Artificial Evolution:
A Language-Theoretic Example

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Abstract: Eco-grammar systems form a conceptual framework based on the theory of formal grammars and languages in order to study some of the structural and behavioral features of real or artificial eco-systems. After a short introduction to eco-grammar systems, some examples are given to illustrate that some of the phenomena related to evolution are reflected by this model.

Keywords: Artificial life, theory of formal grammars and languages, grammar systems, eco-grammar systems, artificial evolution.

1 Introduction

Artificial Life is a discipline devoting to a study of systems that exhibit behaviors characteristic for natural living systems. It can contribute to our understanding of leaving systems by locating life as we know it within the larger picture of life as it could be; cf. (Langton, 1989).

In the field of Artificial Life, life is often characterized – cf. (Farmer, d'A Belin, 1992) – as a *pattern in space-time, rather than a specific material object* (p. 818). Accepting this assumption we have to accept the idea that life can be approached at a symbolic level, with emphasis on the syntax of some of the lifelike phenomena. In order to emphasize syntactical aspects of living agents, in (Csuhaj-Varjú et al., 1997) we have proposed a formal framework – the so called *eco-grammar systems*, shortly EG systems – based on the theory of grammar systems as presented e.g. in (Csuhaj-Varjú et al., 1994) or (Dassow et al., 1997).

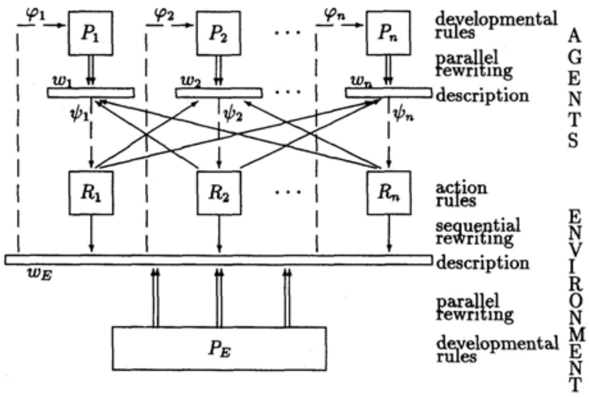
Eco-grammar systems represent a grammar-theoretic framework for describing systems which consist of a community of agents acting in a shared environment, and provide a formal framework for describing systems of agents formalized as simple entities which generate strings of symbols and act through rewriting symbols in a shared simple environment of the form of string of symbols.

The ability of systems to evolve is very closely related to life. In the present paper we characterize evolution in eco-grammar systems as a mechanism of change (growth) of the complexity of systems (structure, behavior) during systems functioning (over time). Conditions in the environment of the eco-grammar systems and conditions in the agents of the systems which lead to the artificial evolution are of interest. We will illustrate on the example the role of agents´ action in this process.

2 Eco-Grammar Systems

Eco-grammar systems consist of a community of agents acting in a shared environment. Agents in the system are formalized as simple entities which generate strings of symbols and act through rewriting symbols in a shared simple environment of the form of string of symbols.

Briefly, an eco-grammar system consists of fixed number (say n) of agents with internal states described by strings of symbols w_1, w_2, ... w_n, and evolving according set of rules P_1, P_2 , ..., P_n applied in a parallel way as it is usual in Lindenmayer (or L) systems; cf. (Rozenberg, Salomaa, 1980). The evolution rules of agents depend, in general, on the state of the environment (in a given moment, a subset of applicable evolution rules is chosen from a whole set of rules of agents). The agents act in commonly shared environment (the states of the environment is described by strings of symbols w_E) by sets of sequential rewriting rules R_1, R_2,... R_n. The environment itself evolves according a set P_E of rewriting rules applied in parallel as in Lindenmayer systems. The model is schematically depicted in the following figure:



The evolution rules of the environment are independent of agents states and of the state of the environment itself. The agents actions have priority over the evolution rules of the environment. In a given time unit, exactly those symbols of the environment that are not affected by the action of any agent are rewritten.

In the EG systems we assume the existence of the so called *universal clock* that marks time units, the same for all agents and for the environment, and according to which the evolution of the agents and of the environment is considered.

