Self-Protection Maintains Diversity of Artificial Self-Replicators
Evolving in Cellular Automata

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Abstract

The concept of “self-protection”, a capability of an organism to protect itself from exogenous attacks, is introduced to the design of artificial evolutionary systems as a possible method to create and maintain diversity in the population. Three different mechanisms of self-protection are considered and implemented on a cellular automata based evolutionary system, the evoloop. Simulation results imply a positive effect of those mechanisms on diversity maintenance, especially when the self-protection is moderate so that it conserves both the attacker and the attacked.

1. Introduction

The maintenance of diversity is as crucial for the design of artificial evolutionary systems as for conservation efforts in real ecology, because of its importance on evolutionary robustness and exploration capability of the system. It is often found in various artificial systems that a simple homogeneous environment typically results in a simple dominance by one and only optimal type of organisms [9]. A key to the creation and maintenance of diversity is the interaction between organisms that mutually changes their fitness landscapes each other, which has been reconstructed in several artificial evolutionary systems [5, 8].

However, things become more complicated when one tries to introduce such interdependence into much simpler models where organismal actions are implemented bottom-up by a coordination of tiny lower-level rules like cellular automata. This question is challenging because atomic components composing artificial organisms in those models have only localized capability of communication and computation. Interaction between organisms therefore must be an emergent phenomenon realized at a far higher scale than the component scale. This problem directly applies to physical embodiment of such distributed artificial systems, because in physical settings all the parts are literally local and their behavior must be coordinated in a bottom-up way.

Here we present a rather different approach to the above-mentioned question. We introduce the concept of what we call self-protection, a capability of an organism to protect itself from exogenous attacks, to the design of artificial evolutionary systems as a possible method to create and maintain diversity in the population. We then apply this concept to a simple evolutionary system on cellular automata, the evoloop [3], to see its effect on the diversity emerging in the system. Simulations are conducted for three different versions of self-protection mechanisms, with several variations added to experimental settings to make sure the robustness of the effects observed. This article briefly reports the outline of the models and the results obtained so far.

2 Self-Protecting Evoloop

Here we define self-protection, quite intuitively for now, as an action or a set of actions taken by an organism to protect its structure and/or function from attacks that may come from the external world, such as physical environment or other organisms in competition. We apply this concept of self-protection to a simple model of evolving self-replicators, the evoloop [3], constructed on 9-state deterministic cellular automata with von Neumann neighborhoods. Table 1 shows the states used in the evoloop cellular automata. An evoloop individual is composed of two basic structures: an inner and outer sheath of square or rectangular shape and a gene sequence of moving signal states. The gene sequence contains several state 7 genes for straight growth of a construction arm of the loop and a pair of state 4 genes for left turning of the arm. After three times of such left turning, the arm collides into itself; this makes the tip and the root of the arm bond together to complete self-replication (Fig. 1). Evoloop populations mutate through direct interaction (collision) of their sheath structures, leading to a change in the gene sequence of offspring loops.
Table 1. States in the evoloop cellular automata. Those newly introduced in this article are shown in bold face.

<table>
<thead>
<tr>
<th>State</th>
<th>Name</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Background</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Core</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Sheath</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Left indicator</td>
<td>Bonder, Sprout generator</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sprout capper, Sprout finisher</td>
</tr>
<tr>
<td>4</td>
<td>Gene</td>
<td>Sprout guide</td>
</tr>
<tr>
<td>5</td>
<td>Messenger</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Umbilical cord dissolver</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Gene</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Dissolving state</td>
<td>Attack detector</td>
</tr>
<tr>
<td></td>
<td>Attack detector</td>
<td>For Poisoning SP evoloop</td>
</tr>
<tr>
<td>9</td>
<td>Attack detector</td>
<td>For Shielded and Deflecting SP evoloops</td>
</tr>
<tr>
<td></td>
<td>Poison</td>
<td>For Poisoning SP evoloop</td>
</tr>
</tbody>
</table>

Figure 1. Self-replication of an evoloop.

We introduce a self-protection capability to the evoloop by adding a new state 9 and some patches of transition rules that mainly describe the behavior of this new state. These patch rules are hand-designed by the author. The transition rules explicitly defined in the original evoloop are all inherited as is, so that the normal self-replicative behavior will not change at all. We call this new model the self-protecting evoloop, or the SP evoloop.

There could be many possible mechanisms to implement self-protection on a system, so are there for the SP evoloop too. We have so far tested three different mechanisms as listed below:

**Shielded:** The attacked loop generates a dissolving state 8 at the tip of the attacker’s arm. Since the dissolving state usually becomes cancelled by the gene flow in the arm, most likely the attacker suffers from only a partial dissolution of the tip of its arm and the same attack occurs repeatedly.

**Deflecting:** The attacked loop generates an umbilical cord dissolver 6 at the tip of the attacker’s arm. The umbilical cord dissolver goes back to the attacker, removing the entire arm, and then deceives the attacker as if the self-replication had been completed. The attacker then starts another attempt of self-replication to a different direction rotated by 90 degrees counterclockwise.

**Poisoning:** The attacked loop generates a poison 9 at the tip of the attacker’s arm. The poison works as a kind of dissolving state with extra strength that will never be cancelled until it deletes the whole contiguous structure. This may be one of the most radical and merciless mechanisms of self-protection.

