Formalising Believability and Building Believable Virtual Agents

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Abstract. Believability is an important characteristic of intelligent virtual agents, however, very few attempts have been made to define and formalise it. This paper provides a formal analysis of believability, focused on diverse aspects of believability of the agents and the virtual environment they populate, approaching the problem from the perspective of the relationship between the agents and the environment. The paper also presents a computational believability framework built around this formalism, featuring virtual agents able to reason about their environment – the virtual world in which they are embedded, interpret the interaction capabilities of other participants, own goals and the current state of the environment, as well as to include these elements back into interactions. As a proof of concept we have developed a case study, a prototype of an ancient Sumerian city (Uruk), where believable virtual agents simulate the daily life of its citizens.

1 Introduction

The term "believability" is frequently used in various disciplines, but is very loosely defined. Believability is an essential requirement of modern video games and distributed virtual worlds, hence the shift of research focus to believable agents. As suggested by [19], "the need for modern computer games is not unbeatable AI, but believable AI". In terms of formalisation the concept of believability resembles similarity with intelligence – it is hard to define and formalise. As the result we are witnessing conflicting definitions in existing works and lack of working formalisms for both concepts.

We argue that believability is a more tangible concept than intelligence. Hence, we seek to better define the concept of believability by constructing a formal model of perceived believability. This paper attempts to summarise existing believability research to tackle those issues. As a result, we present a definition of believability, expand its key components and explain those in a formal way. We extend the fundamental work of [20], which we consider to be the most comprehensive attempt to analyse the concept of believability, by integrating recent research findings and formalising the concept of believability. Based on the resulting formalisation we have developed a technological framework that integrates all the identified believability features through contemporary AI techniques. To illustrate the functionality of this framework, as well as to provide an environment for evaluation of believability, we have developed a prototype of the ancient city of Uruk, which is populated with believable virtual agents simulating the daily life of ancient Sumerians.

The remainder of the paper is structured as follows. In Section 2 we analyse existing works and definitions of believability to identify its key components and define the concept. Section 3 presents the definition and formal model of believability. In Section 4 it is shown how the key components of this formalisation can be implemented. Finally, Section 6 concludes the presentation and discusses future work avenues.

2 The Notion of Believability

The notion of believability originates in the field of animation and theatre. A classical work of Walt Disney Studios on animated characters – the "illusion of life" [30] elaborates on the requirements for believability. Though these characters are not real they continue to impact the audiences' imagination to accept them as believable. Believability and realism have been differentiated by [21] and [8]. According to the authors, a believable character is not necessarily a real character, but *must be real in the context of its environment*. Believable agents and believable characters are differentiated in that believable agents are both computer based and interactive [20].

Contemporary AI uses the term "believability" in relation to engaging life-like systems. Reactivity, interactivity and appropriate decision making are the common characteristics of believability for autonomous agents [26]. These characteristics can also be extended with respect to the environment within which they operate.

2.1 Definitions of Believability

In [21] a believable character is defined as the one who seems life-like, whose actions make sense, who allows you to suspend disbelief. An extended definition of believable characters is given by [20]. Here a character is also considered believable if it allows the audience to suspend their disbelief, but what is also important is a convincing portrayal of the personality of this character. Another definition that emphasises personality and focuses on agents rather than characters is presented in [18]. Here believability is defined as the extent to which the users interacting with the agent come to believe that they are observing a sentient being with its own beliefs, desires and personality. A contemporary definition that is used in relation to video games states that believability of a virtual agent is associated with giving the illusion of being controlled by a human [28].

2.2 Exploring Believability Features

We start with listing the key features of believable agents, specified in [20], as follows:

- **Personality**: Personality infuses everything a character does, from the way they talk and move to the way they think. What makes characters interesting are their unique ways of doing things. Personality is about the unique and not the general.
- **Emotion**: Characters exhibit their own emotions and respond to the emotions of others in personality-specific ways.

