Decision-making Algorithm of an Agent’s Internal Behavior Facing Artificial Market

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Abstract
We formulate a microscopic model of the artificial market based on agents and study the resulting macroscopic phenomena via simulation. In a market of heterogeneity, individuals’ heterogeneity and information asymmetry lead to difference in individuals’ opinions, so we propose the agent built-in system based on cognitive – information – program through the improvement of traditional model based on belief – desire – intention. In the agent built-in system, we focus on the difference of beliefs and preferences of agent in order to divide into different groups, and give each agent population strong cognitive ability, learning ability along with quickly adaptive ability, which not only contributes to the awareness of microscopic individual decision-making process but also alleviate problems result from macroscopic complexity.

Keywords: Artificial Market, Agent, Heterogeneity; Decision-making Algorithm.

1. Introduction
Financial asset pricing model as well as market price formation mechanism has always been the study core in the capital market. However, because of the harsh assumption conditions in mathematical models, abstract mathematical models from complex financial markets could hardly portray the dynamic process of the market as a whole, particularly when there are large numbers of complex interaction among individuals and the environment in the market[1-4]. While trying simulating real financial markets through experimental method provides new ideas and methods for financial theory. In recent years, as the progress complex systems and artificial intelligence made and the extensive application of computers, applying Multi-Agent Systems Technology whose core is complex and large-scale Distributed Problem Solving (DPS) to computer simulation could to a large extent relax restrictions that computer can only calculate passively and non-intelligently and could make Agent-based computer experiments better simulate economic realities in order to serve economic research [5-8]. But since there are large numbers of individuals and complex relationships among individuals within stock markets, especially that it is difficult to portray decision-making process of individual investment, the establishment of scale experiments become a dilemma.

Therefore scholars such as Chowdhury, D (1999) [9], Lux T (1999) [10] proposed that establishing a model should take capturing market behavior characteristics as a premise and should chose heterogeneity Agent with simple trading rules. After that Gaunersdorfer (2000) [11], Chiarella and He (2001) [12], Chiarella and He (2003) [13] established asset price dynamic models based on heterogeneity Agent and studied impact of expected benefits together with risks asset price fluctuations on Agent heterogeneity conviction. Furthermore, Shu- Heng Chen and Ya-Chi Huang (2004, 2005, 2007) [14-16] made a series of simulation about Agent risk preference and wealth status under multi-risk assets conditions on the basis of artificial stock market model (AIE-ASM) and got a conclusion that Agent survival is determined by risk aversion among Agents, saving behavior as well as different levels of savings rate. But this simulation was built on the Agent risk aversion parameter under the same circumstances. In reality, investor’s risk aversion level would change with accumulation of wealth. However, the existing artificial model of stock markets only emphasizes a particular aspect of
Agent heterogeneity such as beliefs or preferences and a more comprehensive description is not given yet. Moreover, the fitness selection over-rely on the spreadsheet and judgment of researchers in the existing research, which often lack scientific plus reliable method to describe Agent dynamic characteristics and Agent learning mechanism [17-19].

Addressing to modeling problems existed in individual Agent feature of artificial model for the stock market, this paper proposed Agent built-in model based on cognitive – information – program through the improvement of traditional model based on belief – desire – intention. In this model we emphasize Agent heterogeneity and pay attention to the differences among Agents in the aspects of beliefs and preferences. In accordance with characteristics of this architecture model, giving Agent strong cognitive ability, learning ability along with quickly adaptive ability, this paper put forward dynamic decision-making algorithm of Agent internal behavior based on object technology, which will not only contribute to the awareness of individual decision-making process but also alleviate problems result from complexity.

2. Agent built-in system

The Agent built-in system mainly reveals the make-up of Agent, functions of each module and the action mode. At present Agent built-in models primarily have the following categories in artificial intelligence field: Deliberative model[20,21], Reactive model[22-24], Hybrid model[25]. In the research of artificial stock market, how to select Agent model is the key not only for construction individual features model but also for coordinated action among Agents. Bratman designs BDI model to deeply study actions intent from philosophy, who believes the only effective solution is to keep rational balance among belief, desire and intention. Bratman holds the idea that, in an open world, the action of rational Agent can not be driven directly by belief, desire and aspirations of these two components and intension based on belief should exist between desire and plan. Currently recognized deliberative architecture of Agent all have BDI structure. Agent action in a rational manner is subject to intention and Agent do not change its intention without justification nor uphold substandard intention, as shown in Figure 1.

