Search for the Application of Complexity Theory to Organization Management: Genetic Algoritm-Based Simulation of Dynamic Organizational Evolution

Choi, Chang-Hyeon, Dept. of Public Administration, College of Law & Public Administration, Kwandong University, 522 Naegok-dong, Kangnung City, Korea, 210-701. E-mail : choich@mail. kwandong.ac.kr

Abstract Complexity is an important variable to organization theory. Here we focus how organization evolves and how organization's routines change according to the degree of complexity. As the complexity of organization depends on the intercorrelation strength among routines, I use NK model to describe the organizational fitness landscape and the degree of complexity. Especially, from the characteristic of evolving organization I use Genetic Algorithms to describe how an organization adapts.
In this process, we show the exponential increment of knowledge and desirable routines as time goes on and the need of exchange information between individual especially in complex environment. Moreover organization should get over the 'premature problem' or 'lock-in effect' trapped in local optimum with the mutation technique such as outsourcing new routines from other organizations. I also find the three developing stages which organization evolves such as dramatical improvement, forming the structure with accumulated improvement and incremental improvement. This suggests that organization's strategy to the environment should be launched according to its history i.e., stages and levels of complexity. I draw 3 by 3 strategy matrix overview how an organization handles this problem.

INTRODCUTION

First this article aims to discuss complex adaptive system (CAS) - a self organizing system of interacting components that evolves by constantly adapting to its changing environment and itself - in the point of organizational theory and the evolutionary adaptive strategy of organization to environments. Even though the traditional organization theory such as scientific management or behavioralism relatively neglects the environment as an exogenous variable, the resource constraint originated from tough competition among organizations doesn't allow such approach. Especially environment itself has changed so rapidly and complexly that to find the way to adapt is not an option but a necessity for organizations to survive.

Second, I'll deal with complexity using Genetic Algorithm (GA) which is developed in biology and computer science to simulate how organizations develop and optimize. The characteristics of organization's dynamic evolutionary process has a similarity with the GA, which enables us to describe the organization's interactive responses to the complex environment.

Third, I will focus on the importance of information as an organizational key resource in dynamic process. Computer science gives us tools that accumulate data and transform it into information that is helpful to decision-making and optimization of organizational evolution. This is the reason I focus on the organizational routines as an integrated information structure.

Fourth, the critical issue in all CAS is the relation and trade-off between the exploration of the new possibilities in the search space and the exploitation of the old certainties. Exploration implies variation, experiment play, and innovation; while exploitation implies selection, implementation and execution, refinement. I briefly explain how GA performs the exploration and exploitation.

2. THE CHARACTERISTICS OF ORGANIZATIONAL EVOLUTION.

I specify the characteristics of organizational evolution in the empirical stance. First, the organization is coerced into adapting to the varied environment by redesigning the organizational routine or restructuring. Because knowledge-based companies such as network industry or high-tech industry are competing in winner-take-most markets in which milieu, management becomes not production-oriented but mission-oriented and a new product needs to be twice or three times better in some dimension such as price, speed, convenience (Arthur, 1996). Second, the organization needs to redesign itself using its accumulated or "learned" information by organizational learning to keep its continuity. Because the organization will pay more sunk costs raised in the redesign process. Third, to perform upper process, the organization needs to estimate the existing organizational routine to decide whether it is favorable or not using the fitness function and to find decision rule. Fourth, in this dynamic process the organization redesigns itself by outsourcing new factors not contained in present organizational routines.

3. BUILDING A MODEL

3.1 Model assumption.

From the characteristics of organizational evolution I suggested above, I make some assumptions to build a model. Assumption 1) The environment is not static but dynamic and complex. Assumption 2) The organization chooses the desirable organizational routines that enhance the adaptability to environment. Assumption 3) The members of an organization change desirable information each other and change information accumulated as an organizational learning. Assumption 4) The redesigning process of organization is stochastic process.

3.2 The basic concept of NK model and GA.

Here I introduce the NK model to construct the fitness landscape and GA to show the dynamic adaptation of organization.

