TOWARDS AN AGENT-AUGMENTED VIRTUAL DESIGN AND CONSTRUCTION APPROACH

Esther Obonyo, Assistant Professor, obonyo@ufl.edu
Mukund Patil, Graduate Research Assistant, mpatil@ufl.edu
Rinker School of Building, University of Florida, Fl
Chimay Anumba, Prof and Head of Department, Anumba@engr.psu.edu
Architectural Engineering, Penn State University, State College, PA, USA

ABSTRACT

There has been a rapid growth in the use of Virtual Design and Construction (VDC) applications for design and functionality analysis in the early stages of the project development process. Although significant strides have been made in refining the functionality of such applications, there is still no overall integration scheme that addresses the challenges inherent in knowledge management for organization learning. There are several initiatives directed at addressing this challenge through leveraging Semantic Web technologies. Some of these efforts are directed at developing the potential for using software agents to automate some of the tasks inherent in information retrieval through enhancing the implementation of dynamic, domain-specific components. This paper discusses the deployment of an agent-based approach to enhance the modeling and simulation of construction activities. The main body of the paper identifies specific roles that can be delegated to agents in the deployment of an intelligent, virtual architecture. The paper also describes a proof-of-concept application that was implemented to assess the feasibility of using agents within VDC applications. The proof-of-concept application models the flow of formwork components in a construction yard. Based on the findings, it is clear that there is great potential for enhancing VDC applications using an agent-based approach. Given that agent-based systems are, by definition, software components that exhibit flexible and autonomous action in dynamic, unpredictable contexts, they can automate functions such as information extraction, structuring and retrieval. These benefits were apparent in the experimental use of the approach. This notwithstanding, the concept of agents is still relatively new in the construction industry and there are several implementation challenges that will need to be addressed if the approach is to be scaled up. The paper concludes with a concise discussion of the implications of the research and identifies specific components of the agent-based approach that will be implemented as part of follow up activities.

Keywords: virtual applications, organizational learning, knowledge management, agents

1. INTRODUCTION

Design and construction professionals are increasingly embracing the use of advanced visualization applications and display systems that allow them to gain a better understanding of the construction process and the resulting facility's performance. Significant efforts have been invested in promoting knowledge management for organizational learning within the construction industry. Such efforts have included implementing Virtual Design and Construction (VDC) applications to facilitate sharing of information and knowledge for improved project performance. VDC applications are increasingly being used to promote organizational learning. The nature of organizational learning depends on one's definition of an organization. The definition adopted in this paper is based on Foil and Lyle's (1985) definition of organizational learning as "the process of improving actions through better knowledge and understanding." Argyris and Schön's (1996) single-loop and double-loop notions of organizational learning have also influenced the approach adopted in this paper. Single-loop learning occurs when individuals respond to changes according to the demands of their internal or external environment by detecting and correcting their errors in order to maintain the central features of the organizational norms and purposes; while double-loop learning occurs when individuals question existing organizational norms and assumptions. Clearly, the seamless flow of knowledge is required for any organization seeking to truly embrace a culture that promotes learning.

Despite many leading construction companies' investment in initiatives directed at managing corporate knowledge bases and creating a corporate memory culture that supports organizational learning, the expected improvements in business processes remain largely unrealized (Vakola and Rezgui, 2000). The key limitations of conventional approaches to managing information and knowledge include (Rezgui, 1998, Kamara et al, 2002 and Vakola, 1999): 1) difficulties in capturing a significant proportion of construction knowledge that resides in the minds of individuals; 2) difficulties in capturing the intent of the decision making; 3) project knowledge being captured and archived at the end of the construction process when key people may have already moved on; 4) lack of a structured approach to managing and disseminating lessons learnt; 5) failure by many companies to maintain accurate historical records for different projects.

Such obstacles to organizational learning have inspired new efforts that promote social construction of knowledge as well as dynamic knowledge generation, storage and dissemination. One avenue that has been explored relies on the use of web-based, virtual environments. Virtual environments are grounded in experiential learning and anchored instruction principles (Sanchez et al, 2005). Simulations (frequently augmented with advanced visualization) and Intelligent Tutoring Systems (ITS) comprise the most common examples of rich, Web-based educational content (Rey-López et al, 2008). Intelligent learning systems apply AI (artificial intelligence) techniques to provide broader and better support for the users of Web-based educational systems (Curilem et al, 2007). There is a long standing tradition of using ITSs to engage users in sustained reasoning activity based on a deep understanding of their behavior. Such systems apply AI (artificial intelligence) techniques. They use knowledge about the domain, the learner, and about teaching strategies to support flexible individualized learning and tutoring (Brusilovsky, 1999).