– **Self-motivation** - Characters don't just react to the activity of others. They have their own internal drives and desires, which they pursue regardless of whether or not others are interacting with them.
– **Change**: Characters change with time, in a way consistent with their personality.
– **Social relationships**: Characters engage in detailed interactions with others in a manner consistent with their relationship. In turn, these relationships change as a result of the interaction.
– **Consistency of expression**: Every character or agent has many avenues of expression depending on the medium in which it is expressed, for example an actor has facial expression and colour, body posture, movement, voice intonation, etc. To be believable at every moment all of those avenues of expression must work together to convey the unified message that is appropriate for the personality, feelings, situation, thinking, and other behaviours of the character. Breaking this consistency, even for a moment, causes the suspension of disbelief to be lost.
– **Illusion of life**: This is a collection of requirements such as: pursuing multiple, simultaneous goals and actions, having broad capabilities (e.g. movement, perception, memory, language), and reacting quickly to stimuli in the environment.

The illusion of life is expanded by [20] in terms of: (i) Appearance of goals; (ii) Concurrent pursuit of goals and Parallel action; (iii) Reactive and Responsive; (iv) Situated; Resource bounded – Body and Mind; (v) Existing in a Social Context; (vi) Broadly Capable; (vii) Well integrated (Capabilities and Behaviours).

Emotional state vs emotions Recent work on the use of emotions in achieving believability [24] suggests the use of *emotional state* of the agent rather than emotions in general, and considers the consistency of agent behaviour across similar situations, coherency and variability of agent behaviour to be significant components of believability.

The role of environment Loyall's work [20] is mainly focused on believable agents themselves and not that much on the environment in which they operate. While situatedness and integrity are listed as important features of illusion of life, little has been said about how believability is being achieved.

The importance of agent integration with the environment is highlighted in [14]. In this work the emphasis is put on the awareness of the agents about their environment, own state in it, other participants and own interaction capabilities. The authors provide evidence that those features significantly improve the overall believability of the agents.

Verbal behavior Two significant components that are missing in [20] are verbal and non-verbal behaviours.

The majority of works on believable verbal behaviour are associated with scripted dialogues or chatter bots like Eliza [34] and ALICE [33] Technically, chatter bots parse the user input and use keyword pointing, pattern matching and corpus based text retrieval to provide the most suitable answer from their "knowledge base" [10], trying to keep a human engaged in a textual or auditory conversation.

Non-verbal behaviour Humans complement verbal communication with non-verbal cues, like facial expressions, body language and gaze.

Facial expressions can be used to complement the word stream through expressing emotions. These emotional expressions have cross-cultural boundaries, but, generally, existing work deals with a list of emotional expressions: (happy, sad, fear, anger, disgust, agreement, disagreement and surprise) as presented in [6].

Gestures allow humans to interact in a lively manner and are an important believability factor. Gesture selection and their correct execution may increase the expressivity of the conversation [11]. Believable gestures are related to gestures selection being correctly aligned with the flow of conversation and the generation of realistic movements of agent's upper limbs during the conversation [11].

Gaze helps to convey the cognitive state of a participant or synchronise a conversation as explained in [17]. Various gaze models like avert, examining the current task, gaze at visitors, etc. were simulated by [12]. They measured the believability of the agent based on factors like satisfaction, engaging, natural eye, head movements and mental load among others; and this study showed the significant improvements in communication between humans and virtual agents. Lance in [29] contributed to investigation of believable gaze by developing a hybrid approach combining head posture, torso posture and movement velocity of these body parts with gaze shift.

Appearance In addition to previously mentioned features from [20], we add *unique and believable appearance* as an important feature of believable agents. Appearance plays an important part in agent believability. Kelley states that human behaviour towards others is shaped depending on differences in first impressions such that people who have favourable impressions of someone tend to interact more with that person than others having unfavourable impressions [16]. First impressions are, therefore, an important basis for whether humans will build relations with others and find their interactions believable [2]. Another important line of research that connects appearance and believability investigates the phenomenon of uncanny valley [22], which states that there is a strong relationship connecting human-likeness and believability, but the correspondence between these is no linear and at some stage as the characters become more human like their believability starts to drop rather than increase.

3 Formalising Believability

Based on the analysis of existing works on believability we try to isolate the key components of believability and define a believable virtual agent as follows.

