AMSE JOURNALS-AMSE IIETA publication-2017-Series: Advances B; Vol. 60; N°1; pp 110-122
Submitted Jan. 2017; Revised March 15, 2017, Accepted April 15, 2017

The Evolution of Artificial Ecosystem Based on the Ecological Chain Algorithm

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Abstract

Aiming at expanding the research scope of artificial life, this paper studies the evolution of artificial ecosystem consisting of five simulated ecological layers, four influence programs and one evolution program. The concurrent execution of all influence and evolution programs is known as the ecological chain algorithm. The author carries out the artificial ecosystem evolution experiment using a set of simulated climate data. It is found that the law that the artificial ecosystem evolves with the simulated climate change is consistent with that of the natural ecosystem. Therefore, the study extends the research scope of artificial life, and provides an alternative to the evolution of natural ecosystem.

Key words

Artificial life, Artificial life population, Artificial ecosystem, Evolution program, Ecological chain algorithm

1. Introduction

The artificial ecosystem (AE) is a simulation of a specific natural ecosystem, which simulates the climate and ecological environment in natural ecosystem through climate and artificial ecological environment simulation, and simulates the biological population in natural ecosystem through artificial life population. As time goes, the simulated climate, artificial ecological environment and artificial life population in different layers of artificial ecological chain interact with each other, and gradually evolve into an artificial ecosystem that evolves according to a certain law [1]. The research of the artificial ecosystem provides an important reference for improving the evolution of existing natural ecosystem [2-3].

Since Von Neumann put forward the idea of artificial life (AL) and CG Langton create the artificial life theory, the academic circle has devoted much attention to the study of artificial life, making rich achievement on artificial life individuals, such as the Von Neumann's Cellular Automata [4], Brooks' robot insect "Genghis" [5], Patties' "ALIFE" [6], etc. Nevertheless, the above studies all focus on simulating the behavior, habit, reproduction and growth of natural life individuals from the perspective of natural life individual. None of them explores the life behaviors and characteristics of artificial life population made up of multiple artificial life individuals [7]. Of course, some models have been developed to explore the life behaviors and characteristics of artificial life population, namely the "L System" of Linder Mayer [8], the "BOLD" of C. Reynolds [9], and the "Xiaoyuan's Fish" of Tu Xiaoyuan [10]. However, these models take the perspective of population, and fail to probe into the interaction and mutual impact of the population with other populations and the environment. Keith Downing's "Eurozone aquatic environment" [11] simulates the pond environment and studies how blue-green algae synthesizes the solar energy and provides the energy to lower animals like water fleas. With a two-layer artificial ecological chain, the artificial ecosystem is too simple and ignores the impact of climate on the environment, not to mention the evolution of artificial ecosystem.

2. The composition of artificial ecosystem

The artificial ecosystem (AE) consists of five simulated ecological layers and one artificial ecological chain. The five simulated ecological layers are simulated climate (SC), artificial ecological environment (AEE), artificial plant population (APP), artificial herbivore population (AHP), and artificial carnivore population (ACP). As shown in Figure 1, the artificial ecological chain has the following links: SC→AEE→APP→AHP→ACP. In the artificial ecological chain, the change of a simulated ecological layer inevitably affects its superior layer. The change law can be expressed by an influence program which simulates the influence pattern of the corresponding ecological layer in the natural ecosystem. As a result, there are four influence programs in the artificial ecosystem, i.e. the simulated climate influence program (SCIP) that simulates the influence of the climate on the artificial ecological environment, the artificial ecological environment influence program (AEEIP) that simulates the influence of artificial ecological environment on artificial plant population, the artificial plant population influence program (APPIP) that simulates the influence of artificial plant population on artificial herbivore population, and the artificial herbivore population influence program (AHPIP) that simulates the influence of artificial herbivore population on artificial carnivore population. Meanwhile, since the artificial life population is constantly evolving, the three simulated ecological layers that contain artificial life population also evolve. Their change law can be expressed by an evolution program that simulates the change law of the corresponding ecological layer in the natural ecosystem. In total, there are three evolution programs in the artificial ecosystem, namely the artificial plant population evolution program (APPEP), the artificial herbivore population evolution program (AHPEP), and the artificial carnivore population evolution program (ACPEP). As above, the artificial ecosystem is composed of five simulated ecological layers, one ecological chain, four influence programs and three evolution programs.

