# Cooperation and Communication in Evolving Artificial Societies

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***Abstract*— This paper reports on experiments with an artificial society simulation package. This work is part of a larger project whose main goal is to investigate the emergence of cooperation and communication in response of (scalable) environmental challenges. The specific goals of the experiments reported here include 1) the study a number of extensions of the classical SugarScape model, 2) to compare two radically different approaches to communication among the individuals of the population. Our results demonstrate that a number of the presented extensions should be taken up in future experiments in artificial societies, and that the decentralised communication protocol has negative effects on the system behaviour.**

## I. INTRODUCTION

The main conceptual framework underlying our investigations is based on adding the possibility to communicate and to cooperate to the standard SugarScape model and to study if communicative and cooperative behaviour emerge under environmental pressure. The standard SUGARSCAPE model is a two dimensional grid, wrapped around the edges. Each position corresponds with an area which can contain multiple agents and an amount of sugar. Our extension is based on two premises regarding cooperation. First, we want a model where cooperation does not result in producing new resources (sugar). Instead, it helps individuals to utilise resources that they could not utilise alone. The second requirement is that the model allows for scaling the necessity for cooperation by a parameter. The role of communication is that it enables cooperation. The rules for cooperation are hard-wired in the sense that under prespecified conditions individuals always cooperate. Communication, however, is not imposed on the population. Whether or not individuals communicate depends on their "personal preferences" and these are subject to evolution (variation and selection). Thus, the question is whether communication evolves, and whether, and how, various communication protocols affect the population's survival.

From a broad perspective our work can be considered complementary to Axelrod's classical experiments [2], [3]: we focus on the emergence of communication making premises on cooperation, while Axelrod focuses on the emergence of cooperation making premises on communication (i.e., assuming there is none).

This paper is organised as follows. In the next Section, we explain the concept of an artificial society. Section III overviews the SUGARSCAPE extensions as investigated here. Section IV and V describe aspects of cooperation and communication researched in VUSCAPE. Section VI reports on the implementation of VUSCAPE. Section VII contains report on the conducted experiments. Section VIII concludes and contains pointers for future work.

## II. ARTIFICIAL SOCIETIES

We let artificial societies be *agent-based models of social processes* [1], [8], [9]. Our approach is based on that of Epstein and Axtel, as we have 1) agents, 2) an environment or space, and 3) rules. An agent then has internal states and behavioral rules, which each can be fixed or flexible. Interactions and changes of internal states depend on rules of behaviour for the agents and the space. Environments can be abstractly defined (e.g., a communication network) or more resemble our own natural environment (e.g., a lattice of resource-bearing sites). The environment is a medium separate from agents, on which the agents operate and with which they interact. Rules can be defined to describe the behaviour of agents and the environment on different interaction levels, i.e., agent-environment (e.g., agents looking for and consuming food), environment-environment (e.g., growing resources), and agent-agent (e.g., combat and trade).

The artificial world used in this paper is VUSCAPE, version 1.2.3 [6], inherently based on the well known SUGARSCAPE world, as introduced by Epstein and Axtel [8] as a generic testbed for social simulation. Like SUGARSCAPE, the VUSCAPE world is a two dimensional grid, wrapped around the edges. Each position corresponds with an area which can contain multiple agents and an amount of sugar. Sugar grows from sugar seeds; each seed has a maximum amount of sugar to which it can grow.

For the purpose of the study described in this paper, we extended the SUGARSCAPE world in a number of ways, thereby introducing the possibility to research the specific emergent phenomena of our interest. Additionally, these adaptations extend the SUGARSCAPE domain in an interesting generic way, opening up possibilities to investigate SUGARSCAPE worlds in wider perspectives.

## III. SUGARSCAPE EXTENSIONS

In the first series of experiments presented here, we extended SUGARSCAPE and investigated the consequences of these extensions. We made the following adaptations to the SUGARSCAPE world:

**Explorative Behaviour** – Agents in VUSCAPE exhibit explorative behaviour in that an agent randomly moves around in case it does not know of any sugar to move to or to eat. Traditionally, in SUGARSCAPE, agents do not exhibit such behaviour but stay at their location in such situations.

**Randomised sugar distribution** – The conventional sugar distribution in SUGARSCAPE is based on two sugar-hills that are located in the world at appropriate distances from each other. In this world sugar is concentrated and grows back at the given location making passive agents viable. To make the world more demanding, we initially distribute so called sugar seeds randomly over the grid and move a seed to another random location if its sugar has been eaten.

**Increased grid-point inhabitance** – We allow for multiple agents to be at a single grid-point in VUSCAPE, whereas this is not allowed in SUGARSCAPE.

