AGENT-MONITORED ANTICIPATORY MULTISIMULATION: A SYSTEMS ENGINEERING APPROACH FOR THREAT-MANAGEMENT TRAINING

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ABSTRACT
Agent-monitored multisimulation provides a powerful paradigm to conceive and perform experimentations not possible by traditional simulation techniques. Multisimulation was developed for simulation-based conflict management and training purposes. Anticipatory behavior has several advantages over reactive behavior. Monitoring multisimulation studies by agents bring additional benefits. First, overviews of several types of threats and the relevance and importance of anticipation are given. Then, the possibilities offered by multisimulation and agent-monitored anticipatory multisimulation are presented. Afterwards, the appropriateness of agent-monitored anticipatory multisimulation is shown for several types of synchronous or asynchronous threat management and training.

Keywords: Agent-monitored anticipatory multisimulation, predictive display, types of threats, simulation-based threat-management training

1. INTRODUCTION

Emerging threats find those individuals, groups, or nations that cannot anticipate and counteract them on time. Merely reacting to events is not sufficient. As shown by Galvani (1737-1798) and Volta (1745-1827), even a dead frog can react. Intelligent entities (humans or advanced software agents) can do better than simply reacting. What is important is the ability to anticipate possible threat(s) and take precautions before it is too late. We realize that an appropriate methodology needs to be developed to help decision makers and concerned individuals to get worthwhile experience (or training) to realize the consequences of and to manage several types of possible threats which may occur synchronously or asynchronously.

Four pillars of our methodology are: (1) behaviorally anticipatory systems, (2) multisimulation (to allow experimentation with several aspects of reality at the same time), (3) agent-monitored simulation to benefit from capabilities of software agents, and (4) systems engineering (to benefit from systems approach and systems engineering to explore solutions for complex social issues).

Agent-monitored multisimulation provides a powerful paradigm to conceive and perform experimentations not possible by traditional simulation techniques. Multisimulation was developed for simulation-based conflict management and training purposes (Yilmaz and Ören 2004; Yilmaz et al. 2006). Anticipatory behavior has several advantages over reactive behavior. Monitoring multisimulation studies by agents bring additional benefits.

The article is organized as follows: Background information about threats and multisimulation are given in sections 2 and 3. Behaviorally anticipatory systems are presented in section 4. Agent-monitored anticipatory multisimulation and simulation-based threat-management training are presented in sections 5 and 6. Section 7 consists of the highlights of a case study. Finally, section 8 covers our conclusion and reports our on-going work on multisimulation.

2. THREATS

A "threat" is an indication of something impending and usually undesirable or unpleasant. It may be: (1) an expression of an intention to inflict evil, injury, or damage on another usually as retribution or punishment for something done or left undone; (2) an expression of an intention to inflict loss or harm on another by illegal means and especially by means involving coercion or duress; or (3) something that by its very nature or relation to another threatens the welfare of the latter. (Merriam-Webster).

Threats can be targeted to individuals, groups, or nations, as well as to environment. A large variety of treats exist. They can be external (exogenous) or internal (endogenous) and they can be subtle or overt. For example, terrorism (which can be exogenous or endogenous) is unfortunately a well known threat. Sometimes, neglect may induce a chain of events which may end up by becoming a threat. In a country, for example, unchecked power of a leader may foster a potential dictator which may then become a treat to the regime of the country and to its citizens. The declining quality of drinking water may become a business opportunity to offer bottled water which may end up by being an environmental threat due to the thrown away empty bottles.

We are well aware of the limits of: (1) rational thinking (Damassio 1994), (2) dysrationalia –which is defined as the inability to think and behave rationally despite adequate intelligence– (Stanovitch 2009), and even (3) the "upside of irrationality (Ariely 2010).

However, we also observe that most types of threats are results of some chains of events. Our thesis is that, as intelligent people, if we are better educated or at least trained to acquire experience in anticipating results of chains of events, we may take precautionary measures on time to avoid unnecessary disasters. For example, denying fundamental rights to a minority (ethnic, religious, or else) in a society would entails reaction and may become a source of serious threat. In another area, it should be possible to monitor, fiscal responsibility of bankers who offer credits to individuals beyond their means, before their practice become a national disaster. Similarly, fiscal responsibility of countries should be possible to be monitored before the chain of events end up by becoming national, regional disasters and threatening world economy.

