Agent-based virtual humans in co-space: An evaluative study

Yilin KANG

Ah-hwee TAN
Singapore Management University, ahtan@smu.edu.sg

Fiona Fui-Hoon NAH

Agent-based Virtual Humans in Co-Space: An Evaluative Study

Yilin Kang*, Ah-Hwee Tan*, and Fiona Fui-Hoon Nah†
*School of Computer Engineering, Nanyang Technological University, Singapore 639798
Email: kang0028, asahtan@ntu.edu.sg
† Department of Business and Information Technology
Missouri University of Science and Technology, Rolla MO 65409, USA
Email: nahf@mst.edu

***Abstract*—Co-Space refers to interactive virtual environment modelled after the real world in terms of look-and-feel, functionalities and services. We have developed a 3D virtual world named Nanyang Technological University (NTU) Co-Space populated with virtual human characters. Three key requirements of realistic virtual humans in the virtual world have been identified, namely (1) autonomy: agents can function on their own; (2) interactivity: agents can interact naturally with players; and (3) personality: agents can exhibit human traits and characteristics. Working towards these challenges, we propose a brain-inspired agent architecture that integrates goal-directed autonomy, natural language interaction and human-like personality. We conducted an evaluative study involving human subjects to assess how virtual characters may enhance user experience in the virtual world. The results show that the fusion ART-based virtual humans receive significantly higher ratings in various performance measures related to user experience, especially Telepresence, Perceived Interactivity and Flow.**

***Keywords*-virtual character; Co-Space; evaluation;**

I. Introduction

Virtual worlds have become a popular platform used in many domains, including education, business, and e-commerce. In our work, we are particularly interested in a special class of virtual worlds called Co-Space, which refers to an interactive virtual environment modelled after a real physical world in terms of look-and-feel, functionalities and services. Through realistic 3D modeling and animation technologies, Co-Space simulates the real world in terms of look-and-feel of the surrounding environment. With the advancement of pervasive sensor networks, Co-Space may also capture and mirror the real world events virtually in real time. Besides providing a much faster and easier access to information and services, the development of Co-Space offers great opportunities for delivering innovative applications and services. Specifically, intelligent agents can be deployed as virtual humans in Co-Space to enhance interactivity and playability.

Despite the appealing potentials [1], a number of challenges must be overcome to make these virtual characters convincingly realistic. Firstly, they should be able to function autonomously within the environment they reside. To do so, they need to understand the context of the environment and the other virtual characters and human users co-existing in the environment. Also, the reasoning process for choosing the appropriate action should preferably not be scripted or predetermined. Instead, they should function autonomously and make decisions proactively in response to events happening in the virtual world around them. Secondly, the interaction between virtual humans and real humans should be as natural as possible, integrating both verbal and non-verbal communication such as facial expressions and body gestures. Thirdly, virtual humans should exhibit human-like traits and characteristics, such as personalities and emotions. All of these require the convergence of a diverse range of technologies and domains, including computer graphics, 3D animation, cognitive science, natural language processing, decision making, dialogue management, speech and gesture generation and human-computer interaction which are complex to integrate [1], [2]. Working towards these challenges, we propose a brain-inspired agent architecture that integrates goal-directed autonomy, natural language interaction and human-like personality.

Extending from a family of self-organizing neural models known as Adaptive Resonance Theory (ART) [3], [4], this paper presents an integrated agent architecture that makes decisions not only based on the situational factors of what are perceived from the environment but also by taking into considerations of various properties, such as the context of both agents and players, as well as their desires, intentions, and personalities. In this way, these agent-based virtual humans are living a more realistic life by going to classes, having dinner with friends and chit-chatting with others. To the best of our knowledge, this is one of the few in-depth works on building realistic agents with autonomous behavior, personification as well as natural dialogue interaction.

