the formation of big groups: were the agents able to develop strong enough cohesive propensities to cope with the disruptive effects of migration or were the big groups formed as a consequence of the spatial distribution of patches of trees?

The sociograms of neutral relationships would be far denser than the ones shown in Figure 5 since the number of neutral memories was much higher than the number of positive ones. For each simulation, I calculated the proportion of memories corresponding to agents remembered

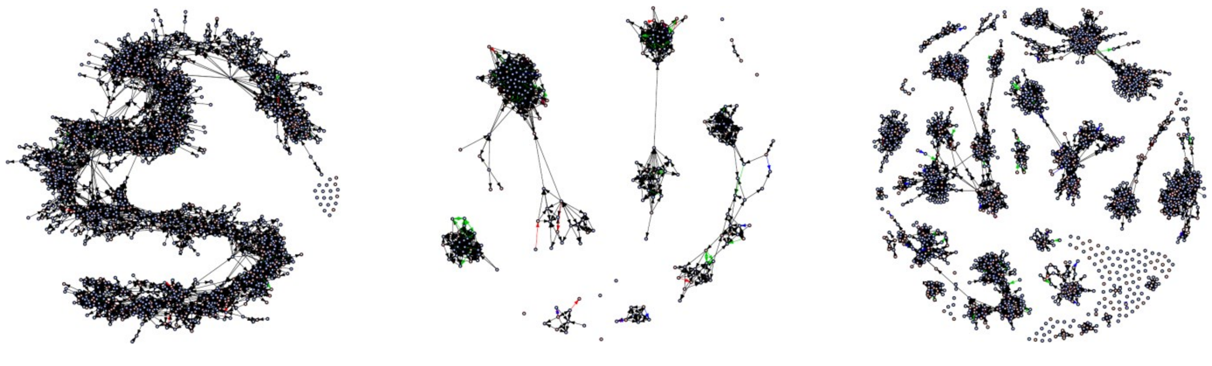

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Figure 5. Sociograms of relationships between friends at the end of selected simulations.

as enemies, intractable agents (negatively remembered, but with a recall value above enmityThreshold), neutrals and friends. Table 10 in Appendix shows the minimum, mean, and maximum values for all 39 simulations. There is a highly significant correlation between the proportion of friendly relationships and alliance formation for territory defence.

It would be necessary to collect more information from the simulations to know if the agents continuously change from one small group to another while remaining in the same community. However, the data already collected show that cells with friends are not highly evaluated. Agents developed mostly positive values in their selectivity of other agents, that is, the probability of a cell being chosen as destination of either migration or move is higher if it is occupied. Selectivity towards friends is not very high when compared with the selectivity towards other types of agents. The mean value attributed by an agent to a cell with a friend was 0,06 for females and 0,08 for males, far below the values of other variables used to evaluate cells, as can be seen in Table 11 in Appendix. Indeed, past cooperative or conflictive interactions do not seem to be correlated with the distance of agents who know each other. The main factor determining the distance between agents who interacted in the past is the time elapsed since the interaction.

The interpretation of the above results was based on results averaged from all simulations, but there was a great deal of variation between the simulations and each simulation may deserve its own „case study“.

CONCLUSION

No one knows what really goes on the mind of chimpanzees (and possibly other anthropoids) when they form alliances to hunt, fight and remain in power positions within their communities. The algorithm of alliance formation presented herein is a hypothesis of how this happens, testable through virtual experiments.

The high level of food share from male to females is mainly due to the control females have over their sexual life: they choose with whom they have sex. A future work could be the development of an algorithm allowing the evolution of male alliance formation to have sexual access to females, as those existing among real chimpanzees.

Although negative values for vengefulness are odd because they imply that agents have a positive remembrance of those who were evil to them, in some simulations this was the path found by the agents to avoid the costs of conflict. However, negative vengefulness and gratitude values turn the analysis of the results more complex than they should be. It would not be a strong restraint on the model if the evolution of negative values for these variables were not allowed, because agents would remain free to develop positive values to remember what real humans commonly agree are bad and negative values to what is usually considered good. They would also remain free to develop negative benevolence.

