A Computational Framework for Expressive, Personality-based, Non-verbal Behaviour for Affective 3D Character Agents

by

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Ethics Statement

Abstract

Badler defined virtual humanoid characters as computer models of humans that can be used in several applications such as training and entertainment. For the humanoid characters to be credible and human-like, they must exhibit realistic and consistent nonverbal behavior. It is this consistency that ultimately instills in human users a sense that the characters have distinct personalities. Despite this importance, relatively little work has so far been done on the consistency of a 3D character's behaviour during interaction with human users and their environments. Current 3D virtual character systems lack the ability to maintain the consistency of their behaviour during real-time interaction which can lead to users' frustration and resentment.

This thesis presents the design, implementation, and evaluation of a system named "RealAct" that controls the non-verbal behaviour of virtual characters. To make the virtual characters behave in a believable and consistent manner, the system controls non-verbal behavior such as gaze, facial expression, gesture and posture to give the impression of a specific personality type. The design and development of different modules of the RealAct system, e.g. for controlling the behaviour and generating emotion, is directly modelled from existing behavioural and computational literature. In addition to these core modules, the RealAct system contains a library of modules that are specifically geared toward real-time behavior control needs such as sensory inputs, scheduling of behaviour, and controlling the attention of the character.

To evaluate and validate different aspects of the RealAct system, four experimental studies using both passive video-based and presential real-time paradigms were performed. The results of these experiments show that the amount of extraversion and emotional-stability that participants attributed to virtual characters depended on a combination of facial expression, gaze and posture and gestures that they exhibited. In summary, it was shown that the RealAct is effective in conveying the impression of the personality of virtual characters to users. It is hoped that the RealAct system provides a promising framework to guide the modelling of personality in virtual characters and how to create specific characters.

Keywords: Nonverbal behaviour; Virtual characters; Personality traits; Five Factor Model; Hybrid architecture; Hierarchical architecture

Dedication

This thesis is dedicated to my husband and family for their endless love and support.

Acknowledgements

I am greatly indebted to my senior supervisor, Professor Steve DiPaola for his continuous advice, and support. This dissertation would not have been possible without his valuable help. I also took advantage of invaluable support and help by my thesis committee members, Professor Tom Calvert, and Professor Liane Gabora. Their effective guidance and insightful ideas throughout the entire project are greatly appreciated. I am also especially grateful to Dr. Ulysses Bernardet for his valuable ideas and stimulating suggestions. He has been a truly dedicated mentor through this journey. I also extend my gratitude to all the participants and experts who contributed their time in sharing their views during the experiments that were conducted in the context of this doctoral research. I thank all the reviewers of the academic publications written in preparation for this dissertation. Finally, I acknowledge the financial support by "Moving Stories" and "Moving+Meaning" projects which were provided by Social Sciences and Humanities Research Council of Canada (SSHRC) and CANARIE grants respectively.

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Publications

Ideas and figures in this dissertation have previously appeared in the following:

1. Saberi, M. (2016) Personality-Based Cognitive Design of Characters in Virtual Environments. In J. O. Turner, M. Nixon, U. Bernardet & S. DiPaola (Eds.), Integrating Cognitive Architectures into Virtual Character Design. IGI Global, Pennsylvania, USA. Chapter 5, 124-150.

2. Saberi, M., Bernardet, U., & DiPaola, S. (2015a). Effect of a Virtual Agent's Contingent Smile Response on Perceived Social Status. In W.-P. Brinkman, J. Broekens, & D. Heylen (Eds.), Intelligent Virtual Agents (Vol. 9238, pp. 488–491). Lecture Notes in Computer Science. Springer International Publishing. doi:10.1007/978-3-319-21996-7_54.

3. Saberi, M., Bernardet, U., & DiPaola, S. (2015b). Model of Personality-Based, Nonverbal Behavior in Affective Virtual Humanoid Character. In Proceedings of the 2015 ACM on International Conference on Multimodal Interaction (pp. 371–372). ICMI '15. Seattle, Washington, USA: ACM. doi:10.1145/2818346.2823296

4. Saberi, M., Bernardet, U., & DiPaola, S. (2014). An architecture for personality-based, nonverbal behavior in affective virtual humanoid character. Procedia Computer Science, 41, 204-211.

