Chaos Study on Evolutionary Simulation in Multi-Agent System

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Abstract. Agents' evolutionary behavior in a multi-agent system, which will generate chaotic phenomena, can be used in studying chaos system in natural environment system. The paper simulated the process of belief transfer and bidirectional, innovational transfer among agents, and proposed a new concept of chaotic basic wave and a ZP model. Through some experiments, the paper concluded that the agent group with bidirectional and innovational transfer phenomena could keep the number of their belief types in a steadily chaotic status, and this chaotic steady status will not be affected by some variables of the system in a macroscopic view.

1. Introduction

There are a lot of chaotic phenomena in natural environments and social economic fields. Chaos shows sensitive dependence on initial condition, and develops a tangled and random path in micro and macro levels. Edward Lorenz, a meteorologist, studied butterfly effect phenomenon in 1963[1]. It can be described that a butterfly flapping its wings in South America can affect the weather in New York in a month. It means that smallest changes of one variable in a Dynamic Open Complex Adaptive System (DOCAS) can produce major differences in the system's behavior over time. In other words, the eventual outcome of a system's behavior is highly responsive to very minor variations in its initial state [2]. Many scientists study the sensitive dependence on initial conditions of chaos systems [3]. All of them agree with the opinion that even though a chaotic system follows a simple set of rules that shape the details of its behavior deterministically - the actual outcomes of that behavior may remain highly unpredictable. This poses some interesting problems for researchers and algorithm designers: Will we live in storms initially caused by butterflies? What kind of variables will essentially affect a dynamic open complex adaptive system? These dynamic problems should be studied by dynamic characteristic tools. This paper tries to answer the problems above by designing an model of evolutionary simulation of belief transfer in multi-agent system, which is a dynamic characteristic tool. And we investigated the data of chaotic data series it generates.

A large number of studies have been conducted on evolutionary simulation techniques. Genetic Algorithm (GA)[6], Genetic Programming(GP)[7], Evolutionary Programming (EP) [8] and Genetic Network Programming(GNP) [9][11]. Many of them focus on techniques of elaborate algorithms and its outcomes, overlooked collateral data series generated by the evolutionary process. Based on the evolutionary simultaion of our multi-agent system in belief transferring, the paper proposes a ZP model relating to an multi-agent group, simulates a dynamic open complex adaptive system, and gives the concept of chaotic basic wave.

2. A MAS-based ZP model

Multi-Agent System (MAS) is a research branch of AI [12]. We regard a software agent as a "person" who can think, help people to search, negotiate, even make transaction. Many researchers accept that the actions of coordination, negotiation, cooperation among agents are produced, processed and completed under the government and control of agents' DBI(Belief, Desire, and Intention) states. Researchers have also given many definitions of Agent's belief, such as: 1) Belief is the knowledge that is not proved to be TRUE yet. 2) Belief is the knowledge that may not be TRUE. 3) Belief is a kind of function that describes the accumulating evidence, which represent the believing degree of some Proposition. Generally, the belief is considered as the agents' knowledge in MAS field [13]. Current researches give little attention to the evolutionary process of agent's belief state [14][15].

The paper proposes a model based on MAS. The model is used to investigate the chaotic phenomena of belief (or knowledge) transfer among agents.

2.1 Definitions of the ZP model. First, some definitions are given to construct the model:

For one agent:

1) An agent can have one and only one kind of belief.

2) An agent can transfer its belief to another agent, which means the other agent get a new belief and lost its original one.

3) As the belief is atomic, one agent can't only affect another agent's belief partially.

For agent group:

4) An agent group consists of several agents which contain identical beliefs.

5) An agent group can transfer its beliefs to all agents in another group. If Group1 transfer its beliefs to all the agents in Group2, the agents in Group2 will have Group1's beliefs and be absorbed into Group1.

6) An agent group can affect part of the agents in another group. If Group1 affects part of the agents in Group2, it means some of the agents in Group2 are absorbed into Group1, and the remaining agents are kept in Group2.

7) New beliefs can be produced when an agent group interacts with another group. That means some of the agents in Group1 renew their belief and create Group3 after Group1 encounters Group2.

We also define the agent society which contains several agent groups. In agent society, many different beliefs can be found.

Then, some hypotheses are listed as following:

1) To make the model simple, we suppose the number of agents in an agent society is N. The number will not change during the evolutionary computation.

2) According to the above definition 7), we suppose the new belief can only be selected from the beliefs at the initial stage. Beliefs are resurrected instead of being invented for the system.