The range of question with certain AL relevance we can ask about an EG system contains e.g. the following items:

- Is the evolution of a system bounded in time or not? In other words: Enters the system a deadlock?
- In the case of the infinite evolution, are non-cyclic evolutions possible?
- What is the effect of „small“ changes, either in the initial configuration or in the evolution/action rules of agents and of the evolution rules of the environment?
- What is the effect of introducing further life-like features into the model to the answers to the previous questions?
- What is the influence of the number of agents on the system properties?

Complete information on the field can be found in www.sztaki.hu/mms/bib.html

In the present paper we will discuss influence of agents action to the environment. This is the reason that the development of the system will be characterized by sequence of strings describing the environmental states. Instead of the precise description of the states of agents it is sufficient to know their total amount and corresponding action rules.

3 Constant Monoculture Agents in EG System

Evolution can be a consequence of changes in ecosystem. This motivates the question how can small changes in EG systems influence their behaviour. In the following examples we illustrate consequences of small random changes in a case of systems with monoculture population.

Population is called the monoculture if all agents are of the same type. They have identical action rules (and identical individual developmental rules).

To specify an *environment* of the eco-grammar system, in our examples, we assume eco-grammar system with linearly growing environment according to rules

$$P_E: \quad a \to ab \qquad b \to b.$$

This mean that

$$|w_n|_a = |w_{n-1}|_a \qquad |w_n|_b = |w_{n-1}|_b + |w_{n-1}|_a$$

the number of elements *a* does not change in the environment and each element *a* produces one element *b* in next derivation step. String w_n of environmental symbols denotes the n-t state of environment and $|w_n|_a$ is the denotation for the number of a-s in w_n.

Example: Let the environment of the system start with ab^4. Then its development is

$$ab^4 \Rightarrow ab^5 \Rightarrow ab^6 \quad .....$$

and its growth after *n* steps is

$$g(n) = |w_n| = |ab^{n+4}| = n+5$$

Generalization: For the starting environment which have *m* occurrences of symbol *a* and *r* occurrences of symbols *b* the environments itself after *n* developmental stages consists of *m* occurrences of *a* and *mn* + *r* occurrences of *b.*

$$g(n) = m + r + m.n.$$

Assume that there is an *agent* in the eco-grammar system which has influence to the development of the environment characterized by action rule

$$R: \qquad b \rightarrow a.$$

It means that in a developmental step the agent changes one occurrence of *b* in the environment to *a* and all other elements of the environment develop according to the developmental rules P_E of the environment. Therefore

$$|w_n|_a = |w_{n-1}|_a + 1$$

$$|w_n|_b = |w_{n-1}|_a + |w_{n-1}|_b - 1 = |w_{n-1}| - 1$$

The number of elements *a* in the environment increases by one and one element *b* disapears (is replaced by *a*) while each of all other *a*-s and *b*-s produces one element *b* in next derivation step.

Example: For environment of the system starting with ab^4 developing by P_E and influenced by one agent acting by R the environment develops for example as follows

$$ab^4 \Rightarrow abb^3a \Rightarrow ab^4aab \Rightarrow ab^5\ ababa \Rightarrow ab^6ab^2abaab....$$

(In the all steps last occurrence of *b* was rewritten by the agent.)

Growth of the environment of the system after *n* steps is

$$g(n) = |w_n|_a + |w_n|_b = 5 + ½n(n+1)$$

and

$$|w_n|_a = n + 1 \quad \text{and} \quad |w_n|_b = 4 + ½n(n-1).$$

***Generalization*:**

Let the starting environment has *m* occurrences of symbol *a* and *r* occurrences of symbol *b* and there is $k(\leq r)$ above specified agents in the system.
The environment after *n* developmental stages consists of $m + kn$ occurrences of *a* and $r+mn + ½k\,n(n-3)$ occurrences of *b*. So:

$$g(n) = ½k\,n^2 + (m-½k)n + m + r.$$

By the example we illustrate that agents can substantially increase the growth of the environment.

4 Small Random Change in Constant Monoculture Agent Population

Main goal of the paper is to compare the behavior of the EG system with its behavior in the case when mutation, in the sense of small random change takes place in the system.

Small random change will mean that *one* action rule of *one* agent changes in the sense that in the original action rule $a\rightarrow w$ *one* letter of *w* is replaced by another one (or disappear). The agent becomes "permanently wrong", i.e. above mentioned change causes its new behavior. Let after first *j* steps agent use new action rule R_c: $b \rightarrow b$ instead of the original rule R: $b \rightarrow a$.