**Randomised age initialisation** – In SUGARSCAPE models, the age parameter of agents is initialised uniformly (at 0), and this brings with it some surprising phenomena that are not necessarily realistic. A typical example of such an effect is that the first generation is born at the same time, starts reproducing together, grows old simultaneously and dies out at approximately the same time. The effects of such a setup echoes through the whole simulation until finished. We initialise the ages of agents randomly (between fixed minimum and maximum values), thereby preventing the mentioned methodological errors resulting from initialisation at 0.

**Sugar Redistribution** – In the SUGARSCAPE world sugar grows back at a given location making passive strategies rewarding: agents can stay put because they are guaranteed a minimal amount of new-grown sugar at the next turn. This way, passive (i.e., not too mobile) agents are viable. As we are interested in explorative behaviour, VUSCAPE moves a seed to another random location if the sugar has been eaten.

**Recovery Period** – After mating, an agent is not able to mate for a while: the recovery period. With this parameter, we can control population dynamics, which has always been an important issue in SUGARSCAPE investigations.

**Cooperation** – Cooperative behaviour of agents is stimulated by means of setting a *cooperation threshold*. This threshold is in the reported work set as the maximum amount of sugar that an agent can eat on its own.

**Communication** – Agents receive information (listen) from other agents about amounts of sugar at their locations and announce (talk) the amount of sugar at their own locations.

The issues of cooperation and communication are described in detail in the next Sections.

## IV. COOPERATION

Cooperation has been widely studied since the early developments of game theory in the 1940s and 50s. The phenomenon of cooperation has been put onto strong footing by social scientist Axelrod [2], [3]. Cooperation is related to our thinking and acting in our social, political and economic relation with others. The question that Axelrod [2] poses underlying this relationship is how cooperation can develop, assuming each individual has an incentive to be selfish. The approach that Axelrod follows to build up an understanding of cooperation is to make assumptions on individual motives (e.g., selfishness) and then analyse consequences of individual behaviours upon the behaviour of the entire system. The novelty of Axelrod's approach lies in the fact that the concerned individuals deciding upon a strategy to adopt, do not exhibit rationality or maximising behaviour, nor is there a need for a central authority, notions of trust, altruism, threats, commitments or exchange of messages.

Axelrod recognised a possible problem with the competition-based approach to finding good player strategies, namely the expectation of each participant on what strategies other participants might submit. To get around this problem, a more objective means was necessary to find good strategies. Such a means was found in the area of genetic algorithms. In [3], Axelrod introduces concepts and techniques of complexity theory (the study of many actors and their interactions) for investigating aspects of competition and collaboration that go beyond the prisoner's dilemma paradigm. The complexity of real-world situations requires approaches being able to cope with this. Axelrod motivates the choice of social simulation as the vehicle for such approaches, thereby distancing himself from game-theoretical models that are based upon the assumption of rational choice. For a detailed game-theoretical review of Axelrod's work, the reader is directed to [4].

## V. COMMUNICATION

In our artificial society, agents are endowed with talk and listen capabilities, which are genetically evolvable. Both talking and listening are evolving features as they undergo variation and selection. The talk feature determines whether the agent performs a communicative action itself, namely informing other agents of: 1) the amount of sugar that is on its location, and 2) the coordinates of its location. The listen feature is used in the observation and decision making processes of the agent. By listening, the agent receives information from other agents about amounts of sugar at the locations of those agents.

After initialisation, the average talk preference and listen preference over all agents is 0.5. With a preference $p$, an agent communicates the amount of sugar at its location with probability $p$ in case it needs help to harvest the sugar at its location, i.e., it is above the cooperation threshold. With a listen preference $q$ the agent takes up received information from other agents in its decision process on where to move to; with probability $1-q$ the agent does not consider received information from other agents.

### *A. Multicast Model*

Communication between agents in the first series of experiments described here, is implemented by means of mul-

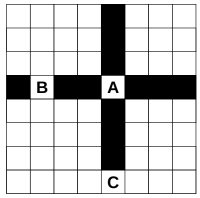



Fig. 1. Multicast communication in VUSCAPE over the axes. In this example, agent A multicasts information, which can be received by agents B and C.

ticasting[1]. Multicasted messages from agents travel over the axes; they are not heard in the whole world, since agents can only move horizontally and vertically. Theoretically, the agents only receive messages from locations to which they can jump immediately.

Figure 1 shows agent A multicasting a message, which is received by agents B and C. In case there are other agents in the world that are not on the same axes as agent A, these other agents will not receive messages from agent A.

The multicast communication is implemented by a centralised messageboard. Agents can post their messages to this board (talking) and they can read out messages from this board (listening). In VUSCAPE, an option can be set such that a message is removed from the messageboard when an agent reads it, when an agent fulfills the request to cooperate or when some given time interval has passed.