Most intelligent tutoring applications have been in educational institutions, typically for language learning, music tutoring, adult education and engineering teaching. Recent examples of such applications include those developed by Corbett et al, (2004) and Graesser et al, (2005). Intelligent tutoring applications have also been used outside of the educational context. Abersek & Popov (2004) described an application used to train staff on optimization strategies in the manufacture of gears. There are also some examples of intelligent tutoring applications in military training (Henke, 2003). In the medical field, such systems are exemplified by the notion of "intelligent health environment" that is used to train medical professionals in concepts such as anesthesia, pre-hospital CPR, laparoscopic surgery and minimally invasive surgery (Gutierrez et al, 2007, Hu et al, 2007).

These examples suggest that there is considerable potential for integrating virtual simulations and models with intelligent learning environments. However, it will be difficult to implement this using traditional AI techniques given that conventional virtual systems do not provide support for using intelligent content (Rodrigues et al, 2005; Rey-López et al, 2008). In addition, the underlying infrastructure that would enable the integrating of ITS with virtual environments is not sufficiently developed. Specific concerns include system robustness, scalability, reusability and maintainability (Lin et al, 2002). Some researchers have proposed to address these issues using an agent-based software architecture that can be easily extended and modified (Mendez and de Antonio, 2008a, b).

Agent-based systems are by definition software components that are designed to exhibit flexible autonomous action in dynamic, unpredictable, domains (Luck et al, 2005). This paper contributes to the discussions on the potentials of the agent paradigm based on the demands of modeling and simulating construction activities. The discussion draws examples from components for concrete formwork. The main body of the paper identifies specific roles that can be delegated to agents in the deployment of the proposed intelligent, virtual architecture. The paper also describes a proof-of-concept application that was implemented to assess the feasibility of using agents within VDC applications. The proof-of-concept application models the flow of formwork components in a construction yard. The paper concludes with a concise discussion of the implications of the research and identifies specific components of the agent-based approach that will be implemented as part of follow up activities.

2. THE AGENT-AUGMENTED METHODOLOGY

The conventional approaches to virtual construction education are inadequate in terms of interaction aspect, intelligence, personality, adaptability, simultaneity and returning feedback information in time (Liang et al, 2008). The closest work to the one proposed in this research is work in the area of construction virtual prototyping where the focus is providing learners with special perception and navigation capability of 3D models. Recent examples of this approach include work by Messner et al (2006) and Huang et al (2007). Another example is Haque et al's (2007) work, 3-D animations and virtual walkthroughs for reinforced concrete that allowed learners to view construction detailing and the final product was based on image visualization or animation, for which detailing was carried out by using VRML and 3ds Max based-design animations and walkthroughs. Follow up work on this has developed into applications that incorporate a game engine (Haque et al, 2009). Other examples have been discussed by Eissa and Lee (2008), and Madrazo et al (2008). All these related applications do not exploit agent-based technologies.

Agent-based systems, with their characteristics (such as autonomy, proclivity, reactivity, sociality, collaboration and intelligence), can result in personalized learning systems. Such applications transcend the functionalities of a classical ITS (which is in effect a single agent system) by using a community of agents to model the complexities inherent in facilitating eLearning. MAS (Multi-Agent System) can help to improve code modularity and reusability; and can help to hide network, system and protocol heterogeneity (Liang et al, 2008). It is important to note that agent technology is a relatively new research area, and although there have been a number of successful applications particularly in the telecommunications sector, the technology is generally viewed with the same skepticism that is accorded to artificial intelligence. Examples in construction remain very limited in their functionality. In the most comprehensive roadmap for agent technology, Luck et al, (2005), ranked the construction industry among the lowest in the uptake of this technology.