Example: For environment of the system starting with ab^4 developing by P_E and influenced by one agent acting by R two steps and then (in the derivation visualized by $\not\Rightarrow$) by R_c the environment developments as follows

$$ab^4 \Rightarrow abb^3a \Rightarrow ab^4aab \not\Rightarrow ab^5\ ab\ ab\ b \Rightarrow ab^5\ ab^2\ ab^2\ b$$

(In the all steps last occurrence of *b* was rewritten by the agent.)

Growth of the system decreases to linear since starting from the third derivation step we have

$$|w_n|_a = |w_{n-1}|_a \qquad |w_n|_b = |w_{n-1}|_b + |w_{n-1}|_a$$

$$|w_n| = |w_2|_a\,(n-2) + |w_2|$$

Growth of the environment of the eco-system is linear (different coefficient)

$$g(n) = 2 + 3n \quad \text{for } n \geq 2.$$

***Generalization*:**

Let the starting environment has *m* occurrences of symbol *a* and *r* occurrences of symbol *b* and there is $k(\leq r)$ above specified agents in the system. Let after first *j* steps agent use new action rule R_c: $b \rightarrow b$.

After *j* steps the environment has the length

$$g(j) = ½k\, j^2 + (m-½k)j + m + r$$

with $m_j = m + kj$ occurrences of *a* and $r_j = r+mj + ½k\, j(j-3)$ occurrences of *b*.

Then k – 1 agents continue with R and reminding one with R_c. Therefore

$$|w_n|_a = |w_{n-1}|_a + k - 1 \qquad |w_n|_b = |w_{n-1}| - k + 1$$

and

$$g(n+j) = ½(k-1)\, n^2 + (m_j - ½k + ½)n + m_j + r_j \quad \text{for } n \geq j+1.$$

In the general case for more then one component in the system growth is quadratic. The following table summarizes the obtained results for R_c discussed in detail above and add the results for R_ε: $b \rightarrow \varepsilon$.

We present results for the case when changes starts from the beginning (denoted by B) and L denotes the fact that result correspond for the case when random change starts later.

agents	no mutation		$b \rightarrow b$	$b \rightarrow \varepsilon$
0	n + 5			
1	$½\, n^2+½\, n+5$	B L	n + 5 2n+3	5 2n + 4
2	n^2+5	B L	$½(n^2+n)+5$ $½(n^2+5n)+2$	$½(n^2-n)+5$ $½(n^2+n)+6$

5 Conclusion

We presented on an example that small changes of the action behavior of agents in eco-grammar systems can substantially influence the development of the agents' environment. For example, in the case of system with one agent the originally quadratic growth of the environment collapses to the constant one. The investigated system is more sensitive to changes in the case of single agent, and in the case when random change appears "very soon" (at the beginning). To solve the problem for arbitrary eco-grammar system we have to present and solve corresponding difference equation for $|w_n|_a$ and arbitrary letter of the environment. Another interesting generalization of the problem is the case of the systems with nonconstant population of agents.

References

Csuhaj-Varjú, E., Dassow, J., Kelemen, J., Paun, Gh.: *Grammar Systems – A Grammatical Approach to Distribution and Cooperation*. Gordon and Breach, London, 1994

Csuhaj-Varjú, E., Kelemen, J., Kelemenová, A., Paun, Gh.: Eco-grammar systems – a grammatical framework for lifelike interactions. *Artificial Life* **3** (1997) 1-28

Dassow, J., Paun, Gh., Rozenberg, G.: Grammar systems. In: *Handbook of Formal Languages, vol. 2.* (G. Rozenberg and A. Salomaa, eds.) Springer, Berlin, 1997, pp. 155-214

Farmer, J. D., d'A Belin, A.: Artificial life – the coming evolution. In: *Artificial Life II* (Ch. Langton et al., eds.) Addison-Wesley, Reading, Mass., 1992, pp. 815-840

Langton, Ch.: Artificial life. In: *Artificial Life* (Ch. Langton, Ed.) Addison-Wesley, Reading, Mass., 1989, pp. 1-47

Rozenberg, G, Salomaa, A.: *The Mathematical Theory of L-systems*. Academic Press, New York, 1980