DOI: https://doi.org/10.26565/2304-6201-2023-59-03

УДК (UDC) 519.6, 51-76

Zolotukhin Volodymyr
student
V.N. Karazin Kharkiv National University, 4 Svobody Square, Kharkiv, Ukraine, 61022
e-mail: zolotukhinvolodymyr@gmail.com
https://orcid.org/0009-0004-0303-0624

Yanovsky Volodymyr
Doctor of Physical and Mathematical Sciences, professor
V. N. Karazin Kharkiv National University, 4 Svobody Square, Kharkiv, Ukraine, 61022; Institute of Single Crystals, National Academy of Sciences of Ukraine, 60 Nauky Ave., Kharkiv, Ukraine, 61001.
e-mail: yanovsky@isc.kharkov.ua
https://orcid.org/0000-0003-0461-749X

Impact of violation of democratic strategies with memory on population evolution

Relevance. The lack of trust in modern society often hinders the development of humanity and sometimes calls into question the future of the human population as a whole. Throughout the history of societal development, there has been an observed phenomenon where a particular idea captures the minds of people, leading them to adopt similar (or very similar) behavioral strategies. To improve understanding of internal processes in a society where the uniform distribution of strategies among the population is disrupted, detailed research is necessary, which is impossible without appropriate software. **Objective.** The aim of the study is to investigate the influence of the number of agents of a particular strategy on the outcome of population evolution as a whole. The study explores the nature of changes in evolution under the conditions of gradual, monotonous increase in agents of a specific strategy from 1 agent to 10% of the democratic population. The research also aims to identify strategies that are evolutionarily viable only under the condition of increasing their carriers in the population. **Research Methods.** The evolution of the population with a full set of behavioral strategies, limited only by a memory depth of 2, was considered with an increased number of agents of a specific strategy. Each agent interacts with every other, including itself, according to the iterative model of the prisoner's dilemma. Rewards are determined by payoff matrices. Each subsequent generation of the population sequentially loses agents of the most disadvantageous behavioral strategy from the previous generation. Agents that bear the chosen strategy interact with each other and with another population according to standard laws. Several strategies were considered, the number of agents of which was increased. Among them were strategies with complexity lower than the average complexity of the population and higher than the average complexity of the population. A variant was also considered where the number of agents of the strategy that won in a democratic society increased. **Results.** The study demonstrates how the presence of a highlighted strategy with an increased number of carriers affects the dynamics of the population. An increase in the final average earnings of the population was observed. It was found that increasing the number of agents does not lead to the victory of a strategy that did not win in the democratic population. **Conclusions.** The results of the study identify the main consequences of the influence of the number of agents of a particular strategy on population evolution.

***Keywords**: aggressiveness, evolution, population, strategy, complexity, society*

How to quote: Zolotukhin V., and Yanovsky V., “Impact of violation of democratic strategies with memory on population evolution”, *Bulletin of V.N. Karazin Kharkiv National University, series Mathematical modelling. Information technology. Automated control systems*, vol. 59, pp.24-34, 2023. https://doi.org/10.26565/2304-6201-2023-59-03

Як цитувати: Zolotukhin V., and Yanovsky V. Impact of violation of democratic strategies with memory on population evolution. *Вісник Харківського національного університету імені В.Н.Каразіна серія. Математичне моделювання. Інформаційні технології. Автоматизовані системи управління*. 2023. вип. 59. С.24-34. https://doi.org/10.26565/2304-6201-2023-59-03

1 Introduction.

The interaction of large collectives of agents has sparked sustained interest for several decades [1-2]. Interest in such a phenomena arises from several different fields. It initially emerged in biology where the central question requiring scientific explanation was the diversity of observed animals. Charles Darwin, leveraging observational data, proposed an explanation that resulted in the creation of the remarkable theory of evolution [3]. This provided a significant impetus for applying similar reasoning to an extraordinarily wide range of questions in other domains. Starting from the evolution of languages [4,5] to the evolution of computer programs and artificial intelligence. In cybernetics, this interest transformed into the management of complex multi-element systems [6], the potential creation of artificial life, and artificial intelligence [7]. Recently, research related to swarm intelligence has gained relevance [8]. Sociology, also being one of these sciences, requires an understanding of interactions among individuals in society and the emergence of macro-behaviors in societies [9,10]. Another intriguing direction is associated with the emergence of altruistic behavior in multi-agent systems [11]. In building population models and models of interaction among individual members of a population, elements of game theory are commonly used [12]. The reward rule is chosen in such a way that mutual cooperation always requires more resources than responding aggressively to cooperation [13]. In other words, local cooperation is always disadvantageous. At each step of evolution, the population discards the agent with the fewest points. By evolution of the population, we mean an algorithm based on three principles: inheritance, variability, and selection.