3. ANTICIPATORY MULTISIMULATION

Multisimulation allows simulation of several aspects of reality at the same time. In its simplest form, while a simulation run is progressing, if a significant development occurs, then in the simulation study a branching can occur. In this case, while the main simulation study continues, a second simulation starts to explore the new development. For example, while simulating functioning of a city, if there is a threat such as an explosion somewhere in the city, an additional simulation of this threat may start. While these two simulations are running, if there is yet another significant event, a third simulation may start. Even if the threats occur in different parts of the city, each threat would require some resources and may have implications for the others, such as need for resources from a common pool; hence they may have some relations. Therefore, multisimulation can provide realistic and valuable experience for decision makers.

In general, when a branching occurs in a simulation study, the old and new simulation runs may use the same or different models –with same or different parameters– under same or different scenarios.

An interesting generalization of the multisimulation concept is its application to thought experiments. In this case, at a given situation, the implications of several alternative scenarios can be explored.

3.1 Multisimulation within a taxonomy of simulation

To appreciate the position of multisimulation with respect to some other types of simulation, Table 1a and 1b outline a taxonomy of simulation based on the characteristics of model behavior generation. (There are many other types of simulation based on other criteria. See for example Ören (2011, 2012). Table 1a is based on hardware used in the simulation, as well as time and purpose of using simulation.

Table 1b is based on the process of generation of model behavior. Gaming simulation or serious (simulation) games are intermittent simulations; i.e., at certain interaction times, simulation is interrupted, some information is made available to players (or decision makers). Based on the available information, the players make decisions, i.e., change values of controllable variables and/or parameters, and if feasible, models. Then simulation resumes.

Table 1a. Taxonomy of Simulation Based on Characteristics of Model Behavior Generation
►Category • Criteria**:** *Type of simulation*

►Hardware use
• Hardware is used: *Simulator (man-in-the-loop-simulation)*
• Hardware is not used: *Simulation*
►Time
• Real-time: *Real-time simulation*
• Compressed time: *Compressed-time simulation*
• Expanded time: *Expanded-time simulation*
►Purpose
• Value-free decision: *Value-free simulation*
• Descriptive decision: *Descriptive simulation*
• Explanatory decision: *Explanatory simulation*
• Predictive decision: *Predictive simulation*
• Normative decision: *Normative simulation*
• Evaluation: *Evaluative simulation*
• Prescription: *Prescriptive simulation*

Table 1b. Taxonomy of Simulation Based on Process of Model Behavior Generation
►Category • Criteria (•• Subcriteria)**:**
Type of simulation (Subtype of simulation)

►Process of *generation* of model behavior
• ***Continuous***: *Simulation run, (Single-run simulation study)*
• **Intermittent**:
•• Multiple runs*: [Multiple-run] simulation study, Antithetic run, Regenerative simulation, Sensitivity simulation*
•• Nested simulation: *Optimizing simulation: (Simulation within optimization, Optimization within simulation)*   *Expert system (ES) & Simulation: (Simulation within ES, ES within simulation)*
•• Interaction among decision makers (players): *Gaming simulation, Game-theoretic simulation, Serious games*   If competition: *Zero-sum games (Wargaming, Business gaming)*   If cooperation: *Non-zero-sum games (Peace games)*   If coopetition: *Cooperative simulation within competitors*
•• Interaction between behavior generation and the real system: *Stand-alone simulation, Integrated simulation*
•• Multiple simulations: (with or without interaction of simulation and real system) (with or without interaction among decision makers (players): *Multisimulation*

So far as interaction between simulation and the real system is concerned, there are two cases: In *stand-*

alone simulation, simulation is independent of the operation of the real system, as it is the case in most simulation studies. *In integrated simulation*, the operations of real system and simulation are either synchronous or interwoven. Integrated simulation is used to monitor the operation of a real system or to enrich its operation.

In the case of multisimulation, at the branching points, decisions can be made as it is the case in serious simulation games, or there can be interaction with real system as it is the case in integrated simulation (Yilmaz et al. 2007).

Anticipatory multisimulation is multisimulation of anticipatory systems. The power of anticipatory multisimulation can be used as predictive displays of the consequences of several alternative scenarios at critical decision points. Hence, the potential undesirable (including catastrophic) states can be displayed, therefore can be avoided, before they happen.