Definition: *Believable virtual agent* is an autonomous software agent situated in a *virtual environment* that is life-like in its appearance and behaviour, with a clearly defined personality and distinct emotional state, is driven by internal goals and beliefs, consistent in its behaviour, is capable of interacting with its environment and other participants, is aware of its surroundings and capable of changing over time.

Consequently, believability is formalised as follows:

$$\beta = \langle A^T, P^T, E^T, L, SR, \Upsilon, \delta, Aw \rangle \quad (1)$$

Here β is the believability of a virtual agent, A^T are the agent's appearance features, P^T is the agent's personality, E^T is to the emotional state of the agent, L corresponds to liveness, Aw represents agent's awareness, which we define later, SR - social relationship, Υ - represents the consistency constraints and δ - is the change function.

Appearance To formalise the appearance, we assume the existence of parametric avatars of agents, which are defined by their visual features, e.g. height, belly size, head size [31]. Each of these parameters has a value in the interval [0,1] where extremes are labeled by the specific state of the visual feature. For example a visual feature height, has a label for the minimum "short" and for the maximum "tall". The appearance a of an individual can then be represented by the following vector:

$$A^T = [\alpha_1 \ldots \alpha_n], \forall i \in [1, n] : \alpha_i \in [0, 1] \tag{2}$$

Personality While formalising the personality we consider the assumption of [9] that a personality has n dimensions, where each dimension is represented by a value in the interval $[0, 1]$. A value of 0 corresponds to an absence of the dimension in the personality; a value of 1 corresponds to a maximum presence of the dimension in the personality. The personality p of an individual can then be represented by the following vector:

$$P^T = [\beta_1 \ldots \beta_n], \forall i \in [1, n] : \beta_i \in [0, 1] \tag{3}$$

Emotional State The emotional state (E^T) is defined following [9] as an m-dimensional vector, where all m emotion intensities are represented by a value in the interval [0,1]. A value of 0 corresponds to an absence of the emotion; a value of 1 corresponds to a maximum intensity of the emotion. This vector, given as

$$E^T = \begin{cases} [\beta_1 \ldots \beta_m], \forall i \in [1, m] : \beta_i \in [0, 1], \text{if t} > 0 \\ 0, \text{ if t = 0} \end{cases} \tag{4}$$

Liveness Liveness is agent's ability to express the illusion of life. It incorporates the illusion of life features from [20], plus verbal and non-verbal behaviour, as follows:

$$L =< IL, V_b, NV_b > \tag{5}$$

Here IL is a vector responsible for illusion of life, V_b represents verbal behaviour and NV_b represents non-verbal behaviour.

Illusion of life We adapt Loyall's [20] specification of "Illusion of life", uniting "situatedness" and "integration" into the concept of immersion in 3D virtual environments:

$$\begin{aligned} IL =< Goals, Concurrency, Immersion, \\ ResourceLimitation, SocialContext \\ BroadCapability, Reactivity, Proactiveness > \end{aligned} \tag{6}$$

Consistency Consistency across the personality of an agent and other believability characteristics is ensured in our formalisation by the set of consistency constraints (Υ). We formalise those constraints as a penalty function that is 0, if emotional state of the agent and liveness features are inconsistent with the agent's personality and 1 otherwise.

$$\Upsilon : P^T \times L \times E^T \rightarrow \begin{cases} 1 \text{ – if consistent} \\ 0 \text{ – if inconsistent} \end{cases} \tag{7}$$

These constraints must ensure the consistency of the agent behaviour over the entire range of its believability features:

$$\forall p_j \in P^T, \forall l_h \in L, \forall e_g \in E^T : \Upsilon(p_j, l_h, e_g) = 1 \tag{8}$$

Change Change (δ) is basically a learning function that updates a believability instance given another instance and the environment state:

$$\delta : EnvState \times \beta_i \rightarrow \beta_i' \tag{9}$$

Social Relationship Social relationship, formally speaking, can be represented by a function, which reflects on how the current role being assumed by an agent relates to the roles of other agents. This function results in a numeric value in a range [0...1]. Here 0 represents no relationship between two roles and 1 - is the highest degree of relation.

$$\forall r_i, r_k \in Roles : SR = f(r_i, r_k) \in [0 \dots 1] \tag{10}$$

Awareness Believability Awareness is essential part of human conversational behaviour. In a conversation we are aware of where we are (environment awareness), who we are (self-awareness) and generally how the interaction is progressing (interaction awareness). Therefore, awareness is an essential component of the believability of embodied conversational behaviour, which we label as "awareness believability". Further, we develop each of the subcomponents of awareness believability.