As a showcase of our work, we have developed a Co-Space that models the Nanyang Technological University (NTU) campus. We have created realistic 3D models of almost all locations in NTU and populated the Co-Space with avatars that take on human appearance and body proportion. We have deployed agent based virtual humans into NTU Co-Space. In order to evaluate the effects of virtual humans on user experience, we have conducted a series of experiments with users where three instances of NTU Co-Space, each populated with a distinct type of virtual agents in the form of avatars, are assessed. The first environment (E1) is populated with virtual humans that display static messages and do not have the capability to interact with the users. In the second environment (E2), virtual humans are designed as embodied conversational agents using AIML [5] technology. The third environment (E3) is populated with intelligent autonomous virtual humans with our proposed fusion ART-based agent architecture. The experiments involved 58 subjects that were randomly assigned to one of the three environments. The subjects were given the context of looking for an overseas university for an exchange program and were visiting NTU Co-Space to help them in making the decision. Each subject was asked to complete a pre-questionnaire and a post-questionnaire before and after they experienced the environment respectively. We captured seven constructs related to their user experience, namely *Telepresence*, *Social Presence*, *Perceived Interactivity*, *Perceived Usefulness*, *Flow*, *Enjoyment* and *Behavioral Intention* (to return to NTU Co-Space). The evaluative results show that the fusion ART-based agents deployed in E3 are more useful in assisting the subjects and E3 is significantly better in *Telepresence* and *Perceived Interactivity* than those of the other two environments. Moreover, the *Flow* experience perceived by the subjects in E3 (i.e., populated with the fusion ART-based virtual humans) is significantly stronger than that in E2 (with the AIML based virtual humans).

II. Related Work

A. Modelling Virtual Humans

Over the past 15 years, a number of research groups have explored different aspects in modelling realistic virtual humans, including autonomous behaviors, interactive non-verbal and verbal behaviors and agents with personality and mood. Table I provides a summary of some representative systems in view of the three criteria, namely autonomy, interactivity and personality.

Different branches of works have been conducted based on various considerations. With the objective of implementing autonomous virtual humans, Merrick and Maher [11] created motivated reinforcement learning agent based virtual villagers in Second Life (SL). These agents explore their environment and learn new behaviors in response to interesting experiences, so that they could adapt and evolve over time. In Edward's work [13], agent based virtual workers simulate human's cognitive processes in operating in dangerous situations at a virtual site named SEVESO.

Another important branch of works is building interactive virtual humans in terms of verbal behaviors and non-verbal behaviors. Laura [6], initially designed to investigate human-computer relationships, is capable of carrying out conversations with players based on scripts and simple mechanisms for remembering past events with players. Max [7] is a conversational virtual agent which has been developed as a guide to the HNF museum. By applying the goal-driven BDI architecture, he is able to interact with visitors and provide them with information. Kenny et al. [10] developed a virtual patient named Justina who is able to act and carry on a dialogue like a real patient with a specific mental condition of interest.

In view of the limitations of monotonous interaction between virtual humans and real humans, many researchers have started to incorporate personality into virtual humans to make them more human-like. Valerie [8] was designed to help the visitors in many ways such as giving directions and checking weather forecast. Her facial expressions would change according to her mood which varies at different times. This creates a vivid feeling when visitors interact with her. Eva [2] was designed as a tutor of digital photography. It was developed based on a memory-based emotion model that used the memory of past interactions to build long-term relationships between the virtual character "Eva" and players.

The works described above have developed a wide range of virtual agents with different features. Our work reported in this paper is one of the few that have developed virtual human agents that exhibit autonomy, interactivity and personifications in real time to make virtual human agents as realistic as possible.

B. Evaluative Studies

Although many approaches have been proposed for building human-like agents in virtual worlds, there have been relatively few studies in investigating the effect of virtual humans on user experience. We briefly review relevant work below.

Within Second Life, in the ancient City of Uruk 3000 B.C., virtual agent based non-player characters (NPCs) serve as the knowledge carriers as well as an important element in establishing the connection between the environment, objects and knowledge [12]. In social simulations, studies have shown that synthetic characters have provided an engaging and believable experience for the trainees in training leadership and negotiation tactics as well as in creating more dramatically interesting game situations [1]. Besides social simulations, virtual patients for the assessment and training of novice clinicians have been evaluated as well. The evaluation shows that they can provide valid, reliable and applicable representations of live patients [9]. Further evaluation also indicates that the interactions between novice clinicians and the virtual patients resulted in a compatible dialectic in terms of rapport, discussion of the traumatic event, and the experience of intrusive recollections [10].

