Research on Behavior Modeling Method of Agent-Based CGF

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***Abstract*—This paper studies the CGF behavior modeling method in Agent-based TBM combat simulation system, which focuses on the decision-making behavior and combat behavior of CGF Agent. Agent entities are divided into three levels, and a three-level organizational structure of Agent has been established. Use Rough Set theory to treat the uncertainty information of decision-making. To reflect the relationship between attack and defense, we establish a BDI model based on rival model to track the status of rival Agent and do real-time response. Finally gives the realization method of TBM combat simulation system.**

***Index Terms*—military simulation; CGF; Agent; decision-making; combat**

I. INTRODUCTION

Nowadays digital battlefield has replaced the large-scale deployments which use heavy equipment and antiquated regulations. Tactical Ballistic Missile (TBM) combat is a major combat form of joint operations. Under the military background of joint campaign in which Red Force and Blue Force attack and defense by using ballistic missile, modeling and simulating the operation process of attack and defense can make the training of the armed forces more realistic and effectively enhance the forces' commanding and decision-making capability and operational capability.

As shown in Fig.1, in the TBM combat simulation system(hereinafter called TBMCSS), there are many complex entities, including missile forces, anti-missile forces, ballistic missiles, interceptor missiles, reconnaissance and surveillance satellite, communications relay satellite, navigation and positioning satellite, early-warning satellite, data receiving station, early-warning radar, etc. If each simulation training requires a lot of opponents and friendly simulating members, that would make the whole system enormous and expensive. Therefore, using computer generated forces (CGF) technology [1] to generate friendly synergy units and opponent enemy units in the operation, instead of a large number of personnel and equipment involved in the simulation, can not only reduce expenditures and improve the operational efficiency of the simulation, but also make the training of troops be closer to actual combat and effectively improve the troops' command and decision-making capacity.

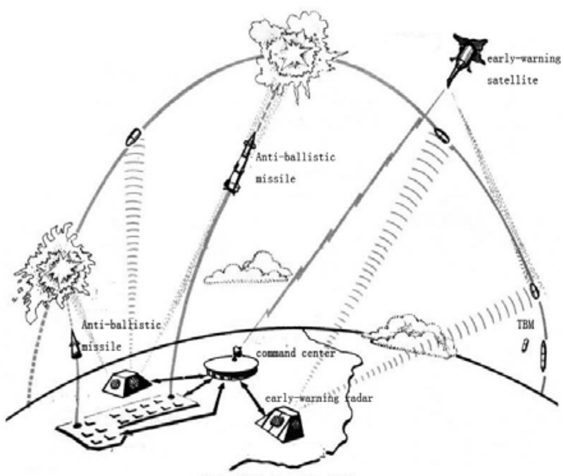

Figure 1. TBM combat system

The definition of CGF given in the US DoD Modelling and Simulation (M&S) Master Plan read as:

"A generic term used to refer to computer representations of entities in simulations which attempts to model human behaviour sufficiently so that the forces will take some actions automatically (without requiring man-in-the-loop interaction)".

CGF systems are often used in training simulations to provide both opposing forces and supplemental friendly forces for human trainees. CGF systems are also used to generate many or all of the entities in battlefield simulations being used for non-training purposes, such as analysis or experimentation. CGF systems model both physical phenomena, such as terrain and combat, and behavior, such as tactical maneuvers; the latter is of primary concern here. .Behavior generation in CGF is based on a library of doctrinal tactical behaviors that can be assigned by an operator to individual entities or groups of entities that compose military units, such as platoons or companies and executed automatically.

II. AGENT-BASED CGF

CGF modeling technology has been attached great importance to the development from a number of different modeling techniques, such as modeling approach based on finite state machine (FSM), rule-based system (RBS)

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modeling method and modeling method based on control theory.

The core issue of CGF is how to generate authentic combat behavior, which refers to the CGF entities' reasoning, decision-making and knowledge learning. Because of the high nonlinearity, strong antagonism and uncertainty of the battlefield environment, general modeling methods mentioned above are very difficult to adapt to the CGF model. CGF system has the characteristics of autonomy and intelligence and has the capabilities of perception, communication and coordination that are the same to Agent, so our approach is to use Agent-based modeling.