In this work, we explore the impact of deviations from the equality of strategies on the evolution of the population by increasing the quantities of a particular strategy. The main question of interest is how such deviations from "democracy" affect the course of evolution and in what manner. It should be noted that, unlike previous works [16-18], agents of strategies will not unite into a cluster, meaning that agents interact directly and not strategies. In each case, the initial population includes agents of all strategies constrained by a memory depth of two. The increase in the quantity of specific strategies in the population starts from 1 up to a maximum of 10% of the total number of all strategies in a "democratic" population. Subsequently, for each population change, its evolution was modeled to obtain collective characteristics of the population that emerged as a result of evolution. This allowed identifying changes in such characteristics with the quantity of added agents of a specific strategy. Through the conduct of multiple series of experiments, it has been shown that an increase in the number of agents of a particular strategy leads to some, sometimes quite significant, changes in the population. The effect of variability in the average complexity of the final population has been observed with a monotonous increase in the quantity of added strategies.

2 Main requirements.

Strategy is an unchanging law, which defines what move a strategy bearer (an agent) must do in certain conditions. Move of the strategy can be zero (0) or one (1), corresponding to aggression or cooperation. Memory of the strategy is an ability of a certain strategy to use information about previous moves of the opponent strategy, which were made against it during the game, to perform a certain move: zero or one. Thus, strategies which use information only about the current move and don’t use information about previous [moves] are called “Strategies without memory”. Strategies that use information about previous moves are called “Strategies with memory”. Memory depth is a value that equals the number of previous moves of the opponent strategy that impact the course of the strategy. In other words, strategies without memory have memory depth that equals 0, and strategies with memory which use information only about the last move, have memory depth that equals 1, and further the same way by analogy.

Strategy without memory has two answers for the opponent’s move: zero or one. The opponent, in turn, as it was mentioned before, also has two possible ways to move: zero or one – aggresion or cooperation. Such a strategy may be described with a binary sequence, where the number of a bit is an opponent’s move, and its value is an answer for that move. This way of displaying differs from the way that was provided in articles written by Kuklin, Pryimak, Yanovsky [16-18]. In those articles, the name of strategy, its representation in the form of a binary sequence, was written from left to right, like words in most European languages. In this paper and in further papers, the way of displaying is reversed, in other words, it is written as a binary number where the least significant bit is to the right. This is done for the convenience of representing the strategy in the program and for the correct implementation of bitwise operations.

So, there are four strategies with a memory depth that equals 0: 00, 01, 10, 11. All of them respond to the opponent's move according to the rules that were described above. But at the first move, there is a situation in which the strategy has to make a move under the condition of uncertainty, in other words, without having information about the opponent's previous moves. This situation very often arises during the interaction of individuals in the society, so it must be simulated realistically. In the above-mentioned articles, the concept of the first step is introduced, a move, which is made in the case when there is a lack of information to make a decision by the main algorithm. Such a move is written before the main name of the strategy in square quotes “[]”. For the strategies without memory, the first move is described with one bit. As a result, the final number of different strategies in the population is doubled: [0]00, [1]00, [0]01, [1]01, [0]10, [1]10, [0]11, [1]11 .

Strategies with depth that equals 1 must do their move taking into account both the opponent's current move and the previous one, in other words, a number with two bits is used to define the bit’s number. That means that the binary representation of a strategy must be twice longer than with the memory depth that equals 0. Further considerations lead us to the fact that the length of the binary representation doubles with every increase of the memory depth index. For all strategies with memory, there is a valid statement that the first move is some strategy with memory depth decreased by one. For instance, for the strategy 1001, there are 8 variants of the first move which fully correspond to the 0 memory depth strategies: [0][00]1001, [1][00]1001, etc. For convenience, below, the strategy means a binary sequence without taking into account moves under conditions of uncertainty. The strategy taking these conditions into account will be called “sub-strategy”. It’s important to focus on the fact that some strategies with memory depth 1 correspond to strategies with memory depth that equals 0. It’s obvious that these are strategies which even having the information about the opponent's previous move make a move without considering that information. For example: 0000 ~ 00, 0101 ~ 01, 1010 ~ 10, 1111 ~ 11. From here we can see, at the memory depth 1, all strategies with memory depth 0 are represented. Thus, we can conclude that all strategies from previous depths including zero are represented at every memory depth.