Their behavioral difference on the collision event is shown in Fig. 2. Details of how to derive a complete set of transition rules for each model can be available online from the author’s web site [4].

Here we note that similar classification of possible modes of interaction between self-replicators has been done recently and independently by Suzuki [7]. In his work, Suzuki examined the effects of five different modes of interaction (Inroad, Offensive, Cancel, Defensive, and Counter) on the evolutionary dynamics of self-replicating cellular automata. Our original, Deflecting, and Poisoning mechanisms correspond to the Offensive, Defensive, and Counter modes in Suzuki’s classification, respectively. There is no counterpart of our Shielded mechanism in his classification.

3 Results

We have conducted simulations of evolution of the proposed SP evoloops, aiming at the evaluation of how much diversity increase the introduction of self-protection brings to the system. The cellular automata space used for simulations consists of 400x400 sites with periodic boundary conditions applied to the edges. Simulations start from a quiescent initial configuration with a single ancestor loop of size 13 that has a genome 774477777777777 (two state 7 genes
preceding a pair of state 4 genes). Evolutionary dynamics is traced over 1M updates for each run, where square loop structures in the space are identified and counted according to their size using the method proposed in [3].

To characterize the diversity within the population, we define a trait distribution entropy $H$, to be

$$H = -\sum_{i} \frac{n_i}{N} \log \frac{n_i}{N} = \log N - \frac{1}{N} \sum_i n_i \log n_i,$$

where $n_i$ is a population of loops of size $i$, and $N = \sum_i n_i$ (total population). This entropy is zero when the system is filled with loops of the same size only, and takes its maximal value $\log N$ when every loop in the system differs from each other (i.e. $n_i = 0$ or 1 for all $i$). This characterization takes into account the size difference only. We have reported the emergence of huge genetic and behavioral diversity in the evoloop world using a more sophisticated identification scheme elsewhere [1, 2], which is not discussed here in detail.

Figure 3 summarizes the difference in average trait distribution entropy between original, Shielded, Deflecting and Poisoning SP evoloops, showing the distribution of entropy values sampled at a regular interval between 200K and 1M updates for each run. Diversity increase is clearly seen for Deflecting and Poisoning cases; actually all the three self-protection mechanisms have statistically significant increase of entropy compared to Baseline (original) since the number of sample points is large (20K points).

To check the robustness of the observed diversity increase, we have also conducted the same simulations with variations added to initial configuration, or transition rules, or both. For a variation of initial configuration, we choose another type of size 13 loop with a different genome 777777777777744. While this loop is also self-replicative, its evolvability is significantly smaller than that of the loop with genome 774477777777777 [3], making the final population composition significantly different. For a variation of transition rules, we additionally introduce a small set of rules that enable state 4 genes to trigger arm bonding at the final stage of self-replication, which was originally possible only by state 7 genes. This modification slightly improve the adaptability of loops but does not change their behavior fundamentally.

The results are shown in Fig. 4. These plots tell that the effect of Poisoning is rather sensitive to the variation in initial condition (and thus in population composition). This observation implies that the significant increase of diversity for Poisoning seen in Fig. 3 may be an artifact specific to model settings, and that the effectiveness of self-protection may depend on the mechanism chosen for its implementation. On the other hand, the diversity increase in Deflecting and Shielded cases seems fairly robust to model variations; the Deflecting mechanism especially marks significant diversity increase constantly. An interesting finding is that both of these robust mechanisms do not kill the attackers at all, which is good for diversity maintenance in the entire population. In contrast, too strong self-protection like that implemented in Poisoning promotes dominance by a single type, causing a negative effect on diversity.

The difference in performance between Deflecting and Shielded can be explained as follows: The Deflecting mechanism diverts attackers to a different place where they may be able to find room to produce their offspring, while the Shielded mechanism simply blocks attackers’ attempt of self-replication so they will remain unable to produce offspring unless some external factor resolves the situation. Such a simple blocking strategy generally results in a greater possibility for a system to fall in a confined region of phase space (limit cycle).

### 4 Conclusion

We have introduced a self-protection capability to a simple artificial evolutionary system, the evoloop, to make their population more diverse. Simulation results have generally indicated a positive effect of the self-protection mechanisms on the diversity creation and maintenance in the evoloop world. In the meantime, however, it is also suggested that the effectiveness of self-protection may depend on the specific implementation of its mechanisms. Among the mechanisms we have tested so far (Shielded, Deflecting, and Poi-
soning), the Deflecting one seems most robust in its effect on the diversity increase.

Finally, we note that implementing self-protection is generally much easier than introducing explicit interspecific interactions if systems are made up in a bottom-up way like cellular automata. For example, introduction of the Deflecting mechanism has been done by adding just 1 new state and 73 related transition rules [4]. This is mainly because the self-protection can be achieved with local efforts only, i.e. everything in the protection process happens within a local region at the interface between organisms and external environment. If complex interspecific interactions among artificial organisms were to be embedded in such distributed models, far more extra states and rules would be needed to hierarchically construct higher-order functions out of local behaviors. We thus expect that the concept of self-protection, still quite abstract and theoretical, may give a general and practical solution to the issue of diversity increase in the design of artificial evolutionary systems. This could be of particular relevance in the context of physical implementation of artificial self-replicator models, which is now launching in evolvable hardware [6].

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References