USING SIMULATION FOR DEVELOPMENT OF BATTLEFIELD INTELLIGENT AGENTS

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ABSTRACT

The battlespace is increasingly dynamic and challenging. The volume of information available to decision-makers is ever increasing. The uncertainties about the battlespace, whether due to cyber attack, miscommunication, mechanical fault, or other problem, prevents rapid, effective, informed decision-making. The mere application of so-called "big data" technologies cannot address the scope of the coming problems. In an environment with great uncertainty and large amounts of data, autonomous intelligent agents on the battlefield can provide the military planner with an invaluable aid for observing, planning, integrating, and interpreting to achieve mission goals.

However, current intelligent systems cannot provide the required decision-making or uncertainty reduction support. The state of the art for automated intelligent behavior relies heavily on the use of predefined scripts, which prevents both adaptability in the intelligent agent response and support for human intent. The prerequisite for successfully creating autonomous intelligent battlefield agents are the Artificial Intelligence (AI) technologies for machine learning, user intent, prediction of actions, and emergent behavior. Improvements across these areas of AI can provide autonomous intelligent behavior in battlefield agents that goes beyond scripted behavior and is far more useful. Simulation can be used to address requirements development and testing of battlefield intelligent agents. Simulation can be used to promote integration of battlefield intelligent agents into military operations at all scales across all the levels of command.

In the paper we discuss battlefield intelligent agents and simulation's role in bringing about their next generation. The paper introduces the technical challenges obstructing battlefield intelligent agents, the challenges of situation awareness, and the AI shortfalls to be addressed. The paper discusses the roles that simulation should play in order to research, develop, and integrate battlefield intelligent agent technologies into operational practice. Finally, the paper discusses the use of simulation technologies to assemble battlefield intelligent agents.

SIMULATION FOR RESEARCH, DEVELOPMENT, AND TEST OF BATTLEFIELD INTELLIGENT AGENTS

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1. INTRODUCTION

Situation understanding and adaptivity are the putative hallmarks of the modern information enhanced battlespace. However, the advantages and improved decision-making promised by information systems have not materialized. The problem and challenge arises from the vast amount of information that is available and the rate of change of information coupled with the unvarying human capabilities for information assimilation and comprehension. A person's brain cannot be changed, but the manner of information presentation and the tools provided to assist each individual in maximizing their personal abilities for information assimilation and comprehension can improve them. All decision support systems are not equal in their ability to convey to users the information they need in specific decision contexts or in the degree to which the decision support system is compatible with basic human information-processing abilities. To overcome inherent human limitations in *information acquisition*, *information understanding*, and *situation assessment*, decision support systems have to be built with user limitations in mind as well as providing capabilities for minimizing taskload. In information intensive environment, humans can benefit from the availability of intelligent assistants to achieve improvements in situation awareness and decision-making. One of the most challenging decision making environments is the cyber warfare environment, due to both the volume and pace of data change. The challenges faced by humans in the extremely information intensive cyberwarfare environment are exacerbated by the lack of tools to support situation awareness in a distributed cyber environment. The paucity of tools for cyber situation awareness calls for the development of intelligent decision aids to assist humans in understanding and acting within the cyber battlespace.

The challenge faced by decision support system designers when developing intelligent aids, usually called intelligent agents, lies in insuring that they provide useful, adaptable, and transparent support for situation understanding and decision-support despite rapid change. Intelligent agents have been a significant research topic for decades but much remains to be done if they are to be useful within future battlefield information environments. In addition to being useful, the battlefield intelligent agents must be robust, resilient, and able to withstand cyberattacks and shield the users' cognitive activities from attack [54-68]. As a result, the battlespace intelligent agent must not only be able to distill and present data relevant to the user's context, it must also continuously assess the information received in order to determine if the data or the data acquisition environment have been compromised. Achieving this combination of goals is beyond the capability of traditional intelligent agent systems. A new intelligent agent architecture coupled with a new method for developing the required knowledge bases is required.

