Toward the Realization of an Evolving Ecosystem on Cellular Automata

Hiroki Sayama
Department of Information Science, Graduate School of Science, University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan

Abstract

We have contrived the *evoloop*[5, 6], a new self-reproducing loop spontaneously evolving on a simple deterministic 9-state 5-neighbor cellular automata (CA) space. In this article, we examine the evolvability and adaptability of the *evoloop* through several experiments, the result of which brings us good prospects for the future implementation of an extraordinary large-scale artificial ecosystem on a superparallel machine environment.

Keywords

evolution, cellular automata, self-reproducing loop, structurally dissolvable self-reproducing loop

1 Introduction

The motivation of this study is to frame the basis for the realization of extremely large-scale evolutionary systems by means of a set of interacting *virtual state machines* embedded in a cellular automata (CA) space[2].

CA is a fine-grained parallel computational model intrinsically scalable and suitable for linear enlargement of simulation size, especially by implementing it on hardware[7, 8]. If we can create artificial evolutionary systems on CA, it will be very significant for the rapid enhancement of simulation scale, and such a great leap in expanding scale will be one of the most important factors for the reduction of gaps between artificial and real life.

Based on this idea, we have been trying to create evolving organisms on CA, and have proposed two improvements of Langton's famous self-reproducing loop[1]. The first improvement we made was the structurally dissolvable self-reproducing (SDSR) loop[4] which was capable of structural dissolution (a form of death) as well as self-reproduction. The second is the evolving SDSR loop, named *evoloop*[5, 6]. Its behavior being introduced in the next section suggests that it is relatively easy to realize evolutionary systems in a simple deterministic CA space.

In this article, we introduce the *evoloop* as the newest product of our study, and examine the evolvability and adaptability of it through several experiments. The result gives us good prospects for the future implementation of an extraordinary large-scale artificial ecosystem on a fine-grained superparallel machine environment with very simple algorithms inherited from the *evoloop*.

2 Evoloop: an evolving SDSR loop

The *evoloop* we have proposed is a new self-reproducing loop model on a simple deterministic 9-state 5-neighbor CA, constructed by enhancing robustness of the state-transition rules of the SDSR loop and slightly modifying its initial configuration. It actually has the ability to spontaneously evolve through the variation caused by direct interaction of phenotypes. Since the details of the *evoloop* will be carried on other literature[5, 6], they are omitted here. Its complete state-transition rule set is available from the author's WWW page introduced later.

Figure 1 shows a typical example of evolution of the *evoloop*. When the simulation begins, an ancestral loop soon proliferate all over the space. Then, self-reproduction and structural dissolution of loops begin to happen frequently in the space, which produce various kinds of variants. A self-reproducing loop of smaller species also emerges by accident from this melee, and once it appears, it is naturally selected due to its quick self-reproductive ability. Such an evolutionary process develops in the space as time proceeds, and eventually, the whole space gets filled with the loops of species 4 which is the strongest one in this world. It is quite characteristic of this evolutionary process that the variation in this world occurs first on phenotype (not on genotype) of the offspring being produced, by direct interaction of phenotypes, and then it consequently leads to alteration of genotype.