The model is highly complex, and much more work would be necessary to improve it and fully explore the heuristic potential of this approach. Given the complexity of the model, it was not possible before running simulations to know which variables and strategies would have a meaningful evolution (and, thus, should be kept) and what would vary randomly (and, thus, should be purged from the model). Instead of keeping the model simple, the approach proposed herein consists of starting with a complex model and subsequently simplifying it. This paper should more properly be considered the partial report on ongoing (or interrupted) individual research than the final report of a finished project.

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REMARKS

[1] The complete revision of literature done for this research is given in my doctorate thesis, in Portuguese, available at http://www.lepem.ufc.br/jaa/tese.pdf.

[2] The source code is available at http://www.lepem.ufc.br/jaa/anthropoids.html.

[3] This variable was not present in the model that I presented in my doctorate thesis, and it is the most important difference between the two versions of the model. Without *enmity threshold* any negative recall value was highly disruptive to social relations.

APPENDIX

Table 1. Average genetic features of the first population.

Variable	**Fem.**	**Males**
gratitude	0.55	0.43
vengefulness	0.42	0.19
time factor	0.37	0.34
f. refusing to share food	0.0	-0.38
f. refusing to join hunt group	-0.68	-0.58
f. refusing no to join alliance	-0.52	-0.35
m. refusing to share food	-0.72	-0.51
m. refusing to join hunt group	-0.43	-0.61
m. refusing to join alliance	-0.59	-0.61
no in sex proposal	-0.58	-0.76
hunt value	1.06	0.85
patrol value	0.37	0.7
value of not fair	-0.50	
generosity	-0.35	0.47
meat generosity	0.48	0.73

pity	0.39	0.73
envy	0.72	0.80
benev. t. agents of oppos. sex	1.13	0.61
benev. t. agents of same sex	-0.14	0.11
benev. t. mother	0.46	0.51
benev. t. sibling	0.51	0.65
benev. t. child	0.38	0.0
importance of migrant age	-0.58	-0.26
importance of migrant friendship	-0.26	0.38
cells with same sex agents	0.19	0.78
the energy of a cell	0.98	0.53
cells with mother	0.45	0.32
cells with sibling	0.55	0.43
cells with friend	0.12	0.24
cells with oppos. sex agents	0.71	0.09
cells with f. in oestrous	-	2.0
cells with child	0.07	-
importance of male energy	0.56	-
importance of male age	0.57	-
promiscuity	0.5	-
child value for male	11.7	13.6
propensity to accept invitation	0.49	0.31
propensity to accept move invitation	0.47	0.47
xenophobia towards males	0.52	0.53
xenophobia towards females	0.56	0.49
xenophobia towards f. with child	0.42	0.50
bravery	1.09	0.09
audacity	0.95	0.7
loyalty	-0.29	0.0
fear of hostile patch	0.49	0.62
fear of hostile patch when has child	0.42	-
propensity to follow Norm	0.4	0.4
propensity to follow Metanorm	0.01	0.02
fairness in meat distribution	1.1	
value of stranger	0.1	
enmity threshold	-0.9	
meat value	0.26	

Table 2. General results of all simulations.