3) The time that an agent takes on transferring its belief to another agent will be defined as a step t. After one t, the belief's status in an agent will be steady.

Based on the hypotheses, the model of MAS belief transfer, ZP, is given. The ZP model is a quaternary composed of L (agent society), B (agent beliefs), G (neighbors), and f (belief updating rules)， $ZP = \{L, B, G, f\}$.

B is the set of beliefs in an agent society. $Agent_i$ denotes one of the agents in the society. B_i denotes the belief of $Agent_i$. If $B_i = m$, we regard the belief of $Agent_i$ as m, $0 < i \le N$, $0 < m \le N$. The agents with identical beliefs m can form a group, noted as $Group[m]$. If B_i's belief is m, then $Agent_i \in Group[m]$. We can also use $Agent_i \in Group[B_i]$ for convenience. The term neighbors of $Agent_i$ means the set combining the agents whose beliefs are equal to $Agent_i$'s and the agents whose beliefs are equal to $Agent_j$'s which will interact with $Agent_i$ in the next step. This set is called G, $G = \{Group[B_i], Group[B_j]\}$. Finally, the belief's rule of updating is f, $f : B_{i+G}^{t+1} = f(B_i^t, B_G^t)$. B_G^t is the set of neighbors G's beliefs at step t. Function f is also called the mapping rules of agent's neighboring beliefs. Different mapping rules used in the experiments make the outcomes of the evolutionary computation different.

2.2 Output of the ZP Model

Sets of evolutional experiments were performed by using different rules of belief updating. These evolutional experiments below, from common belief transfer to bidirectional and innovational transfer, reveal different belief transferring results under different f s.

2.2.1 Common Belief Transfer Experiments

Experiment 1. According to the hypotheses of the model, set N=100 and each agent has a different belief at the initial stage. That is to say, we have 100 different beliefs at first. The rules f for belief updating are as follows:

(1) Randomly select 2 agents, noted as $Agent_i$ and $Agent_j$, if their beliefs are m and n respectively, gather agents with m belief into $Group[m]$, and agents with n belief into $Group[n]$.

(2) If beliefs in $Agent_i$ and $Agent_j$ are equivalent, go to rule (3); Otherwise, transfer $Agent_i$'s belief B_i to the agents in $Group[B_j]$, which makes all the agents with belief B_j change their beliefs to B_i. That makes all the agents in $Group[B_j]$ be absorbed into $Group[B_i]$.

(3) If the number of different beliefs becomes one, then the evolutionary computation ends. Otherwise, step t is increased by 1, go back to rule (1) and proceed.

These rules mainly depict the process that $Agent_i$ transfer its belief B_i to all the agents in $Group[B_j]$. The evolutional results are showed in Fig. 1. In Fig. 1, all agents' beliefs become identical within a limited time. Many beliefs are discarded during the evolvement process, and the number of different belief groups was cut down to one gradually. We performed the experiment ten times, the results are showed in Fig. 2 and Table I. From the experiment results, we will know that, regardless of what initial beliefs are used in the system, the number of different group becomes one finally, although the time spent on those experiments were different.

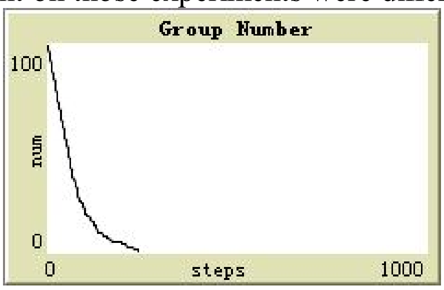

Fig. 1 the curve of Agent Group number in a evolutionary computation

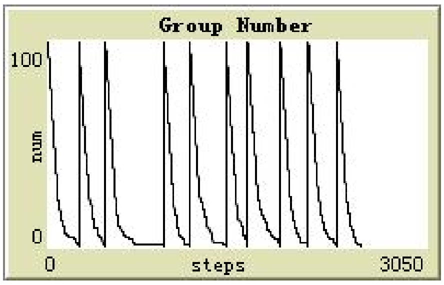

Fig. 2 the curve of Agent Group number in ten repeating experiments

TABLE I STATISTICAL DATA OF EXPERIMENT 1 AFTER TEN REPEATING EXPERIMENTS

The average time of ten experiments (step)	Max. time cost in an experiment (step)	Min. time cost in an experiment (step)	Std.
252.1	465	174	81.72

Result analysis: Evolving from N kind of beliefs to one belief, the time spans in each experiment are different, and the standard deviation is big. It shows that belief transferring process can be affected by many factors. Beliefs can also be transferred from small agent groups to large groups, and vice versa. The final belief accepted by all agents was chosen by probabilities.