Although agent technology, as discussed in this paper, offers additional capabilities to the underlying infrastructure supporting virtual modeling and simulation, it is important to note that agent technology is a relatively new field. There is, therefore, no formal methodology for deploying intelligent virtual learning environments. Over the years significant effort has been directed towards the deployment agent-development platforms that can be used to generate multi-agent systems. Platforms that can be used to generate components for virtual learning that were reviewed as part of this research include Repast, Netlogo, MASON and Flexsim. Flexsim (a visual, object-oriented simulation tool that supports agent-based simulation), was selected for use in the proof-of-concept based on the ease of model development and its analytical capabilities (see Figure 1 and URL1).

The core Flexsim abilities include virtual reality and discrete event modeling. It offers a user the ability to import 3D models from a CAD application thus the agents can operate in an environment that has geometry, shapes and motions. The context for the proof-of-concept model was the control of equipment and managing the inventory on a construction yard for a concrete subcontractor who prefabricates formwork components off site and dispatches them for use in different projects. The production at the yard needs to be balanced against the demand for the formwork components which fluctuates depending on the number of projects being executed concurrently to avoid overstocking or under-stocking components. There is also a need to optimize the production of formwork for different members (walls, slabs, beam or columns) to match the needs of the different projects. Because of the costs associated with idle equipment, the formwork production also needs to be synchronized with the arrival of dispatch trucks as well as the loading processes, which in this case will be based on the use of cranes as the components are too heavy for manual handling. A delay in the dispatch results in a delay in the erection of the forms which in turn affects the schedule for the delivery of ready mixed concrete.

Through leveraging an agent-based approach, the generated model can be used to rapidly simulate different scenarios. As an illustration, a simulation was run based on the flow of 4 different types of formwork components through the construction. The flow of components from the assembly line is identified as the source and is assumed to be continuous during the work days to match peak demand when multiple projects are being executed concurrently. A key benefit of performing the modeling and simulation using an agent-oriented approach is the rapid rate of executing the entire analysis. Three different scenarios were modeled based on loading 4 units, 8 units and 12 units per truck during dispatch. For each of these scenarios, the simulation was further broken down into random and sequenced truck arrivals. All other variables (or objects in this case) were held constant. A 6-day week schedule with Sunday as a non-work day was assumed and the simulation run to mirror second by second flow of materials in the construction yard throughout the week. Each cycle was completed rapidly, averaging 3 minutes per 6 day cycle.

