 ISSN1346-7824

An Idea of an Emergent and Multiple-evolutionary Design System for Architecture, Cities and Society Using Multiple Genetic Algorithms

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(Received 23 July 2005; accepted 27 January 2006)

This paper presents an idea of emergent and multiple-evolutionary system for designing architecture, cities and society using multiple genetic algorithms. Spontaneous evaluation and synthesis of architecture, cities and society are possible with this system using multiple genetic algorithms. Architecture, cities and society are designed autonomously under emergent and multiple-evolutionary consensus formation if design parameters, formation rules, evaluation factors, and evaluation membership functions are given.

Keywords: multiple optimization, genetic algorithms, fuzzy membership function

1.INTRODUCTION

Architecture, cities and society have been originated spontaneously. However, in many cases, their fates came to be determined by top-down economic and political forces. Nevertheless, nowadays, the aspects of architecture, cities and society are changing in terms of development and distribution because of information technology (IT).

Architecture, cities and society are composed fundamentally based on their internal enhancement and their requirements for residents. Therefore, external conditions should be considered as necessary adjustments. The authors have already proposed an Inte-life (intelligence and life) co-evolutionary system [1] with progressive intelligence and evolutionary formation of objects. Herein, the authors develop the system and present an emergent and multiple-evolutionary design system for architecture, cities and society using multiple genetic algorithms [2].

2.SINGLE AND DOUBLE OPTIMIZATIONS IN INTE-LIFE CO-EVOLUTIONARY SYSTEM

The authors proposed the Inte-life Co-evolutionary System-I (shown in Fig. 1) based on the above-mentioned principle of formation through internal enhancement.

In this system, a unit space proliferates as an imitation of plants' growth processes. A mass of unit spaces is evaluated using a fuzzy system [3] and is optimized using GAs. Fig. 2 shows an example of optimization for single architecture [4]; an example of optimization for cities is shown in Fig. 3 [5].

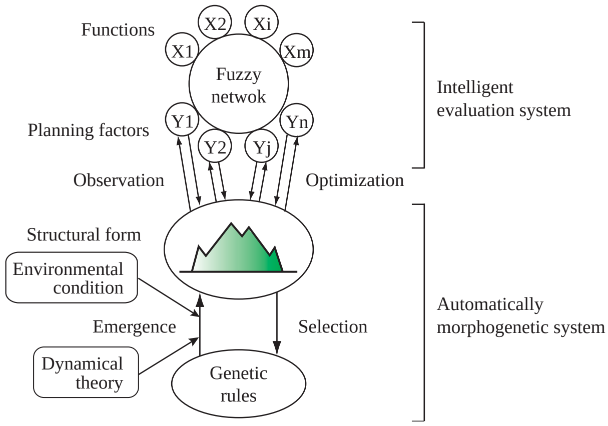

Fig. 1. Inte-life Co-evolutionary System-I (with single GAs) [1].

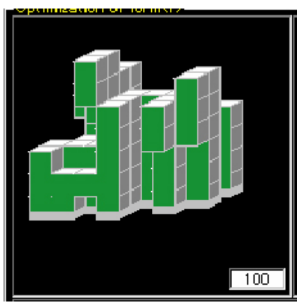

Fig. 2. An example of optimization for single architecture [4].

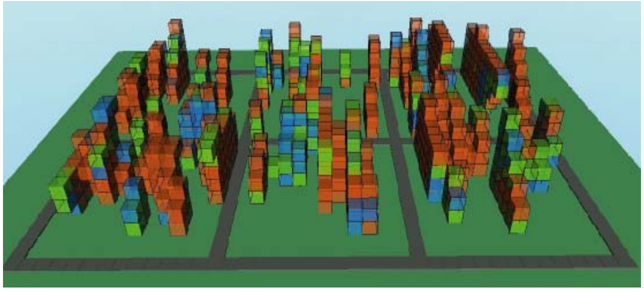

Fig. 3. An example of optimization for cities [5].

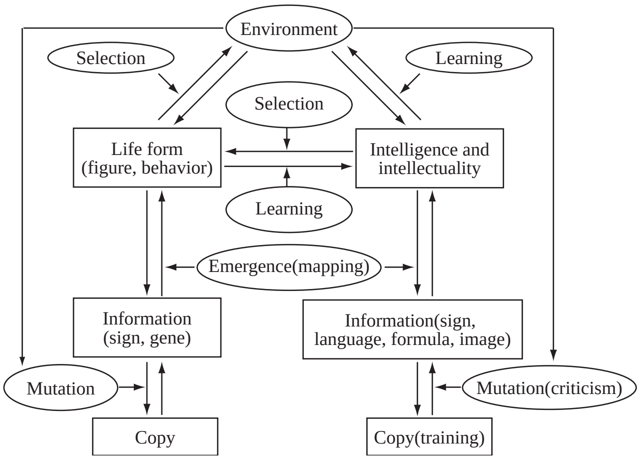

Fig. 4. Inte-life co-evolutionary system-II (with double GAs) [6].