3.2.1 NK model and Fitness Function.

A useful starting point for an analysis of adaptation and selection processes is a specification of a mapping from a characterization of an organization's form to a statement of its relative fitness or likelihood of survival, i.e., fitness landscape.
Kauffman (1993) demonstrates that the topology of the fitness landscape is determined by the degree of interdependence of the fitness contribution of the various attributes (genes) of an organism. In the NK model, N is the number of genes randomly assigned fitness contributions of 0.0 to 1.0, drawing from a uniform distribution. K stands for the average number of other sites that are interdependent with the N sites. The web of intercorrelation (complexity) grows in size, the likelihood that a particular N^{th} site will achieve higher than average fitness tends toward zero (Kauffman, 1993; McKelvey, 1996). So when K=0, the fitness landscape is single peaked landscape and as K grows, the fitness landscape is multipeaked landscape.
To simplify the model, I define N=8, each with 2 allele (0,1) and K will be a parameter describing the uncertainty. Here I use the fitness landscape in three cases that single-peaked, smooth correlated fitness landscape, and high correlated fitness landscape corresponding to the K=0, 0<K<7 and extremely random fitness landscapes having multipeaks to the K=7.

Table 1: Comparison of the evolution biology and organization science terminology

Notation	Biology	Organization Science
N	No. of genes	No. of organizational routine
K	No. of interaction	No. of interactions among organizational routines
A	No. of alleles	No. of possible selections

3.2.2 Genetic Algorithm.

GA is a search algorithm based on the mechanics of natural selection and natural genetics that has two main goals: (1) to abstract and rigorously explain the adaptive processes of natural system, and (2) to design artificial systems that retains the important mechanisms of natural systems(Goldberg, 1989). From the 4 model assumptions, I can use GA to describe the dynamic adaptation of organization.
The main operator is reproduction, crossover, and mutation operator that enable parallel search in uncertain environment. I show why organizational learning increases in exponential mode using the schema theory. This can well operate in the well-structured information database which enable the selecting the desirable figures.
Here I also discuss the premature problem that causes the local optimum settling and the usage of mutation and crossover. The mutation plays a role in introducing the new information to the organization and the crossover plays a role in sharing the well-fitted information among the individuals who consist of the organization.

Table 2: Comparison of Biology, GA and

Organization Theory terminology

Biology	Genetic Algorithm	Organization Theory
Choromosome	String	Individual
Gene	Feature, character	Routine
Allele	Feature value	The number of possible options that each routine has
Locus	String position	The order among routines
Genotype	Structure	Individual's routine type
Phenotype	A decoded structure	The input value of organization's fitness function.

In the case of organization, the organization itself is regarded as a population, the characteristic of an individual is phenotype and each routine that an individual has is mapped to genes. In the end, an individual responses to every organizational routines on his or her own way which is evaluated according to the fitness function's value and organization will use the desirable individual's routine to the next generation's design with high probability.

Let's look over more specifically in example how GA is different to the traditional searching method so called hill-climbing method.

I have an equation (eqa.1) and given interval of x, y and finding maximum value is our goal.

$F(x,y)=Sin(x^* Sin(y))$ s.t.) $0<x, y<=7$ …. Eqa. 1.

As you see, Eqa. 1) shown in below graph, It will be hard to find maximum value.