Employing intelligent agents to enhance situation awareness (SA) and decision-making in both the cyber and real world battlespaces cannot relieve the user from the need for acquiring deep, situational-oriented understanding and acting upon the situation as they understand it. In general, situation awareness begins by perceiving information about the environment and coupling that perception with comprehension of the meaning of the information in light of the user's goals. SA requires more than merely being aware of all of the data in an environment or all of the most pertinent pieces of data. SA requires an understanding of the situation, which requires developing and maintaining a mental model of the situation. Maintaining a model of the situation requires estimating the likely future state(s) of the environment and developing a model of the progression of the situation toward those state(s). In a complex environment, SA cannot be achieved without training to prepare the user for both the breadth of the situations and the pace of change in the situations. Even given intelligent aid assistance, situation awareness-oriented training must focus on training operators to identify prototypical situations associated with different types of cyberattacks/cyberthreats by recognizing critical cues and what they imply. Decision-makers must also learn in the course of the training that situation awareness is not a passive process; they must actively seek out and comprehend the information they require. Training can help decision makers to develop the situation recognition and behavioral skills they need, but serves to complement the activity of intelligent agents. Because of the challenges that decision-makers face, intelligent agents must be designed to support user situation awareness development and maintenance.

The situation awareness challenges faced by the real-world and cyber battlespace decision-makers are complicated by the characteristics of the environments within which they operate.

The read-world and cyber battlespaces are highly dynamic and uncertain environments. In such environments a battlespace autonomous agent should have the ability for integrated observing, interpreting, communicating, planning, decision-making, and otherwise working to reduce workloads for the warfighter. In a highly dynamic battlespace, momentary lapses in SA can have catastrophic repercussions as illustrated in the recent Fukushima plant or Chernobyl failures. Because of the complexity of the real-world and cyber battlespace environment the corresponding intelligent agent knowledge bases are complex and difficult to develop. We discuss a method for addressing the intelligent agent complex knowledge base development challenge in this paper.

In this paper we discuss battlefield intelligent agents and simulation's role in bringing about their next generation. The paper introduces the technical challenges obstructing battlefield intelligent agents, the challenges of situation awareness, and the AI shortfalls to be addressed. The paper discusses the roles that simulation should play to research, develop, and integrate battlefield intelligent agent technologies into operational practice. In the next section we discuss the challenges of situation awareness and the roles that intelligent agents can play in building and maintaining situation awareness. In the third section, we discuss the uses of simulation to develop improved battlespace intelligent agents. Section four contains a summary and conclusions.

2. BACKGROUND

The objective for battlespace intelligent agents is to improve situation awareness. However, to improve SA, the intelligent agents (IA) must behave in a manner that enhances development and maintenance of situation awareness, allow users to concentrate on significant aspects of the battlespace and not on the IA, and serves to minimize the user's taskload. First, though, a short discussion of SA in light of current cyber warfare technology is warranted[6-53]. The development of the concept of information warfare and of modern electronic networking technologies has given rise to the implicit assumption that military staffs will be able quickly to access information and rapidly develop a shared situational awareness that facilitates decision-making[1-5]. The presumption is that information processing capabilities will permit a faster response to challenges by reducing the response time and complexities of the military administrative and command structure [1-5]. The contention is also that these technologies will permit staffs to perform those duties in a distributed environment as efficiently as in a collocated environment.[1] Exploiting information dominance may be much more difficult than expected, especially in the face of cyber attacks, which will adversely affect situation awareness. In order to deploy intelligent agents to assist in developing SA, we first require an understanding of SA and how it arises. The following discussion introduces SA and its development.

Endsley[10] defines individual situational awareness (SA) as the following: *the perception of the elements in the environment within a volume of space and time, the comprehension of the elements' meaning, the projection of the elements' status into the near future, and the prediction of how various actions will affect the fulfillment of one's goals*. Situational awareness is a

[1] Naval Aviation Schools Command, "Situational Awareness," http://www.actnavy.mil/Situational Awareness.htm; Kip Smith and PA Hancock, "Situation Awareness is Adaptive, Externally Directed Consciousness," *Human Factors,* 37, 1 (1995), p. 137; Vice Adm. Arthur K. Cebrowski, "Network-Centric Warfare: An Emerging Military Response to the Information Age," *1999 Command and Control Research and Technology Symposium*, June 29, 1999, http: //www.nwc.navy.mil/press/speeches/ccrp2 htm;, Endsley, M. (1995) "Toward a Theory of Situation Awareness in Dynamic Systems," *Human Factors*, vol. 37, no. 1, p. 35-64.