The authors put forward the Inte-life co-evolutionary System-II [6] (shown in Fig. 4), in which evaluation functions themselves are selected and evolved by upper evaluations using double GAs. By this evolution, this optimization system can make great progress for evaluation from external perspectives. Figs. 5 and 6 show results of the Inte-life co-evolutionary system-II. The former shows the process and result of evaluation functions and single architectural formation [7]. The latter shows a result of multiple architectural formations on the same site under architectural planning and volume conditions [8].

3.EMERGENTANDMULTIPLE-EVOLUTIONARYSYSTEM OFARCHITECTURE,CITIESANDSOCIETY

3.1. Systematized architecture, cities and society

Fig. 7 shows that it can be assumed that the system of architecture, cities and society comprises three elements: unit space, space distribution, and temporal-spatial interrelation.

3.2. Emergent and multiple-evolutionary system

As a more comprehensive system than the Inte-life co-evolutionary system-I, and system-II, the authors propose an emergent and multiple-evolutionary design system of architecture, cities and society in this paper using multiple-GAs shown in

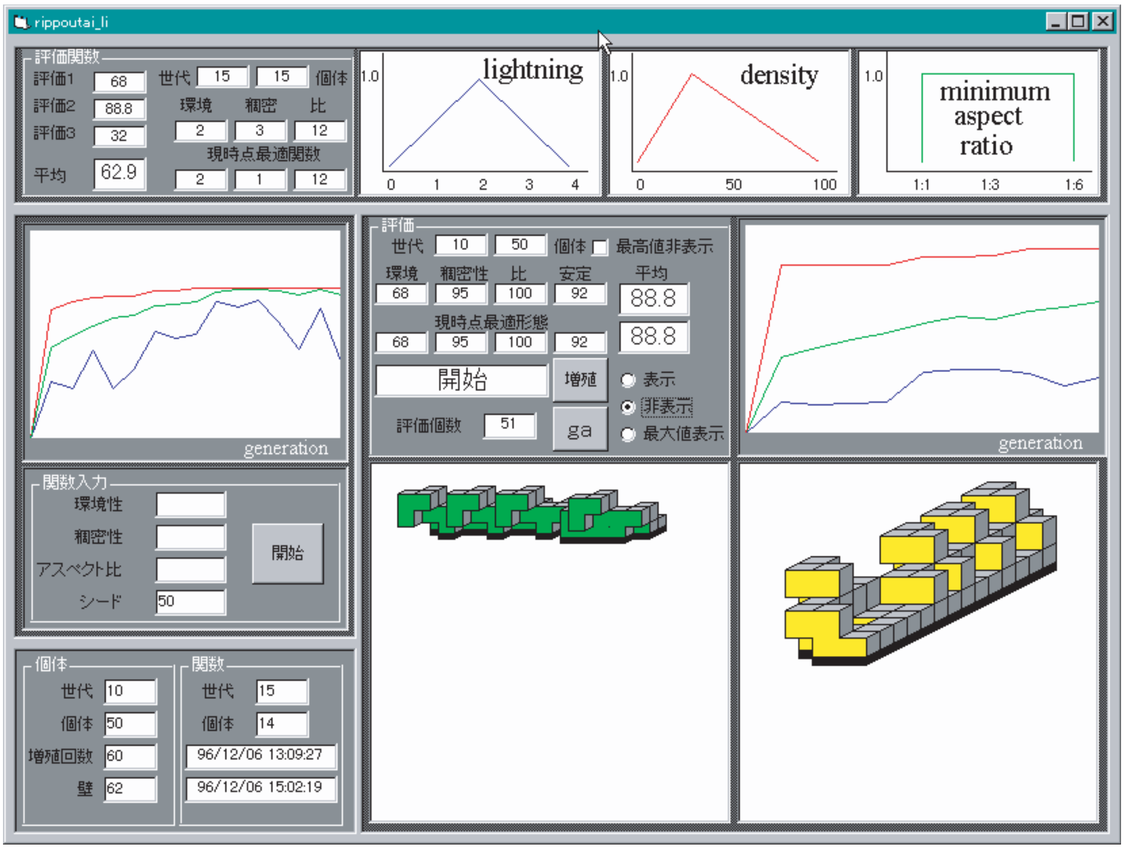

Fig. 5. Example of the Inte-life co-evolutionary system for single architecture [7].