In artificial intelligence, an Intelligent Agent (IA) is an autonomous entity which observes and acts upon an environment and directs its activity towards achieving goals [2]. Intelligent agents may also learn or use knowledge to achieve their goals.

Intelligent agents have been defined many different ways. Russell & Norvig group agents into five classes based on their degree of perceived intelligence and capability [3]:simple reflex agents, model-based reflex agents, goal-based agents, utility-based agents and learning agents.

Some of the sub-agents that may be a part of an Intelligent Agent or a complete Intelligent Agent in themselves are:

- Decision Agents (that are geared to decision making);
- Input Agents (that process and make sense of sensor inputs - e.g. neural network based agents);
- Processing Agents (that solve a problem like speech recognition);
- Spatial Agents (that relate to the physical real-world);
- World Agents (that incorporate a combination of all the other classes of agents to allow autonomous behaviors).
- Believable agents - An agent exhibiting a personality via the use of an artificial character (the agent is embedded) for the interaction.
- Physical Agents - A physical agent is an entity which *percepts* through sensors and *acts* through actuators.
- Temporal Agents - A temporal agent may use time based stored information to offer instructions or data *acts* to a computer program or human being and takes program inputs *percepts* to adjust its next behaviors.

Agent has the properties of autonomy, social ability, reactivity and pro-activeness. Agent-based modeling takes a "bottom-up" modeling approach without centralized controlling and Agents pursue their goals by collaboration and competition, which is suitable for modeling and simulation of complex adaptive system and is a perfect method for CGF behavior modeling.

III. THE ARCHITECTURE OF THE TBM COMBAT SIMULATION SYSTEM

In the TBMCSS, we mainly model and simulate on the campaign and tactical layers. According to the different offensive and defensive point of view, the focus is different. For the simulation of missile penetration capability, its focus should be on the anti-missile defense system simulation; for the research of missile tactical operation, its focus should be on the simulation of the missile attack.

The research and development of TBM combat simulation framework should be based on Artificial Intelligence theory and realized on the approach of distributed interactive technology. When using Agent technology to build CGF system, it is a typical multi-Agent System (MAS). From the viewpoint of MAS theory, a CGF entity can be regarded as a single Agent, and the entire Agents that perform the task in the battlefield can be regarded as a multi-Agent system. Single CGF Agent entity, which can use a composite Agent architecture, has reaction behavior and cognitive behavior. In this architecture, the low-level reaction behavior and higher cognitive behavior combine with each other and use Agent-oriented software development method to achieve.

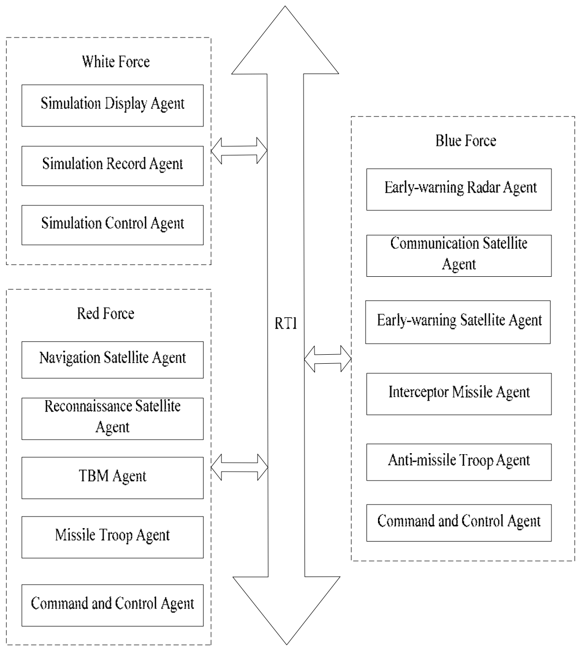

Figure 2. Architecture of the TBMcombat simulation system.