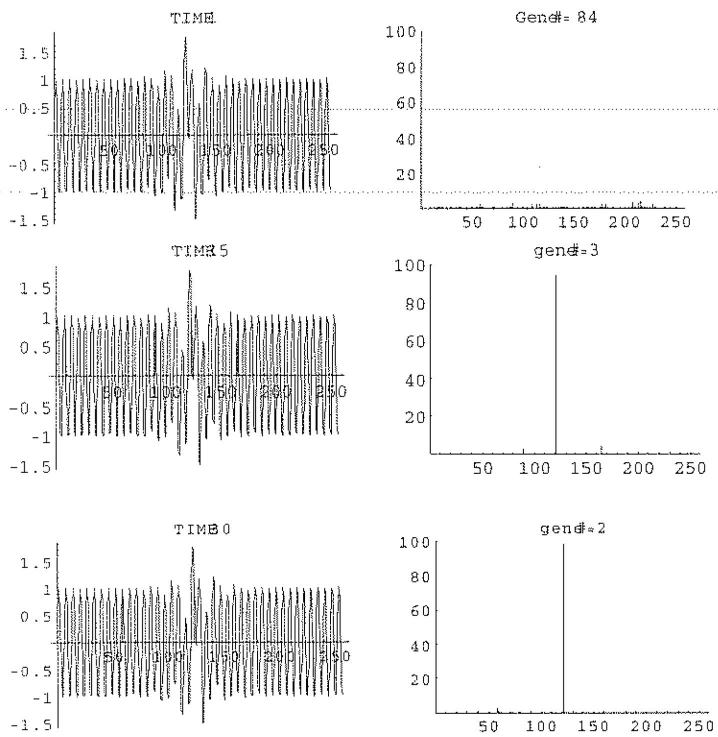
[fig. 1] Example of mutipeak landscape

4. SIMULATION RESULT & CONCLUSION

The following graphs are one of simulation results of organizational evolution in the high degree of complex environment.

Figure 1

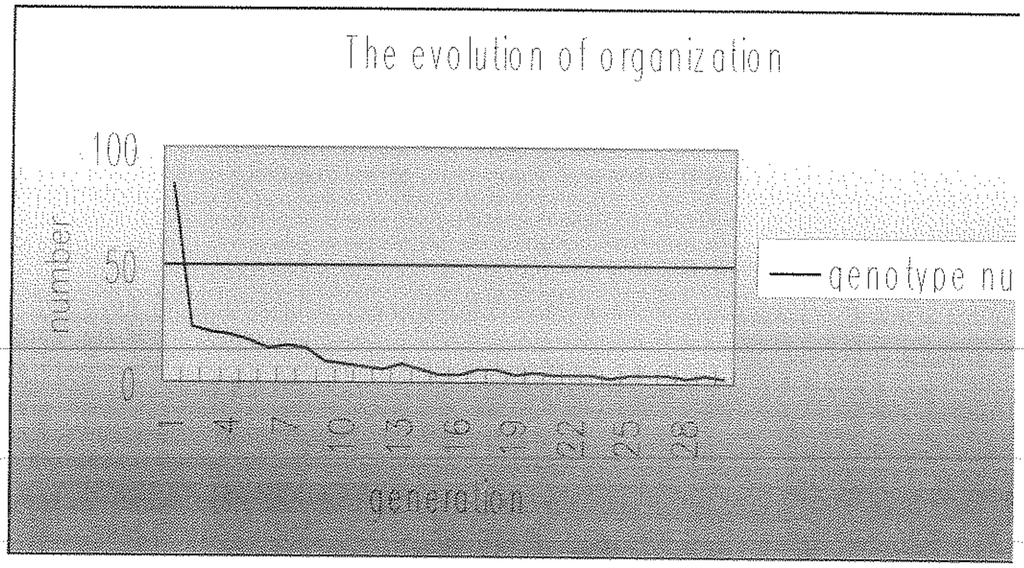
Simulation result in high level uncertain environment]



The above graphs show that there are 84 kinds of genotypes in generation 1 and the number of individuals who have a same genotype are described with the height of bar. We get a desirable solution as the generation goes on that in the 15th generation most of the individuals gathered to the desirable value x=121. In the 30th generation, there are two genotype and the most individuals have a same genotype 01111001, phenotype x=12.

To see more detail, We draw the genotype number according to the generation goes on.

Fig. 2 Evolution of organization in the given environment



Organization gets some standard routines structure.