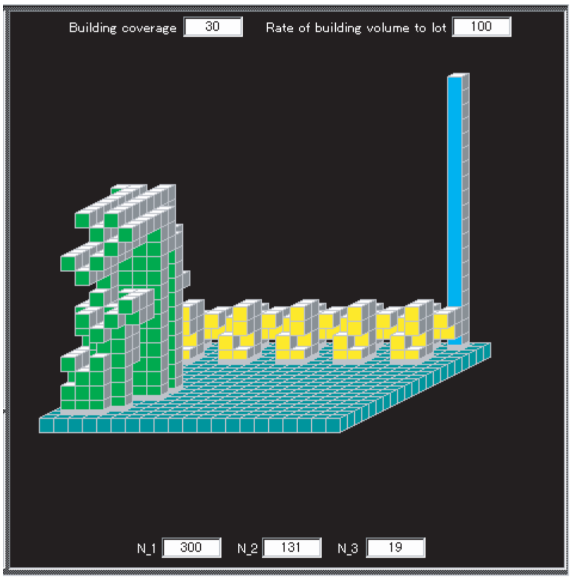

Fig. 6. Example of the Inte-life co-evolutionary system for multiple architecture [8].

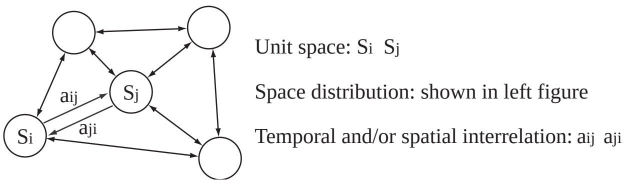

Fig. 7. System modeling of architecture, cities and society.

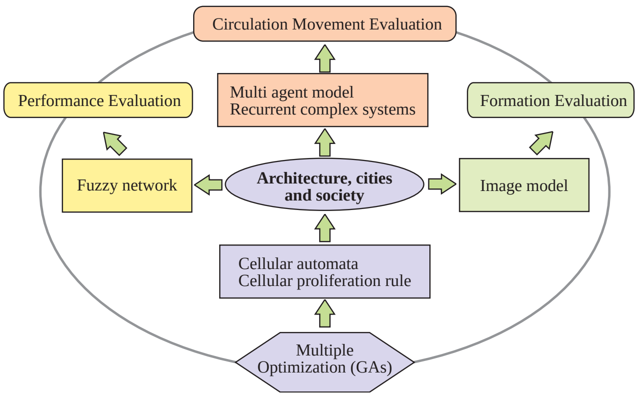

Fig. 8. Emergent and multiple-evolutionary system (with multiple-GAs).

Fig.8 based on the system models shown in Fig. 7. The algorithms of these multiple GAs will be explained in Chapter 4.

In this system, three different evaluation items are employed. They correspond to the elements in Fig.7 as follows:

1) Performance evaluation: Unit space, Total system.

2) Molding form evaluation: Unit space, Space distribution.

3) Circulation movement evaluation: Temporal-spatial interrelation.

Each evaluation item above corresponds to the interrelation of the Inte-life co-evolutionary system-II (shown in Fig. 4). Thereby, this system comprises three kinds of such system-II with double GAs; it is optimized and evolved by multiple-GAs as a total system.

In the first stage, cellular proliferation methods including cellular automata [9] and the L-system [10] form architecture, cities and society. In the second stage, their respective performances are evaluated using a fuzzy network, thereby forming an image model and circulation movement by multi-agent model. This system is distinctive in that evaluation functions also change and adjust themselves as they evolve by learning under multiple interactions.

3.3. Formation of architecture, cities and society by rules of cellular proliferation

The cellular automata and the L-system models are applicable to morphogenesis by cellular proliferation. The space unit is defined as a cubic cell: only the leading edge of cells grows prodigiously. Fig. 9 shows the proliferation space. Fig. 10 shows the rules of cellular proliferation that determine the direction of proliferation depending on the surrounding cells' conditions.

Fig. 11 shows an example of a process of single architectural

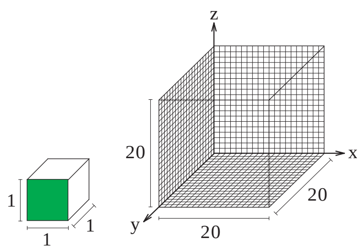

Fig. 9. A proliferation space by 3D-cellular automata [7].