Beyond the computer science field, some work has also been done in the domain of information systems. Chaturvedi et al. [14] have examined the design, development, validation, and use of virtual worlds, especially those using agent-based simulation as the underlying technology. They derive a set of design principles based on deep versus emergent structures while developing extended design principles to

Table I
COMPARISON OF THE REPRESENTATIVE VIRTUAL HUMANS.

	Affiliation	Application	Autonomy	Interactivity	Personality
Laura [6]	MIT	Real-Estate Agent	No	Yes	No
Max [7]	Bielefeld U.	Museum guide	No	Yes	No
Valerie [8]	CMU	RoboCeptionist	No	Yes	Yes
MRL [11]	U. of Sydney	Villagers	Yes	No	No
Justina [10]	USC	Virtual Patient	No	Yes	No
MASVERP [13]	UTC	Virtual operators	Yes	No	No
Eva [2]	U. of Geneva	Geography teacher	No	Yes	Yes

facilitate their integration. Nowak and Biocca [24] conducted an experiment to examine the influence of agents on presence, copresence, and social presence in a virtual environment. The result shows that people respond socially to both humans and agents. Barfield and Hendrix [15] found that agents shaking continuously or appearing to move between large discrete positions will likewise diminish a participant's sense of presence.

III. THE INTEGRATED AGENT MODEL

Using fusion ART [4] as a building block, our proposed agent is designed to fulfil the critical requirement of autonomy, interactivity and personification. As shown in Figure 1, the integrated agent model consists of a *Perception Module* receiving situational signals from the environment through a set of sensory Application Programming Interfaces (APIs) and an *Action Module* for performing actions through the various actuator APIs. If the sensory signals involve a text input, the *Chat Understanding Module* interprets the text for the player's intention. The outputs of *Situational Assessment* and *Chat Understanding Modules* thus serve as part of the working memory content. The *Inference Engine* then identifies the most appropriate action, by tapping a diverse pool of knowledge, in accordance to the desire, intention and personality of the virtual agent. The knowledge learned and used by the Inference Engine include declarative knowledge of self, players, and environment, as well as procedural knowledge of goal-oriented rules, which guide an agent in fulfilling goals, and social rules, for generating socially appropriate behavior. The decision of the *Inference Engine* again forms part of the *Working Memory*, which maintains the context of the interaction. For actions involving a verbal response, the *Natural Language Generation Module* translates the chosen response into natural text for presentation.

Working cooperatively, the various components described above give rise to the three key characteristics of virtual humans, namely autonomy, interactivity, and personification, described as follows.

Autonomy Based on a family of self-organizing neural models known as fusion Adaptive Resonance Theory (ART) [4], the *Inference Engine* of the proposed agent architecture performs a myriad of cognitive functions, including recognition, prediction and learning, in response to a continual stream of input signals received from multiple pattern channels. As a result, an agent makes decisions not only based on the

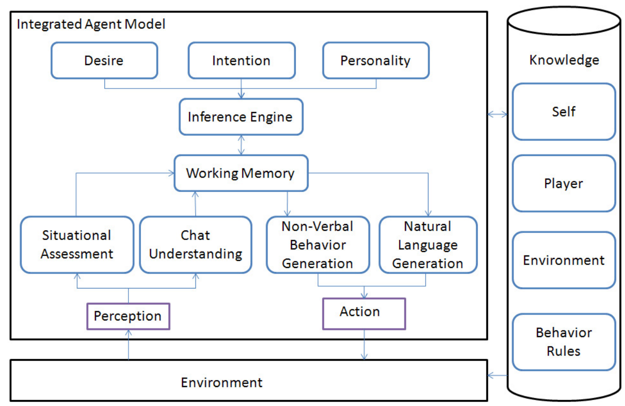

Figure 1. A schematic of the integrated agent model.

situational factors perceived from the environment but also on her mental states characterized by desire, intention and personality. By modelling the internal states of individual agents explicitly, the virtual humans can live a more complete and realistic life in the virtual world.