2.2.2 Innovational Brief Transfer Experiments

Experiment 2. We introduce an innovation mechanism by modifying the second rule of belief renewing in experiment 1. That is if $Agent_i$ transfer B_i to all the agents in $Group[B_j]$, and some members of the newly created $Group[B_i]$ change their belief to p by innovating (belief p can be selected randomly from the N=100 initial beliefs) , we get the result that the number of different belief groups was cut down to one gradually as Experiment 1 did. For new belief p sometimes equals B_i, belief transfer between two groups can still have the opportunity to make one belief vanished when two groups of agents meet, though new belief, other than B_i, created most of time at each step. After a long enough time, beliefs in the agent society will still be unified.

2.2.3 Bidirectional and Innovational Brief Transfer Experiments

*Experiment 3***.** In the experiments above, $Agent_i$'s belief B_i, replaces all agents' beliefs in $Group[B_j]$ when $Agent_i$ interacts with $Agent_j$, which makes B_j vanished at every interaction. This experiment keeps some agents with belief B_j in $Group[B_j]$ unchanged each time by modifying the second step of the rules of belief renewing in the Experiment 2. Then B_j has the chance to transfer to other agent groups in next turns.It also has the opportunity to transfer to $Group[B_i]$ and make some of the agents' belief back to B_j. So we call this process as bidirectional transfer.

According to the hypotheses of the model, set N=100 and each agent has a different belief at the initial stage. So we have 100 different beliefs at beginning. The rules f for belief renewing are as follows:

(1) Randomly select 2 agents, noted as $Agent_i$ and $Agent_j$, if their beliefs are m and n respectively, gather agents with m belief into $Group[m]$, and with n belief into $Group[n]$.

(2) If beliefs in $Agent_i$ and $Agent_j$ are equivalent, go to rule (3); Otherwise, transfer $Agent_i$'s belief B_i to one half of the agents in $Group[B_j]$, that is, one half of the agents in $Group[B_j]$ set their beliefs to B_i and move into $Group[B_i]$. Another half of the agents unchanged are still kept in $Group[B_j]$. Then X of the agents in $Group[B_i]$ change their beliefs to p (belief p can be selected randomly from the initial 100 beliefs, and X=1 in this experiment) , and the innovated agents are moved into $Group[p]$.

3) If the number of different beliefs becomes one, finish the evolutionary computation. Otherwise, Step t is increased by 1, go back to rule (1) and proceed.

Result analysis: From the output chart of this experiment (Fig. 3, containing two independently experiments), the number of different belief groups forms a zigzag time series curve. The time series are varied each time when this experiment runs repeatedly. The reason of the difference is that the initial random selection of $Agent_i$ and $Agent_j$ makes agent group's number unable to develop steadily. Will these charts' group number shrink to 1 as the Experiment 1 and the Experiment2 did? We make further experiments.

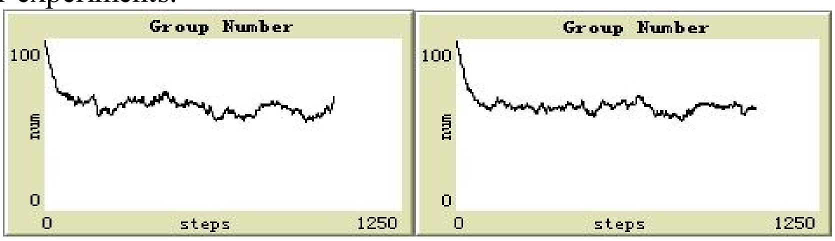

Fig. 3 the curves of agent group number in two different evolutionary computation

For convenience, we define the multi-agent system following the rules of f in the Experiment 3 as the most important ZP model, which produce a zigzag picture in the output chart of group number. When we look at the long-term (>5000 steps) output of the ZP model, we can see a steady chaotic wave in Fig. 4. The number of different agent groups seems to vary from 50 to 70. And Fig. 5 is the distribution chart of different agent groups' number occurred in this period.