rapidly changing, ephemeral mental model of an environment that must be assembled over time and continuously updated. Assembling the mental model requires knowledge of the current state of the environment. SA arises by perceiving information about the environment and coupling that perception with comprehension of the meaning of that information in light of operator goals. SA requires more than merely being aware of all of the pieces of data in an environment, the significance of the elements (individually and in combination), or even all of the most pertinent pieces of data in an environment. SA requires an understanding of the situation, which equates to developing and maintaining a mental model of the situation, including likely future state(s) of the environment as well as a model of the progression of the situation toward the future states. The challenge faced by the decision-maker is placing the elements of the environment together into a meaningful, coherent pattern, which yields a holistic picture of the environment that helps the decision-maker in comprehending the significance of objects and events. Because SA is time-dependent, the individual must refresh the SA as the environment changes. SA does not refer only to static factors such as the knowledge of established procedures, doctrine, and skills; SA also refers to one's perception of the dynamic state of the environment.

Endsley identified four components of situational awareness: 1) *perception* (what are the facts in the environment), 2) *comprehension* (understanding the facts), 3) *projection* (anticipation based upon understanding), and 4) *prediction* (evaluation of how outside forces may act upon the situation to affect your projections.) These components are not stages, but instead are interlocking cycles that progress in relation to each other. As illustrated in Figure 1, the factors that promote individual SA are both structural and situational and combine with information and training to give rise to SA. Structural factors include background, training, experience, personality, interests, and skill.

Situational factors include the mission that is being performed and the circumstances prevailing in the environment. Several factors can cause degradation of individual situational awareness including the following: 1) ambiguity (arising from discrepancies between equally reliable sources), 2) fatigue, 3) expectations and biases, 4) prior assumptions, 5) psychological stress, 6) misperception, 7) task overload (too much to do), 8) boredom (not enough to do on the tasks to maintain focus), 9) information shortage, 10) information overload, 11) information interruption, 12) irrelevant information, 13) mission complexity, 14) fixation/attention narrowing, 15) erroneous expectations, and 16) lack of experience Situational awareness appears to be the result of a dynamic process of perceiving and comprehending events in one's environment, leading to reasonable projections as to possible ways that environment may change, and permitting predictions as to what the outcomes will be in terms of performing one's mission, as illustrated in Figure 2.

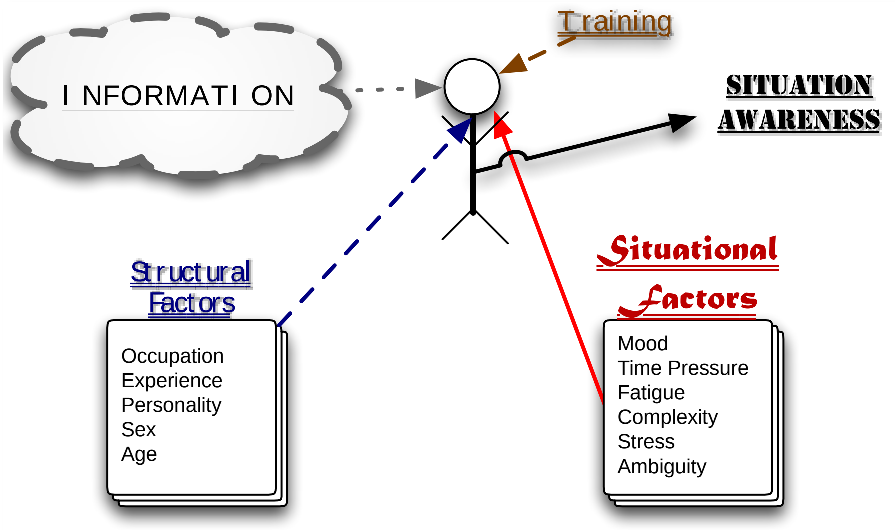

Figure 1: Situation Awareness Development.