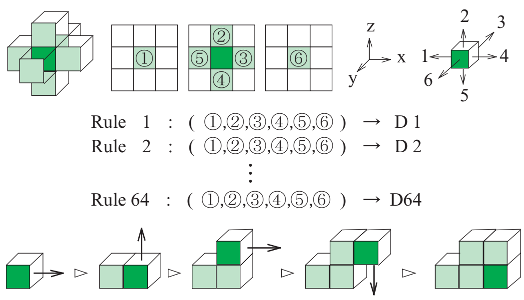

Fig. 10. Rules of cellular proliferation deciding the direction of proliferation [7].

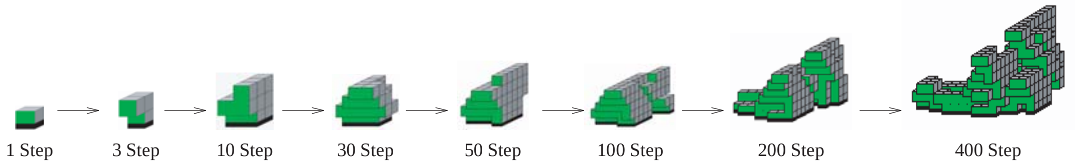

Fig. 11. An example of a process of single architectural formation [7].

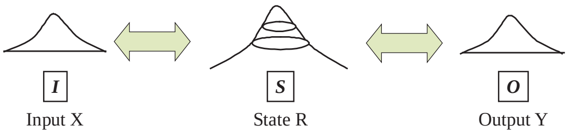

Fig. 12. Model of bi-directional fuzzy system [12].

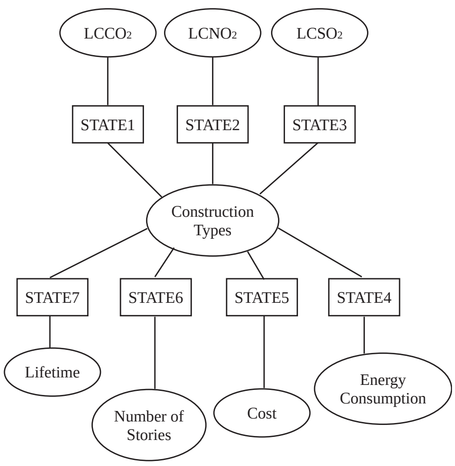

Fig. 13. Fuzzy network for optimal building construction types [12].

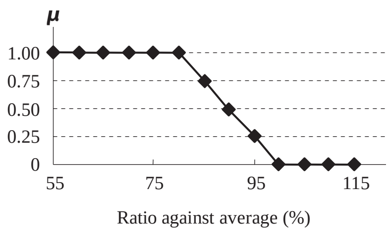

Fig. 14. Input of carbon dioxide emission data [12].

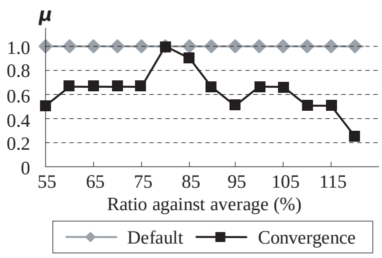

Fig. 15. Output of energy consumption relative amounts [12].

formation. The optimization examples shown in Figs. 2, 3, 5, and 6 are given finally.

3.4. Performance evaluation

Major divisions of architectural performances are generally recognized to include economics, safety, amenity, ambiance, and others. Nevertheless, contention surrounds the conversion of physical and geometric data of architecture to evaluation items and their criteria for subsequent evaluation.

The authors proposed a fundamental concept of fuzzy network [11] comprising fuzzy systems shown in Fig. 12, and presented a method of its application to structural planning and performance evaluation.

Fig. 13 shows a model of a fuzzy network for optimal building construction types [12] by which one can consider global environments and evaluate environmental loads.

Required variables are obtainable as fuzzy sets through inputting given data and solving the fuzzy network. For example, when a requirement for carbon dioxide emissions is input, as shown in Fig. 14, energy consumption is obtained as the fuzzy sets shown in Fig. 15.

Fuzzy sets allow perfectly natural and human calculation and information processing, when uncertainty, ambiguity and subjectivity exist among data (and variables) and their evaluations regarding architecture, cities and society.

3.5. Circulation movement evaluation

People, materials, money, information and energy are moving among architecture, cities and society. Circulation and flow efficiency are important evaluation measures for dynamic behaviors of architecture, cities and society. The multi-agent model (shown in Fig. 16) can be applied practically to simulate this system.

Some applications are performed in the authors' laboratory. A model of a circulating system of structural members is shown in Fig. 17 [13]. That model can be considered as a kind of artificial society. Fig. 18 [13] shows a result of this system and changes of structural members in a stockyard agent.