From all the aforementioned, it is possible to extract formulas of the dependency of the number of strategies from memory depth. Based on the fact that to describe the strategy with memory depth that equals k, 2^{k+1} bits a needed from which $2^{2^{k+1}}$ sequences can be built and that each strategy has a number of sub-strategies that equals the number of strategies from the previous memory depth (2^{2^k}), we can conclude that the formula of the number of the strategies that take into account unique first moves looks like:$2^{(2^{k+2}-1)}$.

3 Distribution of rewards.

In the paper, the same model of distribution as in articles by Kuklin, Pryimak, Yanovsky [16-18] is used, where, at the same time, Robert Axelrod’s model for prisoner's dilemma[13] is used. Every agent (a bearer of the strategy) may choose aggression or cooperation, points are counted by the payoff matrix that was also suggested by Axelrod (Table 1):

Table 1 – payoff matrix

	0 (aggression)	**1 (cooperation)**
0 (aggression)	1	5
1 (cooperation)	0	3

This table implies that by answering aggression with aggression, every agent receives a point. If responds to aggression with cooperation, an aggressive agent receives 5 points, and the other – zero. This rule works the same way in reverse, like a response to cooperation with aggression.Each agent receives 3 points if cooperation is responded with cooperation. Thus, maximum total profit is reached by mutual cooperation, but maximum personal [profit] is reached by betrayal, in other words by responding to cooperation with aggression.

It is important to mention that the represented matrix (Table 1) is not the only right. There may be different other payoff matrices, but all of them should be guided by the rule:

$$t > r > p > s \tag{3.1}$$

where t – the amount of points received by the agent who responds to cooperation with aggression.

r – the amount of points received by the agent who responds to cooperation with cooperation.

p – the amount of points received by the agent who responds to aggression with aggression.

s – the amount of points received by the agent who responds to aggression with cooperation.

4 Population's characteristics.

There are typical characteristics for every population: aggression, complexity, average amount of points received for a move. Version of populations with uneven distribution of agents among strategies involves one more characteristic: the amount of agents of a certain strategy in the population. For our case, which is the series of experiments with modeling evolution of strategies agents' population with a gradual increase in the number of a certain strategy's agents at the first stage of its evolution, it's advisable to use final characteristics of society.

The complexity of the strategy is defined according to the principle of describing the complexity of finite 0 and 1 sequences, assuming that a polynomial of a greater degree is more complex than polynomial of a lesser grade. Such a sequence may be considered as a function, then complexity of this function is perceived as a display like $A: M \to M$, if:

$$y = Ax \tag{4.1}$$

where $= y_1, y_2 \ldots y_n$, sequence, which elements are defined as:

$$y_i = x_{i+1} - x_i \tag{4.2}$$

where $i = 1,2,\ldots,n$ is an element of the sequence.

The amount of received points, or income, is defined as the average value of received points per every agent's move.

Aggression is the average value of the amount of all agents' aggressive moves. The connection between the income and aggression is examined[16-18] and is expressed by ratio:

$$A(t) = \lambda * (P_{max} - P(t)) - \alpha \tag{4.3}$$

where $\lambda = 5.3/8;\ \alpha = 0.2$ – selected empirically coefficients,

P – income of the strategy.

This particular ratio is used for calculations of aggression in this paper. The direct calculation of the number of zeros that were made is associated with an excessive increase in the requirements for calculating power, so a more computationally simple way was chosen.

5 Terms for running experiments.

The purpose of the modeling is to determine the impact of increasing the quantity of a particular strategy on the evolution of the strategy population with a memory depth of 2. In a certain sense, the strategies lose equality in this process. Then, by increasing the initial quantity of a specific strategy in the population, the evolution of a new population is simulated. Upon completion of evolution, collective characteristics of the population that emerged as a result of evolution are obtained from the simulation data. The increase in the initial quantity of the designated strategies ranges from 1 to 3276. The maximum number of added strategies is equal to 10% of the total number of agents in the population in the classical scenario with a memory depth of 2 [3-4]. Thus, this quantity can be considered small in comparison to the size of the "democratic" population with an equal number of all strategies. Therefore, in each series of experiments, the increase in the initial quantity occurs discreetly with a step of 3276/10. Then, in each series, a complete evolution of the population with an increased number of strategies is performed. The obtained data allows determining how collective characteristics of the final population change depending on the quantity of initially added strategies. These dependencies help identify characteristic changes that arise with a change in the quantity of a particular strategy.