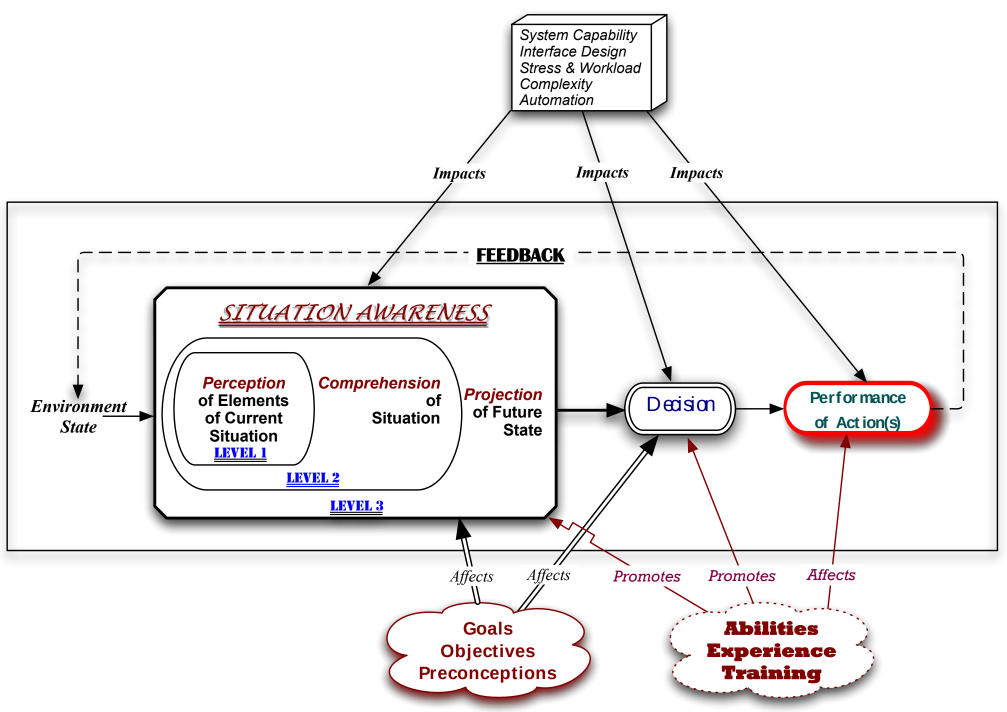

Figure 2: Situation Awareness Cycle. *Based on Endsley[10]*

As shown in Figure 2, the core of the situation awareness cycle is perception, comprehension, and future state projection for the environment, which is simply perception->comprehension->projection->decision->action->repeat. However, the cycle is affected by external factors that serve to make SA development complex and challenging. SA development is affected by the individual's goals, objectives, and preconceptions. These same factors affect the decision. The decision, in turn, leads to action(s) that have an effect upon the environment, the effect is supplied to the individual in conjunction with the state of the environment in order to begin a new cycle of SA development, decision, and action. As illustrated in the Figure 2, the abilities, experience, and training possessed by the individual can promote improved SA and decisions as well as affect the quality of the action(s) that are performed. Additional factors can come into play to affect SA development and action within the environment. These factors include the system capability and interface design, stress, environmental complexity, workload, and task automation. Intelligent agents can play many roles in assisting the individual within the environment, including assisting the individual in developing SA for all three levels, reaching a decision, monitoring the results of action(s), moderating workload, reducing environmental complexity, and enhancing the abilities, experience, and training possessed by the individual. To play each of these roles, the intelligent agent requires a knowledge base with sufficient scope and breadth so that its support is useful in real-world situations.

3. USING SIMULATION FOR INTELLIGENT AGENT DEVELOPMENT

Simulation environments can provide the realism required to develop intelligent agent systems with the capabilities needed to assist decision-makers in developing situation awareness in real-world situations. To develop intelligent agents for use to provide battlespace assistance, knowledge bases to support the operation of the cyberspace and real-world agents are needed. The intelligent agents for the real world and cyberspace must be designed and deployed with user support as the primary purpose and with the capability to continuously provide assistance in all four components of SA. Without proper support from the intelligent agent systems, the decision-maker can be overwhelmed with information from the battlespace, not all of which is either accurate or pertinent to the decision-maker. Additionally, the decision-maker can be faced with the additional arduous task of requesting information about real-world and cyberspace activities and status that the decision-maker may deem to be appropriate. Useful intelligent agents for the battlespace would assist the user by minimizing the taskload associated with acquiring information, assessing information accuracy, assessing information relevance, and in presenting the information in a manner that aids the user in developing cyberspace and real-world situation awareness. The cyberspace intelligent agents must be tasked with assessing accuracy and security of the information used by the real-world intelligent agents in addition to providing direct support to the decision-maker. Intelligent agents can serve to help the decision-maker to acquire data, develop SA, develop decision alternatives, and monitor action outcomes. There are many complex aspects and interactions in the environment in which SA must be developed and maintained. The complexity continues to increase in conjunction with the challenges of operating in both the cyber and real-world battlespaces.