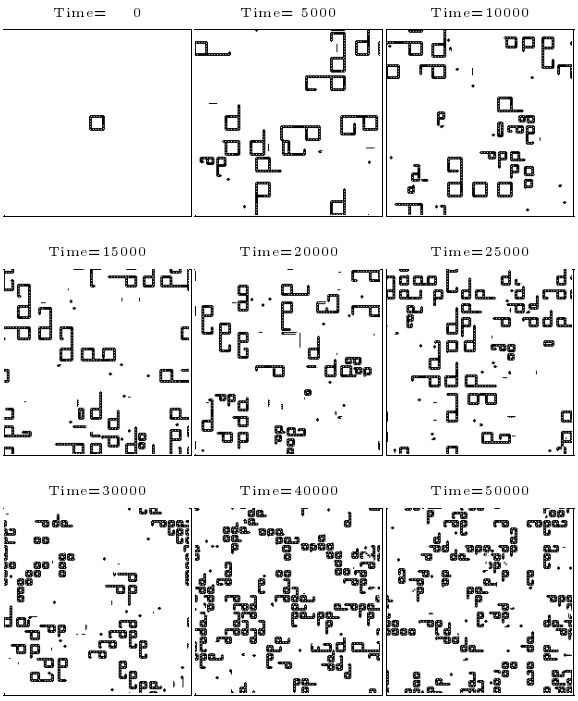

Figure 1: Temporal development of spatial configuration in a evolutionary process of *evoloops*. The ancestor is of species 13. The space is of 200 × 200 sites with periodic boundary conditions. As time proceeds, the smaller loops emerge and get superior to larger ones. The whole population gradually evolves toward smaller species, and finally the space gets filled with the loops of the strongest species 4.

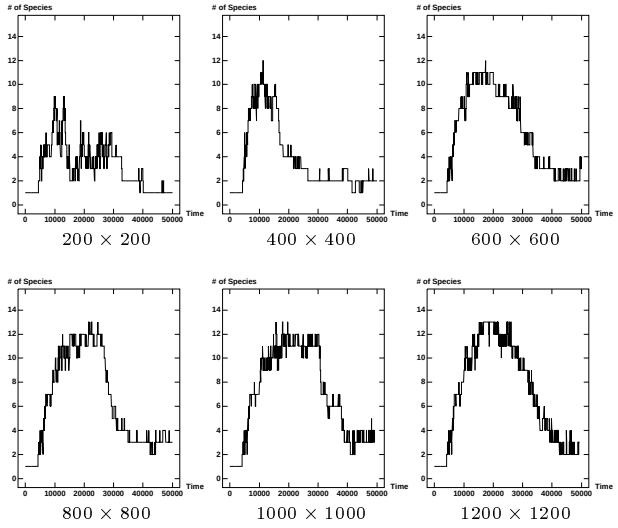

Figure 2: Temporal development of the diversity (the number of species) of *evoloops* in several cases with different sizes of space. Figures placed under each graph represent the size of space in that case. It is observed with respect to the cases with spaces smaller than 1000 × 1000 that, the larger the size of space becomes, the more easily various species can appear and co-exist with each other due to larger capacity of space.

3 Evolutionary/adaptive behaviors of the evoloop

In this section, we investigate the evolvability and adaptability of the *evoloop* from a viewpoint anticipating the future implementation on hardware.

3.1 Relation between the resource size and the evolvability

We expect that the size of the artificial world being simulated can be enlarged greatly by implementing it on hardware. The basic reason why we hope it is that we believe the larger the scale of simulation becomes, the more complexly and diversely the artificial system evolves. Here, we first examine this belief within the *evoloop*'s world.

In order to investigate the relation between the size of available resource and the evolvability of loops, the

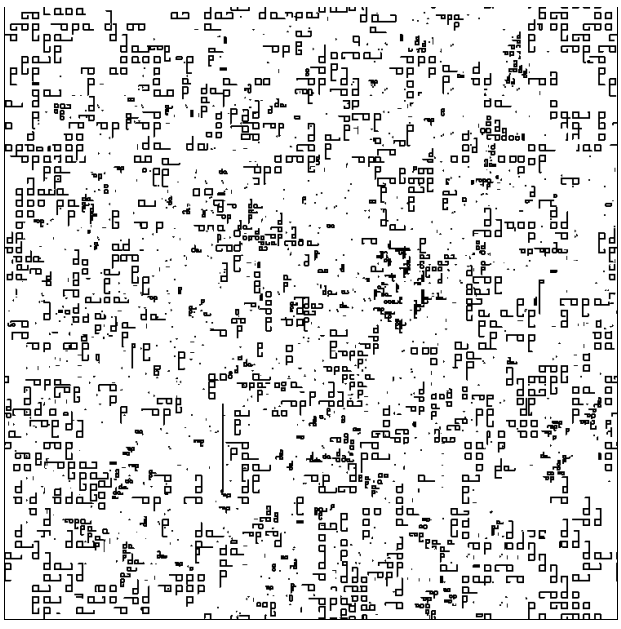

Figure 3: A snapshot taken in the evolutionary process of *evoloops* in the space of 1500 × 1500 sites (Time=20000). The space is islanded with the colonies of loops of various species.