Interactivity For interaction between the agents and the players, an intuitive user interface is provided, through which a player may ask typical questions and provide quick responses by button clicks. The player may also enter free-text sentences via the chat box. The dual communication mode provides the players both ease of use and flexibility. While interacting with player, the agent builds an internal model of the player, with his/her profile, interests and preferences. The player model in turn allows the agent to make intelligent conversations on topics relevant to the player.

Personification For improving the believability of virtual humans, our agents adopt the Five Factor Model (FFM) [16], which characterizes personality in five trait dimensions. By giving a weightage to each dimension, a unique personality can be formed by a combination of the traits. Comparing with traditional pattern-matching-based conversational agent, our agents with strong *openness* and *extroversion* personality are much more warm and friendly as they do not stay idle and wait for input queries. Acting pro-actively, they approach the players, offer help, and initiate conversations.

IV. NTU CO-SPACE

The NTU Co-Space [17] is implemented using the Unity3D [18], a 3D game engine that can be deployed into different platforms including Microsoft Windows^{TM}, Apple

Mac OS™, and mobile devices. In our implementation, the Co-Space is embedded into a web page that can be easily accessed using typical web browsers such as Internet Explorer™, Google Chrome™, Safari™and Mozilla Firefox™.

The overall architecture of the NTU Co-Space is depicted in Figure 2. At the back-end, two application servers, Apache Tomcat™and SmartFox™, support the multi-user environment. A dedicated database is used for the storage and retrieval of environmental and content data.

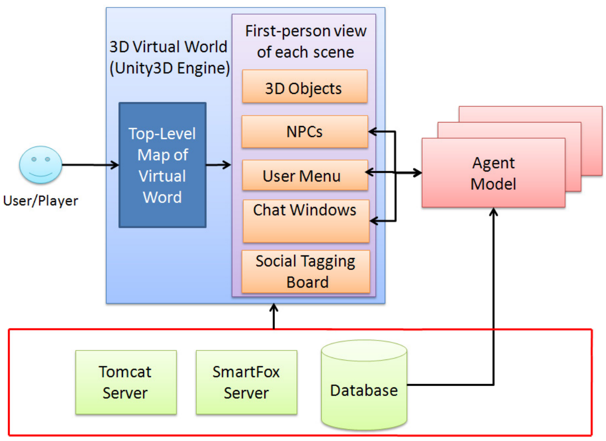

Figure 2. System architecture of NTU Co-Space.

As illustrated in Figure 3, a player can roam around the virtual NTU campus on his/her own for self-discovery or interact with autonomous virtual humans or other players. Besides showcasing the intelligent agent technologies, the NTU Co-Space can be played by any prospective students and general public who are keen to know NTU. A video clip of the NTU Co-Space can be viewed on YouTube (http://www.youtube.com/watch?v=bYIthOYjrxw). During the user trial, multiple players will be able to log in and experience the NTU Co-Space concurrently.

Figure 3. A player touring the NTU Co-Space.

A. Agent Instantiation

We have built several virtual human characters, each with a different profile and behaviour. Our main virtual agent, named David, has a set of four personal goals: (1) To stay healthy, (2) To graduate with a degree, (3) To make friends and (4) To stay wealthy. Following the Five Factor Model (FFM), he has an open and extrovert personality.

Knowledge of Self: Besides the desire, intention and personality, a virtual agent should be aware of its identity, background, and current activities. Such knowledge of self is represented using the Concept-Relation-Concept (CRC) tuples [20], which are generic in form and easily expandable. A sample set of the agent self-knowledge is shown in Figure 4.

Figure 4. An example of agent profile model.

Knowledge of Environment: Inhabiting in the virtual environment, a virtual agent should have the knowledge and situational awareness of its surrounding. A sample set of knowledge about the NTU Co-Space, also in the form of CRC tuples, is given in Table II.

Table II
EXAMPLES OF KNOWLEDGE OF CAMPUS IN THE FORM OF CRC TUPLES.