In our view, intelligent agents exist to assist the decision-maker in mission accomplishment and to minimize the decision-makers taskload associated with accomplishing the mission in both its cyberspace and real-world aspects. Intelligent agents should aid the decision-maker in all phases in situation awareness development, perception and comprehension of the situation, projection of future status, correlation of goals and objectives with the situation, development of alternatives in light of the mission, goals and objectives, monitoring of the decision, monitoring of actions, assessment of actions, and assessment of the environment reaction to the decision. The decision-maker is the key actor; responsible for not only developing and maintaining situation awareness of the cyber and real-world components of the battlespace, but also for using the mission as the foundation for developing and maintaining objectives and plans for activities in cyberspace, the real-world, and in the intersection/interplay between these environments. The decision-maker's perceptions, preconceptions, abilities, experience, and training should all influence the behavior of the intelligent agents that are aiding the decision-maker. The objectives and plans are affected by activities in the real-world and in cyberspace and the interplay between the plans for real-world and cyberspace objective accomplishment. With cyberspace and real-world objectives in hand, guidance and tasking for the intelligent agents can be developed, with the results of their activities serving to support the decision-maker. Furthermore, the cyberspace intelligent agent must use its knowledge about the state and security of the cyber battlespace to inform the decision-maker and the real-world intelligent agents about the reliability of the data they are using and thereby constrain their data scope to the data that has the lowest probability of having been tampered or altered. The cyberspace intelligent agents are broadly tasked with determining the security state and data reliability of the decision-maker's sources of information as well as directing the activities of supporting cyberspace intelligent agents in their activities to secure data sources and to inspect the sources for indications of tampering, evidence of decreased data reliability, or inaccurate data. The real-world intelligent agents use data acquired from available, sufficiently reliable sources in conjunction with the decision-maker's plans and objectives to drive decision-support systems activities including aiding in focus of attention, activity monitoring, SA model maintenance, plan alteration, and other support for mission accomplishment.

Building the knowledge bases required by all of the intelligent agents is a significant challenge. In our approach, we refine each intelligent agent/knowledgebase pair iteratively by refining each pair in turn. As illustrated in Figure 3, the key is to use subject matter experts (SMEs) to develop relevant guidelines and rules for the cyberspace and real-world intelligent agents by involving them in creating the training scenarios, developing baseline knowledgebases, and in evaluating the performance of the intelligent agent after each training session. The first step is development of training scenarios that are described using UML and XML, followed by selection of a intelligent agent/knowledgebase pair to be refined. After selecting the pair, the training scenarios are modified based upon the intelligent agent's task and the knowledgebase structure. The baseline knowledgebase for the intelligent agent is then assembled using SME expertise. We associate each SME-produced knowledge base with a single intelligent agent. Each intelligent agent/knowledge base pair is augmented in turn, the content of the knowledge bases for the other intelligent agents are frozen. To augment the content of the knowledge base, we insert the intelligent agent into a simulation environment wherein the intelligent agent specific training scenarios are executed. By executing the scenarios within a simulation environment, we obtain maximal fidelity and complexity in scenario content with a minimum of additional development and minimal risk of exposure or compromise due to a real-world scenario mishap.

We enhance the knowledge bases by using successive refinement based upon the performance of the intelligent agents within simulation environment based scenarios. Refinement of intelligent agent performance is accomplished by repeatedly presenting the knowledge base and intelligent agent pair with the scenarios. At the conclusion of each refinement run, the knowledgebase for the intelligent agent is updated. Discussion of the refinement process for knowledge base architecture-specific aspects of this approach are beyond the scope of this paper. Suffice it to say that the implementation of the refinement technique must be tailored to the architecture and implementation of the knowledgebase being refined. Then the performance of the intelligent agents is evaluated by the SMEs and the decision-makers supported by the intelligent agent. If the results of both evaluations indicate acceptable performance, a different intelligent agent and knowledgebase pair is selected. If the evaluations indicate unacceptable performance, the scenarios are executed again to further refine the knowledge base.