Definition of human behaviors using a basic model of a pedestrian agent shown in Fig. 19 allows tracing a trajectory like

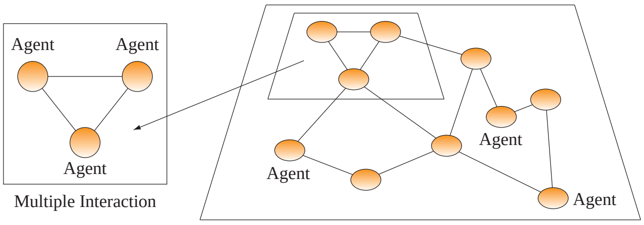

Fig. 16. An example of a multi agent system.

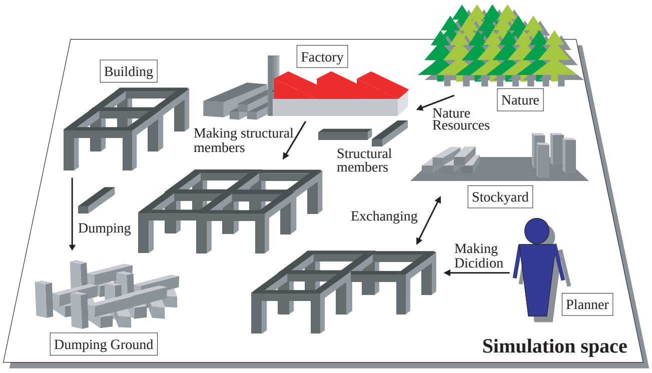

Fig. 17. Model of the structural members•f circulation system [13].

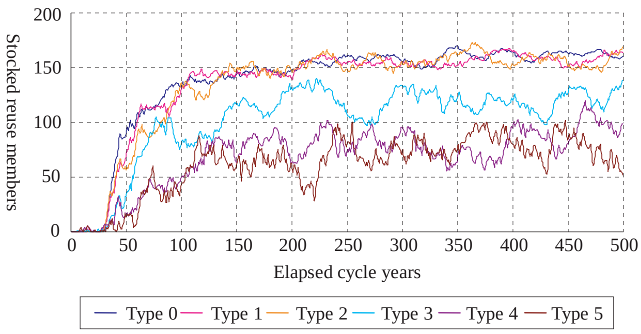

Fig. 18. Changes of structural members in a stockyard agent [13].

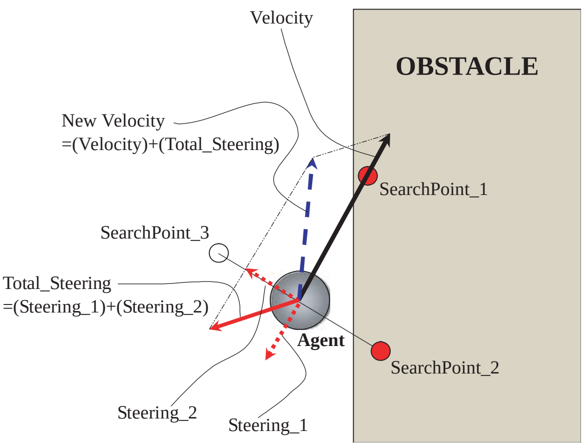

Fig. 19. Basic model of a pedestrian agent [14].

that shown in Fig. 20. It is applicable to a dynamic system aiming at verification of architectural spaces and functions [14].

3.6. Formation evaluation

The optimization system for the third evaluation, formation evaluation, is under development in the authors' laboratory. Therefore, this paper presents only the following fundamental idea.

Image of form implies vision, graphics and formation; it can be evaluated viscerally, intuitively, subjectively, aesthetically or through preference. Fig. 21 shows an abstract painting similar to Kandinsky's. This painting includes much information from the aspect of formation: lines and curves, a horizon, verticals and skewed lines, stability and instability, complexity and simplicity (fractal dimension), duplication, density, branch, diffusion, dispersion, concentration, radiogram, periodicity, shading, colored and achromatize, color tone, numerous graphical elements, and so on.

However, Fig. 21 depicts numerous features that are analogous to those of architecture, cities and society. It is difficult to describe the features verbally or numerically, but it is easy to do so through analysis of Figure like Fig. 21 because Figures help us to intuitively understand.

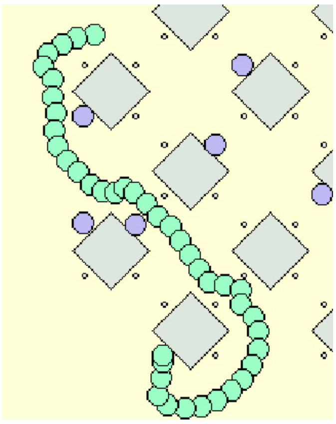

Fig. 20. Trajectory of a pedestrian agent [14].