### B. Newscast Model

The newscast computing model is a fully distributed information propagation protocol for large-scale peer-to-peer computing [11], [10]. Theoretical and empirical investigations have shown that the newscast computing engine is fault tolerant and extremely scalable. These properties manifest themselves in the unharmful impact of adding and deleting agents to and from the population. Adding agents to the population only requires knowing the name of an arbitrary agent and for the removal no action is necessary. In the model, different types of applications can be supported like multicasting, resource sharing, monitoring and controlling large systems, computational intelligence, distributed datamining, and the modeling of social phenomena. The application of newscast in VUSCAPE is an example of the latter.

The main idea of newscast is that each agent maintains a cache of $c > 0$ information items received from other agents, together with the the names (IDs and addresses) of the senders of these items. These senders are the "friends" of the agent. An agent can only communicate to a friend, a communication act amounts to sending over his entire cache, including the information times and their sender ID's. As the cache size is limited, at fixed time intervals, the agent updates the information in its cache by making a selection of $c$ of them, thereby also updating its list of "friends". As such, in the

[1] In previously reported work, we called this type of communication broadcasting. We hereby acknowledge the anonymous reviewer who pointed out that we truly use multicasting (messages reaching a subset of the population) instead of broadcasting (messages reaching everyone in the population).

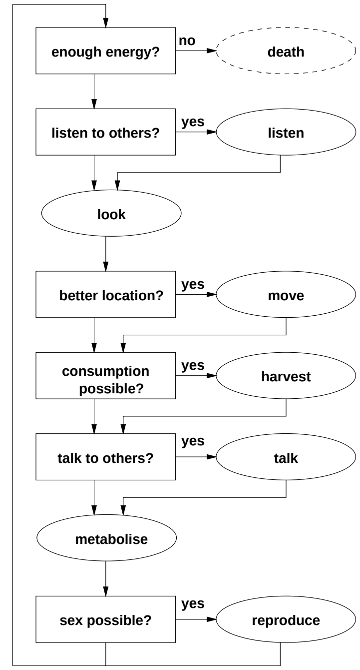



Fig. 2. The agent control loop in VUSCAPE.

VUSCAPE implementation of newscast, friendship only comes from this mechanism and is thus not influenced by aspects such as kinship of having cooperated in the past. The cache entries define a communication graph, which is constantly changing with time. This graph has a very low diameter and is very close to a random graph with out-degree $c$.

## VI. IMPLEMENTATION

The VUSCAPE world evolves with discrete time steps, called cycles. In one such an execution cycle, the world (including agents) is updated. More precisely, the stages as shown in figure 2 take place in chronological order within a single execution cycle.

1) An agent *gathers information* about the presence of sugar by listening (to other agents along the axes) and looking (at the directly surrounding locations along the axes and the current location). Upon completion of this stage, the agent has an array of locations and amounts of sugar on these locations.
2) Based on this array, the agent picks out the location with most sugar and *moves* to this location. In case there are multiple locations with the most amount of sugar, the agent chooses randomly.
3) Having arrived at the sugar, this sugar is *harvested* in case the amount is under the cooperation threshold. If the amount is above the cooperation threshold, the agent cooperates immediately if there are more agents at the location. Otherwise, it *tells* (with some probability) the other agents along the same axes that it needs help.
4) If possible, the agent *reproduces* and generates offspring.

In VUSCAPE it is possible to monitor a variety of variables that describe the system behaviour. In Table I we briefly enumerate the predefined monitors here. Generally, monitors refer either to variables within the *agent* or within the *world*.

An agent consists of and possesses some particular *features* that determine the make-up of a particular agent. From the traditional SUGARSCAPE model [8], we took the basic agent features which make up an agent. These features include

| Type | Name | Denotes | Domain |
|---|---|---|---|
| Agent | age | age of the agent | [0:100] |
| Agent | talkPref (p) | whether agent talks | [0:1] |
| Agent | listenPref (q) | whether agent listens | [0:1] |
| Agent | sugarAmount | sugar contained by an agent | [0:$\infty$] |
| World | inNeedOfHelp | percentage of agents on location where | [0:1] |
| | | sugar $>$ coopThresh | |
| World | cooperating | percentage of agents that cooperates | [0:1] |
| World | exploreCell | percentage of agents that moved to a new cell | [0:1] |
| World | hasEaten | amount of food that agent has eaten | [0:4] |
| World | numberOfAgents | number of agents | [0:$\infty$] |
| World | numberOfBirths | number of just born agents | [0:$\infty$] |
| World | numberOfDeaths | number of just died agents | [0:$\infty$] |

TABLE I

AN OVERVIEW OF VUSCAPE MONITORS.