The whole architecture and fundamental of the TBMCSS is as Fig.2. The system utilizes the High Level Architecture (HLA) and Run-Time Infrastructure (RTI) to link the Agent federates as a multi-agent system, which can successfully resolve the issues of coordination between friend Agents and combat between enemy Agents. The other parts of the TBMCSS (e.g. environment federate, monitor federate, data gathering federate) are regarded as the white federates to interact with RTI directly.

IV. SCENARIO-BASED DECISION-MAKING WITH XML

In the TBMCSS, low-fidelity virtual objects representing missile launching vehicles, early-warning satellite, early-warning radar and other combat platforms interact on a digital terrain. TBMCSS simulates the hierarchy of military units and their associated behaviors. The massive amounts of information need to be in a flexible format that can be transformed readily to support disparate systems. The fundamental components within the environment are behaviors, physical models, and behavior agents. Software agents control planning and manipulate the behaviors. Complex behaviors are created in a behavior definition language (BDL). An XML schema has been developed for mapping to BDL and representing these composite behaviors, specifically temporal and data dependency relationships.

The HLA standards were developed to create a common architecture applicable across all types of simulation environments. The HLA Working Group has developed the following standards:

1. Framework and Rules (IEEE P1516) – defines the standard Simulation Object Model (SOM) for HLA-compliant systems.

2. Federate Interface Specification (IEEE P1516.1) – describes the interactions between simulations and a Run-time Infrastructure (RTI).

3. Object Model Template (OMT) Specification (IEEE P1516.2) – the objects, attributes, interactions, and parameters that are required for a SOM.

In order to share higher-level information between simulations, it is necessary to describe the context under which SOMs are manipulated within each simulation. XML is considered the primary bridge between commercial web standards and developing simulation environments. XML can also be used to map legacy simulation environments into the distributed, interoperable frameworks being developed within HLA.

A scenario is defined as a form of narrative consisting of a collection of episodes with the purpose of describing the actions of characters within an environment. Scenario-based design has become a powerful technique for system specification and design.

Agent message is the XML metadata that interchanges between Agent members, which is the foundation of coordination between Agents. By wrapping XML metadata into HLA's interaction class, we can integrate the Agent message based on XML to HLA framework. First define the interaction class AgentMsg.

```
（interactions
  （class AgentMsg reliable timestamp
     (parameter Sender)
     (parameter Receiver)
     (parameter Content)
  )
 ……
 )
```

Parameter Content is a string type, which has the following form in actual interaction.

```
<command>
<receiver>SAT1</receiver>
<runtime>2011 April 6 22:13:00.00 </runtime>
<action>launch missile </action>
……
</command>
```

Then complete the AgentMsg class through RTI interface.

V. BEHAVIOR MODELING OF AGENT-BASED CGF

Behavior modeling, also called human behavior representation (HBR), means using computing formula, program or simulation method to represent the behavior of individual or organization. In the domain of military simulation, the task of behavior modeling is to simulate the behavior of individual or group by using simulation models on computer.

.When CGFs are used for training (and other purposes), the primary goal is to replicate the behavior of a human; that is the behavior should be realistic [4]. Without realistic, human-like behavior, the danger is that human trainees interacting with the CGFs will have negative training. Therefore, a CGF should obey appropriate doctrine and tactics, and have the same strengths and weaknesses as humans both in physical and mental abilities. In the limit, this includes human behavioral characteristics such as response to battlefield stress (e.g. fatigue), emotions (e.g. frustration, anger, fear), and other psycho-physiological human characteristics.

It is intended that the behavior of the simulation entities generated by a CGF system be both doctrinally accurate, so as to provide a reliable basis for training or analysis, and plausibly human, so as to be realistic and engaging.