So we can formalise awareness believability as follows:

$$Aw =< EA, SA, IA > \tag{11}$$

Environment Awareness As suggested by [14], the key features of environment awareness include the positions of objects and avatars in the environment, how these evolve with time and the direction vectors associated with avatars. Thus, environment awareness is formalised as follows:

$$EA = \{Objects, Avatars, Time\} \tag{12}$$

Here *EA* is the set of components of environment awareness and includes the objects in the environment, other avatars representing agents and human participants with respect to the current time.

Self-awareness Knowing own context and state within the environment (being self aware) is essential for a virtual agent to interact believably [8]. The formalisation of self-awareness proposed by [14] is as follows:

$$SA = \{G, P, B, Sc, St, ObjUsed, Role, Gest\} \tag{13}$$

Here *SA* represents the set of components of self-awareness and includes the local goals of the agent (G), its current plans (P) and beliefs (B), current scene where the agent participates (Sc), its state within this scene (St), objects used by the agent ($ObjUsed$), the role it plays ($Role$) and the gestures being executed ($Gest$).

Interaction-Awareness Human behaviour in interactions is a result of the mix of being rational, informed, impulsive, and the ability to influence others and cope with the influences from others. All these nuances impact the richness of human interactions, hence, must be taken into account when considering the believability of interactions between virtual agents and humans. Interaction-awareness is defined as the state of an agent who is "able to perceive important structural and/or dynamic aspects of an interaction that it observes or that it is itself engaged in" [7]. The components of the interaction-awareness model as outlined in [14] are presented below.

$$IA = \{AV_{vis}, AV_{sc}, Act, Obj, State, Pos, Or\} \tag{14}$$

Here IA represents the set of components included in our interaction awareness model. AV_{vis} corresponds to the set of currently visible avatars. The AV_{sc} is a set of all avatars within the scene where the agent participates in a given moment. Act represents the set of actions each of the agents in the current scene is able to perform given its state. Obj refers to the list of objects the avatar can use. $State$ is the state of the avatar in the world. Pos is the position of the agent in the virtual world and Or is agent's orientation vector in the virtual world space.

4 Implementation: The I^2B Framework

Now that we have a formalisation of believability, next we present our attempt of developing a computational framework implementing this believability formalism. This framework supports the implementation of believable virtual agents for virtual worlds and game engines and is labelled I^2B (Interactive, Intelligent and Believable). It is important to mention that here we do not attempt to develop a comprehensive general-purpose believability framework, but rather present a suggestion on how the aforementioned formalism can be practically implemented (with no claims for this implementation to be the most optimal, unique or comprehensive). The aim of this section is simply to show that the formalism from the previous section is practically useful and can act as a guide for building believable agents. Next we show how each of the components of the above believability formalism can be practically implemented using standard methods and best practices from the literature that were adjusted to fit the formalised models.

4.1 Appearance

Both Second Life and Unity, the platforms we have selected for testing our implementation, offer mechanisms to represent virtual agents as avatars and define them through a set of parametric features, e.g. (height, head size, arm length, skin colour, etc.). This way of modelling avatars is consistent with the aforementioned formalism.