**Figure 1. BDI Model**

On one hand, in order to achieve computability, BDI model is not chosen by most artificial modeling of stock markets because in real market transaction the investors intentions and desires will changes with their own conditions and environment, such process is too complicated to control. The choice of a single-Agent Model is beneficial to calculation but not conducive to the description of the real market or the interaction relations. On the other hand, BDI model is the analysis about ration and intent on philosophy level, which depicts a intension objectivity and central position in rational balance but in real financial markets more investors (including institutional investors) will show more non-rational characteristics. So the model should consider the selection of beliefs and preferences on the basis of calculation. According to investors’ behavior characteristics in real markets, Agent should not only interact with other Agents and the environment in systems through its thinking and behavior but also recognize the interactive Agents. Furthermore, Agent decision-making process is dependent on the
expression of Agent cognitive and information operation between data structure. Therefore, this paper puts forward Agent Architecture Model based on Cognition - Information – Program, as shown in Figure 2.

![Agent Architecture Model](image)

**Figure 2. Agent Built-in System Based on Cognition - Information – Program**

The behavior reasoning ability of Agent is a comprehensive based on the basic ability. First, Agent may establish their own faith according to the perception rooted in the environment or communication with other Agent, set up their own goals to storage as its knowledge data bank. Second, the combination of the mental state reasoning machine and the action reasoning machine makes a behavior effect on the environment, or has a intention to communicate with other Agent, until the Agent has realized that target has been finished, or target is still inaccessible, or target has changed, and has to give up the original intention to update the information-plan – cognition library.

In a word, the structure of the Agent can be prior established based on Multi Agent System(MAS), and it may be configured or established according to the degree of the task which has been finished. Usually, the first step is to establish the basic system structure of Agent, and the second step is to allocate the corresponding function modules according to its responsibility and position. Such as, we can establish the corresponding utility structure according to the Agent is cooperation, selfish or hostile.

### 3. Agent decision-making algorithm

#### 3.1 Formal Description of Behavior

The key is to control the evolution process of Agent-based artificial model in stock market, which includes the fitness selection and learning mechanism of trading system. Because the limitation of the adapting ability, learning and forming strategy could be given to Agent and some kinds of norms, rules and empirical knowledge could also be given to Agent, a certain artificial intelligence methods is required. But the existing studies lack a reliable method of artificial intelligence about dynamic characteristics and learning mechanism of Agent. Consequently, there should be a clear understanding about behavioral characteristics of the Agent. First of all, interaction between the various Agents is a dynamic evolution process; Secondly, individual Agent in the market use inductive logic instead of
interprets logic to make a decision. The evolution of the market is expected by individual Agent. Agent’s own adaptability determines that it will timely make adjustment with the market evolution. Furthermore, the adaptability of the individual Agent in turn will increase the dynamics of the market. And there are mutually influences between evolution of individual and overall market. The formal description of Agent is including Agent behavior patterns, Agent perception, Agent state, and so on.

Individual Agent makes reasoning, learning and updating to the stimulation of external information according to its own internal state. Internal state concludes information base, the knowledge and the plan. Agent behavior patterns are defined in table 1.

<table>
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<tr>
<td>{ all b : Behavior }</td>
<td>// to All element b in behavior sets</td>
</tr>
<tr>
<td>{(b in Action) &amp; &amp;</td>
<td>// (b means a action and</td>
</tr>
<tr>
<td>(some b.corresponding_constraint) &amp; &amp;</td>
<td>// existing a constraint condition at last</td>
</tr>
<tr>
<td>( b.corresponding constraint in Behavior )))</td>
<td>//The constraint is some action element or</td>
</tr>
<tr>
<td>(b in Behavioral constraint) &amp; &amp;</td>
<td>// ( b is a constraint and</td>
</tr>
<tr>
<td>( some b.constrained_action ) &amp;&amp;&amp;</td>
<td>//b contains an action at last</td>
</tr>
<tr>
<td>(b.constrained_action in Behavior))</td>
<td>//the action is behavior element</td>
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### 3.2 Agent decision-making model based on information processing

According to the above Agent behavior, this paper constructs Agent decision-making model based on information processing which giving the Agent designed proactive and reactive through different information processing mechanism to BDI and general information. This algorithm not only avoids uncalculating of direct maintenance of Agent desire and intentions based on BDI model but also reveals dynamic conviction features of Agent.