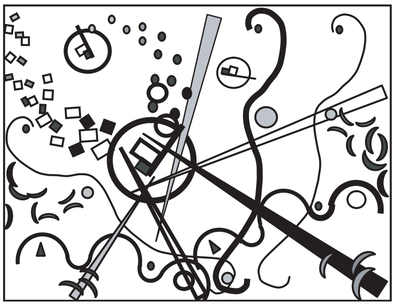

Fig. 21. An abstract painting like Kandinsky's.

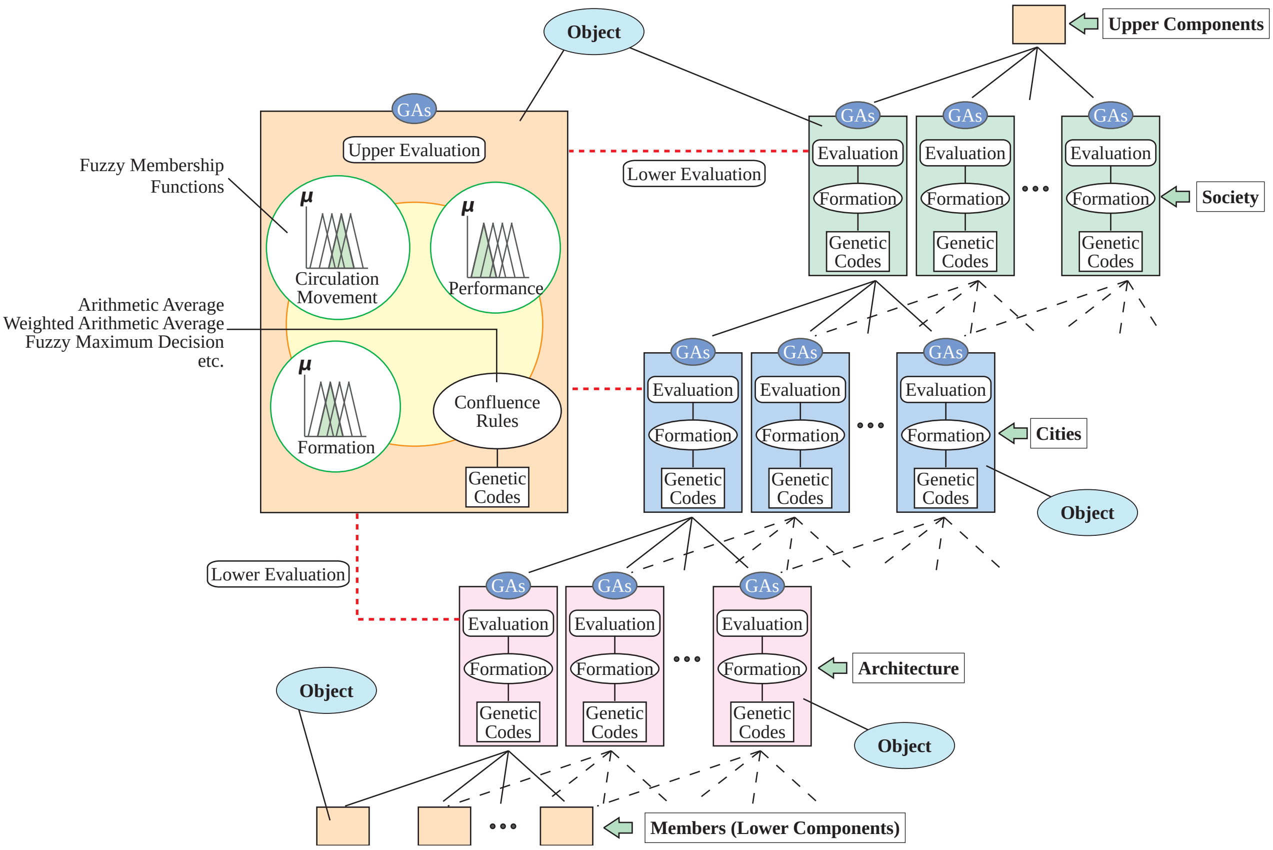

Fig. 22. General concept of multiple-GAs with fuzzy membership functions.

4.MULTIPLE-GAs

4.1. General concept of multiple-GAs

In the Inte-life co-evolutionary system-I with single GAs shown in Fig. 1, through an optimization by genetic rules for automatically morphogenetic system, only forms of single architecture or cities are optimized. The fuzzy network can reflect users' opinions to this system. Furthermore, in the Inte-life co-evolutionary system-II with double GAs shown in Fig. 4, both genetic rules of form and its evaluation are employed. Therefore, more intelligent simulation can be performed in the system-II. The lower morphogenetic system in the system-I (Fig. 1) corresponds to plants, the system-I to animals with brains, and the system-II (Fig. 4) to human beings.