5. Bernardet, U., Saberi, M., & DiPaola, S. (2016). Simulink Toolbox for Real-time Virtual Character Control. In Intelligent Virtual Agents (forthcoming). Lecture Notes in Computer Science. Springer International Publishing.

6. Gabora, L., & Saberi, M. (2011, November). How did human creativity arise? An agent-based model of the origin of cumulative open-ended cultural evolution. In Proceedings of the ACM conference on cognition & creativity (pp. 299-306).

7. Gabora, L., & Saberi, M. (2011, November). An agent-based model of the cognitive mechanisms underlying the origins of creative cultural evolution. In Proceedings of the 8th ACM conference on Creativity and cognition (pp. 299-306). ACM.

8. Gabora, L., & Saberi, M. (2011, November). ACM Conference on Cognition & Creativity. Atlanta, GA. Title of talk: How did Human Creativity Arise? An Agent-based Model of the Origin of Cumulative Open-ended Cultural Evolution.

9. Gabora, L., & Saberi, M. (2011, August). American Psychological Association convention in Washington DC. Title of talk: Should Everyone Be Creative? A computer simulation.

The RealAct system detailed in this thesis and above publications (1 to 5) was designed, coded, and evaluated solely by me. I worked closely with and received the supervision of my senior supervisor, Steve DiPaola, and post-doctorate and lab-leader, Ulysses Bernardet. I solely designed and ran four experiments to evaluate the RealAct which took place in iVizLab. I was a member of the lab. I also worked closely with my committee member, Liane Gabora, to develop a module for an agent-based model of the origin of cultural evolution (6 to 11).

Chapter 1.

Introduction

3D human-like virtual characters are computer models of humans that can be designed to autonomously sense, perceive, and react to their surroundings [56][53][46][23]. They are increasingly taking the roles of museum guides [110][111], sales bots [112], web based receptionists [113], interactive drama actors [114][115], story-tellers [116], tutors [117], and therapists [118][119]. Considering human-human communication as a highly desirable and efficient means of interaction, human-like virtual characters can be used to improve human-computer interaction since they can use multiple channels of behaviour such as gesture and facial expression [21]. These channels should behave coherently and consistently throughout the interaction to create a more efficient and pleasant experience for human users [77][44][79][80].

In the field of psychology, personality refers to consistent patterns of behaviour, emotions, and thoughts that persist over time and situations [44][120][63][48]. Similar to humans, the consistent behaviour of 3D human-like characters is interpreted by human users as personality types. For instance, a 3D character that shows positive facial gestures and moves fast creates a different impression of personality from a character that moves slowly and shows negative facial expressions [44][45]. To make the virtual characters behave in a believable and consistent manner, the RealAct system controls non-verbal behavior such as gaze, facial expressions, gestures, and postures to give the impression of a specific personality type.

In this chapter, I first state the problem this dissertation addresses. Then, goals, limitations, hypotheses, approach, and the contributions of this research are discussed. In the last section, the thesis structure is briefly presented.

1.1. Problem Statement

In this thesis, the following problem is addressed:

Current 3D virtual character systems lack the ability to behave in a human-like way by maintaining the consistency of their behaviour during real-time interaction with humans [131][134][135][137]. I address this problem by designing, implementing and evaluating a hybrid event-based, emotionally-continuous system (RealAct) that allows the virtual characters to behave in a more believable and consistent manner, perceived as personality, through a combination of computer generated behaviour (gaze, facial expressions, gestures and postures), and in response to the users' actions.

1.2. Goals, Limitations, Hypotheses, and Approach

The goal of this thesis was to design and implement a system that preserves the believability of a realistic 3D real-time character over time by generating consistent behaviour while being responsive to a live interacting human user. By believability, I mean the behaviour should be natural, consistent, smooth and responsive to events happening in the environment. Personality traits that are described by psychology as consistent patterns of thoughts, emotions, and behaviour, are used to create harmony in the behaviour of the 3D virtual character [65].