4.2 Personality and Emotional State

One of the most popular modern personality models used in computational psychology is OCEAN (or "The Big Five") model proposed in [15]. We rely on this model in our framework. This model defines the following five personality traits: {Openness, Consciousness, Extroversion, Agreeableness and Neuroticism}. For modelling the emotional state we rely on the well known OCC emotional model proposed in [23] and with computational implementation proposed in [1]. In order for agents to be able to select an appropriate action reflective of its emotional reaction to the state of the environment that is most relevant for their personality, such action has to be annotated by the following *personality facets* [13]: *temptation, gregariousness, assertiveness, excitement, familiarity, straightforwardness, altruism, compliance, modesty* and *correctness*. Using values of personality facets, the agent selects an action that provides the highest utility for its personality type [1] [13]. Thus, personality (P^T) and the emotional state (E^T) are implemented as an array of variables, where each variable represents a personality feature or an emotional state feature correspondingly.

4.3 Liveness

The implementation of various features of Liveness (L) is based on Second Life[1] and Unity 3D technology[2] and the adaptation of a number of contemporary AI techniques.

Goal Generation A critical aspect in the illusion of life (IL) is to make an agent show that it has certain goals, which it can pursue in a concurrent fashion, as well as change them and prioritise in a reactive and proactive manner. We have developed and integrated all these features with Unity and Second Life [32]. Agent goal generation is based on agent *motivation*. In the current model, we support physiological motivation where agents proactively try to fulfil their physiological needs, such as hunger, thirst or fatigue. As part of our future works we want agents to consider other motivations, such as safety or belonging (social realisation). Furthermore, our model implements the BDI approach [25], allowing for all the standard features of agent-oriented programming offering C# classes for agents, events, plans, beliefs, goals and supporting the message communication, plan selection on receipt of an event, priority planning, etc. Programmers of virtual agents can express beliefs and desires of their agents, decide on the types of events they react to and design the plans to handle those events.

[1] http://secondlife.com
[2] http://unity3d.com

Planning Every agent in our system relies on a number of plans to satisfy its goals. A plan is a set of instructions, triggered in response to some event. Those events arise as a result of a human- or agent-controlled avatar sending a text command or as a result of an environment state change. The I^2B framework supports static planning - when the entire plan is prescribed by a programmer and is executed by the agent without variation; and dynamic planning, when the agent can sense its current state in the environment and can react to environment changes re-evaluating its current plan. Rather than having a complete recipe for every situation the agent can encounter - the agent is simply given the list of possible actions and has to find a way of combining those to reach its goals. This search is done using a classical depth-first search algorithm [27], in which a path between the current state and the goal state is found by evaluating all available actions and analysing their pre-conditions and post-conditions.

Obstacle Avoidance and Locomotion In order to believably immerse into its virtual environment and to support the illusion of life while interacting with its environment, the agent must be able to move around without being stuck at an obstacle. This required the implementation of obstacle avoidance techniques. Unity 3D (Pro) offers agent obstacle avoidance based on A^* algorithm. For Second Life, we have also implemented obstacle avoidance adapting the Artificial Potential Fields (see [4] for more details).

Object Use An important aspect of believability is the use objects in the environment (i.e. grabbing a spear, jumping on a boat). We have developed a designated library that provides a set of classes allowing agents to identify an object in the virtual world, attach it to the default attachment point, play a certain animation (i.e. rowing) associated with a given object, wear an object that is a piece of clothing, detach the piece of clothing, drop an object to the ground and detach the object and hide it in the avatar's inventory.

Non-Verbal behaviour Each agent is supplied with a list of possible gestures. Depending on the current emotional state an agent can select a certain gesture and play the corresponding animation. I^2B agents are also supplied with a programming solution dealing with idle gaze behaviour. When the agents are moving around, their gaze is not fixed. The gaze focus keeps changing by our attention-based model. The agent shifts its gaze between objects and avatars depending on the level of its interest in those. The increase and decay of the agent's interest in the surrounding objects will determine the shift in the gaze focus.

Verbal Behaviour The verbal behaviour of the I^2B agents is currently limited to exchanging text messages with other agents and text chats with humans. For chatting with humans I^2B agents employ the ALICE chat engine [33] based on the AIML language. Each agent uses a number of AIML files that represent what can be seen as a common sense database. Additionally, every agent is supplied by personalised AIML files that define its personality and the data relevant for its role within the virtual society.