| experiment | | Agent | |
|---|---|---|---|
| numberOfRuns | 10 | maxSugarHarvest | 100.0 |
| **Scape** | | singleStep | false |
| height | 50 | initAgeZero | **exp** |
| width | 50 | minVision | 1 |
| runLength | 1000 | maxVision | 6 |
| reseedSugar | **exp** | minSugarMetabolism | 1 |
| initialPopulation | 400 | maxSugarMetabolism | 4 |
| sugarSeed.uniqueCell | false | minDeathAge | 60 |
| sugarDistributionUnif | 1 | maxDeathAge | 100 |
| sugarGrowBackRate | 1.0 | sexRecoveryPeriod | **exp** |
| sugarRichness | 1.0 | minReproductionSugar | 50 |
| sugarDistributionType | **exp** | maxReproductionSugar | 100 |
| maxSugarSize | 4 | minInitialSugar | 50 |
| **Cell** | | maxInitialSugar | 100 |
| allowMultipleAgents | **exp** | preferNearestCell | **exp** |

TABLE II

AN OVERVIEW OF THE VUSCAPE PARAMETERS USED IN THE EXTENSIONS EXPERIMENTS. PARAMETERS INDICATED WITH **EXP** ARE VARIED THROUGHOUT THE EXPERIMENTS.

metabolism, gender, child bearing, death, vision, allow sex and replacement. We extended these features by including a cooperation threshold, reproduction threshold and initial amount of sugar.

Each agent has at its disposal a maximum amount of sugar that it can harvest on its own. As mentioned previously, this amount is called the *cooperation threshold*. If an agent is at a location at which the amount of sugar is over this threshold, it needs other agents to harvest the sugar. If there are more agents at such a location, these agents harvest the sugar together and the sugar is evenly distributed over these agents. In the empirical investigations described below, the cooperation threshold is the same for all agents.

After reproduction, agents are not able to have sex for a period of time, called the *sex recovery period*. This period is measured in number of elapsed execution cycles.

As agents realistically need energy (here: sugar) to reproduce, VUSCAPE offers the possibility to set the amount of sugar needed for mating by setting the *reproduction threshold*. If the amount of sugar contained in an agent is over this threshold, then (in prevailing circumstances) this agent is able to reproduce. The offspring of two parents receives half of the amount of sugar from each parent at birth. Whereas in SUGARSCAPE, the reproduction threshold (called *endowment* in SUGARSCAPE) is implemented as being the same value as the initial amount of sugar an agent received, the VUSCAPE implementation enables one to set this parameter independently of the initial amount of sugar.

## VII. EXPERIMENTS

This Section presents two experimental sessions. The first one investigates the extensions of VUSCAPE compared to SUGARSCAPE as we presented above. The second session investigates the evolution of communication under strict cooperation requirements.

For the "extensions" session, we conducted seven series of experiments[2], each one varying another extension. This session functions as to compare the effectiveness of each extension on the artificial society. For this reason, we have experimented with all other parameters ceteris paribus – leaving all the other parameters to the default value that they have in the traditional SUGARSCAPE. Because we investigate the effects of cooperation and communication in the second session, the artificial society research in this session does not include cooperative and/or communicative agents.

For the "communication" session, we conducted two series of experiments, each consisting of 10 independent runs: one experiment with centralised (multicast) communication and another with decentralised (newscast) communication[3]. In both experiments, the cooperation threshold is 1. The lifetime of the world is 2,000 iterations. The height and width of the world are both 50. The initial population contains 1,000 agents. All sugar is redistributed every iteration. Talk and listen features are inherited from the parent with the most sugar. The mutation sigma is 0.1. For further details of the independent variables in our experiment, we redirect the reader to [7]. Also, for reasons of space, we have not included all obtained graphs, and redirect the interested reader to [5] and [7] for the omitted graphs.

Agents need to eat sugar in order to survive. Also, they are incapable to consume large quantities of sugar on their own. As such, agents need to work together to live their maximum age. Immediate consequences of this "imposition" include the impossibility of agents staying at regrowing sugar seeds and individually consuming the regrown sugar, as this amount will eventually exceed the maximum capacity they can eat on their own. Also, the world is too harsh for agents to

[2] In addition to the six presented extensions, we investigated the effects of fixing the values for vision and metabolism.

[3] We also conducted an experiment without communication. The outcome of this experiment was that agents did not adapt and survive. Neither was balance reached in population size, for the population peaked in the beginning and then went extinct.

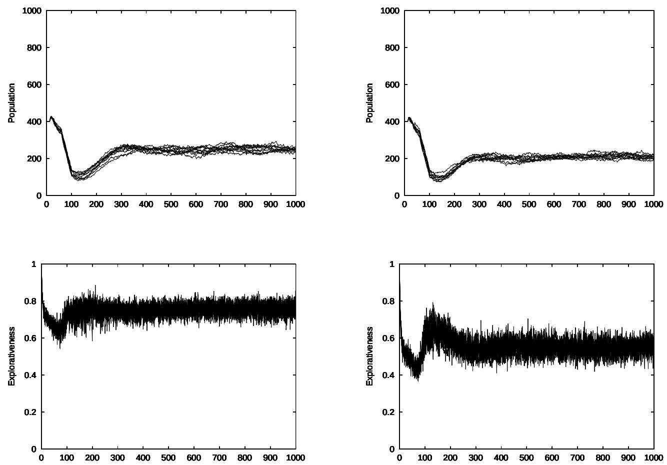



Fig. 3. Session *extensions* – explorative behaviour. Development of the population size (above) and explorativeness (below).