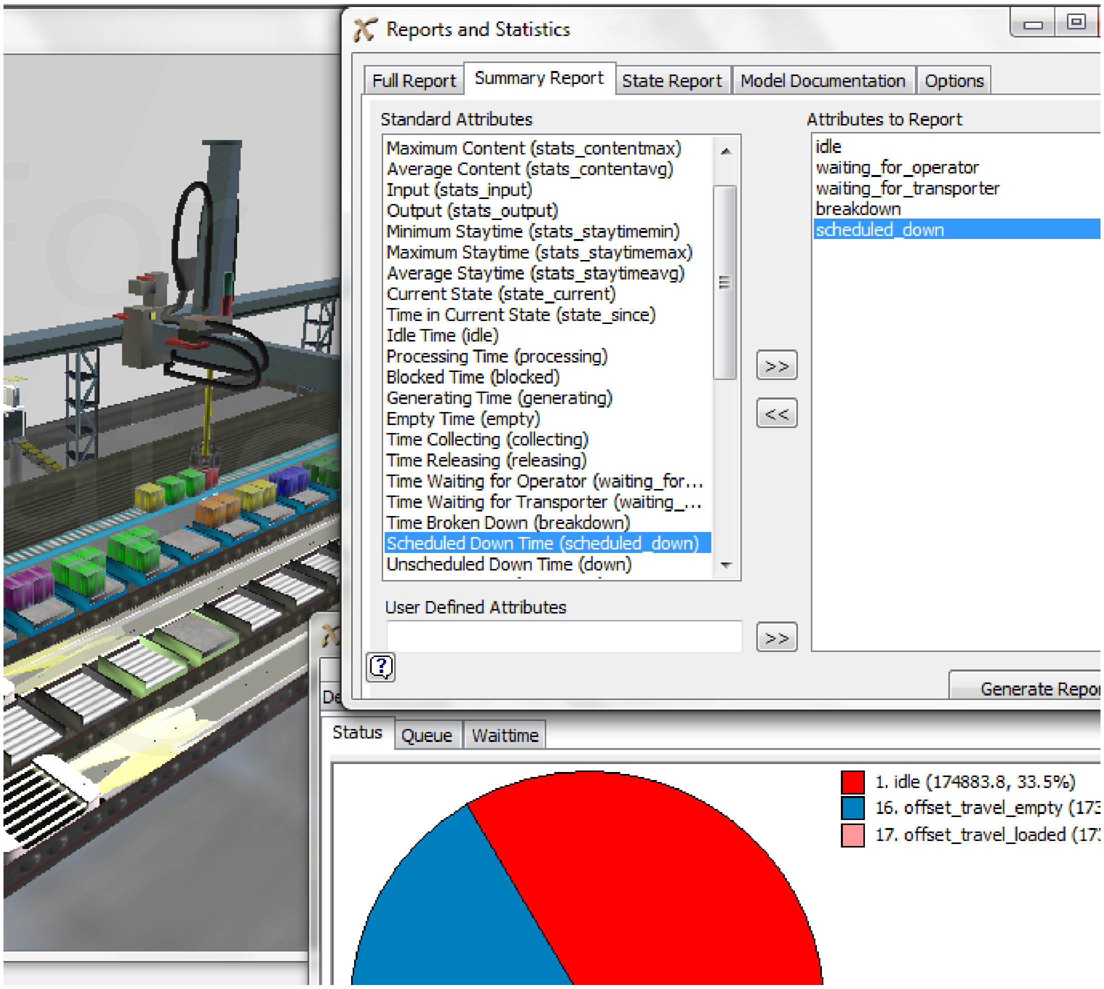

Figure 1: Agent-Augmented Material Flow Modeling and Simulation

The agent-augmented environment also supports the processing of simulation results into reports, pie charts, graphs and MS Excel spreadsheets based on user-defined attributes. For example, the analysis report for equipment use in the flow of formwork components, could detail idle time per equipment, time spent waiting for the operator, time spent waiting for the transporter or scheduled downtime. Several other attributes can be selected for analysis. Table 1 shows a summary report for the main pieces of equipment indicating the idle time associated with them for the different scenarios. Several objects with no idle time have been excluded from this discussion, what remains included is the source of the prefabricated components which as indicated operates on a continuous basis.

3. RESULTS

Table 1: Using Agents to Project Idle Time (in hours) for Equipment based on Loading Capacity

	Loading 4 Units/ Truck		**Loading 8 Units/ Truck**		**Loading 12 Units/ Truck**	
Object	**Random Arrivals**	**Sequenced Arrivals**	**Random Arrivals**	**Sequenced Arrivals**	**Random Arrivals**	**Sequenced Arrivals**
Source1	0.00	0.00	0.00	0.00	0.00	0.00
ASRS vehicle1	44.98	53.61	45.23	46.94	45.05	51.75
Crane1	48.29	57.75	48.58	52.17	48.31	54.35
Crane2	49.15	58.25	49.43	52.10	49.24	55.59
Combiner1	19.79	5.66	20.04	5.73	19.80	5.71
Combiner2	18.45	5.29	18.50	5.46	18.45	6.16
Combiner3	15.06	7.06	15.15	4.94	15.12	6.33
Combiner4	14.07	6.57	14.17	4.54	14.07	5.61
Combiner5	12.22	5.27	12.31	4.05	12.22	4.91
Combiner6	9.93	5.62	10.06	3.68	9.99	5.03
Combiner7	9.05	4.18	9.13	4.47	9.06	4.86
Combiner8	18.34	4.45	18.47	4.70	18.37	6.16
Combiner9	15.30	5.56	15.42	5.02	15.38	5.84
Combiner10	14.91	4.94	14.92	4.68	14.92	5.30
Combiner11	13.07	7.90	13.18	4.98	13.13	6.58
Combiner12	12.63	5.65	12.71	5.33	12.64	6.08
Combiner13	11.38	5.64	11.41	5.55	11.38	6.08
Combiner14	10.73	5.99	10.82	5.78	10.74	6.47
TaskExecuterFlowitems	144.21	144.66	145.14	144.08	144.48	144.35
	144.22	144.66	145.15	144.08	144.48	144.36
	144.22	144.66	145.15	144.08	144.48	144.36
	144.23	144.67	145.16	144.08	144.48	144.36
	144.23	144.67	145.16	144.09	144.49	144.37
	144.23	144.67	145.16	144.09	144.49	144.37
	144.23	144.68	145.17	144.09	144.49	144.37
	144.24	144.68	145.17	144.09	144.49	144.38
	144.24	144.68	145.17	144.10	144.50	144.38
	144.24	144.68	145.18	144.10	144.50	144.38
	144.24	144.69	145.18	144.10	0.00	144.38
	144.25	144.69	145.18	144.11	0.00	144.39
	144.25	144.69	145.18	0.00	0.00	144.39
Total Idle Time	**2212.38**	**2130.16**	**2226.69**	**1949.19**	**1782.75**	**2119.65**