evoloop was bred up in the spaces of various sizes ranging from 200 × 200 to 2000 × 2000 sites. Figure 2 indicates temporal development of the diversity (the number of species living in the space) of *evoloops* in several cases with different sizes of space. Since the number of possible species of the *evoloop* is limited, the diversity is saturated around the case of 1000 × 1000 sites. Nonetheless, it is possible to say with respect to relatively small spaces before the saturation that, the larger the size of space becomes, the more easily various species can appear and co-exist with each other (for a while) due to larger capacity of space. Figure 3 is an example of spatial configuration in such a state of diverse evolution emerging in a large space.

These results support the above-mentioned belief that large resource affords large diversity of evolution, and also suggests that, when we design much more complex organisms (like *Tierran*[3] creatures) on CA in the future, we need much larger resource in order to keep their diversity.

3.2 Emergence of self-reproducing organisms

We can observe the emergence of self-reproducing organisms from empty space by introducing a few additional state-transition rules and embedding small devices into space. The device used here is a nondeterministic finite-state automaton as small as a single site of the CA, and behaves stochastically to generate possible signal sequences meaningful in the *evoloop*'s world. Figure 4 depicts the state-transition diagram of this device. It generates random signal sequences filled with a mixture of a signal '7' (which means straight growth of the construction arm of the loop) and a pair of signal '4's (which mean left turning of the arm). Figure 5 shows a typical example of the emergence of self-reproducing organisms realized by using this device.

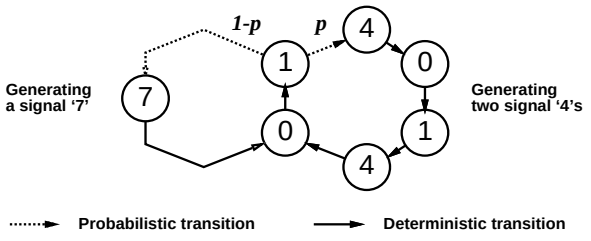

Figure 4: A state-transition diagram of the stochastic device used here. Probability p is set to be 0.05 in this study.

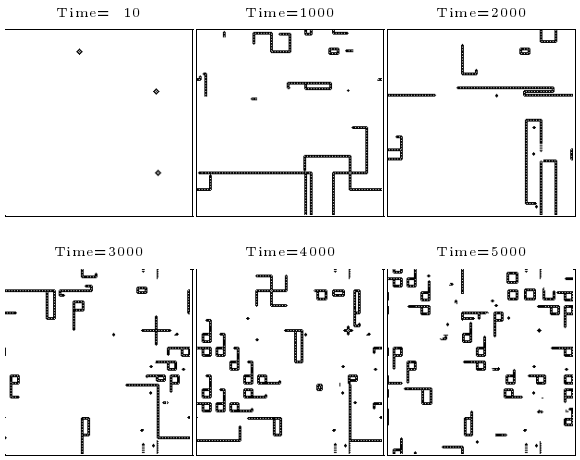

Figure 5: An example of the emergence of self-reproducing organisms from empty space. Three stochastic devices are randomly distributed in the space of 200 × 200 sites. These devices generate random signal sequences which cause the growth of pre-biotic arms. Self-reproducing organisms can emerge by accident from the interaction of these arms, and gradually proliferate over the space.

This phenomenon may be applicable for searching for configuration of viable organisms in an artificial world where only the grammer of genotypic signal sequence is known. This kind of method to embed small additional devices in a uniform array of machine modules would be easier and more practical if they were implemented on hardware.

3.3 Fault tolerance

Fault tolerance is an important feature of the model when its possibility to be implemented on hardware is considered. The more tolerant of faults the model becomes, the lower the level required for the hardware performance becomes, accordingly the easier the enhancement of circuit integration gets.

Here is the fault tolerance of the *evoloop* measured. Two kinds of faults are supposed in this measurement: the errors of state-transition rules which simulates unstableness of hardware modules, and the distribution of state-fixed blocks which simulates breakdown of hardware modules. The probabilities that the self-reproductive activity of *evoloops* will continue for 10000 updates are measured with the rates of the above two faults being changed.