Given the challenging nature of this new research space and complexity of implementing a full sensor-based computational real-time 3D character system and evaluating it in dynamic real-time interaction with live users (see Figure 3.1), I narrowed down the scope of the research to nonverbal behaviour where no speech is involved. I also limited the behavioural scope to the strategic turn-taking interaction between the character and the user. In addition, the evaluation, verification of the research was limited to studies modeling the two traits of the Big Five model of personality [6]: extraversion and emotional-stability. These traits were mapped to a limited set of extracted movement descriptors such as duration of the mutual gaze and speed of the hand movement. Exploring the impression of Big Five's other traits, and other nonverbal behaviour is left for the future work.

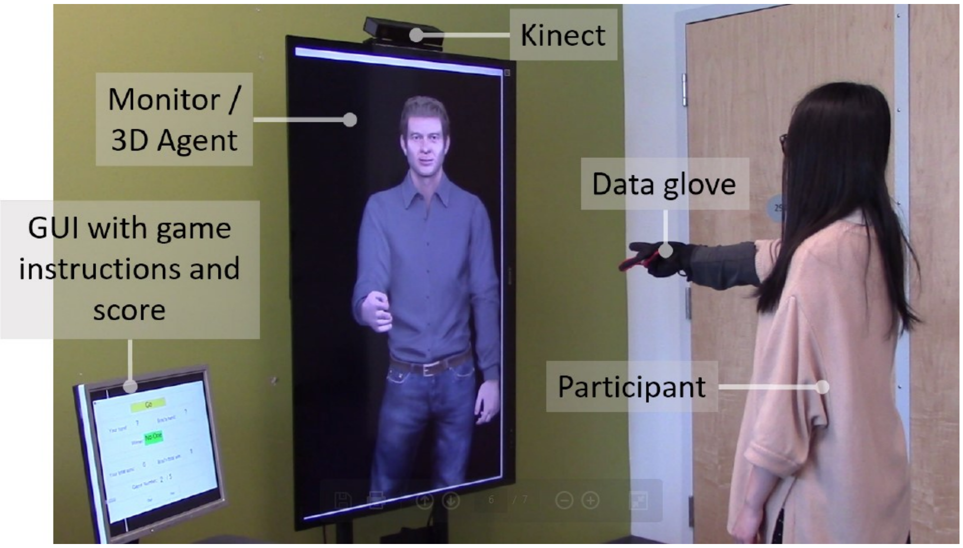


Figure 1.1. Using a Kinect sensor [127] and our designed data glove the participant's position and gesture are recognized by the system, at which time the character responds back.

The research problem of this dissertation is addressed by the designing, implementing, testing, refining, and finally evaluating the RealAct system through the following loosely defined hypothesis statements:

Hypothesis S1- The amount of extraversion that participants attribute to a virtual character depends on the combination of behaviour (gaze, facial expressions, gestures, and postures) it exhibits.

Hypothesis S2- The amount of emotional-stability that participants attribute to a virtual character depends on the combination of behaviour (gaze, facial expressions, gestures, and postures) it exhibits.

Hypothesis S3- The presential user interaction experiment when the virtual character exhibits behaviour towards the subject during the interaction: a) will strengthen the perception of extraversion for intended extraversion and b) will strengthen the perception of emotional-stability for intended emotional-stability for the virtual character. By intended personality I mean the personality that was portrayed by the virtual character and by rated personality I mean the personality traits that participants rated for the virtual character using Ten Item Personality Measure [108] (see 4.3.2).

Hypothesis S4- The framing of the behaviour (the face vs. the whole body) affects the impression of a) extraversion and b) emotional-stability personalities.

The null hypothesis, for the above hypotheses are as follow: the amount of extraversion and emotional stability that participants attribute to a virtual character do not depend on the combination of behaviour (gaze, facial expressions, gestures, and postures) it exhibits (which is specified with the RealAct). This means the RealAct system was not successful in creating the impression of extraversion and emotional stability through the specified nonverbal behaviour. In addition, the presential user interaction experiment when the virtual character exhibits behaviour towards the subject during the interaction does not have any effect on the perception of extraversion for intended extraversion and does not have any effect on the perception of emotional-stability for intended emotional-stability for the virtual character. Finally, the framing of the behaviour (the face vs. the whole body) does not have any effect on the impression of extraversion and emotional-stability personalities.