Several important issues can be assessed based on the results shown in Table 1. In general, sequenced activities should result in higher productivity. However, because the system being modeled is a complicated one with several levels of interdependencies, scheduling trucks without factoring the impact of any change on all the interdependencies can, at times, result in lower productivity levels. For example, when loading is limited to 4 units, the cranes have a higher idle time with trucks arriving at sequenced intervals rather than at a random rate. This is not to suggest that random arrival is better. The significance of this idle time is relative to other variables such as the cost of the associated idle time for crane compared to, for example, the cost of increasing the capacity of the truck to accommodate 8 loading units or 12 loading units. Other things that must be taken into consideration include the total cost associated with the total idle time for all the pieces of equipment in the operation.

For the modeled use case, if the superintendent is to schedule the loading of 12 units per truck the total idle time for all the equipment is actually higher under scheduled truck arrivals than random arrivals. The learning emphasis here is on the need to adjust the settings for other objects in the virtual model to match the increased capacity of the truck. Much of the work involves trial and error adjustments, which when done manually could prove to be very time consuming. Through the use of the agent-oriented modeling and simulation approach, the effect of changing the settings for one object can be simulated rapidly. The traditional approach to modeling and simulation would require the end users to spend a much longer time assessing the impact of changing one variable for all the different scenarios. The level of manipulation required to deliver knowledge dynamically flows would involve going through non trial data mining tasks if not automated. Because of the use of its use of AI techniques, the proof of concept has demonstrated how agents can be used to rapidly extract relevant linkages that exist between variables or between causes and effects. More specifically, through the leveraging on an agent technology the approach has provided: 1) a more efficient way of browsing and processing databases with vast quantities of dependent and independent variables.

Within the showcased agent-augmented environment, the end users are able to understand the significance of different actions when planning and scheduling material flow to a job site. They are also able to analyze the problem from different perspectives (or scenarios) without spending too much time on manual tasks. The need for active learning is satisfied through enabling the users to actively explore and control environmental variables. Although the first set of implemented components specifically focused on demonstrating how an agent-oriented approach can enhance the modeling and simulation of the flow of formwork materials to match material demands on different projects, the scope can be readily extended to capture other aspects of construction.

4. DISCUSSION AND CONCLUSIONS

The need for techniques that improve learning in both academic and industrial setting has resulted in the deployment of technology-enabled learning. The initial set of applications based on such technologies focused on content delivery. As more recent paradigms such as the notion of Semantic Web and grid computing become more robust, there is an opportunity for enhancing-learning solutions to facilitate interactive and adaptive learning. Despite the significant investments that have been made to promote knowledge management within the construction industry, the expected improvements in business processes remain largely unrealized. The paper has discussed an intelligent, virtual learning approach that would provide users with the ability to dynamically generate, store and disseminate knowledge. This would in turn promote organizational learning through providing a mechanism for running through simulations and analysis without spending too much time on hard coding data.

The preceding sections have discussed this concept from the perspective of intelligent virtual design and construction application. From the simulated use case, it is clear that an agent-augmented VDC approach can result in intelligent virtual environments that advance organizational learning through enhancing knowledge management. Within the showcased agent-augmented environment, the end users are able to understand the significance of different actions when planning and scheduling material flow to a job site.

They are also able to analyze the problem from different perspectives (or scenarios) without spending too much time on the manual tasks. The need for active learning is satisfied through enabling the end users to actively explore and control environmental variables. Although the first set of implemented components specifically focused on demonstrating how an agent-augmented approach can enhance the modeling and simulating the flow of formwork material to match material demands on different projects, the scope can be easily extended to capture other aspects of construction. Despite such promising results, the deployment of agents within VDC applications will need to be executed in phases. The autonomy, flexibility and dynamism that is inherent in multi-agent systems is not easy to conceptualize using conventional software engineering approaches. Given that the agent paradigm is still maturing, such implementation issues will have to be resolved before robust, agent-augmented approaches can be scaled up for use in VDC applications. It is necessary for the methodologies that have already been proposed to be tested in different application domains so that the most robust ones can be developed into standards.