4. SYSTEMS ENGINEERING

4.1 What is System Engineering?

A system is a construct or collection of different elements related in a way that allows the achievement of a common objective (Thayer 2005). The elements of the system include hardware, software, people, facilities, policies, and other factors coordinated to achieve system objectives.

System engineering (SE) involves the application of engineering and management practices to transform the user needs into a system specification and realization that most efficiently meets the need. SE entails the technical management functions that controls and coordinates the overall system development activities. As such, it revolves around a generic problem solving process that gradually evolves specifications toward a realization of the requirements that satisfy objectives set forth at the beginning of a project.

4.2 The Functions of System Engineering

System Engineering involves:

- *System conception* that deals with the process of involving users in conceiving an application and identifying tentative requirements.
- *Problem specification*, which identified and formulates the needs and constraints imposed by the problem domain. Domain analysis constitutes the fundamental component of problem specification. Application analysis entails the description of the parts of the system that are visible to the user.
- *Solution analysis*, which determines the set of possible ways to satisfy requirements, overviews the solutions, and selects an optimal strategy.
- *Process planning* that identifies the tasks, their scheduling and interdependencies, estimates the size and cost of the project, and determines the required effort to complete the project.
- *Process control and product evaluation* that determines the strategies to control and measure the progress and evaluates the product via testing, inspection, and analysis.

In (Yilmaz and Ören 2009; Ören and Yilmaz 2009; Ören and Yilmaz 2012), we elaborated on how M&S and SE can support each other. Here, we discuss the role of M&S in systems, why M&S requires SE, and why Simulation Systems Engineering (SSE) is necessary. Simulation is becoming a dominant technology in many systems engineering applications. In defense-related training systems, simulations are being embedded to create virtual scenarios. Symbiotic simulation systems have been proposed as a way of solving this problem by having the simulation and the physical system interact in a mutually beneficial manner.

4.3 Why does M&S Require SE?

As discussed above, M&S systems are becoming more and more complex and they are being embedded with other system in a system of systems context to serve larger objectives. In developing such simulations the solution space must be defined before assigning functionality to various components. The SE perspective provides an opportunity to specify the solution for the acquirer prior to allocation of functionality onto hardware, software, and simulation systems.

4.4 Why is SSE Necessary?

M&S development costs are rising partly due to increased complexity. Craftsmanship approach to M&S in the small does not scale to M&S in the large. Consequently, such complex and extremely large simulation systems require technical system management and SE oversight. Unless such oversight is present, the following problems are likely to emerge.

- Simulation system becomes unmanageable.
- Costs are overrun and deadlines can be missed.
- Greater risk exposure arises.
- Requirements may not be met.
- The simulation fails to satisfy its objectives.
- Maintenance costs increase.

5. BEHAVIORALLY ANTICIPATORY SYSTEMS

An anticipatory system is a system whose next state depends on its current state as well as the current perceptions of its future state(s) (Ören and Yilmaz 2004). That is, a behaviorally anticipatory system incorporates perceptions of future states into decision-making to improve its effectiveness in developing actions that lead to situations with high utility and payoffs. That is, in a threat scenario, having an anticipatory perception in terms of predictive models of opponents and/or the threat environment is expected to improve decision-making. Specifically, in evolving threat situations, predefined course of actions and strategies may be obsolete, and reactive strategies that cannot properly anticipate effects fail to reliably respond to emerging activity in a timely manner. Also, reactive behavior is severely inertial for tasks where multiple goals need to be pursued. Therefore, purposive reliable course of actions should not simply be reactive to situation, but also consider anticipations of the effects expected.

The role of anticipation in threat-management training can be conceptualized in terms of the elements of anticipatory behavioral control, shown in Figure 1.

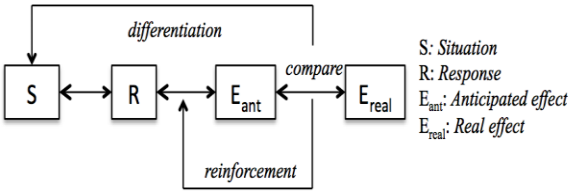

Figure 1: Anticipatory Behavioral Control

According to theory of anticipatory behavioral control, (1) behavioral act or response (R) is accompanied with an anticipation of its effects, (2) anticipated (simulated) and real effects are compared, (3) the credit assigned between response and anticipation is strengthened when the anticipations are accurate and weakened otherwise, (4) finally, R – E_{ant} relations are differentiated by behavior relevant situational stimuli.