As shown in figure 3, when the Agent observer the external information flowing by information it is firstly to examine the information records in according with the inner information library. If there can be recorded with the recorded information, the external information will be further processing. Otherwise, the external information will be rounded down. To each group, Agent will execute the "information / plan dependency detection” according to plan library, and gets “correlation plan set”. Choosing accordant plan of Agent’s belief from the previous relevant plans, and producing plan examples set. Then, according to character of the information, the information will be divided into general information and BDI information. The general information is executed by the example selected randomly from plan examples set, whether succeed or failure of the implementation of the outcome will be discontinued. It is necessary to take meta-level reasoning technology for BDI information. For the first place, a set of plan examples in accordance with priority is generated from different mechanisms. Then implement the project by priority in the follow-up activities of “choice plan”. It is not until all projects in the project examples fail that Agent stops processing BDI information. The above process, from project selection to implement mechanisms, shows that Agent has dynamic feature. Cognitive library will be revised constantly during the information processing, which reflects learning characteristics that Agent has.
4. Performance analysis of the algorithm

Individuals' heterogeneity and information asymmetry lead to difference in individuals' opinions, their ability to gather and analyze information.

Assumption 1 In this section we show the most simple nontrivial case, the case of two investor populations, informed agents $k_0$ and uninformed agents $k_1$, who have different behavior criteria. This is still a very simplified case, but it will present a complex and realistic dynamics process.

Assumption 2 Agent's wealth includes high-risk assets and risk-free assets. Income tax rate of high-risk assets is 0. Before the trade at time $t + 1$, the wealth of agent $i$ is:

$$W_i(t) + N_i(t)P_t + (W_i(t) - N_i(t))r$$

(1)

Agent only trade with other agent which it can contact, and its behavior is random. After the transaction, the capital of agent will gain or loss. Thus, the hypothetical wealth of agent $i$ after the $t+1$ trade, $W'_i(t)$ will be:
Assumption 3  We establish different population sizes $M(k_i)$, and birth-rate $\gamma$.

As shown by the curved lines in Fig.4, from Fig.4 (a) to Fig.4(d), we study a two-population case, where initial uninformed agents $k_1$ are 110, informed agents $k_0$ are 20 or 40 (shown in Table 2), and we can find that the population of observed agents is increasing or decreasing with their interaction each other. First, the initial population of informed agents is a decisive factor in the market prosperity and development. If there is relatively large number of informed agents, the decay rate of the market will be very rapid, and there are ultimately no winners in the market. Second, the growth rate of informed agents should be lower than informed agents. Otherwise, the investors will also quick failure. All that means that market regulators need make strict regulations to insure fair information transmission.

<table>
<thead>
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<th>Table 2 Different agent populations and birth-rate</th>
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<tr>
<td>uninformed agents</td>
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<td>population sizes</td>
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<tr>
<td>(a) 110</td>
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<td>(c) 110</td>
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<td>(d) 110</td>
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Figure 4  Performance of different agent populations

Figure 4 depicts schematically the following exaggerated situation: Compared with uninformed agents, informed agents have their advantage in information, and can know in advance some private information having influence on risk assets price. It is assumed that the number of uninformed agents with the trading target of maximizing profits; uninformed agents use specific data of system to deduce the probability of informed agents holding information and the real value of risk assets.
5. Conclusion

In this paper, we formulate a microscopic model of the artificial market based on cognitive – information – program and the corresponding algorithm for dynamic decision-making. We revise Agent’s belief, desire and intention in BDI theoretical model, and add errors description in individual Agent cognitive, expand the connotation of the concept model, avoid the maintenance to desire and intentions and thus achieves the basis of calculation for Agent architecture model. And the research on dynamic decision-making algorithm of Agent internal behavior based on information processing fully demonstrates the initiative and learning ability, which will contribute not only to the settlement of modeling but also wide use of this theory and methods in financial markets.

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7. References