A. *Decision-making Behavior Modeling of Agent-based CGF*

Military operation is an action with very strict discipline, its response action on certain situation is not entirely arbitrary, which is clearly defined by operational thoughts, operational principles and operational doctrines thus reduces the complexity of decision making. Operational decision-making behavior is one of the fundamental behaviors of operational decision-maker, which includes decision-maker's explicit behaviors to determine the decision goal, formulate the initial plan, assess the optimal selection scheme and make the final choice of action, and also includes decision-maker's implicit mental activities of analysis, judgment and reasoning. It is confrontational, dynamic and difficult to independently complete. For the implementation of decision-making behavior, the conduct rules and tactical doctrines are firstly written to the database. When needed, utilize the "matching-selecting-applying" cycle mechanism to make decision. Intelligent learning algorithms are utilized for the matching and selection.

In the TBMCSS, the Agents are divided into reactive type and hybrid type. The reactive type Agent, such as missile launcher Agent and tactical missile Agent, does not reason and make decision, but directly map the perceptive information to a certain action from the knowledge base. The hybrid type Agent, such as the command Agent, has reactive action and cognitive function with high intelligence. If percepts the simple or emergent situation, the hybrid Agent takes direct action from the knowledge base, else if percepts the complex situation, it fuses the information and make decision based on the knowledge base to generate combat missions.

Take the Red Force for example, as shown in Fig.3, corresponding to the command level and operation level in the battle, we describe Agent entities below three levels, few cognitive Agents, some rule-based Agents and many simple Agents. At the top level are the command and control Agents that have the supreme command. They perceive the battlefield information, analyze the situation, make decision by the inference engine and knowledge base, and issue the decision-making results to the subordinate Agents in the form of combat commands. At the middle level are the middle layer commander Agents, they receive superiors' orders and instructions, report progress action to their superiors, request support, exchange information with the same level commanders, and issue operational orders to subordinates. At the lowest level are the combat Agents, whose movement, interactions and other behaviors are represented only by orders, instructions and rules in the knowledge base. They do not participate in decision-making.

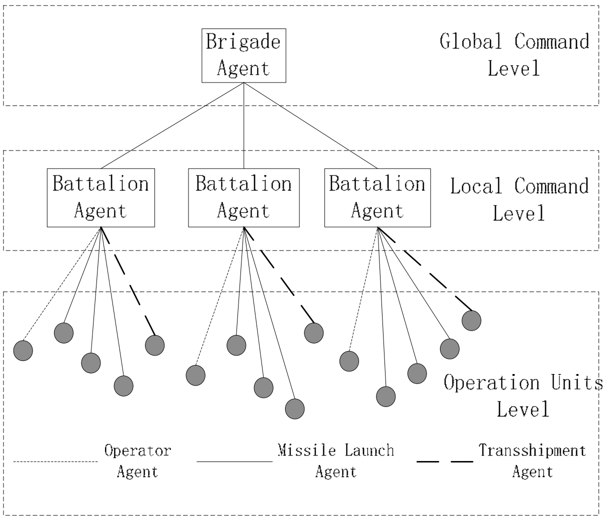

Figure 3. Three levels architecture of Agent Entities

The general methods of CGF decision-making include rule-based reasoning, neural networks, finite state machine and case-based reasoning, which have their special advantages and disadvantages.

Operational decision-making problem is the decision-making under incomplete information. Since the eighties of last century Bayesian network and rough set theory have been developed, which are the theories of dealing with imprecise, uncertain and incomplete data. They both are the new methods of knowledge representation and data reasoning that can effectively analyze incomplete information. In our TBM combat simulation system, Bayesian network has be used for the realization of CGF reasoning uncertain knowledge. Rough set theory and neural networks are combined to realize CGF knowledge acquisition, which can effectively speed up the learning.

B. Uncertain decision-making based on Rough Set

Battle conditions are filled with uncertainty. High-level planners are often confronted with enormous uncertainties, some of which imply risks and others of which signal potential opportunities. For high-level decisionmakers in particular, many uncertainties are likely to be deep.

An example of deep uncertainty relevant to defense planners is imagining the strategy of a future adversary commander in a future war in a future set of circumstances, all of which are hypothetical and unknowable.

Clausewitz described the uncertainty that commanders face in battle and aptly termed it the fog and friction of war [5].