Knowledge of Campus
(Campus, Name, NTU)
(Campus, Location, Western part of country)
(Campus, Number of colleges, 4)

Knowledge of Others: In a virtual world, virtual humans live alongside with other virtual humans and human avatars. As such, knowing other people is also key to interacting with the others. Specifically, by remembering the profile and activities of the human players, virtual agents will be able to interact with players in a more intelligent and natural manner [19]. Likewise, knowledge of others can be represented as CRC tuples.

B. Agent Embodiment

The input state of the agent consists of three categories of context factors: Environmental context, virtual human context and player context. The environmental context consists of global factors, such as time and location. The virtual human context comprises six types of attributes, including desire, personality, intention, previous performed action, natural language understanding and self model. The player context includes the player model and attributes such as, whether the player is approaching, whether the player starts a conversation, and whether the player requests something. A summary of these attributes together with the possible values is given in Table III. All attributes adopt a binary encoding scheme in the state vector.

Table III
ATTRIBUTES AND POSSIBLE VALUES IN THE STATE SPACE.

Attributes	Values
Time	Morning, Lunch time, Afternoon, Dinner time, Evening, Bed time
Location	LT, Canteen, Shop, Hall, Library, Sports facility, Schools, Admin building, Banks, Other buildings
Agent's Previous Action	Approach, Guide a tour, Follow schedule, Wandering, Start a conversation, End the conversation, Greeting, Talk about player's interest, Talk about campus, Offer help to player, Describe nearby landmark, Ask what player means, Ask what player want to know/do, Rephrase the question, Reply player's request, Provide suggestion, Continue conversation
Player Verbal Input	Type, Subject, Object, Modifier, Verb
Player Model	New/old player, Personality, Interest, Interaction preference, Goal
Agent Model	Personality, Interest, Interaction preference, Goal
Player Activity	Wandering, Approach virtual human, Start conversation, Make request, Following guidance, Respond to virtual human, Give feedback to virtual human

The virtual humans are designed to inhabit in the virtual world, behave autonomously, and interact with players and other virtual humans. The action field thus consists of three categories, namely chat related behaviors, social behavior and other behaviors. A summary of these attributes together with the possible values is given in Table IV.

Table IV
CATEGORIES AND ATTRIBUTES IN THE ACTION SPACE.

Categories	Attributes
Non-Verbal Behavior	Approach, Guide a tour, Follow schedule, Wandering
Verbal Behavior	Start conversation, End conversation, Greeting, Offer help to player, Talk about campus, Talk about player's interest, Describe nearby landmark, Ask what player means, Ask what player want to know/do, Continue conversation, Rephrase question, Reply player's request, Provide suggestion

For interacting with the players, the virtual agent is initialized with a set of basic interaction rules and social rules. By using fusion ART as the inference engine, the agent is able to operate based on inserted rules and create additional rules when necessary using reinforcement learning. Illustrative samples of the interaction and the social rules are given in Table V and Table VI respectively.

V. EVALUATIVE EXPERIMENTS

A. Research Methodology

We developed three versions of NTU Co-Space, each with a distinct type of virtual agents in the form of Non-Player

Table V
A SAMPLE INTERACTION RULE.

IF	Personality is Agreeable
AND	Player asks for guidance to X
AND	No immediate planned activity
THEN	Guide player to X

Table VI
A SAMPLE SOCIAL RULE.

IF	Personality is Agreeable
AND	Player initiates conversation
AND	Distance is far
THEN	Walk towards the player

Characters (NPCs). The first environment (E1) provides the baseline control condition, wherein the NPCs are only able to display static messages but do not have the capability to interact with the users. The second environment (E2) is the first treatment condition, wherein the virtual humans are designed as embodied conversational agents using the Artificial Intelligence Mark-Up Language (AIML) [5]. AIML is an XML-compliant language that was developed by the Alicebot free software community. It is considered as a rule based repository of knowledge where the engine performs pattern matching to select the most appropriate output based on the input utterance. We have encoded as many AIML patterns as possible to enhance the conversational abilities of the agents. The third environment (E3) is the second treatment condition, wherein autonomous agents using our proposed fusion ART-based agent model are populated. Although the agents we described in the previous sections have different personalities, for the purpose of this study, we remove the variation in personality by deploying only friendly agents.