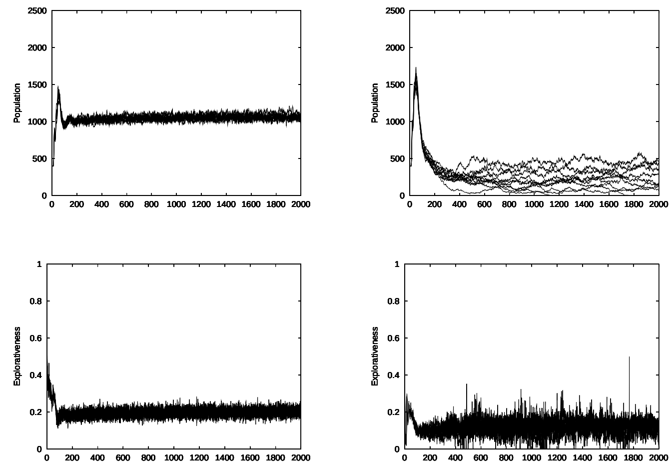



Fig. 4. Session *extensions* – Vision and Metabolism. Development of the population size (above) and explorativeness (below).

survive solely on the basis of amounts of sugar they can eat individually. Living without cooperation in this world means that a maximum age can be achieved, but life is necessarily without reproduction since an agent cannot accumulate enough sugar to reproduce. For two (or more) agents to successfully cooperate, they have to be on the same location and the amount of sugar at that location must exceed the maximum amount an agent can eat individually. Cooperation means that the agents together consume the sugar at the location. After cooperation, the amount of sugar is divided equally among the agents.

A final remark on our concept of cooperation must be made. The benefit of cooperation for an agent is twofold. On the one hand, agents profit from consuming resources that they otherwise could not have consumed. On the other hand, deciding to travel to the location with most sugar is somewhat self-deceptive towards agents. This is because large resources must be shared, while the agent decides to travel there on the basis of the whole resource instead of a part. It cannot be well predicted what behaviour emerges and whether the beneficial or disadvantageous force of cooperation is stronger. Despite these counteracting forces, our empirical results demonstrate that still cooperation emerges.

Our scenario is as follows. An agent encounters a sugar pile that exceeds his msh value, so he needs help from another agent. He has an ability to communicate (talk) this need to other agents, by sending a message across the axes of the scape. This message is a signal containing a grid location and a sugar amount. Talking will be initiated with a certain preference (probability): If an agent is at grid location $(x, y)$ and failed to harvest sugar because $sugar > msh$ it will emit a message in the format $\langle (x, y), sugar \rangle$ with probability $pref_{talk}$. Agents on that axis can receive (listen) the $\langle (x, y), sugar \rangle$ tuple and use this information in their vision/movement decision procedure. This listening is also done with a certain preference: With a probability $pref_{listen}$, an agent collects messages from the axes of the scape. This gained information will be used in the Move rule.

If the sugar amount on this distant cell is greater than in the immediate vicinity of the agent, it will move directly (i.e. "jump") to that cell, where he can share the local sugar pile with the original sender of the help-call through cooperation.

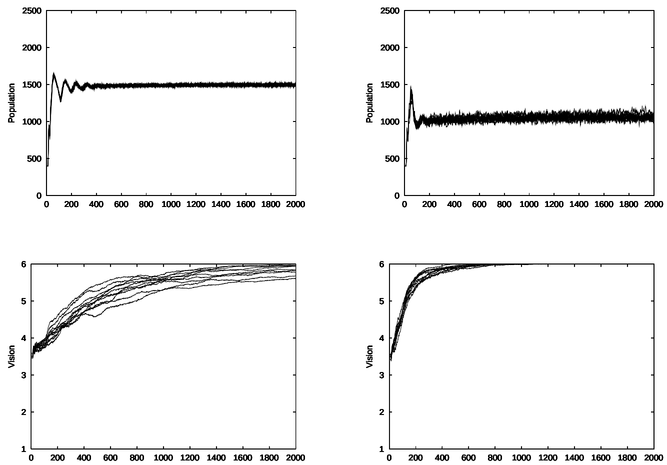
### *A. From SugarScape to VUScape*

A selection[4] of the obtained results for the extensions experiment session is shown in Figures 3 to 9. In accordance with the methodology, we measured the change in population size, explorativeness, vision, metabolism, age and birth rate for the presented extensions, i.e., explorative behaviour, increased gridpoint inhabitance, randomised sugar distribution, randomised age initialisation and recovery period.