Based on these characteristics, a behaviorally anticipatory threat-management and training system needs to incorporate interpretation facilities as a precursor to (1) comprehend and draw accurate inferences about the evolving and volatile threat environment, (2) have context-sensitive pragmatism by considering the likely effects of course of actions, and (3) have situational definition as a direct input to action recommendation. Drawing inferences about the world requires presence of predictive models for the generation and understanding of effects. In principle, a behaviorally anticipatory system is a system containing predictive model of itself and/or of its environment, which allows it to change at an instant in accord with the model's predictions pertaining to a later instant. This ability can also be used to compensate for the absence of or fuzziness in information and data available during training. Anticipation and anticipatory learning during a threat-management training scenario can involve generation of a multitude of dynamic models of course of actions in a given practical situation and the resolution, through a reward or punishment mechanism, of their threat in an action.

Figure 2 illustrates components of a hypothetical anticipatory learning framework in threat-management training. The training system is coupled with a multisimulation system to explore expected effects of identified plausible course of actions. Due to uncertainty, models executed by the multisimulation system can examine the effects of strategies in multiple possible environments. As the user gains better insight about the threat and develops more accurate predictive threat models, the system can shift from exploratory analysis to exploitation of increasingly accurate environmental models to discern effective strategies under the given

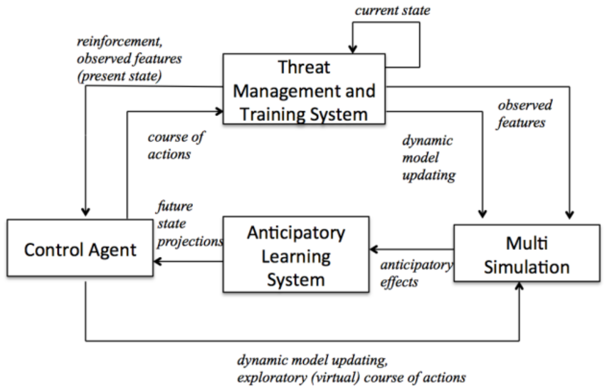

Figure 2: Anticipatory Learning in Threat Management

environment. In this context, multisimulation can be construed as generator of futures. Situation-Response (S-R) training systems are slow since they are able to propagate reward only one step at a time and only in direct interaction with the environment. An anticipatory learning/training system will be able to form explicit environmental models and use them to propagate reward faster. The control/interface agent (or trainee) uses the future state projections generated by the learning system. On the other hand, before acting on the actual training scenario, the user can continue to experiment in the virtual environment via further experimentation using the multisimulation engine. As the threat environment and the scenario unfold in real-time, the models executed by the multisimulation system need to be in synch with the emerging behavior in the threat scenario. This requires proper dynamic model and parameter updating mechanisms.

6. AGENT-MONITORED ANTICIPATORY MULTISIMULATION FOR THREAT-MANAGEMENT TRAINING

Multisimulation with multimodels, multiaspect models or multistage models needs mechanisms to decide when and under what conditions to replace existing models with a successor or alternative. The control agent, shown in Figure 2, monitors the multisimulation subsystem through the anticipatory learning component. The control agent partly enables branching into contingency plans and behavioral rules in response to scenario or phase change during experimentation. Graphs of model families may facilitate derivation of feasible sequence of models that can be invoked or staged. More specifically, a graph of model families can be used to specify alternative staging decisions. Each node in the graph depicts a model, whereas edges denote transition or switching from one model to another.

Model recommendation in multisimulation can simply be considered as the exploration of the model staging space that can be computed by reachability analysis of the graph. There are two modes for the usage: (1) Offline enumeration of paths using the graph and performing a staged simulation of each model in sequence one after the other, unless a model staging operation becomes infeasible due to conflict between the transition condition and the precondition of the successor model and (2) run-time generation of potential feasible paths as the simulation unfolds. In both cases, a control agent plays a key role to qualify a successor model. The first case requires derivation of sequence of models using a traversal algorithm. The edges relate families of models. Therefore, the actual concrete models, the preconditions of which satisfy the transition condition need to be qualified, since transition to some of these model components may be infeasible due to conflict between a candidate model and inferred situation.