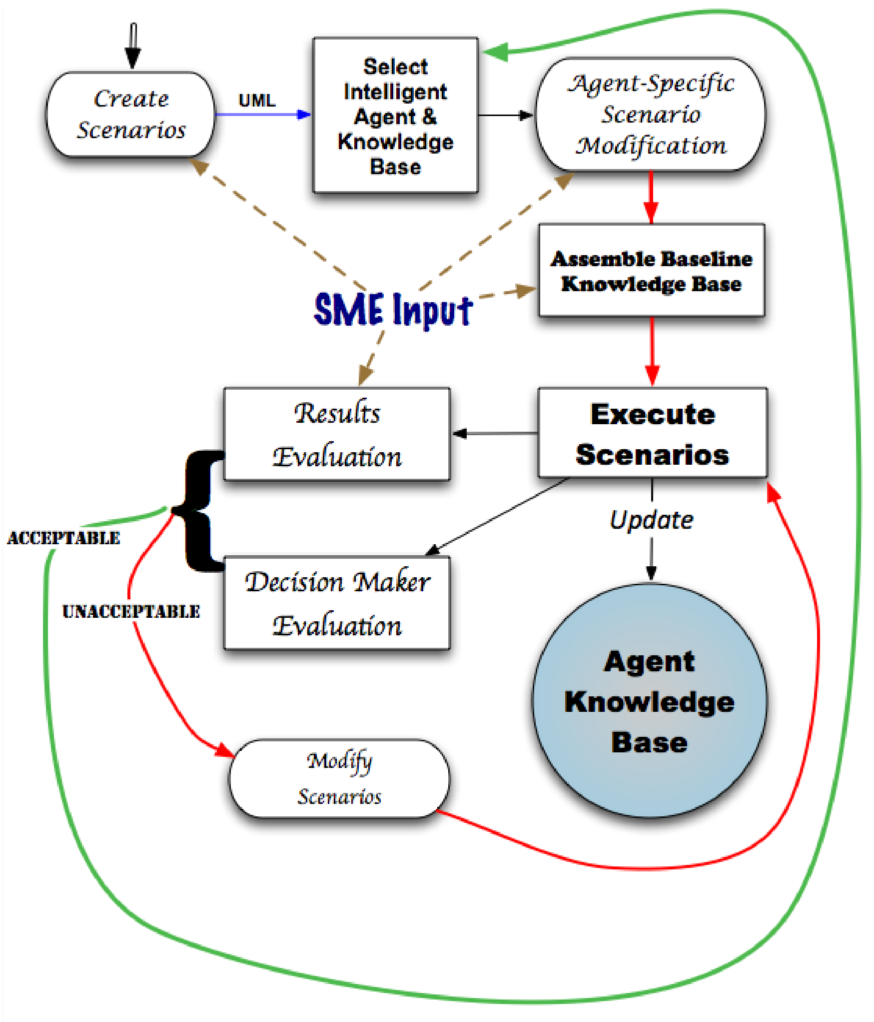

Figure 3: Knowledgebase Development Process

The cyberspace and real-world intelligent agents must perform a broad variety of tasks to support the decision maker. The most critical task for the intelligent agents is to act to support development and maintenance of situation awareness by the decision-maker. SA development and maintenance support requires help for the user to keep their SA model "current." The intelligent agents should act to acquire data for the decision-maker, both in *response to* specific requests and in *anticipation of* needs as well as to analyze data on behalf of the decision-maker. The cyberspace intelligent agents should maintain a watch for indicators of malware infestation and data corruption as well as act to insure data security, reliability, availability, and timeliness. The cyberspace and real-world intelligent agents must act and cooperate to help the decision-maker maintain appropriate focus of attention in the real-world and in cyberspace. The cyberspace and real-world intelligent agents must be able to infer user intent, objectives, and changes in plans without requiring the decision-maker to actively engage the IA systems to alter their behaviors. The cyberspace and real-world intelligent agents must be capable of acting to suggest alternative courses of action in their respective domains as well as monitor progress of the action(s) toward the decision-maker's objectives and in support of the decision-maker's plans. The cyberspace and real-world intelligent agents should be capable of proactively identifying relevant collaborators in decision scenarios, insuring data sharing among collaborators, and collaborating with other intelligent agents. Communication between intelligent agents is secured and authenticated.