The third stage, the organization pursues an incremental improvement and consistently accepts the new organizational routines, the mutation. But in this stage, the fitness improvement is small. Of course, if the mutation introduces the chaotic factors, the organization will faces new phase. Especially chaotic factor will destroy the established structure, which brings about the much cost. We sometimes see the big and old company (dinosaur) is bankrupted because of its inertia.

This three stage is similar to the organization's history, that is birth, growth, and declination. And we also find this pattern in other two case 2(medium level of uncertainty), case 3 (without any uncertainty).

In the complex environment, the organization has three stages. First stage (from generation 1 to 9), the dramatical improvement of the organizational routines with high fitness to environment is achieved by reproduction effect and share information among the individuals. In this stage, the inferior routines are removed rapidly and the diversity of genotype is decline.

Second stage (from generation 10 to 18), the accumulated improvement forms the structure that dominates the genotype that will be described in organization theory as an SOP (Standard Operation Procedure).

But above simulation doesn't always guarantee the global optimum, x=121 with fitness 1.75448. Sometimes we get the local optimum like below figure even though same parameter was given.

Here we find important implications of how complex environment influences dynamic organizational evolution to lock in the local optimum x=27 and fitness value 0.965331.

When we calculate the neighbor values x=26 and x=28, fitness are 0.768951 and 0.281522 representing the complex environment which has sharp peaks.

If the local optimum values are accepted in the stage 1), it will have a great influence in the searching process of dynamic optimization. The crossover operator spreading desirable but not the best information to offspring causes this inertia in the uncertain environment. This implies that organization has a dependency on the initial population's information suggested in Chaos theory as "the sensitive dependence on initial conditions" and stage 1) is very important to determine the organization's survival. This phenomenon is called "path dependence" as Paul Krugman captures the idea in a succinct definition: "the powerful role of historical accident in determining the shape of the economy" and Arthur suggest "lock-in" effect (Arthur, 1996). In path dependence, getting "locked-in" means that one have to accept inferior standards or products, even though superior alternatives exist, even though it is known that superior alternatives exist. Arthur claims that Microsoft's success in the personal computer software market are due not to its best quality but to consumers' inability to escape from a path controlled by Microsoft (Leibowitz and Margolis, 1995). To overcome this situation, we could give a high mutation rate to exit from the local optimum by instilling the diversity to the organization.

Organization's CEO generally prefers the stable status to the dynamic status exposed to the risk and uncertainty. But the above figure shows that the stable status will lead a local optimum and at last fail in the competition to the more optimized organization. So the successive redesign by accepting the new organizational routines not contained present organization or forgotten routines is essentially necessary as long as the cost of redesigning is cheaper than the improvement.

I try 3 cases of environments according to the uncertainty. And also try to find the implication of crossover, mutation and population size. In this process, I find the fact that the organization has typical three growth path that dramatical improvement, forming the structure with accumulated improvement, and incremental improvement as time goes in given environment whether it is certain or not. This suggests that the age or history of the organization affect the adaptation strategy.

Also I find the role of crossover and mutation is more important in the complex environment. This also suggests that environmental complexity affects the adaptation strategy of organization. I summary the dynamic evolution strategies with 3 by 3 matrix shown below using the simulation results.

Table 3: The Strategy of the organization according to the history and complexity

	Stage 1 (child)	Stage2(adolescence)	Stage 3 (old)
Low complex environment	□Directive leadership with creative innovation	□Directive leadership to focus in producing the organizational structure	□Directive leadership to keep organization continuity with incremental change
Medium complex environment	□Lower-level management leadership □Creative innovation should be emphasize	□Management by Exception □Network such as crossover should be emphasized □Check the inertia caused by structure	□Creative minority should be encouraged
High complex environment	□Autonomy of individuals □Sustain a diversity. □Parallel search	□Team work is emphasized □Coordinate the Interested groups	□Successive reinventing organization using mutation

Acknowledgement: This work was supported by Korea Research Foundation Grant

References

Arthur,B., *Increasing Returns and the New World of Business*, Harvard Business Review, July-Aug 1996.