**Explorative behaviour –** It can be observed that the explorativeness is higher in the experiments where agents randomly exploration than in the experimental series where they do not. Another observation is that with randomly exploring agents, the population size is slightly larger. This may meaning that individuals that have a more explorative nature can establish a more successful population: one may contemplate that their increased mobility enables the agents to have more contact, resulting in more offspring. A third thing to report is the connection between the dramatic population fall in the first 100 iterations and the simultaneous drop in the average metabolism rate. This would suggest that a high metabolism value (i.e. higher than 1) is such a disadvantage that they immediately die.

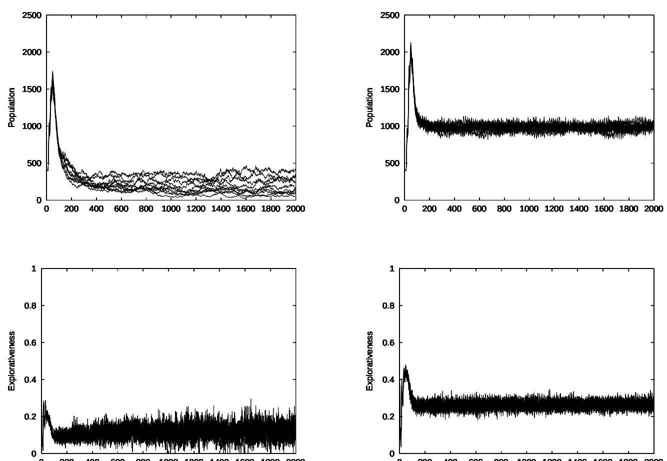
**Constant vision and metabolism –** We investigated the effects of fixing the values of vision and metabolism (both

[4]For a full overview, please see [5]. The reader can find the graphs in readable format on http://www.cs.vu.nl/ci/eci/cec04/.



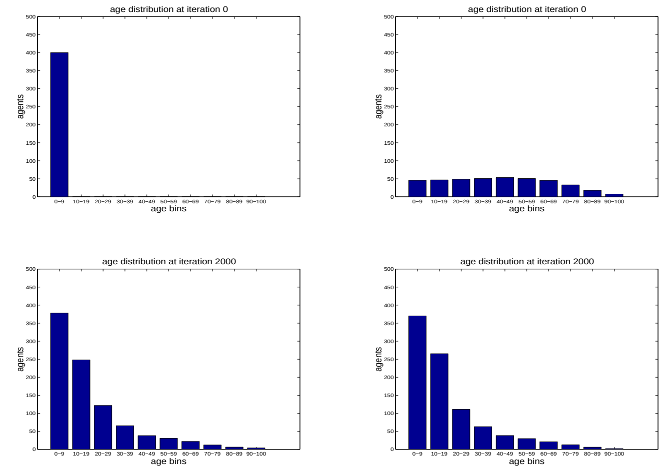

2-hills distribution    uniform distribution

Fig. 5. Session *extensions* – Randomised sugar distribution. Development of the population size (above) and vision (below).



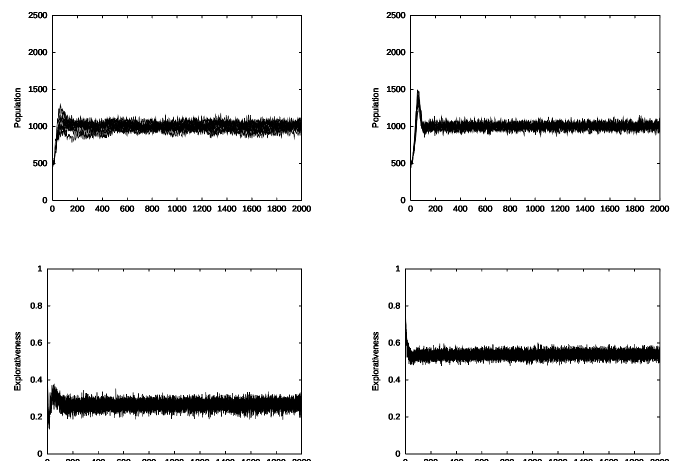

single-agent cells    multi-agent cells

Fig. 6. Session *extensions* – Increased grid-point inhabitance. Development of the population size (above) and explorativeness (below).




zero age initialisation    random age initialisation

Fig. 7. Session *extensions* – Randomised age initialisation. At iteration 0 (above) and iteration 2000 (below).