The result is indicated in Table 1. It is understood from this table that the *evoloop* is actually tolerant of faults to some extent. The main reason of it is that the

Table 1: Probabilities that the self-reproductive activity of *evoloops* will continue for 10000 updates. The probability in each case was calculated based on the results of ten simulations of breeding *evoloops* of species 10 in the space of 200 × 200 sites with different seed values of random numbers. Emphasis is added on the probabilities not less than 0.5.

		Rate of errors of rules ($\times 10^{-6}$)				
		0.0	2.0	4.0	6.0	8.0
Rate	0.0	**1.0**	**0.8**	**0.8**	0.3	0.0
of	0.5	**1.0**	**0.5**	0.3	0.1	0.0
fixed	1.0	**0.7**	0.3	0.1	0.0	0.0
blocks	1.5	0.2	0.2	0.1	0.0	0.0
($\times 10^{-3}$)	2.0	0.1	0.1	0.0	0.0	0.0

evoloop can eliminate irregular configurations caused by faults quickly from the space, owing to its capability of structural dissolution. This feature may be regarded as quite favorable for hardware implementation. It is expected that the *evoloop* will be more tolerant of faults with further modification of refining the state-transition rules to be simpler and more robust.

4 Summary and future work

In this article, we introduced the *evoloop* spontaneously evolving in a simple CA space, and showed a couple of its features suitable for the future implementation on hardware: the increase of evolutionary diversity according to the increase of resourse size, the ability to autonomously search for self-reproductive configuration, and the fault tolerance. Of course, the model in this stage is too simple to produce enough complexity compared to real life; it still has plenty of room for improvement. However, we believe that it will be possible in the near future to synthesize an evolving ecosystem of unprecedented scale on super-parallel machine modules by utilizing the basic concept of the *evoloop* and refining the details of its model.

Finally, we should note here that a serious problem remains being unsolved, that is, the difficulty of observation of the behavior of evolutionary systems in CA space. Generally, meaningful configurations in CA are merely spatial collections of local states, thus all the judgments—which configuration is living or dead, how the genealogy of organisms is formed, when and where the variation occurs, e.g.—are left to the observer. This means that the observation of such a world needs enormous computation for image processing in order to extract significant information from the temporal development of configuration of the whole CA space. As the image processing also is a good target for the application of CA, we are planning to solve this problem by utilizing another CA specialized for image processing.

A WWW page which provides information about the *evoloop* is open at the URL below:
`http://proton.is.s.u-tokyo.ac.jp/~sayama/sdsr/`

Acknowledgments

We are grateful to Chris Langton, Yoshio Oyanagi, Yasuhiro Suzuki and Mari Sayama for their valuable help and advice in proceeding with this study.

References

1. Langton CG (1984), Self-reproduction in cellular automata. *Physica D* 10:135–144.
2. Langton CG (1986), Studying artificial life with cellular automata. *Physica D* 22:120–149.
3. Ray TS (1990), An approach to the synthesis of life. In: Langton CG, Taylor C, Farmer JD, Rasmussen S (eds), *Artificial Life II: Proceedings of the Workshop on Artificial Life*, Santa Fe, NM, Feb 1990, pp.371–408.
4. Sayama H (1998), Introduction of structural dissolution into Langton's self-reproducing loop. In: Adami C, Belew RK, Kitano H, Taylor CE (eds), *Artificial Life VI: Proceedings of the Sixth International Conference on Artificial Life*, Los Angeles, CA, Jun 1998, pp.114–122.
5. Sayama H (1998), Spontaneous evolution of self-reproducing loops implemented on cellular automata: A preliminary report. In: Bar-Yam Y (ed), *Proceedings of the Second International Conference on Complex Systems*, Nashua, NH, Oct 1998, forthcoming.
6. Sayama H, A new structurally dissolvable self-reproducing loop evolving in a simple cellular automata space. Submitted.
7. Sipper M, Mange D, Stauffer A (1997), Ontogenetic hardware. *BioSystems* 44:193–207.
8. Toffoli T, Margolus N (1987), *Cellular Automata Machines*. MIT Press, Cambridge, MA.