6 Case with an increased number of agents of strategy 1011.

Strategy 1011 belongs to a memory depth 1 strategy, with a complexity of 4. That is significantly less than the average complexity of the population, which is 8 with a memory depth of 2. At first glance, it seems that such a strategy should not significantly influence the complexity of the strategies that emerge as a result of evolution. However, the obtained data indicates quite irregular fluctuations in complexity when changing the quantity of this strategy (See Fig. 6.1). The amplitude of these fluctuations is quite significant, ranging from a maximum of 8 to values as low as 2, even lower than the complexity of strategy 1011 that is being added. The structure of the minima is shown on Fig. 6.1 to the right when changing the quantity with a smaller scale in the minima region. It is easy to notice that the number of such fluctuations increases with the reduction in the scale of changes in the initial quantity. Thus, the complexity of the strategies that remain after evolution is a variable function of the initially added strategy quantity.

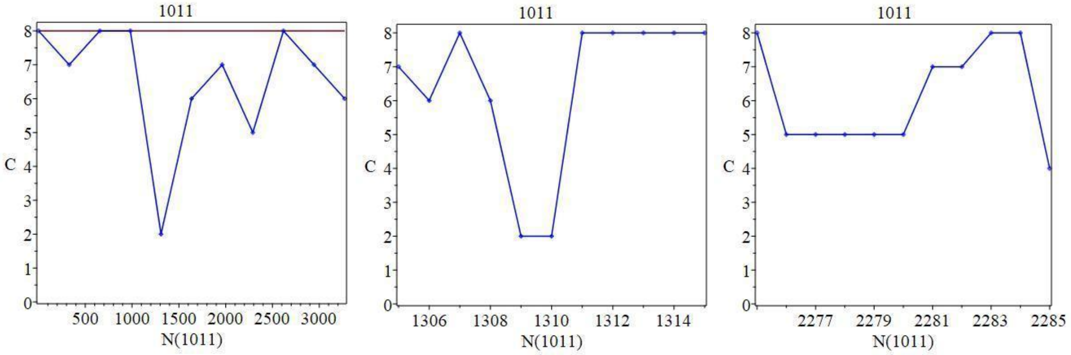

Fig. 6.1 On the left, the dependence of the average complexity of strategies that "survived" on the initial quantity of strategy 1011 is shown. The brown color represents the complexity of strategies that survived in the "democratic" population. On the right, the structure of minimal outliers is shown with a smaller scale of changes in the initial quantity of strategy 1011. The intervals of changes in the figures on the right correspond to [1305-1315] and [2285-2295], respectively.

A more detailed investigation of complexity with a smaller scale of changes requires significant time resources. However, it can be stated that it will be a variable function even on small scales. It is interesting to note that the relative part of the interval of changes in the quantity of 1011 on which the complexity reaches the complexity of the democratic population is significantly less than one. If we estimate this ratio from Fig. 6.1 (left), it equals 1/10. In other words, adding the 1011 strategy typically causes a decrease in the complexity of the population that remains after evolution. However, with a monotonic change in quantity, unforeseen intervals of changes occur where the complexity of the populations reaches the maximum complexity of 8. Interestingly, the average memory depth of the surviving strategies does not show such variability. It remains constant throughout the entire interval of changes in the quantity of the 1011 strategy and equals 2.

The next collective variable of interest is the average number of points a strategy receives per move. In a certain sense, it characterizes the efficiency of strategies in the population. The dependence on the quantity of added 1011 strategies is illustrated in Fig. 6.2. The modeling results indicate that the changes in payoff per move do not vary significantly (see Fig. 6.2).

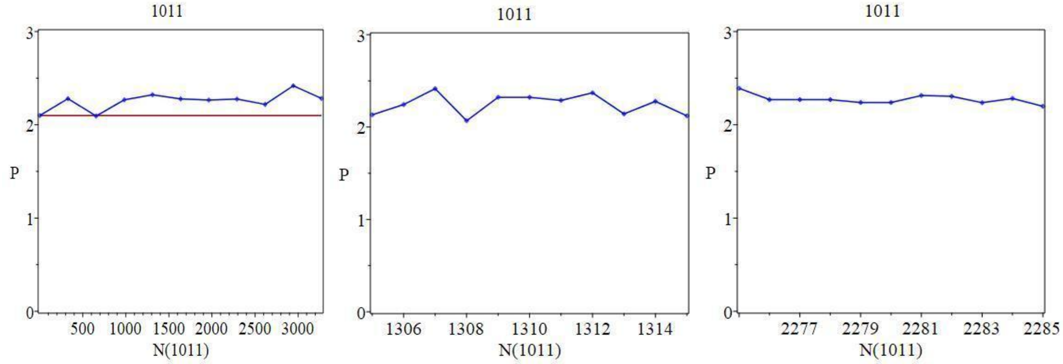

Fig. 6.2 On the left, dependence of the average payoffs per move for strategies surviving the evolution on the initial quantity N(1011) of 1011 strategies. Brown color represents the payoff level in the "democratic" population. On the right, behavior of average payoffs per move within the intervals specified in Fig. 6.1.