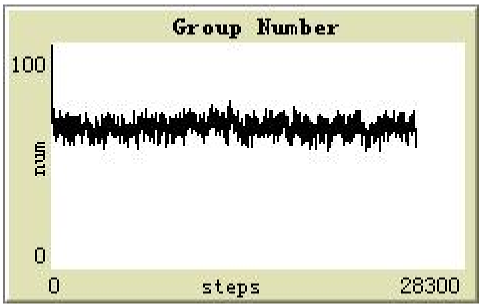

Fig.4 the curve of the agent group number (or belief number) in an evolutionary computation (28000steps) when X=1(having one innovational agent in one time)

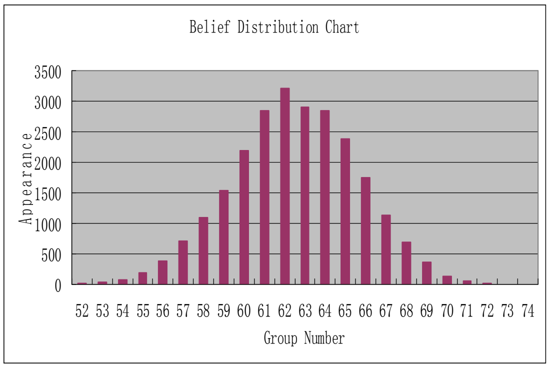

Fig. 5 Agent group number (or belief number) distribution chart when X=1(having one new belief in one time)

Fig. 4 and Fig. 5 show the situation of agents in bidirectional and innovational brief transfer while X is 1, which means one agent's belief in $Group[B_i]$ innovated into p (belief p is selected randomly from the 100 initial beliefs each time) after two groups of agents met. When X is 3, it refers that three agents' beliefs in $Group[B_i]$ innovated into p each time, the output curve of the agent group number is like the curve in Fig. 4, showes in Fig. 6, and Fig. 7 is the distribution chart of different agent groups' number occurred in this period. According to these long-term output charts of the ZP model, we can see that the wave patterns show a kind of steady mean-reversion phenomenon. The number of groups does not go down to 1, or go up to N(N=100). It vibrates near a steady line.

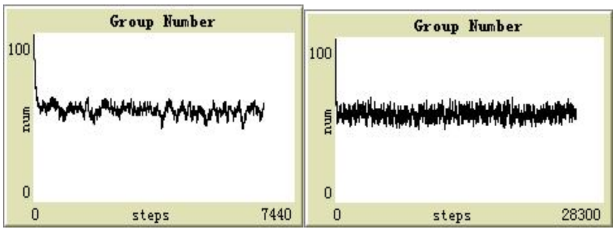

Fig. 6 the curve of the agent group number in a evolutionary computation (7300 and 28000steps) when X=3(having three innovational agent in one time)

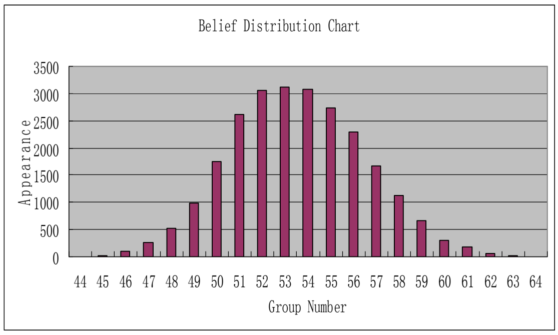

Fig. 7 An agent group number (or belief number) distribution chart when X=3 (having three new beliefs in one time)

3. Verification on the Chaotic Characteristics of the ZP Model's Output Chart

Like in Fig. 3, 4 and 6, the output chart of the ZP model is a chaos-like time series. Traditionally, we have some methods to analyze chaotic time series, like Lyapunov index, correlation dimension, Kolmogorov entropy, R/S analysis, and so on[16]. Here we choose R/S analysis to analyze our output of ZP model.

R/S statistical method, also called the "Rescaled range" method, is used to analyze the fractal features and long-term behaviors of time series. Its core content is: For a time series $\{x_t\}$, divide it into M subintervals whose lengths are equal to N. Each subinterval has the definition:

$$X_{t,n} = \sum_{u=1}^{t}(x_u - M_n)$$

M_n denotes the mean of $\{x_u\}$ in the nth subinterval. So $X_{t,n}$ is defined as the partial sum of the first t deviations of x_u from the mean value M_n.