To address the above hypothesis statements the following approach is applied in this dissertation (outlined in Figure 1.2 and explained in the dissertation).

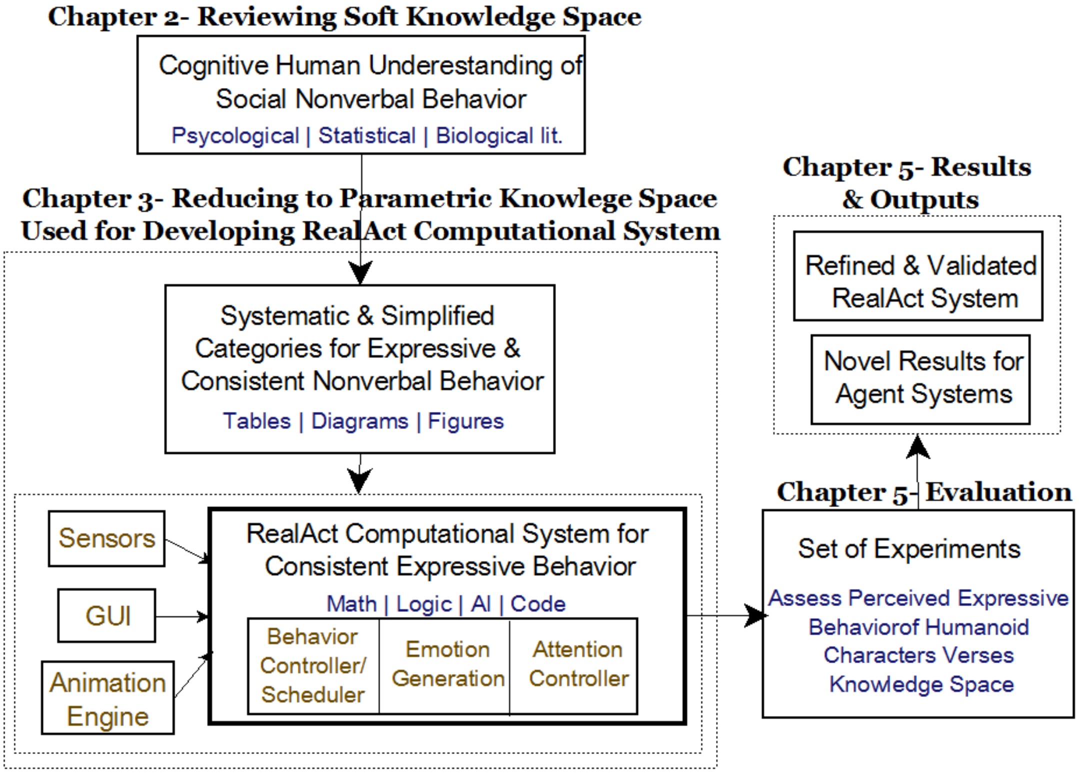


Figure 1.2. **The process of this thesis research includes: 1) analyzing qualitative social behaviour data, 2) filtering, simplifying and categorizing the cognitive data to a set of tables, figures, and diagrams used in the computational design, and 3) develop the RealAct system, and 4) evaluate the system through four experiments. The research output is parametrized data on expressive nonverbal behaviour, and a refined system for generation of expressive behavior for 3D virtual characters.**

First, the qualitative cognitive data on human social behavior is analyzed. This data is then filtered, simplified and categorized to a set of definitive parameters using tables, figures, and diagrams useful to computer model researchers. Then, the RealAct system is designed and developed using these parameterized data. Finally, the system and assumptions are evaluated through four still, video and interactive experiments. The archived open sourced output of this research consists of parametrized data on expressive nonverbal behaviour, and a refined system for generating expressive behavior for 3D virtual characters (see Appendix B).