It is noticeable that the variability of the dependencies in Fig. 6.2 is significantly smaller than the average complexity. Thus, fluctuations in complexity do not affect the payoffs per move. This is evident from minor changes in the figures on the right, constructed within the intervals of sharp changes in average complexity. Typically, in most cases, an increase in the quantity of strategies emerging in the population through evolution results in higher payoffs per move than in the "democratic" population.

The quantity of points obtained is closely related to a characteristic known as the aggressiveness of strategies. In previous works [X, Y], relationships that align well with simulation data were obtained. After verifying them in the case considered in this work and to expedite computation time, this relationship was utilized for calculating aggressiveness. Therefore, aggressiveness is computed on the basis of the simulation data of payoffs per move. Figure 6.3 illustrates the dependencies of aggressiveness on the quantity of initially added strategies 1011.

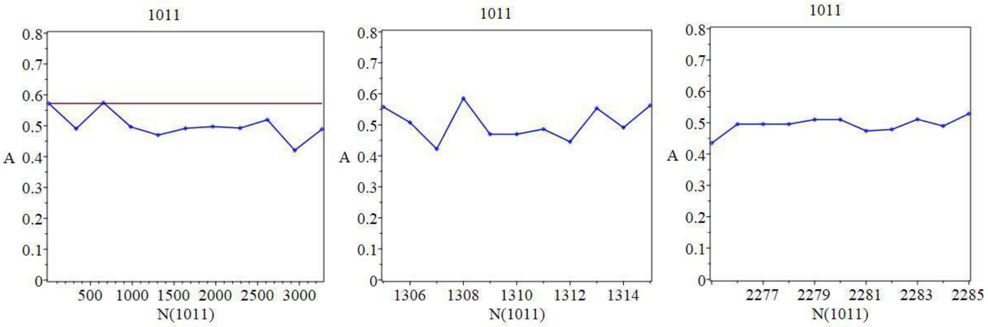

Fig. 6.3 On the left, the dependence of the average aggressiveness of strategies that "survived" on the initial quantity of strategies 1011. The level of aggressiveness in the case of the "democratic" population corresponds to the brown line. On the right, aggressiveness within the intervals [1305-1315] and [2285-2295], respectively.

Thus, aggressiveness, for the majority of initial quantities of strategies 1011, decreases compared to the aggressiveness of the "democratic" population (see Fig. 6.3). An exception is observed when N(1011)=655, while the average aggressiveness of surviving strategies is higher than the aggressiveness of the corresponding strategies in the "democratic" population. Clearly, with this initial quantity of strategies 1011, the payoffs per move are lower than in the "democratic" case. Among the finalists of evolution, strategy 1011 is absent.

7. Case with an increased number of agents of strategy 01001011.

Now let's consider the impact of increasing the quantity of a more complex strategy on the evolution of the population. Strategy 01001011 belongs to a depth-2 memory strategy with a complexity of 8. This is greater than the initial average complexity of strategies in the "democratic" population with a depth-2 memory. Again, the main question is to determine the collective characteristics of the strategies that remain as a result of evolution. Figure 7.1 presents data on the average complexity of strategies formed through evolution based on the quantity of added strategies 01001011.

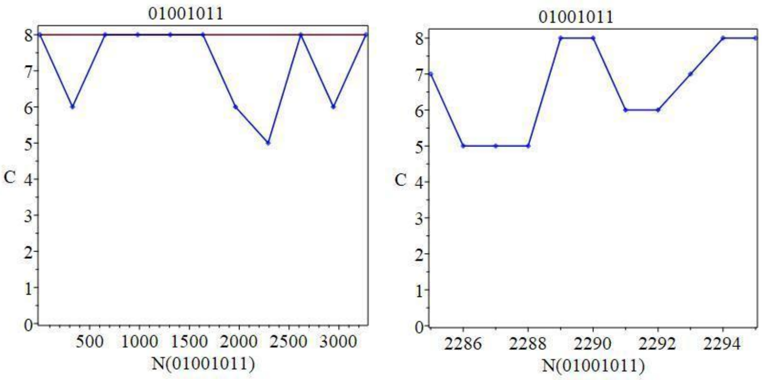

Fig. 7.1 On the right, the dependence of post-evolutionary average complexity on the initial quantity of added strategies 01001011. The complexity level in the "democratic" population corresponds to the brown line. On the left, a portion of the dependency is shown where a minimum is observed with a smaller scale of changes in the interval [2291; 2292].