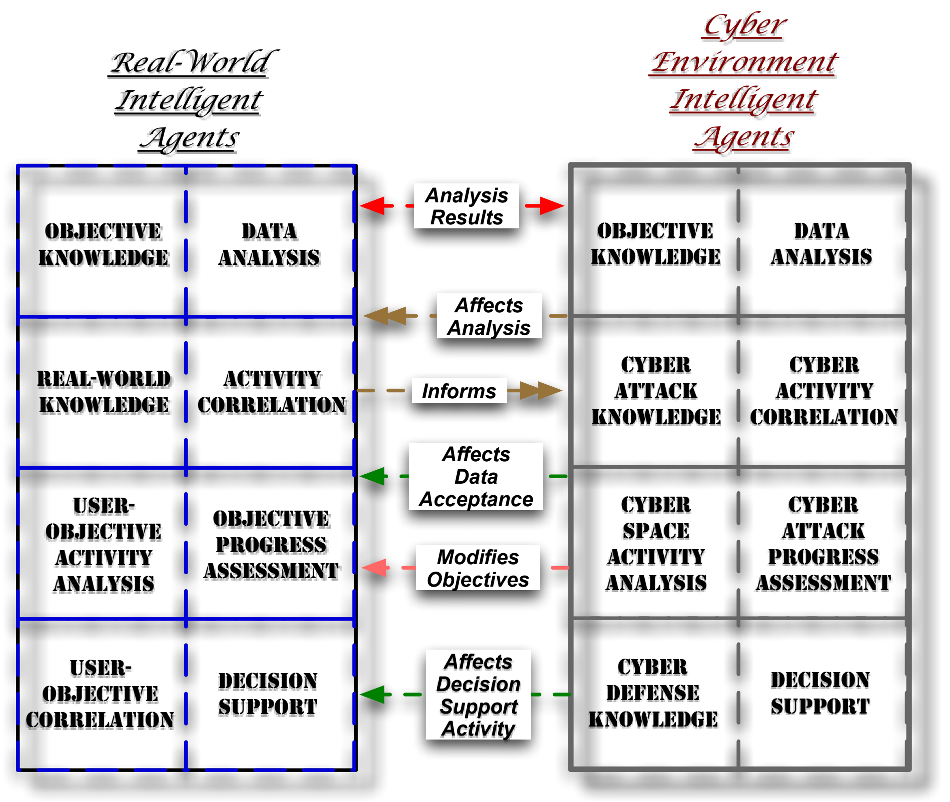

Figure 4: Battlespace Intelligent Agents – Realworld and Cyberspace Agents Components and Interaction Classes

Figure 4 presents a notional set of the knowledge bases for the cyberspace and real-world intelligent agents determined according to the functionality that each intelligent agent provides to the user.

Because of the manner in which we factor the intelligent agents along user support and functionality lines, we employ a hierarchy of intelligent agents to provide increasingly sophisticated support to the decision-maker. In the hierarchy, the lowest level agents provide the least complex support to the decision-maker, higher levels of the hierarchy have more complex knowledge bases and provide more complex support that involves not only analysis of low-level agent outputs but also analysis of the activities of peer intelligent agents. The hierarchy provides a second advantage, the intelligent agents in the lowest levels of the hierarchy can be developed in parallel within the simulation environment because they have no interaction with other intelligent agents. Only at the higher levels of the hierarchy is it necessary to develop intelligent agents within the simulation environment one at a time, which is due to their requirement for inputs from subordinate and peer intelligent agents. In our approach, each intelligent agent's reasoning system is the one that best suits the individual agent's decision environment or the reasoning system can be a combination of reasoning approaches. Whichever reasoning approach is adopted for an intelligent agent, knowledge base changes are made after the diagnosis of the cause(s) of performance errors is complete; the knowledgebase development is not automated.

After a change is made, the intelligent agent is tested using its scenario set to insure that the error has been corrected and that no new errors have been introduced.

4. SUMMARY AND FUTURE WORK

Intelligent agents are a technology that promises a means for improving situation awareness and decision-making in cyberspace and the real-world. However, to achieve their promise, an approach for the development of the complex knowledge bases is needed. In this paper we presented an approach to intelligent agent knowledgebase development that relies upon a decomposition of the decision-maker's real-world SA, cyberspace SA, and decision-support needs. The decomposition allows for the separate development of required knowledge bases for the two types of intelligent agents using simulation to present the intelligent agents with scenarios that can be used to train and evaluate each intelligent agent's operation. The approach supports successive refinement of intelligent agent performance as well as testing of the performance of integrated intelligent agents systems in their support of decision-maker SA in cyberspace and in the real-world.

In future work we plan to improve the scenario fidelity by incorporating existing simulation scenarios, thereby reducing scenario development time. We plan to extend the situation awareness and decision-support capabilities provided by the intelligent agents by investigating their use in developing and maintaining group situation awareness in cyberspace and in the real-world. A third challenge we plan to address is improvement of decision-makers' situation awareness concerning the intelligent agents' activities and reasoning.

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