4.4 Social Relationships

The Virtual Institutions [3] technology manages the social interactions and social relationships of the I^2B agents. The approach taken in Virtual Institutions is to "program" the environment first, in terms of the roles of the agents, their presence, possible scenes, the role flow of the agents between these scenes, interaction protocols of every scene, etc (see [3] for more details on this process). With the help of the underlying Virtual Institution I^2B agents can also understand which social roles are being played by other agents or humans, and change their roles over time. Based on this information they can engage into believable social interactions and build social relationships. An agent's personality and the emotional state are impacted by social interactions with others.

4.5 Consistency

Virtual Institutions manage the set of rules (social norms) for all participants in the given virtual environment, subject to their roles, hence they manage the consistency (Υ) of the agent behaviour. The institutional formalisation helps an I^2B agent to assign context to own actions and actions of other participants, thus being able to make the corresponding adjustments to its emotional state, personality and liveness.

4.6 Change

The I^2B technology supports the change (δ) through imitation learning. The agents can be trained to respond to certain situations in a desired manner. They can learn at multiple levels of abstraction as described in [5]. The Virtual Institution structures the learning process and provides the context for learning. Through imitation the agents can learn new plans for various goals. Such plans are represented as recursive-arc graphs (similar to recursive decision trees) with probabilities being assigned to the arcs of the graph as the training continues. We have also created a method for training the I^2B agents to perform different verbal behaviour in various situations. Our method of modifying the AIML rules and assigning context to those is described in [14].

4.7 Awareness

Virtual Institution is essential in enabling the environment-, self- and interaction-awareness of the I^2B agents. The institution helps the agent to understand which scene it is currently in, what is the current state of the scene, how other participants can change this state, etc. In combination with the ability to sense the surrounding objects and understand their types through annotations created by designers, the agents can include references to those objects in conversations with humans and into their decision making. The details on integrating these features are presented in [14].

5 Case Study: The City of Uruk 3000 B.C.

As a case study we have used the I^2B framework for building a virtual reality simulation of the ancient City of Uruk in the Second Life and Unity 3D, based on the results of archaeological excavations and under supervision of subject matter experts. While in Second Life we were able to run a maximum of 15 agents, in Unity 3D we have created a population with hundreds of agents that simulate the behaviour of its ancient citizens[3]. Figure 1 shows the overview of the city of Uruk.

[3] A video illustrating the key aspects of Uruk agents can be found at: https://www.youtube.com/watch?v=ZY_04YY4YRo

Fig. 1. Overview of the city of Uruk.

The agents populating this city show a slice of the Uruk society among which are fishermen families, priest, king and professional workers. All agents are supplied with a number of internal goals and plans to reach those. For some simplistic activities, like fishing it was more efficient to utilise static planning, while for others, like spear making and pot making we utilised dynamic planning, so that the agents can better adjust to environment changes and interact with one another to resolve problems. The agent appearance was generated automatically using approaches from [31]. Figure 2 shows some selected agents performing their activities in Uruk.