It is evident that the addition of 2288 agents of the 01001011 strategy results in a sharp decrease in complexity to 5 (see Figure 7.1 on the right). The structure of this decline is shown on the left and exhibits a variable pattern. In a certain sense, similar to the previous case, the average complexity of surviving strategies has a variable structure with significant fluctuations in average complexity. The relative proportion of intervals of initial quantity of added strategy where the maximum complexity of 8 is achieved, compared to the case of division by 6, increases and reaches 3/10. Thus, the complexity of the added strategy affects this indicator.

Now let's move on to the changes in the average payoffs per move of the strategy. The results obtained during the evolution modeling are presented in Figure 7.2.

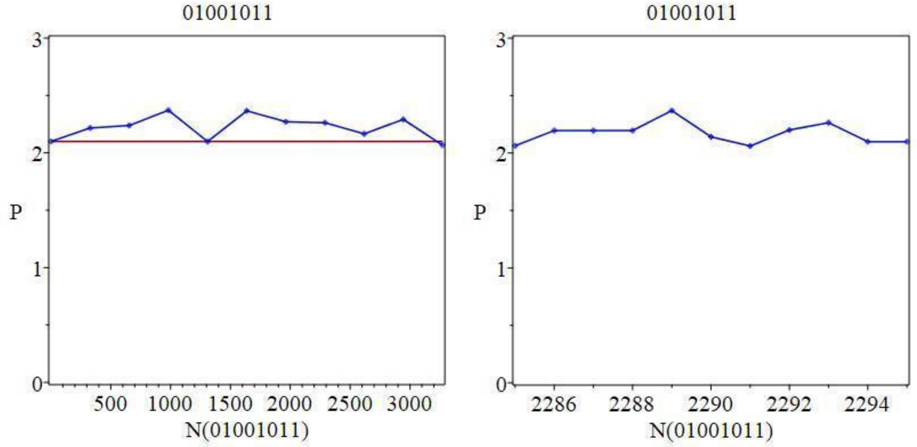

Fig. 7.2 on the right illustrates the dependence of payoffs per move on the initial quantity of 01001011 strategies. On the left, a part of the dependence is shown where a minimum is observed with a smaller scale of changes in the interval [2291; 2292].

In this case as well, at certain initial quantities of 01001011 strategies, it is observed that the obtained profits per move are lower than in the "democratic" scenario. However, it is typical to achieve higher payoffs per move with an increase in the quantity of the additional strategy, although these increases are quite modest. It is evident that the average aggressiveness of strategies after evolution will be lower than in the "democratic" case (see Figure 7.3).

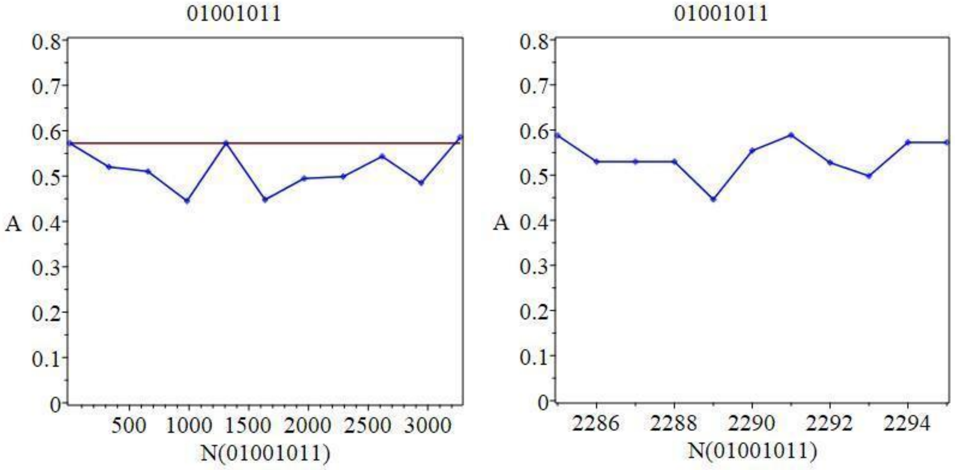

Fig. 7.3 on the right, dependence of aggressiveness on the initial quantity of 01001011 strategies. On the left, a part of the dependency with a smaller scale of changes in the interval [2291; 2292].