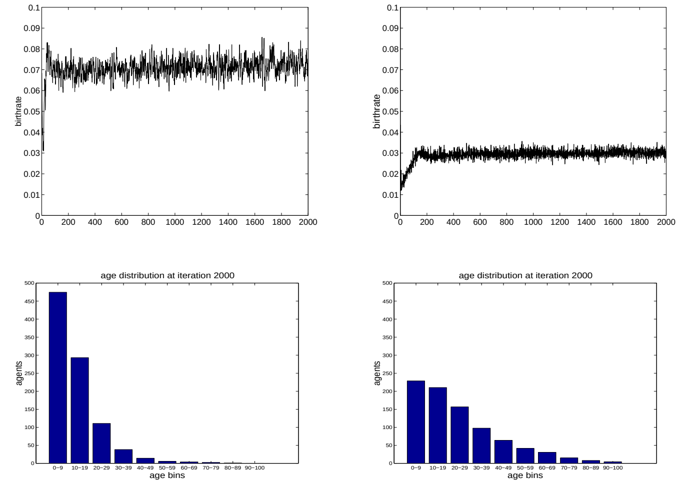

reseeding    no reseeding

Fig. 8. Session *extensions* – Sugar redistribution. Development of population (above) and explorativeness (below).

to 1) instead of making them evolvable. Figure 4 shows that a reduced vision range (in fixed-values experiment) does not pose great problems with creating a viable society. However, it does have an impact on the population size and the stability of a population. The vision limitation has a direct negative influence on the mobility of an agent.

**Randomised sugar distribution** – We draw two conclusions. First, comparing the vision graphs in Figure 5, it is clear that a high vision range gives a greater advantage in case of a random sugar distribution. The reason for this is that an agent always has to look for new sugar resources. Second, though the population sizes differ, in both cases the society reaches some kind of equilibrium, resulting in a more or less stable population plot. This may mean that a SUGARSCAPE society is not dependent upon its sugar topology, which is important when we want to draw general conclusions.

**Increased grid-point inhabitance** – Allowing multiple agents on a cell results in larger populations. This means that the population development in the previous experiments was not only determined by the sugar availability of the environment, but also by spatial limitations. When we drop those limitations the agents have more candidate locations to "flow" to, even when the region is crowded. This offers possibilities for much more smooth population dynamics compared to the blocking situations that can occur with the single-agent cells. This smooth mobility may very well be the main cause for the




no recovery period

recovery period = 5

Fig. 9. Session *extensions* – Recovery period. Development of birth rate (above) and age distribution at iteration 2000 (below).

rise in explorativeness. No longer hampered by neighboring agents who effectively block an individual's move-possibilities the agents can now move through in their search for new sugar. The blocking situations were an artifact of the two-dimensional torus grid: They were not induced by agent or sugar behaviour, but were an inevitable result of the "single-agent cell" methodological choice. The multi-agent cells are meant to alleviate the scape of this effect and thus measure agent/sugar interaction more purely.

**Randomised age initialisation –** We see in figure 7 that the zero age initialisation leads to stormy population drifts at the start. The random age initialisation method seems to inhibit this rough behaviour and approximate better the following steady phase. Though the age initialisation highly influences the society at the start, after circa 150 time steps both methods produce an average age of 19. After that point there seems to be little difference between the two experimental sessions. This is confirmed by the age distribution bar plots at iteration 2000. As the distributions are totally different at the start, iteration 100 the distribution shapes are very much alike – The zero age variant has significantly more youngsters ($< 20$), but the randomised population contains relatively more 60+'ers. At the end of the run (and even well before that) the effects of the initialisation method have diminished totally.

**Sugar Redistribution –** The goal of the sugar redistribution was to make the population more mobile by "hiding" the sugar again once an agent has found and harvested it. We can observe that this is indeed the case: the average explorativeness of the agents has increased considerably. This reseeding was meant to make life harder for the agents. It is remarkable in that respect that the population size is not affected by this major methodological change. Apparently the agents are strong enough to adapt to the new environment.

**Recovery Period –** We can first of all observe that the population size in influenced by our birth control mechanism. A sex recovery period of 5 iterations produces a population drop of 11%. We have found in earlier research that this parameter can be used to tune the population size and also that long recovery periods (like e.g. 10) lead to quick extinction. This birth control parameter proves to be a very powerful tool and clearly deserves further investigation. Secondly, our results show that in the no-recovery-period experimental series we measured an average birth rate of $0.07$, while the recovery period of 5 was responsible for a birth rate of only $0.03$. And because the birth rate in a stable society is equal to the death rate this is good news for all agents. Finally, the age distributions show that the populations are more evenly structured regarding to age. It clearly indicates that the average age is higher when there is a sex recovery period.