Regarding society and cities as human crafts, every system consists under human consideration and action. Simply speaking, a society consists of cities, a city consists of architecture, and architecture consists of members. Using GAs, a system can be optimized when its formation rules and evaluation methods are given. Therefore, the optimization system shown in Figs. 1 and 4 can evolve into such a general concept of an emergent and multiple evolutionary system with multiple-GAs shown in Fig. 8 and 22. A salient feature of this system is that fuzzy membership functions and their confluence rules perform the parallel and hierarchical evaluations. That feature enables us to optimize the evaluations themselves using GAs, as shown at the upper left-hand side of Fig. 22.

According to the concept shown in Fig. 22, formation rules (and design parameters) are given for architecture, cities and society, and fuzzy membership functions, along with evaluation factors and their confluence rules. Using them, we can perform emergent and multiple evolutionary optimization using multiple-GAs.

4.2. Component of multiple-GAs

Basically, a single architecture built in site is the smallest component of multiple-GAs system. In order to optimize the architecture, evaluation functions shown in Fig. 23 are considered.

City is taken into account as upper component of the architecture. When evaluating cities, for example, evaluation functions shown in Fig. 24 are considered. These evaluation functions consist of evaluations calculated from location of architecture that is a lower component of city and those calculated from whole cities themselves. In case of consideration of interaction among architecture, cellular automata [9] model is effective when evolving architecture and site, because spatial

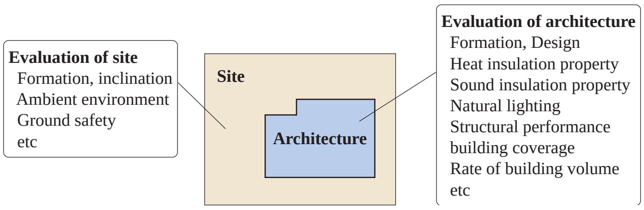

Fig. 23. Evaluation indexes of architecture and site [15].

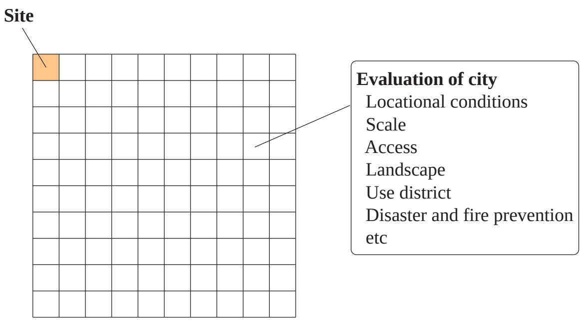

Fig. 24. Evaluation indexes of city [15].

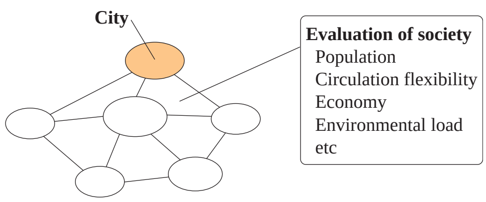

Fig. 25. Evaluation index of society [15].

accessibility has a significant effect on the architecture and the site.

Furthermore, a society is taken into account as upper component of cities. When evaluating society which is set of city network, for example, evaluation functions shown in Fig. 25 are considered. Nowadays, transfers of materials, information and energy among cities are very active and easy. Therefore, in case of consideration of interaction among cities, multi agent model is effective when observing and evaluating cities.

Generally, in GA operations, genetic parameters such as a crossover ratio and/or a mutation ratio are set up in accordance with a problem domain. So, in this system, it is assumed to employ Parameter-free GA (PfGA) [16], because PfGA need not configure genetic parameters. In this algorithm, local clusters are selected from whole solution space, and more local clusters called 'family' which consists of four individuals are selected from the local clusters. Parameters of mutation ratio and/or crossover ratio can change flexibly. In the process of evolution, number of individuals in the local clusters changes depending on fitness of individuals in the 'family'. The algorithm is characterized by a change of number and content of individuals in the local clusters.

In case of executing a simulation on the architecture and/or the city, it is necessary to take account of not only evaluation functions calculated numerically and objectively but also those determined by subjective judgments of human beings simultaneously. In this system, fuzzy system using type II fuzzy set is employed. In type II fuzzy set, evaluations are performed by linguistic variables, and objective and subjective evaluation functions with different rating scales can be treated simultaneously and in the same manner. By using fuzzy system, various evaluation functions with trade-off relationship can be taken into account in the same level and be applied to decision-making based on experience and/or subjective judgments of human beings. This method is actually applied in the authors' research [17].