Subjects were randomly assigned to one of the three conditions. The scenario given to the subjects is that they were looking for an overseas university for an exchange program and were visiting NTU Co-Space to help them in making the decision. Each subject was asked to complete a quest in the form of a mini-game, where they would experience the key places of the NTU campus through the quest. The quest involves finding five check-points on campus where the clue to each check-point was given at the previous check-point. To maintain information equivalence across the three environments, an interactive navigation map, containing essential information of the campus, is provided to the players in all three conditions.

The objectives of the experiment are two-fold. First, we want to observe whether deploying virtual humans in the virtual world will benefit the player's experience. Second, we assess how virtual humans with different levels of intelligence may affect the player's experience, especially in terms of the following constructs, namely *Telepresence* (TP), *Social Presence* (SP), *Perceived Interactivity* (PI), *Perceived Usefulness* (PU), *Flow* (FLW), *Enjoyment* (ENJ) and *Behavioral Intention* (to return to NTU Co-Space) (BI). **Research procedures:** Subjects participated in the experiment in a computer lab. They were provided with a set of detailed instructions on the experimental procedures. Before the experiment began, the experimenter conducted a short tutorial session to familiarize the subjects with the basics of the environment and how to perform basic functions such as walking, talking and using maps in NTU Co-Space. After the tutorial, the subjects were asked to fill out a pre-questionnaire and then carry out the experiment by completing the quest given to them. For subjects in the E1 (control) condition, they completed the quest by using the map in the system to navigate the virtual world, check up information on different parts of campus and teleport to the respective checkpoints without receiving any help from NPCs. For subjects in the E2 (i.e., first treatment) condition, they were not only provided with the interactive map in the E1 condition, but they could also talk to the embodied conversational agents to ask for assistance before teleporting through the interactive map. For subjects in the E3 (i.e., second treatment) condition, in addition to being provided with the interactive map, they were also offered the assistance of fusion ART-based NPCs that have the ability of performing autonomous behaviors both in proactive and responsive ways; moreover, since these NPCs are embedded with a Natural Language Processing module, they can understand input sentences in a flexible way. Hence, subjects were able to interact with the intelligent autonomous NPCs to request for and obtain the information they needed. Because the NPCs are autonomous, they could even offer teleport service to the specific locations requested. After the subjects have completed the quest, they filled out a post-questionnaire which assessed their experience. This questionnaire captured various aspects of user experience which would be discussed in the latter part of the paper.

Subjects: Subjects were recruited from an Introduction to Management Information Systems (MIS) class at a large Midwestern US university. In line with the institutional board review requirements, participation in this study is voluntary and will be compensated with extra credit for the course. Altogether, 58 subjects participated in this study. Specifically, 18 subjects were randomly assigned to E1, 20 subjects to E2 and 20 subjects to E3.

Pre-Questionnaire: Before the subjects started playing the *Amazing Quest*, a pre-questionnaire was used to assess the players' profile, covering demographics information, computer experience (internet, gaming, 3D virtual world), immersive tendencies, and 3D virtual world skills. Except for demographics information, all factors were measured using a five point Likert scale, from 1 (not at all) to 5 (to a very great extent).

Post-Questionnaire: After the subjects finished playing the game, another questionnaire was issued to them. The subjects were first asked for the acronym followed by the full name of the university to assess their level of recall. The main part of the questionnaire then captured the subjects' assessment of the seven constructs (as described earlier) related to NPC functions. In addition, 3D virtual world skills was also captured to examine their perceived improvement of skills after experiencing NTU Co-Space.

Among the various constructs, *Perceived Usefulness* could be objectively assessed through the time taken to complete the Amazing Quest. The less time spent to complete the Amazing Quest, the more useful the agents are. *Flow* was captured through providing the description of *Flow*, and then asking subjects to rate the degree of *Flow* they experienced and the frequency in which they experienced *Flow*. The other constructs were captured using measurement items. At least five items were used to measure each construct. The items used to measure *Telepresence*, *Enjoyment* and *Behavioral Intention* were derived from Nah [21]. The scale for measuring *Social Presence* and *Interactivity* were adopted from Animesh et al [22]. The items were captured using a seven point Likert scale where 1 refers to strongly disagree and 7 refers to strongly agree. Given the limited space, we present a sample set of these items in Table VII.