### *B. Cooperation and Communication*

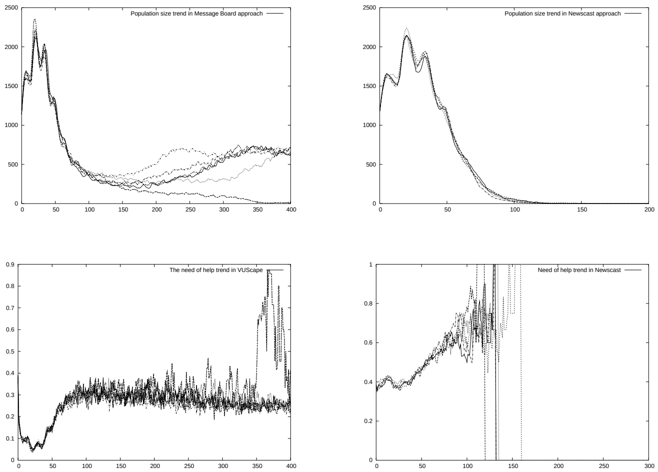
For the experimental session on cooperation and communication, a selection of the obtained results is shown in Figures 10 and 11.

The most important trend that we observe in our empirical findings is that populations using newscast communication die out, while the multicast populations do not: newscast communication is less effective in the VUSCAPE world than multicast, i.e., it does not provide sufficient information that is helpful for the agents. Instead, the newscast communication allows, unintentionally, the propagation of timed out messages. In the case of these 'lies', agents listen to messages, move to the heard location, and find the food already eaten. The listening success rate (food is still there on arrival) is about 57% of the cases; for multicast communication, around 91% of the cases the agents listen to a message, move to the listened location, and successfully eat food. We hypothesise that the lies emerge with newscast communication because of the very structure and characteristics of the protocol: it cannot prevent spreading of outdated information. Because of this outdating, agents may "jump" to an announced location where the sugar was consumed by a earlier listener.

Another surprising outcome is that although the cases of nothing heard is much bigger in the newscast approach and the nothing saw cases is quite the same, the total number of uninformed movements is smaller in the newscast approach. A possible explanation comes from the exploratory behaviour in the newscast that is also lower. The low exploratory behaviour and a low percentage of uninformed movements, even if there is no rich information about food that should make a movement informed, makes it reasonable to believe that agents are not moving much in the newscast. The number of movements is much smaller with newscast than with multicast, which justifies the outcome.

## VIII. CONCLUSION

This paper has presented an investigation on the effects of communication and cooperation in an artificial society. We have reported on two experimental sessions that we conducted




centralised commun | decentralised commun

Fig. 10. Session *communication* – Development of population (above) and in need of help (below).

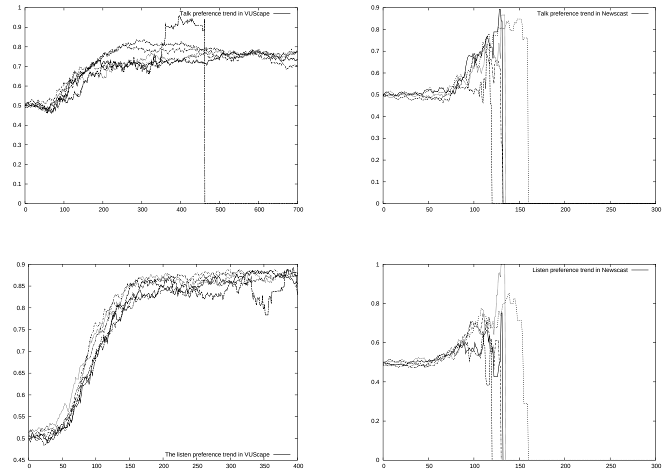



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Fig. 11. Session *communication* – Development of talk (above) and listen preference (below).

in an artificial society. In the first session, we have experimentally investigated the differences between VUSCAPE and SUGARSCAPE. The most important changes are the multi-agent cells (allowing more than 1 agent on a grid location), the random sugar distribution (as opposed to the classical 2 hill landscape) and random age initialisation (agents are all initialised with age 0 in SUGARSCAPE). The VUSCAPE agents have more mobile behaviour because they are able to randomly explore the environment. In the second session, we have investigated the effects of adding cooperation and communication to our artificial society. This session aimed at indicating the effects of centralised and decentralised communication methods in an artificial society. For this purpose, we conducted a series of experiments researching the use of centralised (multicast) and decentralised (newscast) communication, where the communication capabilities of the agents are genetic features that undergo variation and selection.

Our empirical results demonstrate that communication (i.e., individual preferences to talk and to listen) does emerge by evolution, cf. Fig. 11. Furthermore, in the given setup populations using newscast communication die out, while populations using multicast communication do not, cf. Fig. 10. Our experimental findings show that the newscast communication allows, unintentionally, the propagation of timed out messages. This leads up to the newscast protocol being less effective than the multicast protocol in the researched society. This society has been a relatively small world that is fully connected, which is not in the niche of the newscast protocol. In a follow-up study we intend to research communication protocols in different environmental settings and on a different population scale. For other future work, we propose research on the advantage for agents of being in each other's list of friends, where the update mechanism of this list favours to keep those who have sent useful information. Additionally, we contemplate to endow agents with life-time and social learning capabilities, i.e., agents can learn during their lifetimes and from each other.

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