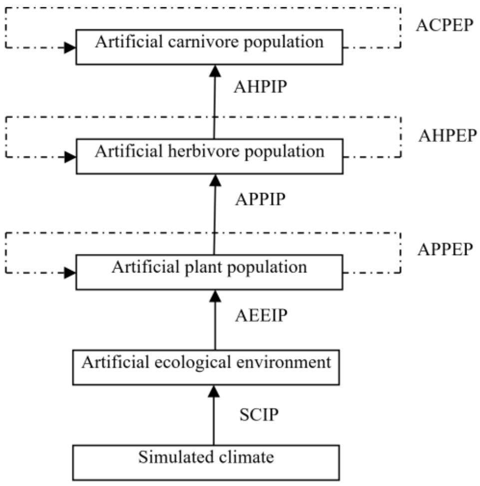

Fig.1. The composition of artificial ecosystem

According to Figure 1, the simulated climate lies at the bottom of the artificial ecosystem. Its changes drive the evolution of the artificial ecosystem. In contrast, the artificial carnivore population lies at the top of the artificial ecosystem. Its changes reflect the results of the evolution of the artificial ecosystem. Since the simulated climate is constantly changing, the artificial ecosystem is a time-varying system.

3. The expression of artificial ecosystem

3.1 The expression of simulated ecological layers

3.1.1 Time period

Time period is the basic unit to measure the temporal variation of the artificial ecosystem. Take unit of temporal vibration of the simulated climate as a time period T, and the temporal variations of other simulated ecological layers would be integer multiples of the time period. The time axis is sequentially divided into different time periods which are numbered as T_0, T_1, T_2, …, T_{n-1}.

3.1.2 Simulated climate (SC)

The SC of a certain time period can be expressed as a multi-field data SCD_i (Figure 2a).

T_i	AC	PW	SI	GGAC

a Simulated climate data

T_i	LA	EL	SLE	MT	AP	CS

b Artificial ecological environment data

T_i	NFP	NMP	SAPP	AE

c Artificial plant population data

T_i	NFAH	NMAH	SAHP	AM

d Artificial herbivore population data

T_i	NFAC	NMAC	SACPP	EPACP

e Artificial carnivorous population data

Fig.2. Data format of each simulated ecological layer in the artificial ecosystem

T_i: The field of the current time period, normally expressed as a binary data with a fixed length;

AC: The field of atmospheric circulation, normally expressed as a 2-bit binary data. It describes the 4 states of the atmospheric circulation of SC in the current time period;

PW: The field of the prevailing wind, which can be expressed as a 2-bit binary data. It describes the 4 states in the prevailing wind belt of SC in the current time period;

SI: The field of sun intensity, which can be expressed as a multi-bit binary data. It describes the sunlight intensity (lux) of SC in the current time period. The more the bits, the finer the expression;

GCAC: The field of the average concentration of greenhouse gases, which can be expressed as a multi-bit binary data. It describes the weighted average of the contribution (ppm) of the main greenhouse gases in SC-carbon dioxide, methane, and nitrous oxide-to global warming at the current time period.

3.1.3 Artificial ecological environment (AEE)

The artificial ecological environment (AEE) of a certain period can be expressed as a multi-field data $AEED_i$ (Figure 2b), in which each field can be represented by a multi-bit binary data according to the specific accuracy and requirements.

T_i: The field of the current time period, same as the T_i in AC;

LA: The field of land area, which describes the area of land occupied by AEE (m^2);

EL: The field of latitude and longitude, which describes the latitude and longitude of the center point of AEE;

SLE: The field of elevation, which describes the mean elevation of AEE;

MT: The field of mean temperature, which describes the mean temperature of AEE in the current time period;

AP: The field of amount of precipitation, which describes the amount of precipitation of AEE in the current time period;

CS: The field of the category of soil, which describes the category of soil (latosolic red soil, red soil, desert soil, meadow soil) of AEE in the current time period.

3.1.4 Artificial plant population (APP)

The uniform distribution of individual plants of the APP in the artificial ecological environment in a certain time period can be expressed as a multi-field data $APPD_i$ (Figure 2c), in which each field can be represented by a multi-bit binary data according to the specific accuracy and requirements.

T_i: Same as above;

NFP: The field of the number of female plants, which describes the total number of female plants of APP in the current time period;

NMP: The field of the number of male plants, which describes the total number of male plants of APP in the current time period;

SAPP: The field of the structural rationality of artificial plant population, which describes the rationality of the structure made up by different aged female and male plants of APP in the current time period. The higher the value of SAPP, the more rational the composition of the population;

AE: The field of accumulated energy, which describes the total accumulated energy of APP in the current time period.

3.1.5 Artificial carnivore population (AHP)

The AHP in a certain time period can be expressed as a multi-field data $AHPD_i$ (Figure 2d), in which each field can be represented by a multi-bit binary data according to the specific accuracy and requirements.