Table VII
A SAMPLE SET OF POST-QUESTIONNAIRE.

Item	Measurement
TP 1	I forgot about my immediate surroundings when I was navigating in the virtual world.
SP 1	During the virtual tour, the interaction with the virtual humans were warm.
ENJ 1	I found the virtual tour to be fulfilling.
BI 1	I would consider visiting this virtual world site again.

B. Data Analysis

Overall performance: Table VIII shows the overall performance in the three environments based on whether subjects completed the quest, the time taken to complete the quest and whether the subjects could recall the acronym of the virtual campus. We observe that subjects in all the three environments were able to complete the quest successfully. However, subjects in E3 spent the least amount of time and the percentage of subjects who could correctly recall the acronym of the campus is higher than those of the other two environments. This indicates that the autonomous agents deployed in E3 are more useful in helping the subjects than those of the other two environments.

Table VIII
OVERALL PERFORMANCE

Evaluation Measures	E1	E2	E3
% of players complete the quest	100%	100%	100%
Time to complete the quest	20m31s	25m32s	**16m56s**
% of Players recall the acronym of the campus	44%	25%	**45%**

3D virtual world skill: Table IX shows the 3D virtual world skill before and after subjects experienced NTU Co-Space in the three environments, where SD means STANDARD DEVIATION and CI represents CONFIDENCE INTERVAL. It was captured using a seven point Likert scale, where 1 refers to strongly disagree and 7 refers to strongly agree.

Table IX
3D VIRTUAL WORLD SKILL

Environment	Measurement	Before	After	Difference
E1	Mean	3.61	4.33	0.72
	SD	0.54	0.55	0.01
	CI	3.08-4.14	3.79-4.87	
E2	Mean	3.93	5.03	1.10
	SD	0.43	0.14	-0.29
	CI	3.51-4.34	4.88-5.17	
E3	Mean	3.50	4.66	**1.16**
	SD	0.60	0.33	-0.27
	CI	2.92-4.08	4.33-4.99	

Table IX indicates that in E2, subjects perceived highest levels of 3D virtual world skill both before and after experiencing NTU Co-Space. However, in E3, the subjects' skill have been increased the most compared with the other two conditions. The results on confidence intervals suggest that with a confidence level of 95%, E2 has the highest rating of skills before experiencing NTU Co-Space while that of E3 is the lowest. After experiencing NTU Co-Space, subjects in E2 still have the highest rating of skills whereas subjects in E3 perceived higher skill than those in the control condition (E1). This indicates that with the interaction with autonomous agents, users feel more comfortable and perceived themselves to be more skillful with the virtual worlds.

Descriptive Statistics: Table X shows the means, standard deviations (SD), and confidence intervals (CI, with a confidence level of 95%) of ratings in E1, E2, and E3 in terms of *Telepresence* (TP), *Social Presence* (SP), *Perceived Interactivity* (PI), *Enjoyment* (ENJ), *Flow* (FLW) and *Behavior Intention* (BI). All of the constructs were measured using the seven point Likert scale. From the table, we observe that for E3, the rating of *Telepresence*, *Social Presence*, *Perceived Interactivity*, *Flow* and *Behavior Intention* have better results than E1 and E2. This means by employing autonomous agents, these factors are perceived to be stronger than those in the environment with dummy and AIML based agents. However, we note that for enjoyment, the rating in E2 is the best of the three environments. Referring to Table IX, subjects in E2 appear to have the best 3D virtual world skills compared to the other two. As prior work have shown that a higher level of skill is likely to enhance the feeling of enjoyment [23], we believe the rating obtained in E2 could be affected by the higher level of 3D virtual world skills.

Furthermore, a one-way analysis of variance (ANOVA) is used to analyze the results. Specifically, the F-test is used to evaluate the hypothesis of whether there are significant differences among the statistic data means for those constructs. The F values are calculated by the variances between conditions divided by the variance within the conditions. The p values, on the other hand, represent the probability of test statistic being different from the expected values and are directly derived from the F test. A small p value thus indicates a high confidence that the values of those constructs are different. A summary of the F values and p values among E1, E2 and E3, between E1 and E3, and between E2 and E3 are given in Table XI.