The maximum of the $X_{t,n}$ minus the minimum of this same sequence of partial sum is called the range R. S is the usual standard deviation estimator. R/S is defined as rescaled range statistic. Hurst gives the function of R/S complied with K*(n)H after study[17], and gets the expression:

$$R / S = K * (n)^H \quad (1)$$

By getting the logarithm of the expression, formula (1) is deduced to:

$$\log(R / S)_n = H \log(n) + \log(K) \quad (2)$$

From formula (2) and the data of $\log(n)$ and $\log(R / S)_n$, we can get the value of H which can be regressed from the experimental data. The H value of Hurst exponent can be used to determine the correlationship of a time series. When H=0.5, the time series is stochastic. In other words, the current value of a time series will not affect the value afterward, like a stock time series and the stock's earning ratio assumed normal distribution. When $0.5 \leq H < 1$, the time series shows a kind of constant or "strong" tendency. This kind of time series looks like a biased stochastic process whose offset depends on the difference value of H and 0.5. In this kind of situation, if current trend of time series is upward, the time series has high probability going upward in the future. When $0 < H \leq 0.5$, the time series shows that if the current values are up, then next values have high probability to go down. It is called anti-constance.

For convenience, we put logarithmic process on the rate of return of the long-term ZP model's output, and remove linear correlation with AR(1) residuals[18], showed in Fig. 8. Then we put R/S analysis on the model's output, and get the value of logRS/logN based 2 logarithm, showed in Fig. 9.

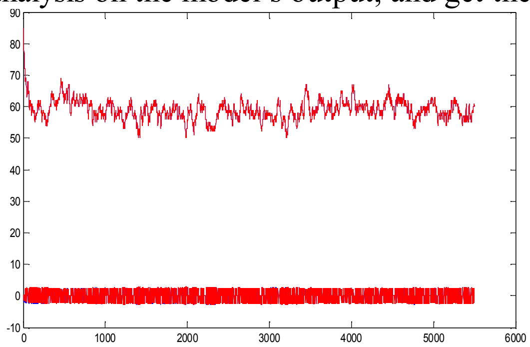

Fig.8 Logarithmic process on the rate of return of the ZP model's output(upper curve) and removing linear correlation (lower curve)

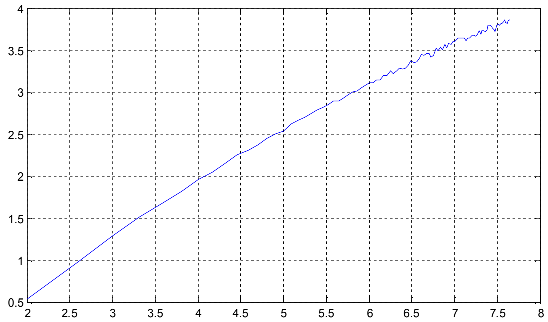

Fig. 9 R/S analysis of the output of the ZP model

The result of R/S analysis showed in Fig. 9 indicates that the time series has the property of $0 < H \leq 0.5$. It means that the output of the model is chaotic and anti-constance. The past and the future of the time series exhibits negative correlation. That means that the past tendency may suggest more possibility of the opposite tendency in the future. We regard the output curve of the ZP model as chaotic base-wave.

By modifying the second step of the rules of belief renewing in *the Experiment 3*, we adjust the changable portion of agents in $Group[B_j]$ which changed to $Group[B_i]$'s belief each time. That is to say, we adjust the variable: PARTIAL, which is 1/2 in the Experiment 3, to 1/3 or 1/4. When PARTIAL changes from 1/2 to 1/3 or 1/4, the output curve of the model doesn't change much and R/S analysis is the same. That means changes of some variables of a chaotic system will not affect the system's behavior in a macroscopic view although some microscopic vibrations will take place in the system.

4. Conclusion

From experiments of the evolutionary simulation above, we observed that 1)when agents communicate with each other and transfer their beliefs, the group number of beliefs will evolve into one or vibrate around a certain value chaotically. The agent group with the ability of bidirectional and innovational transfer could keep the number of their belief types in a steadily chaotic status. 2) the vibrated state of data series curve will not be affected by some variables of the agent system in a macroscopic view, though the shapes of the data series are changed in a microscopic view. In other words, the chaos system can be seen as steady in a long period or in a macroscopic view, even the system is affected by some factors. As a butterfly's flap can be seen as a minimal factor to the atmosphere system(like a ZP system), we can expect that the slight impact on a big chaotic system will not change the macroscopic trend of the atmosphere system. Our future research will focus on finding variables which can affect chaotic systems dramatically.

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