Therefore, when choosing a strategy of maximum complexity, a decrease in the aggressiveness of the strategies that remain after evolution should be expected. Thus, the influence of this strategy has a moderate nature due to its absence among the finalists of evolution. It altered the course of evolution at intermediate stages. Hence, the average aggressiveness of finalists is typically lower than the average aggressiveness of the "democratic" population.

8. Case with an increased number of agents of strategy 10001011

In this section, let us consider the winning strategy of evolution in the "democratic" population. Strategy 10001011 belongs to a memory depth 2 strategy with a complexity of 8. This strategy emerged victorious in the classic evolution scenario [3-4]. In this case, it is expected that neither the average memory depth nor the average complexity of surviving strategies change with different initial quantities of this strategy, and they remain at their maximum values. In this sense, they do not provide insight into the events occurring during evolution. Therefore, let's consider the more informative characteristic - the number of agents specifically with the 10001011 strategy that remain in the population after evolution.

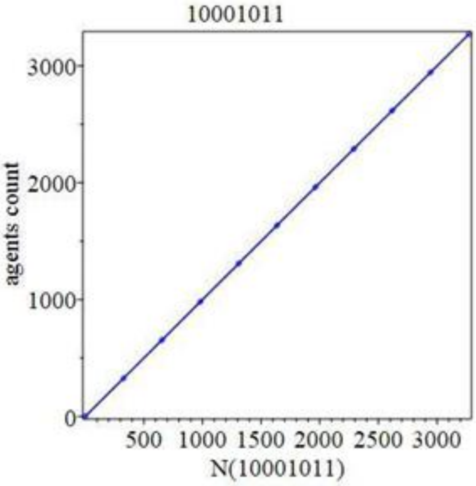

Fig. 8.1 The number of agents with the strategy 10001011 among the winners of evolution.

From the obtained data, it is easy to notice that all added strategies are retained during evolution. Therefore, there are no changes in either the complexity or the depth of memory in the population as a result of evolution. This creates a special case of "democracy" violation. The number of payoffs per move for the strategy, according to the modeling data, is shown in Fig. 8.2 and is determined by the dominance of this strategy during evolution.

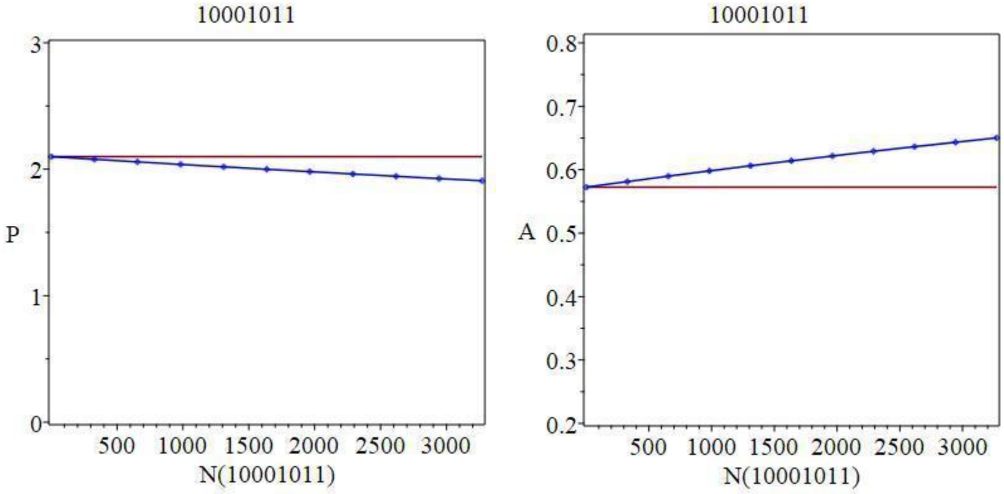

Fig. 8.2 On the left, the change in average payoffs per move for the surviving strategies with evolution. On the right, the average aggressiveness of these strategies.

Therefore, adding the winning strategy, with an increased quantity, reduces payoffs per move and increases the average aggressiveness of the population. This may indicate that with an increase in agents, there is a growing "competition" among the strategy agents.