Combat in today's world is far different from that of Clausewitz's era. Modern Western armies utilize an impressive array of Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) systems in combat. Some military tacticians believe that today's C4ISR systems are capable of removing Clausewitz's fog and friction of war from the battlefield; in reality, his two concepts are more valid than ever.

Today's battlefields are immense in size, encompassing entire nations or global regions. The problem of scope and size exists at the strategic/operational levels. For example, each of the United States Combatant Commanders (COCOMs) is responsible for entire continents and wide swaths of the globe. The US Pacific Command (PACOM) Commander alone is responsible for 39 countries covering an area of 105 million square miles and nearly 60% of the world's population. No C4ISR system, or system of systems, can possibly cover an area of responsibility of that size. Today's battlespace is comprised of land, sea, air, space and cyberspace. C4ISR systems cannot keep pace with their enemy's ability to adapt, change and overcome technology advances. For example, it is generally agreed that computer technology changes every six months, but the terrorist's IED tactics change every 30 days.

In the future battlefield, combat between TBM and Anti-TBM systems is the essential combat between certainty and uncertainty. The defense forces utilize early-warning satellite and early-warning radar to detect TBM's launching parameter, determine its orbit by using the computer and then launch the interceptor missiles to destroy it. On the other hand, the attack forces utilize multiple independent reentry vehicle(MIRV) and terminal maneuver to increase the uncertainty of the process and avoid interception.

So in the TBMCSS, for the command and control Agents, how to control the uncertainty in the battlefield and make a correct decision is very important for the victory of the combat.

Rough set theory [6] is a mathematical tool proposed by Pawlak to synthesize the approximation of concepts from a given set of data. Rough set theory can be regarded as a new mathematical tool for imperfect data analysis. The theory has found applications in many domains, such as decision support, engineering, environment, banking, medicine and others. We think rough set theory in CGF decision-making is a very promising tool.

Rough set based data analysis starts from a data table called a decision table, columns of which are labeled by attributes, rows – by objects of interest and entries of the table are at tribute values. Attributes of the decision table are divided into two disjoint groups called condition and decision attributes, respectively. Each row of a decision table induces a decision rule, which specifies decision (action, results, outcome, etc.) if some conditions are satisfied. If a decision rule uniquely determines decision in terms of conditions – the decision rule is certain. Otherwise the decision rule is uncertain. Decision rules are closely connected with approximations. Roughly speaking, certain decision rules describe lower approximation of decisions in terms of conditions, whereas uncertain decision rules refer to the boundary region of decisions.

An information system is a pair $S=(U,A)$, where U and A, are finite, nonempty sets called the *universe*, and the set of *attributes*, respectively. With every attribute $a \in A$ we associate a set *Va*, of its values, called the domain of *a*.

Any decision table induces a set of "if ... then" decision rules.

Any set of mutually, exclusive and exhaustive decision rules, that covers all facts in S and preserves the indiscernibility relation included by S will be called a decision algorithm in S.

C. Confrontation Behavior Modeling of Agent-based CGF

In the military operation, confrontation is a popular activity. Agents in the same side command, coordinate and consult with each other, but confront between the two opposite sides. At present more researches have been done for the coordination and consultation between Agents but less for the confrontation. We have established a rival mental state Agent model based on BDI and related algorithms which can track the opponent Agent's state of mind in real-time, recognize the intention and plan, and support decision for the decision-makers in a dynamic open environment, especially in the case of incomplete information.

Agent2 is Agent1's opponent, its model is

$$O=<B,D,I_s,I_p,I_w,H> \tag{1}$$

where set *B* includes Agent2's all Believes that Agent1 knows, *D* includes Agent2's all possible Desires, I_s includes Agent2's certain Intentions, I_p includes Agent2's possible but uncertain Intentions that concluded by BDI information, I_w includes the Intentions which Agent1 cares in Agent2's all possible Intentions, *H* records opponent events in a definite time.