The approach adopted in this paper is based on the premise that an ideal agent-based methodology captures all the elements necessary for the implementation of a multi-agent community. An agent-based model comprises a set of agents, set of agent relationships and a framework for simulating agent behaviours and interactions (Macal and North, 2005). A key challenge here has been identified as modeling the specific skills, knowledge and personal characteristics of the human end users. Embedding this ability in a VDC application will result in a more personalized interaction. It would not render the human users redundant. Further work in this research will focus on capturing the targeted end users' abilities and beliefs/knowledge using Herrero et al's (2005) three-layered agent architecture depicted in Figure 2.

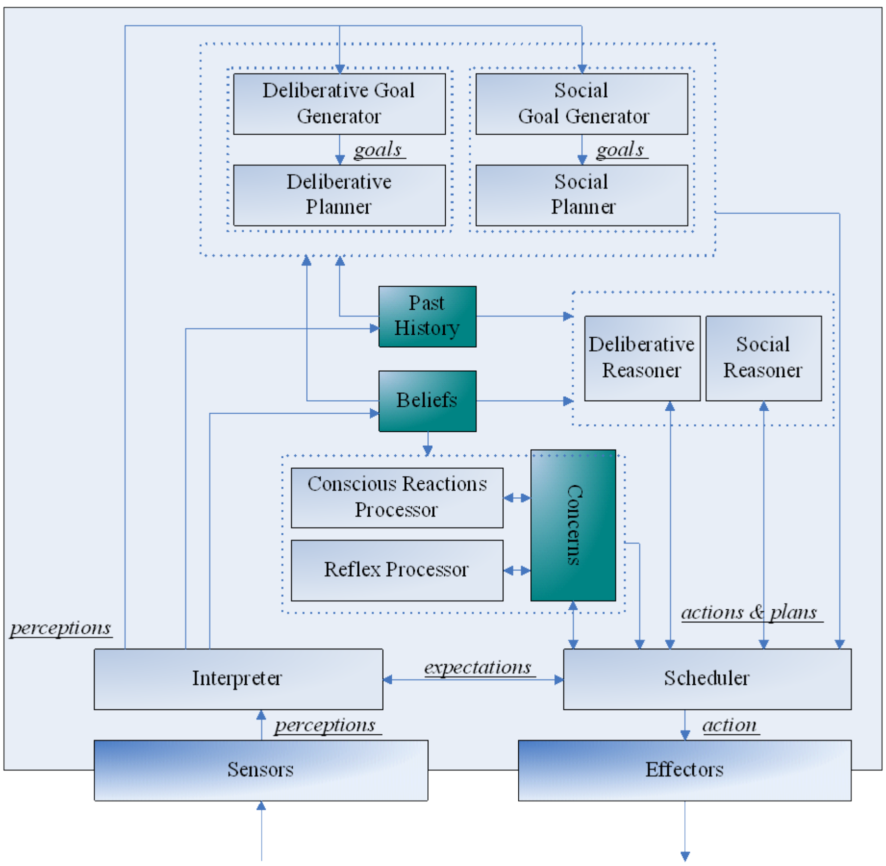

Figure 2: Internal Agent Structure
Source: Herrero *et al* (2005)

Within Herrerro's approach, the reactive, deliberative and social layers share a common knowledge structure, that is, the personal model. This personal model, manages agent beliefs about Defining Characteristics (DCs) of the end user. It uses each user's DC to provide all the other agents with better predictions about the user's behavior. The personal model also maintains beliefs about the user's Transient States (TSs) encapsulating attributes such as emotional motivations, attitudes and concerns. Because of the inherent uncertainty, such elements will be modeled using fuzzy logic. An Agent representing the end user manages all the beliefs that the system has about them. Using all this information, this Agent infers a plausible learner's behavior for each situation, based on both logical and emotional reasoning. Logical reasoning is based on the traditional BDI (Belief-Desire-Intention) logic. In the recent years, there has been an interest in getting agent to mirror the emotional aspects of human intelligence (see Hu et al, 2006). Such knowledge will be used to adapt the training strategy. The subsequent proof-of-concept will exemplify these functions.

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