Simulation	No. of hunters	NA 1	NA 2	Food Share				N. Gen.
				M. to M.	F. to F.	M. to F.	F. to M.	
01	1.34	1.22	0.65	0.484	0.000	0.882	0.000	38483
01a	1.15	1.31	1.20	0.000	0.041	0.003	0.000	13431
01b	1.28	2.14	1.80	0.000	0.000	0.000	0.000	41350
02	1.02	1.12	1.06	0.000	0.000	0.000	0.000	43273
02a	1.05	0.24	0.08	0.063	0.000	0.028	0.000	66043
02b	1.02	1.03	1.03	0.014	0.004	0.101	0.005	44309
03	1.00	1.00	0.07	0.007	0.000	0.011	0.000	25154
03a	1.72	3.00	1.45	0.847	0.000	0.924	0.000	17771
04	1.00	1.00	1.00	0.000	0.007	0.000	0.003	22905
04a	1.17	0.00	0.00	0.779	0.000	0.928	0.000	24558
05	1.00	1.00	1.00	0.719	0.000	0.939	0.007	1923
05b	1.00	0.98	0.96	0.513	0.007	0.018	0.032	2084
06	1.58	2.87	3.22	0.543	0.001	0.999	0.007	3260
06b	1.00	1.00	0.89	0.000	0.000	0.163	0.003	3668
07	1.67	2.64	1.55	0.260	0.023	0.552	0.063	994
07b	1.11	1.32	1.09	0.108	0.049	0.169	0.105	1092
08	2.10	0.50	0.00	0.067	0.001	1.000	0.003	1908
10	1.77	1.99	3.03	0.197	0.000	0.731	0.000	35112
11	1.36	1.62	1.62	0.048	0.130	0.000	0.078	23460
12	1.22	2.59	0.44	0.001	0.000	0.152	0.040	24485
13	1.44	2.64	0.08	0.009	0.080	0.352	0.308	2115
14	2.97	7.60	3.72	0.252	0.019	0.999	0.010	3368
15	1.73	4.69	1.73	0.364	0.048	0.029	0.069	954
16	1.86	1.75	0.58	0.214	0.013	0.999	0.154	1724
17	1.00	0.84	0.19	0.000	0.064	0.000	0.112	25320
19	1.10	1.16	1.06	0.674	0.034	0.996	0.000	10375
20	2.33	13.10	5.14	0.483	0.000	0.998	0.000	6821
21	2.51	4.80	5.40	0.037	0.011	0.996	0.036	932
22	1.48	1.76	1.82	0.085	0.013	0.998	0.100	1720
23	2.13	3.39	1.38	0.100	0.003	0.993	0.025	522
24	2.10	1.02	0.37	0.151	0.000	0.999	0.064	888
26	1.72	2.09	2.24	0.000	0.000	0.004	0.000	6181
27	1.00	0.94	0.88	0.971	0.000	0.926	0.000	10985
28	1.00	1.00	1.00	0.055	0.000	1.000	0.000	9286
29	1.64	1.00	0.35	0.112	0.005	1.000	0.041	883
30	2.33	3.49	1.94	0.048	0.017	0.999	0.112	1733
31	1.86	1.38	0.49	0.104	0.025	0.994	0.113	542
32	1.30	2.56	1.02	0.047	0.041	1.000	0.105	874
32a	1.71	3.87	2.26	0.077	0.019	0.997	0.018	743
mean	1.51	2.25	1.38	0.216	0.017	0.587	0.041	13365

Table 3. Average genetic propensity to share food of last populations.

Variable	Females	Males
generosity	-1.00	-0.34
meat generosity	-0.07	0.19
pity	0.99	0.85
envy	0.59	0.36
benev. t. opposite sex	1.39	1.05
benev. t. same sex	-0.49	-0.69
benev. t. mother	0.43	0.58
benev. t. sibling	0.56	0.21
benev. t. child	-0.03	-

Table 4. Average genetic propensity to move and migrate of last populations.

Variable	Females	Males
importance of migrant age	-1.49	-1.01
importance of migrant friendship	1.09	0.93
cells with agents of the same sex	0.28	0.49
the energy of a cell	1.92	1.16
cells with mother	0.70	0.67
cells with sibling	1.07	0.74
cells with friend	0.06	0.07
cells with agents of opposite sex	0.93	1.39
cells with females in oestrous	-	2.46
cells with child	0.62	-

Table 5. Average genetic propensities related with territory conflict of last populations.

Variable	Females	Males
xenophobia t. males	0.50	0.54
xenophobia t. females	0.48	0.48
xenophobia t. females with child	0.46	0.53
bravery	1.66	0.78
audacity	0.57	1.56
loyalty	-0.68	0.38
fear of hostile patch	0.48	0.44
fear of h. patch when has child	0.49	-
propensity to follow Norm	0.40	0.40
propensity to follow Metanorm	0.03	0.04

Table 6. Average genetic propensities related with memorization and recalling of last populations.