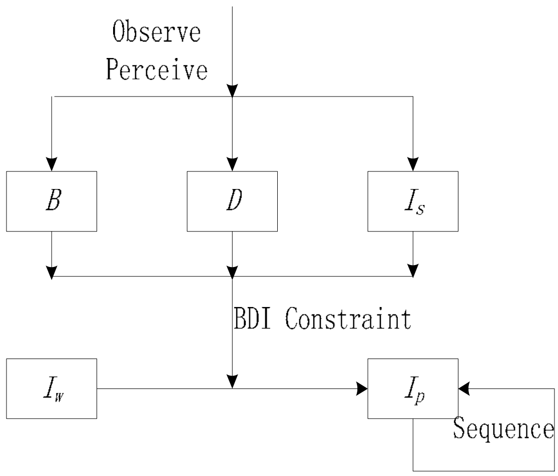

Figure 4. schematic diagram of the opponent model

As in Fig. 4, the running of the model has two phases as follow.

First, initialize all the elements. The values of B, D, I_s, H are dependent on Agent1 having a priori knowledge of Agent2, the value of I_p is set to $\varnothing$ and I_w is dependent on Agent1's own requirement. After initialization, the system takes a loop execution from step 1 to step 4.

Step1 Agent1 updates the values of B, D, I_s by capturing the information of opponent.

Step 2 Revise the value of I_p according to the constraint of B, D, I to eliminate internal contradiction of mental states.

Step 3 Add possible Intention to I_p.

Step 4 There are many possible but uncertain intentions in values of I_p and we must sequence them in the light of degree of confidence which can provide real-time and direct support to decision-making.

D. Simulation process of the TBMCSS

The whole simulation flowchart of the CGF system is as shown in Figure 5. Firstly the White Judgment Agent initializes the operating environment, and then generates simulation scenario based on the knowledge base, and issues a simulation starting command, the Red Force and Blue Force begin to simulate fighting, and finally the White Judgment Agent assesses the simulation results, which mainly assesses the damage effect of the ballistic missiles on the target and the intercept effect of the anti-missile interceptor.

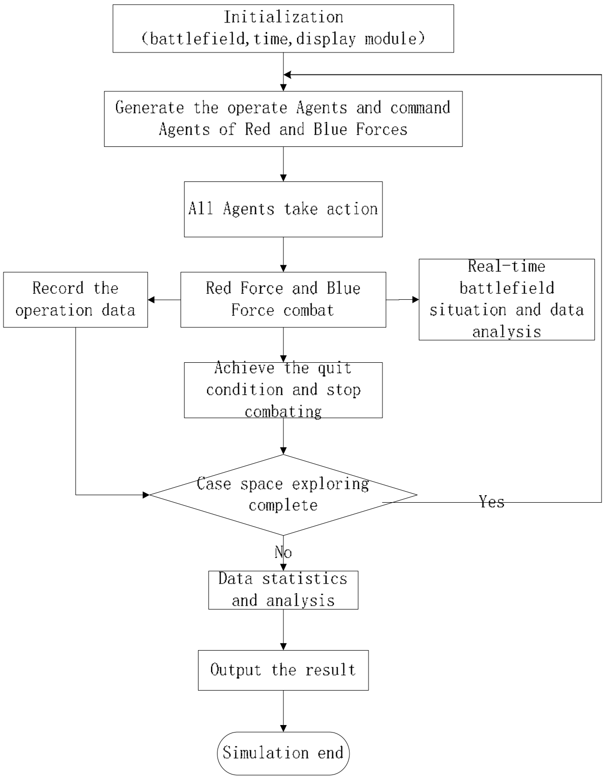

Figure 5. Flowchart of the simulation process

VI. CONCLUSION

In this paper, under the background of joint military operations, we study the CGF behavior modeling method in Agent-based TBM combat simulation system, which focus on the modeling methods of decision-making behavior and combat behavior of CGF Agent. According to the command hierarchy features of military operations, Agent entities are divided into three levels, and a three-level organizational structure of Agent has been established. To reflect the relationship between attack and defense system, we establish a BDI model based on rival model to track the status of rival Agent and do real-time response. Finally give the flow chart of TBM combat simulation system, which can help to clearly understand the whole simulation process and realization of system, lay a solid foundation for the development of CGF, and has a certain methodology significance and reference value.

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