Bruderer,E., *Organizational evolution, Learning, and selection*: A genetic algorithm based model, Academy of management Journal, Vol.39,No.5,1322-1349,1996.

De Jong,K., *Analysis of the behavior of a class of genetic adaptive systems* , Ph.D Dissertation University of Michigan Ann Arbor, 1975.

Falkenauer, E., *Genetic Algorithms and grouping problem*, John Wiley & Sons, 1998.

Fisher, F., *Evaluating Public Policy*, Nelson-Hall Publisher, 1994.

Freeman, C., *The Economics of Industrial Innovation*, 2nd ed., Frances Pinter, London,1991.

Goldberg,David E., *Genetic Algorithms; in search, optimization, and machine learning*, Addison-Wesley Publishing Company,INC, 1989.

Greiner, Larry, E., *Evolution and Revolution as Organizations Grow*, Harvard Business Review, July-August 1972.

Helmreich, Stefan , *Recombination ,Rationality, Reductionism and Romantic reaction :culture, computer, and the genetic algorithm*, Social Studies of science 28/1,Febuary,1998; 39-71.

Holland, John H., *Adaptation in Natural and Artificial Systems*, MIT Press, Cambridge, 1992.

Laszlo,E., *The systems view of the world-A Holistic Vision for Our Times*, Hampton Press Inc.1996.

Leibowitz, S. and Margolis,S.E. *Policy and Path Dependence From QWERT to Window 95*, Regulation Vol. 18, No. 3, 1995.

Kauffman.Stuart.A., *The Origins of order*: Self-Organization and selection in Evolution, Oxford University Press, 1993.

Kauffman, Stuart.A.,. At Home in the Universe - The Search for the Laws of Self-Organization and Complexity, New York: Oxford University Press, 1995.

Koehler,G.J., *New Direction in Genetic Algorithm Theory*, url: http://www.cba.ufl.edu/dis/faculty/koehler/.

Kogut,B. & Zander,B. , *Knowledge of the firm, combative capabilities , and the replication of technology*, Organization Science,3:591-612,1992

Michael L.Mauldin, *Maintaining Diversity in Genetic Search*, Appeared in the The Proceedings of the National Conference on Artificial Intelligence (AAAI-84), August, 1984.

Mitchell, M., Forrest, S. and Holland.J.H., *The royal road for genetic algorithms: Fitness landscapes and GA performance,* In F. J. Varela and P. Bourgine, editors, Proceedings of the First European Conference on Artificial Life. Toward a Practice of Autonomous Systems, Dec 1992. MIT Press. pp 245—254

McKelvey, B., *Complexity vs. Selection Among Coevolutionary Firms: A Complexity Theory of Strategic Organizing,* unpublished manuscript, Anderson School, UCLA, LA, 1996.

Morgan, G., *Creative Organization Theory* ; A resourcebook, SAGE publication, 1989.

Rucker,R., *Artificial Life Lab*, Waite Group Press, 1993.

Simon, H. A. , A Behavioral Model of Rational Choice," in H. A. Simon, *Models of Man*, New York: John-Wiley, 1957

Simon,H.A..*The Science of Artificial.* Cambridge,MA:MIT Press, 1969.

Spears,W.M., *Handbook of Evolutionary Computation*, IOP Publishing Ltd and Oxford University Press, ;E1.3, 1995.

Tanese,R. *Distributed Genetic Algorithms for Function Optimization.* Ph.D. thesis, University of Michigan, Ann Arbor, MI, 1989.

Terry Jones, Stephanie Forrest , *Genetic Algorithms and Heuristic Search* , Santa Fe Inst. Jan. 1995; Waldrop, M. Mitchell, *Complexity: The Emerging Science at the edge of Order and Chaos*, New York: Simon & Schanster, 1992.

Wolfram,S. *Emerging Syntheses in Science*: Proceedings of the Founding Workshops of the Santa Fe Institute, Addison-Wesley, 1988;pp. 183-189.