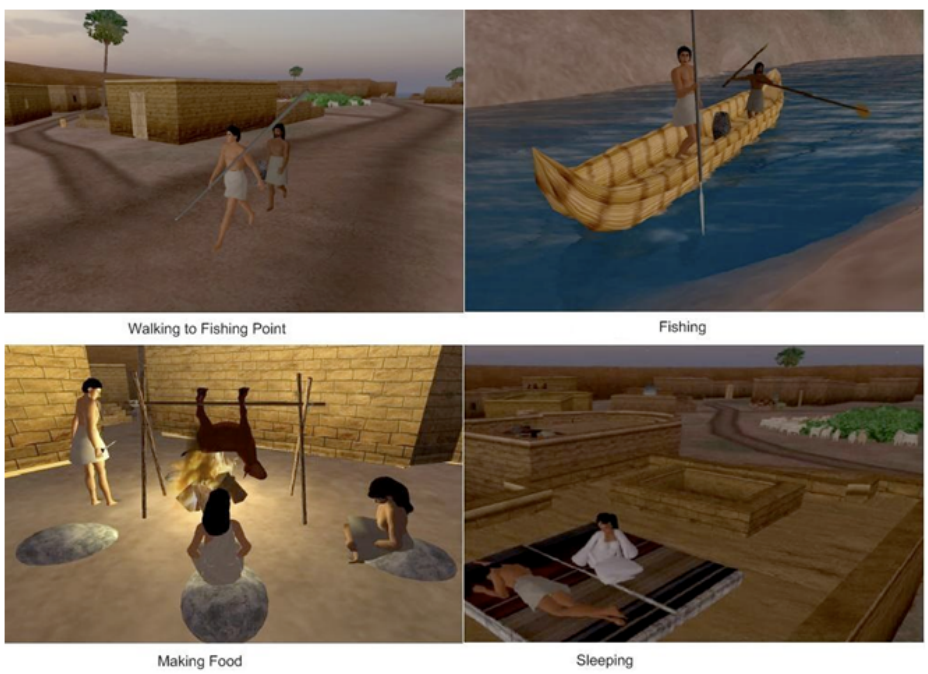

Fig. 2. Selected Agents in Uruk

To give an example of the complexity of agent actions, consider the case of the pot maker (Koko Karsin). When there are no pending goals, the agent explores the city by choosing a random path through city streets. When it recognises the need for social interaction - it seeks for an interaction partner, approaches it and engages in a conversation. Meanwhile, the agent's hunger, thirst and fatigue levels are raising, possibly passing the threshold value, when the agent generates the goals: "hungry", "thirsty" or "tired". This tells the agent that it has to perform a specific action, such as feed, drink or rest. From its knowledge base the agent can read all its possible actions and then use them to dynamically find a plan that leads to the goal. Koko Karsin is only allowed to rest after finishing work (which is making a clay pot). Thus, its plan is: Rested = Add Water, Make Clay, Make Pot, Rest. To show the dynamic nature of planning - the water pot is deleted after every 3 pots made. So, by attempting to perform Add Water the agent approaches the location where the water pot is supposed to be, will sense that there is no pot, will fail the current plan, update the environment state to NoWater and will create the new plan that will also have the Get Water action before Add Water.

All agents can sense their environment. For example, they can detect danger (i.e. a donkey cart moving close to them and will often try to run away from it) or detect a high ranked person (the King) at close proximity and praise him. They can also perform various group activities. One of those activities is a prayer. The prayer is announced by the city priest as a goal with very high priority. Using our priority planning mechanism, when such an event is received – the agents are capable of dropping their current activity and start running towards the temple and then perform a prayer ritual. They have a number of plans, each for handling a different type of situation. Each plan has a different associated priority, which makes it possible for the agent to decide that the prayer is more important than an exploratory walk or a chat with a friend.

The users can interact with the agents via chat facilities. User commands are given the highest priority, followed by the pray request from the priest. Next comes praising the king (the agent will fall face down when the king is at close proximity). Finishing work and resting are the normal priority plans. Finally, the low priority is allocated with the exploratory walk and the social chat with other agents.

For chat responses to human users the agents rely on the set of AIML rules. Those rules can be modified via imitation by authorised subject matter experts. To illustrate the awareness believability, in their conversations the agents can refer to certain objects in the city and provide relevant explanations, can explain why are they doing things in a certain way, relate to their state in various scenes or make references to current or future possible actions of other agents[4].

6 Conclusion and Future Work

We have analysed existing literature in relation to believability of virtual agents. Based on this analysis we have produced a revised definition of believability and a formal model. With the help of this formal model we have implemented a believability framework that can be used for simulating believable virtual agents. This framework was tested by developing a virtual reality simulation of an ancient Sumerian city, where virtual agents believably simulate the daily life of its ancient citizens.

[4] A video showing awareness believability aspects of our framework can be found at: http://www.youtube.com/watch?v=VAnoeupxo9c

The resulting formalisation of believability that was developed here is an early work that needs further development and extensive evaluation. Future work will include further investigation of believability features and advancing the formalisation. In order for the developed believability model to be scientifically sound, we plan to conduct a comprehensive set of evaluation rounds, where the significance and correct implementation of each of the identified believability features is tested in isolation to determine that it does, in fact, correlate with improving the perception of agents being more believable with this feature being implemented.

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