T_i: Same as above;

NFAH: The field of the number of female individuals, which describes the total number of female individuals of AHP in the current time period;

NMAH: The field of the number of male individuals, which describes the total number of male individuals of AHP in the current time period;

SAHP: The field of the structural rationality of artificial herbivore population, which describes the rationality of the structure made up by different aged female and male individuals of AHP in the current time period. The higher the value of SAHP, the more rational the composition of the population;

AM: The field of the amount of meat, which describes the total amount of meat that the AHP can provide for the artificial carnivore population in the current time period.

3.1.6 Artificial carnivore population (ACP)

The ACP in a certain time period can be expressed as a multi-field data $ACPD_i$ (Figure 2e), in which each field can be represented by a multi-bit binary data according to the specific accuracy and requirements.

T_i: Same as above;

NFAH: The field of the number of female individuals, which describes the total number of female individuals of ACP in the current time period;

NMAH: The field of the number of male individuals, which describes the total number of male individuals of ACP in the current time period;

SACPP: The field of the structural rationality of artificial carnivore population, which describes the rationality of the structure made up by different aged female and male individuals of ACP in the current time period. The higher the value of SACPP, the more rational the composition of the population;

EPACP: The field of extinction of ACP, which is the highest level of artificial ecological chain. Its extinction shows the imbalance of the evolution of artificial ecosystem. This field is represented by a 1-bit binary data. EPACP=1 indicates that the artificial carnivore population is not extinct in this time period; EPACP = 0 indicates the artificial herbivore population is extinct in this time period.

3.2 The expression of artificial ecosystem

Because the artificial ecosystem (AE) is a time-varying system, the artificial ecosystem AE_i in a certain time period can be expressed jointly by the data of each simulated ecological layer, i.e. AE_i={SCD_i, $AEED_i$, $APPD_i$, $AHPD_i$, $ACPD_i$}.

4. Ecological chain algorithm

The four influence programs of the artificial ecosystem are executed in parallel. However, the evolution programs and influence programs are executed serially, and the evolution programs are always executed after the influence programs. In other words, APPEP is executed after the completion of AEEIP, AHPEP is executed after the completion of APPIP, and ACPEP is executed after the completion of AHPIP. Therefore, there are 4 concurrent execution processes in the artificial ecosystem.

1) Process 1: the dynamic execution process of SCIP; its execution cycle is n_1T, also the change cycle of AFE;

2) Process 2: the dynamic execution process of AEEIP→APPEP; its execution cycle is n_2T, also the change cycle of APP;

3) Process 3: the dynamic execution process of APPIP→AHPEP; its execution cycle is n_3T, also the change cycle of AHP;

4) Process 4: the dynamic execution process of AHPIP→ACPEP; its execution cycle is n_4T, also the change cycle of ACP. The above four processes act on different simulated ecological layers in the artificial ecological chain. Executed concurrently, they pass parameters to each other. Their concurrent execution constitutes the ecological chain algorithm (AECA).

Suppose that AE_0={SCD_0, $AEED_0$, $APPD_0$, $AHPD_0$, $ACPD_0$} at the time period T_0. After the initial parameters are given, the ecological chain algorithm AECA runs from the time period T1to the time period T_n, covering a total of n time periods. Although the processes of AECA are executed concurrently, they pass parameters to each other. The outputs of all time periods constitute AEi. The current state of the artificial ecosystem can be obtained by AE_n={SCD_n, $AEED_n$, $APPD_n$, $AHPD_n$, $ACPD_n$}.

5. Evolutionary experiment of artificial ecosystem based on ecological chain algorithm

In the experiment, the author selects a SAE (sample of the artificial ecosystem), which is a simulation of a natural ecosystem. There are one artificial plant population, one artificial herbivore population and one artificial carnivore population living in the SAE, whereas the latitude, elevation and land area remain constant. In the experiment, import the three groups of simulated climate data in the order from T_1 to T_9, which change according to different laws. Starting from the initial state, let SAE evolve by the AECA algorithm, where n_1=2, n_2=2, n_3=3 and n_4=2, to obtain the state of the artificial ecosystem at T_9. Then, the author studies the results of the experiment.

5.1 The expression and meaning of the simulated ecological layers of SAE

In SAE, the SCD data has 32 bits and the AEED data has 64 bits. See Table 1 for the data length and code meaning of each field in SCD and AEED.