9. Conclusion.

Thus, it can be noted that an increase in the number of agents of a certain strategy by 10% does not lead to the dominance of that strategy. In all series (except the last one), fluctuations in final complexity were observed, indicating a variable nature of changes with monotonous increases in the initial quantity of added strategies. An increase in the number of agents undoubtedly leads to changes in the population, but these changes do not result in the victory of the increased group. Therefore, it is typical at the final stage to observe a decrease in the aggressiveness of the strategies. It should be noted that with an increase in the quantity by more than 10% from the number of strategies in the democratic population, the dominance of some additional strategies and an increase in population aggressiveness compared to the level of aggressiveness in the "democratic" population should be expected. This can be observed from the behavior of the strategy 01001011 when its quantity is maximally increased (10%), resulting in the population's aggressiveness exceeding the level of aggressiveness in the "democratic" population. Additional research is required to determine the possibility of such a peculiar phase transition. It is worth noting that the evolution of the population requires significant computational resources; therefore, a relatively large scale of changes in the quantity of added strategies was chosen to reduce equipment requirements. This scale was 1/10 of the maximum initial quantity which, in turn, constituted 10% of the size of the "democratic" population. This prevented the identification of changes on smaller scales throughout the entire interval [1, 3276]. These additional complexities arise when attempting to increase the quantity of added strategies.

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Золотухін Володимир Олександрович
студент магістратури
Харківський національний університет ім. В.Н. Каразіна, майдан Свободи, 4, Харків, Україна , 61022
e-mail: zolotukhinvolodymyr@gmail.com
https://orcid.org/0009-0004-0303-0624

Яновський Володимир Володимирович
д. ф-м. н., професор
Харківський національний університет ім. В.Н. Каразіна, майдан. Свободи, 6, Харків, Україна , 61022
Інститут монокристалів, Національна Академія Наук України, проспект Науки, 60., Харків, Україна, 61001.
e-mail: yanovsky@isc.kharkov.ua
https://orcid.org/0000-0003-0461-749X

Вплив порушення демократії стратегій з пам’яттю на еволюцію популяції

Актуальність. Брак довіри у сучасному суспільстві часто є тормозить розвиток людства та, іноді, ставить під питання майбутнє людської популяції в цілому. Протягом всієї історії розвитку суспільства спостерігається явище, коли та чи інша ідея захоплює розуми людей, що призводить до того, що вони притримуються однакової (або дуже схожої) поведінкової стратегії. Для покращення розуміння внутрішніх процесів у суспільстві, в якому порушено рівномірність розподілу стратегій по членам популяції, необхідні детальні дослідження, які неможливі без відповідного програмного забезпечення.

Мета. Метою роботи є дослідження впливу кількості агнетів певної стратегії на результат еволюції популяції в цілому. Досліджується характер змін в еволюції за умови поступового, монотонного збільшення агентів певної стратегії від 1 агнета до 10% від демократичної популяції. Дослідження також має на меті встановити стратегії, що є еволюційно доцільними тільки за умови збільшення їх носіїв у популяції.

Методи дослідження. Розглянуто еволюцію популяції з повним набором стратегій поведінки, обмежених тільки глибиною пам’яті 2,зі збільшеною кількістю агентів певної стратегії. Кожен носій агент з кожним, включаючи себе згідно з ітеративною моделлю дилеми ув’язненого. Винагороди визначаються за матрицями виплат. Кожне наступне покоління популяції послідовно втрачає агентів найбільш невигідної стратегії поведінки попереднього покоління. Агенти, що є носіями обраної стратегії взаємодіють між собою та з іншою популяцією за стандартним законом. Розглянуто декілька стратегій, кількість агентів яких було збільшено. Серед них стратегії зі складністю нижче ніж середня складність популяції, вище ніж середня складність популяції. Також було розглянуто варіант, коли збільшилась кількість агентів стратегії, що перемогла у демократичному суспільстві.

Результати. В роботі показано, як наявність виділеної стратегії зі збільшеною кількістю носіїв впливає на динаміку популяції. Виявлено зростання кінцевого середнього заробітку популяції. Встановлено, що збільшення кількості агентів не приводить до перемоги стратегії, що не перемогли у демократичній популяції.

Висновки. За результатами роботи визначено головні наслідки впливу кількості агентів певної стратегії на еволюцію популяції.

Ключові слова: *агресивність, еволюція, популяція, стратегія, складність, суспільство*

Надійшла у першій редакції 27.07.2023, в останній - 12.08.2023.
The first version has been received on 27.07.2023, the final version - on 12.08.2023.