Candidate models and associated simulations can be maintained by the control agent using focus points. A focus point manages branch points in the simulation frame stack. Suppose that a goal instance (i.e., stage transition condition) is at the top of the stack. If only a single model qualifies for exploration, then it is pushed onto the stack. Yet, if more than one model matches the condition, a simulation focus point is generated to manage newly created simulation branching (discontinuity) points, each one of which have their own contexts.

When a path is exhausted, the closest focus point selects the next available model to instantiate the simulation frame or return to the context that generated the focus point. As threat management scenarios are explored, a network of focus points is generated. Determining which focus point should be active at any given time is the responsibility of the control agent. When more than one model is qualified, then the agent needs to decide which one to instantiate. Control rules can inform its decision. Three steps involve in deploying a new simulation frame in such cases: matching, activation, and preference. The matching step should both syntactically and semantically satisfy the request. The activation step involves running a dynamic set of rules that further test the applicability of models with respect to contextual constraints. Finally, the preference steps involve running a different set of rules to impose an activation ordering among the active frames.

7. HIGHLIGHTS OF A CASE STUDY

7.1 **Advance Warning Systems and Protection for Sustaining Humanitarian Operations**

In humanitarian operations, carrying supplies and food aid to those in need is increasingly becoming a challenging task. Supply convoys are routinely disrupted to undermine international conflict resolution efforts.

Consider the problem of escorting a convoy along an unknown territory. Smaller convoys use high-speed as a means of defense while larger convoys are restricted to lower speeds and must make numerous stops to maintain formation and navigate through cities. A cyber-physical escort system using UAVs could enhance the safety of the convoy. Among the goals of such a Cyber-Physical System (CPS) of UAVs is to cooperatively follow friendly convoy vehicles along both known and unknown routes and provide situational awareness information to determine whether road ahead/behind and sides are clear. As a team of UAVs conduct cooperative search, tracking, and acquisition, collision avoidance becomes critical, as any scenario that considers dynamic updating of paths requires deconfliction of flight plans of cooperating vehicles. This scenario gets complicated further due to failure of UAVs to anticipate ground vehicles' turn direction, lack of maneuvering agility, difficulty in managing multiple simultaneous views of targets, and mechanical limits of the sensor's gimbal system. Also, radar and optical sensors will have limitations in terms of range, resolution, sensitivity in low light/obscured conditions, and motion stability. These limitations bring with them uncertainties in target detection, identification, and tracking. Furthermore, a cooperative UAV team should be able to track an unfriendly moving target when requested, while also accounting for obstructions to viewing and terrain changes. As a result, robust strategies are needed to cope with uncertainty as well as ambiguity (lack of clarity). In such evolving situations, predefined control strategies may be obsolete and reactive control methods that cannot properly anticipate effects fail to reliably respond to emerging activity in a timely manner. Also, reactive control systems are severely inertial for tasks where multiple goals need to be pursued. Therefore, purposive reliable behavior should not simply be reactive to situation, but also consider anticipations of the effects expected.

7.2 **Application of Anticipatory Multisimulation**

A multisimulation system coupled with a convoy escort system can leverage real-time observations using an input exploration component responsible for conducting input analysis and selecting appropriate distributions for the environmental models. At this stage, dynamic model updating to attain consistency between the cyber (simulation) and physical components is critical. Samples from these distributions can then be integrated with controller parameters to form one model ensemble for each Agent-based Simulation Process (ASP) in a multi-simulation. Ideally, each ASP can be mapped to one or more CPU cores. If the simulation population is large or if hardware resources are limited, multiple ASPs can run on a single core. Outputs from the ASPs may take the form of fitness and robustness measure of the individual simulations averaged across all of the replications. While robust strategies generated by symbiotic adaptive multisimulation can be used by the agent controller to update the coordination behavior of physical and/or simulated UAVs, anticipatory learning could improve over time both the self-simulation and the physical system by rewarding effective control strategies.

8. CONCLUSION

Chains of some events may end up by becoming major threats to individuals, groups, or nations. Proper education and training of individuals may help them to realize the importance of anticipatory consideration and evaluation of alternatives and to take precautions to avoid –at least certain types of– disasters. A systems engineering approach, coupled with multisimulation methodology would even allow them to acquire necessary experience by allowing simulation of several aspects of reality at the same time.

Our research will continue (1) refining the methodology, including cognitive simulation such as understanding and misunderstanding in human behavior simulation and (2) in developing examples.

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