Table 1. The data length and coding meaning of each field in SCD and AEED

Data of simulated ecological layers	Field name	Data length (bit)	Code meaning
SCD	T_i	8	Sequentially encoded in accordance with time period
	AC	2	00: the rising monsoon airflow in cold front cloud with low vapor content; 01: the sinking trade wind airflow in subtropical anticyclone with high vapor content; 10: the rising trade wind airflow in warm-core cyclone with high vapor content; 11: the sinking westerly wind airflow in cold anticyclone with low vapor content.
	PW	2	00: polar easterlies; 01: prevailing westerlies; 10: southeast trade winds; 11: northeast trade winds
	SI	12	The minimum value represents 0.1 lux; the maximum value represents 104,857.6 lux, evenly encoded
	GGAC	8	The minimum value stands for 300 ppm; the maximum value stands for 556 ppm, evenly encoded
AEED	T_i	8	Sequentially encoded in accordance with time period
	LA	10	The minimum value: 100, 000m^2; the maximum value: 10,240,000 m^2
	EL	17	The higher 9 bits indicate the longitude and the lower 8 bits indicate the latitude
	SLE	7	The minimum elevation: 0m; the maximum elevation: 3,840m
	MT	7	The top bit is the sign bit, and the remaining bits are numeric bits. 1,111,111 is -64°C, 0,111,111 means +64°C.

	AP	11	The minimum value: 0 mm; the maximum value: 20,480 mm, evenly coded
	CS	4	0000~0011 are respectively the four types of soil: latosolic red soil, red soil, desert soil, and meadow soil.

In SAE, the APPD data has 64 bits and the ACPD&AHPD data has 64 bits. See Table 2 for the data length and code meaning of each field in APPD, ACPD and AHPD.

5.2 The initial state of SAE

The initial state of SAE, SAE_0, is illustrated by the data of each simulated ecological layer at the time period T_0. SAE_0={SCD_0, $AEED_0$, $APPD_0$, $AHPD_0$, $ACPD_0$}. See Table 3 for their specific values. It can be seen that the EPACP in $ACPD_0$ equals 1, indicating that the artificial carnivore population is not extinct.

Table 2. The data length and coding meaning of each field in APPD, ACPD and AHPD

Data of simulated ecological layers	Field name	Data length (bit)	Code meaning
APPD	T_i	8	Sequentially encoded in accordance with time period
	NFP	20	The minimum value stands for 0 unit; the maximum value stands for 1,024x10^4 units
	NMP	20	The minimum value stands for 0 unit; the maximum value stands for 1,024x10^4 units
	SAPP	8	It stands for 256 degrees of rationality. The larger the value, the higher the degree of rationality.
	AE	8	The minimum value stands for 8 units; the maximum value stands for 2,048 units
AHPD	T_i	8	Sequentially encoded in accordance with time period
	NFAH	8	The minimum value stands for 0 unit; the maximum value stands for 10,240 units
	NMAH	8	The minimum value stands for 0 unit; the maximum value stands for 10,240 units
	SAHP	4	It stands for 16 degrees of rationality. The larger the value, the higher the degree of rationality.
	AM	4	The minimum value stands for 0 unit; the maximum value stands for 64 units
ACPD	T_i	8	Sequentially encoded in accordance with time period
	NFAC	10	The minimum value stands for 0 unit; the maximum value stands for 2,048 units
	NMAC	9	The minimum value stands for 0 unit; the maximum value stands for 1,024 units
	SACPP	4	It stands for 16 degrees of rationality. The larger the value, the higher the

			degree of rationality.
	EPACP	1	0 stands for “extinct”; 1 stands for “not extinct”

Table 3. The initial state of SAE (hexadecimal)

Data of simulated ecological layers	SCD_0	$AEED_0$	$APPD_0$	$AHPD_0$	$ACPD_0$
Numerical value	0068 8F0F	00201023 C7838FF8	00800004 0000F8E9	0086 4AEC	0043 16CD

5.3 The input data of the experiment

The input data of the artificial ecosystem evolution experiment based on the ecological chain algorithm are three groups of simulated climate data which change according to different change laws. The simulated climate data changes once in each time period. There are 9 time periods from T_1 to T_9. Thus, each group has 9 simulated climate data, i.e. SCD_1, SCD_2, SCD_3, SCD_4, SCD_5, SCD_6, SCD_7, SCD_8, and SCD_9 (Table 4). For the first group of data, the general atmospheric circulation and prevailing wind change while other parameters remain the same; for the second group of data, the sunlight intensity gradually increases while other parameters remain the same; for the third group of data, the concentration of greenhouse gases gradually rises while other parameters remain the same.