Table XI
F-TEST RESULT

	E1, E2 & E3		E1 & E3		E2 & E3	
Constructs	F	p	F	p	F	p
TP	**5.47**	**0.004**	11.22	0.001	4.55	0.034
SP	0.58	0.561	1.10	0.295	0.01	0.903
PI	**5.71**	**0.004**	4.00	0.047	12.12	0.001
ENJ	0.15	0.862	0.33	0.566	0.17	0.68
FLW	1.62	0.199	0.28	0.595	3.12	0.079
BI	1.23	0.294	2.40	0.120	0.10	0.751

This data analysis revealed the significant effects of the three kinds of virtual humans in virtual worlds on *Telepresence* and *Perceived Interactivity*: $F(2,519) = 5.47, p < 0.01$ for *Telepresence* and $F(2,345) = 5.71, p < 0.01$ for *Perceived Interactivity*, where the two parameters enclosed in parentheses after F indicate the degrees of freedom of the variances between and within conditions respectively. Consistent with the statistics in Table X, the fusion ART-based virtual human generate higher levels of *Telepresence* and *Perceived Interactivity* than the other two types of virtual humans, with a mean of 4.41 for E3 (versus 3.86 for E1 and 4.08 for E2) for *Telepresence*, and a mean of 5.02 for E3 (versus 4.66 for E1 and 4.37 for E2) for *Perceived Interactivity*. Although the effect of E1, E2 and E3 on *Flow* is smaller than that of *Telepresence* and *Perceived Interactivity*, the difference in *Flow* is perceived to be marginally significant between E2 and E3, with $F(1,198) = 3.12, p < 0.1$, and a mean of 4.58 for E3 (versus 4.21 for E2). This means the *Flow* experience perceived by subjects who interacted with the fusion ART-based virtual human is stronger than those who interacted with the AIML based virtual humans. No significant difference was found for the rest of the constructs.

VI. CONCLUSION

We have built and deployed realistic agents in an interactive 3D virtual environment known as NTU Co-Space. With the virtual characters befriending and providing personalized context-aware services, we hope players will find virtual worlds more fun and appealing. To the best of our knowledge, this is one of the few in-depth works on building realistic agents in virtual worlds with autonomous behavior, natural interactivity and personification.

More importantly, we have carried out a systematic experimental study to assess whether the use of agents-based virtual humans can improve user experience in the virtual worlds. Our study has so far mostly supported the validity of our agent systems. Moving forward, we shall extend our studies to agents with different personalities. Specifically, we would like to assess whether the resultant more dynamic virtual environment would offer players a different experience. In terms of agent architectures, we wish to develop more complete cognitive architectures that incorporate emotion

Table X
DESCRIPTIVE STATISTICS

Constructs	E1 Mean	E1 SD	E1 CI	E2 Mean	E2 SD	E2 CI	E3 Mean	E3 SD	E3 CI
TP	3.86	0.34	3.64-4.08	4.08	0.49	3.76-4.40	**4.41**	0.42	4.14-4.68
SP	3.63	0.44	3.28-3.98	3.82	0.43	3.47-4.16	3.84	0.65	3.32-4.36
PI	4.66	0.67	4.13-5.19	4.37	0.58	3.90-4.83	**5.02**	0.66	4.49-5.54
ENJ	4.42	0.44	4.04-4.81	4.50	0.33	4.11-4.90	4.31	0.72	3.68-4.94
FLW	4.47	0.54	4.00-4.94	4.21	0.28	3.96-4.46	**4.58**	0.68	3.98-5.18
BI	4.23	0.71	3.61-4.56	4.51	0.30	4.24-4.78	4.58	0.40	4.23-4.93

modelling and expressions as well. Since the emotion model may influence the decision making process and provide the attentional mechanism which can also help in natural language processing, it could have a broader impact on both the affective and cognitive functions of virtual humans.

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