4.3. Effectiveness of multiple-GAs

In this section, for example, an optimal planning system of seismic retrofitting which corresponds to the optimization of members shown in Fig. 22 is introduced, and the effectiveness of multiple-GAs with the evolution of evaluations is clarified.

A co-evolutionary fuzzy system on structural performances is developed by using multiple-GAs and is applied to an optimal planning of the seismic retrofitting. In this multiple optimization system, both optimization of a planning and that of evaluation functions are performed simultaneously. As for evaluation functions, a construction cost, an incremental load capacity, and a deterioration of dwelling ability are employed. In the inner level, a planning of the seismic retrofitting is optimized based on a certain set of evaluation functions. In the outer level, a set of evaluation functions described by membership functions is also optimized by using the results in the inner level. Here, as for evaluations in the outer level, it is assumed that evaluation values in the inner level become high and almost same, and that an optimal solution exists under employed evaluation functions. This multiple-GAs mentioned above can be transformed to the general single GAs by managing genotype of a planning on the seismic retrofitting and evaluation functions.

Here, single and double GAs are performed under the same evaluation indexes and the execution time (i.e.; a few minutes). In each case, ten simulations are carried out with different random seeds. Results of each simulation are shown in Table 1 [18]. Results in Table 1 show that more suitable solutions can be obtained in case of the double GAs in any cases such as maximal, average and minimal values of the fitness and it is verified and clarified that multiple-GAs can explore extensively

Table 1. Comparison result of the simulations of single and double optimization [18].

case	The fitness of result (single optimization)	The fitness of result (double optimization)
1	0.512	0.586
2	0.599	0.603
3	0.587	0.582
4	0.492	0.581
5	0.559	0.599
6	0.586	0.599
7	0.582	0.596
8	0.558	0.580
9	0.576	0.603
10	0.599	0.601
min	0.492	0.580
max	0.599	0.603
average	0.565	0.593

and is hard to fall into local solutions.

4.4. Future aspects

Judging from computational and practical viewpoints, multiplication of GAs engenders a great merit: we need not use an astronomically great number of combinations in a total system. Only necessary items that are linked with the upper GAs are taken into account in such a multiple-GAs method. Furthermore, a GAs procedure can be considered as an object. Therefore, an object oriented programming concept can be employed.

Then many kinds of combinations of GAs procedures can be considered as shown in Fig. 26, where a hollow circle expresses a GAs procedure. Multiple-GAs systems of network types reflect the real world. However, their algorithmic solutions are not yet given and remain as a subject for future examination.

Here, the purpose of this paper is to presents a scheme of methods as integration, coordination, extension and development of the authors' laboratory's research achievements. So, in order to enhance this scheme, the authors would like to introduce the latest research achievements.

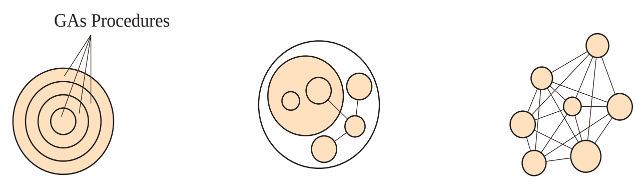

Fig. 26. Combination types of GAs procedures.

In references [19] and [20], a circulation-type society is expressed and described with multi-agent model which consists of the following agents: user, builder, reuse maker, fabricator, waste disposer, material maker and earth bank. Structural members, materials, resources and monies move among these agents. Reasonable prices [19] of structural members and environmental taxes [20] can be optimized by PfGA in this system considering equal distribution [19] of monies among agents and reduction [20] of carbon-dioxide (CO_2) emissions, resource consumption and waste materials. Such economic considerations evolve those dynamic circulation systems.

In references [21] and [22], fractal dimension is applied to analysis of architectural and urban landscape and that of urban space planning. This method is under development, though it has a potentiality for the objective formation evaluations (Fig. 8).

5. CONCLUSION

The authors have demonstrated that it is possible and effective to apply a multiple-GAs system to design architecture, cities, and society. Through this system, architecture, cities and society can evolve autonomously and adapt themselves to their circumstances and be optimized under emergent and multiple evolutionary consensus formation among people.

ACKNOWLEDGMENTS

This study was supported by the Japan Society for the Promotion of Science (2004 Grants-in-Aid for Scientific Research, Scientific Research (A)(1), No.14205087), and supported in part by the Twenty-first Century Center of Excellence (COE) Program “Design Strategy towards Safety and Symbiosis of Urban Space” awarded to Graduate School of Science and Technology, Kobe University. The Ministry of Education, Culture, Sports, Science and Technology of Japan sponsors the Program.

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