Variable	Females	Males
gratitude	0.48	0.50
vengefulness	0.50	0.04
time factor	0.42	0.49
female refusing to share food	-0.34	-0.57
female refusing to join hunt group	-0.91	-0.68
female refusing no to join alliance	-0.72	-0.82
male refusing to share food	-0.73	-0.94
male refusing to join hunt group	-0.41	-0.17
male refusing to join alliance	-0.70	-0.71
no in sex proposal	-0.75	-1.27
hunt value	1.09	0.97
patrol value	0.07	0.82
unfair meat distribution by female	-0.29	-0.49
unfair meat distribution by male	-0.75	-0.74

Table 7. Average genetic propensities related with reproduction of last populations.

Variable	Females	Males
importance of male energy	0.22	-
importance of male age	0.88	-
promiscuity	0.48	-
child value for male	10.05	13.10

Table 8. Regression Summary for *fLife* as dependent variable.

Coefficient	Est.	SE	*p*
(Intercept)	0.472	0.040	0.000
Male gratitude	-0.015	0.010	0.144
Male vengefulness	0.069	0.013	0.000
Male benev. t. opp. sex	-0.012	0.008	0.169
Male benev. to sibling	-0.013	0.008	0.130
Male veng. strategy 2	0.140	0.070	0.056
Male meat generosity	0.028	0.009	0.004
Male audacity	0.019	0.008	0.028
Male loyalty	-0.024	0.007	0.003
Female bravery	0.025	0.011	0.032
Female loyalty	-0.052	0.010	0.000

Multiple R^2: 0.7438, Adjusted R^2: 0.6523.

Table 9. Regression summaries for *Number of Hunters* and *Food Share* as dependent variables.

Coefficient	NHunters	FS-MF	FS-FM	FS-FF
(Intercept)	1.15^{**}	0.24^{*}	0.01	0.02^{**}
	(0.13)	(0.11)	0.02)	(0.01)
Patches	0.22	0.40^{**}		
	(0.15)	(0.13)		
Tree Density	9.61^{**}	6.85^{*}	1.13^{**}	
	(3.30)	(2.77)	(0.39)	
Prey Density			0.04^{*}	0.02^{*}
			(0.02)	(0.01)
Drought			-0.03	-0.02^{**}
			(0.02)	(0.01)
Adjusted R^2:	0.212	0.308	0.289	0.219

* $p < 0.05$; $^{**}p < 0.01$.

Table 10. Minimum, mean, and maximum proportion of memories representing different kinds of relationship.

	enemies	intractable	neutrals	friends
Min.	0.0000	0.0000	0.7195	0.0056
Mean	0.0078	0.0159	0.9238	0.0525
Max.	0.1295	0.0844	0.9892	0.2643

Table 11. Mean value of some variables used to evaluate cells.

Variable	Female	Male
cells with friend	0.063	0.075
cells with children	0.625	-
cells with mother	0.698	0.666
cells with opposite sex agents	0.927	1.395
cells with sibling	1.072	0.738
the energy of a cell	1.922	1.158
cells with females in oestrous	-	2.459

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KOOPERACIJA VIRTUALNIH ANTROPPOIDA U KOMPLEKSNOJ OKOLINI

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SAŽETAK

Članak prikazuje model agenata za simulaciju evolucije kooperacije u kompleksnoj okolini. Antropoidni agenti spolno se razmnožavaju i žive u svijetu gdje je hrana prostorno nejednoliko raspoređena, a sezonski generirana. Agenti mogu dijeliti hranu, formirati grupe za lov i za migraciju, a sposobni su sklapati saveze za podjelu teritorija. Agenti pamte svoja međudjelovanja s drugim agentima, a njihova djelovanja prvenstveno su upravljana emocijama, modelirana kao težnje specifičnom načinu reagiranja na akcije drugih agenata i uvjete okoline. Rezultati pokazuju kako je spolno razmnožavanje vrlo bitno – u predloženom modelu, kooperacijaje intenzivnija između agenata suprotnog spola.

KLJUČNE RIJEČI

evolucija kooperacije, komputacijski model, antropoidi