Table 4. The three groups of input data of the experiment (hexadecimal)

Group / Data	Group 1	Group 2	Group 3
SCD_1	01F88F0F	01689F0F	01688F17
SCD_2	02E88F0F	0268AF0F	02688F1F
SCD_3	03C88F0F	0368BF0F	03688F27
SCD_4	04B88F0F	0468CF0F	04688F2F
SCD_5	05A88F0F	0568DF0F	05688F37
SCD_6	06988F0F	0668EF0F	06688F3F
SCD_7	07788F0F	0768FF0F	07688F47
SCD_8	08588F0F	08690F0F	08688F4F
SCD_9	09388F0F	0968A00F	09688F57

5.4 The experiment procedures

Because the input data of the experiment are three groups of simulated climate data which change according to different change laws, the artificial ecosystem evolution experiment based on the ecological chain algorithm is carried out independently for each group of simulated climate data but following the same procedures. Each time, the initial state of the SAE is set as SAE_0={SCD_0, $AEED_0$, $APPD_0$, $AHPD_0$, $ACPD_0$}; starting from the time period T_1, the SAE receives the input data SCD_1, SCD_2, SCD_3, SCD_4, SCD_5, SCD_6, SCD_7, SCD_8, and SCD_9, and executes the ecological chain algorithm AECA. The process terminates at the time period of T_9. Thus, the AECA runs a total of 9 time periods. The execution cycles of Processes 1, 2 3 and 4 are respectively 2T, 2T, 3T and 2T. The execution result of ecological chain algorithm AECA reflects the status of SAE in time period T_9, SAE_9. Hence, SAE_9={SCD_9, $AEED_9$, $APPD_9$, $AHPD_9$, $ACPD_9$} is also the output data of the experiment.

5.5 The output data of the experiment

The output data of the experiment correspond to the three groups of simulated climate data which change according to different change laws. There are three different output data SAE_9 (Table 5).

Table 5. The output data corresponding to the three groups of input data (hexadecimal)

SAE_9	SCD_9	$AEED_9$	$APPD_9$	$AHPD_9$	$ACPD_9$
Group 1	0938 8F0F	09201023 C7841008	09800804 0066F6E8	0988 40EB	0942 D68D
Group 2	0968 A00F	09201023 C7A002F9	0930ACE2 0C684463E	0926 1A53	091A 8D68
Group 3	0968 8F57	09201023 C7B001FA	0910A6F0 F4762D17	0914 0922	0909 C484

When the first group of data is imported, for which the general atmospheric circulation and prevailing wind change while other parameters remain the same, there is no significant change to each ecological layer in the artificial ecosystem from the initial state after the SAE has evolved through 9 time periods to the time period T_9: the artificial carnivore population on the top layer is not extinct. When the second group of data is imported, for which the sunlight intensity gradually increases while other parameters remain the same, there is significant changes to each ecological layer in the artificial ecosystem from the initial state after the SAE has evolved through 9 time periods to the time period T_9: the temperature rises and the amount of precipitation decreases in the artificial ecosystem; the number of plants in the artificial plant population shrinks, the population structure becomes irrational, and less energy is accumulated; the number of individuals in the artificial herbivore population plunges, the population structure is less rational, and the amount of meat available for artificial carnivore population drops significantly; as a results, the number of individuals of artificial carnivore population falls dramatically, undermining the rationality of population structure and resulting in extinction. When the third group of data is imported, for which the concentration of greenhouse gases gradually rises while other parameters remain the same, the state of each ecological layer in the artificial ecosystem after the SAE has evolved through 9 time periods to the time period T_9 is even worse than that in the simulation based on the data of Group 2 and the artificial carnivore population on the top layer also vanishes into extinction. As above, how the artificial ecosystem evolves with the simulated climate data is in good agreement with how the natural ecosystem changes with climate change as reported in literatures [12-14].

Conclusion

The study of the evolution of artificial ecosystem based on ecological chain algorithm enriches the research of artificial life. Giving full consideration to the climate influence on the artificial ecosystem, the study expands the scope of artificial life research from artificial life individual to artificial life population, and from a single population to the artificial ecosystem consisting of multiple populations. According to the experiment results, it is discovered that how the artificial ecosystem evolves with the simulated climate data is in good agreement with how the natural ecosystem changes with climate change. This means the evolution of artificial ecosystem based on ecological chain algorithm is a scientific method to study the evolution of natural ecosystem. It can replace the natural ecosystem evolution targeted at natural ecosystem, which greatly shortens the research cycle of natural ecosystem evolution.

Acknowledgments

This paper is made possible by the generous support from Anhui Provincial Natural Science Foundation (1508085MF124).

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