1.3. Contributions

Considering the goal of creating a framework for expressive, personality-based, behaviour for 3D characters, and the process of the research depicted in Figure 1.2, the following related contribution areas in the fields of computational nonverbal behavioural modelling, and affective computing are proposed:

1. I undertook a comprehensive review of the psychological and biological research on non-verbal indicators of personality. This is then used to extract patterns of human behaviour which affect the perception of personality. These "soft" data sets are then reduced integrated, and categorized to definitive data useful to computational modeling. The categorized and structured material on the association of personality and nonverbal behaviour is a useful repository for cognitive and affective computing researchers.

2. The structured and categorized data are then extensively programmed into a computational framework using artificial intelligence and computer simulation based techniques to create the RealAct system with the following features:

    (a) I proposed a novel **hybrid** structure for the RealAct system (Figure 3.1) to follow two distinct patterns of human behaviour: 1) plan-based and logical (RealAct's Event-based module), 2) reflexive and emotional (RealAct's Emotionally-Continuous module).

    (b) Several sophisticated real-time bio gesture and movement **sensor systems** are tested, setup and eventually implemented in RealAct to create an emotive real-time character responsive to users' movements, facial expression, and hand gestures. In addition, RealAct is based on our Movement + Meaning (m+m) architecture [167], which is a software platform which facilitates adding new modules to RealAct for capturing and recognizing the movement data.

    (c) To promote the future use by other researchers, I programmed the RealAct system as a set of encapsulated and reusable blocks saved in the open source RealAct library. In addition, RealAct used an open standards system for sending behaviour commands to the animation toolkit which can be used by other animation engines (Behaviour Markup language [129]). The RealAct framework and its documentation are available online (see Appendix B). The following is the summary of available blocks of the RealAct library, and the novel incorporation of personality traits "extraversion" and "emotional-stability" in them:

        (i) The **Gaze controller** is a combination of eye, head, torso, chest, back and blink behaviour control module. It refines the Eyes Alive model of gaze [100] to create a gaze behavior following the human ocular behaviour. The expression of personality is reinforced by controlling the following gaze parameters: chance of occurrence of averts or mutual gazes, gaze direction, duration of avert and mutual gazes, and speed of head movements (Table 3.2**Error! Reference source not found.**).

(ii) The **Postures and gestures controller** proposes the following expressivity dimensions to reflect emotional-stability and extraversion personality traits: 1) Posture-shift behaviour, 2) Self-adaptor behaviour, 3) Leaning behaviour (lean forward, no lean and lean backward) 4) Twitches (true or false) and 5) Spacious gestures (true or false). These dimensions can have three different frequencies (high, mid, low) and three speeds (fast, mid, slow) (Table 3.3).

(iii) The **Facial expressions controller** adapts Boukricha et al's model to associate the emotional valance and arousal values [82], generated in "emotion generation module", with facial muscle movements [71]. The impression of personality is created through changing the intensity of emotions, filtering of emotions, and facial twitching (Table 3.4).

(iv) The **Emotion generation module** uses three kinds of triggers to elicit the emotional valence and arousal [51]: 1) triggers activated during interaction with the user and environment, 2) triggers regarding the interaction scenario, and 3) internal triggers when no external event is happening. Based on their importance, triggers can have different impacts on the generation of arousal and valence (see Figure 3.4). Personality affects the generation of emotion (see Table 3.4). New triggers with desirable impacts can easily be added to RealAct.

(v) The **Attention controller** module makes the 3D character attentive to sudden environment changes, and events regarding the scenario of the interaction. Based on the body parts involved two attention types are proposed: gaze, body. If the attention signal only requires the attentiveness of the gaze, other body parts can continue with their idle behaviour. The same rule applies to the body.

(vi) The **Behaviour scheduler** prioritizes and selects a behaviour from multiple behaviour requests generated by behaviour controllers using three priority queues for high, mid and low priority behaviour (Figure 3.15). The behaviour with the highest priority is then sent to the animation engine.

(d) Different aspects of the RealAct system were tested, and refined through four experiments. In the first three experiments, I evaluated how users perceived still images of facial expressions and videos of the behaviour of 3D character generated by the RealAct. Then, by refining the RealAct system using the feedback received from the users, a comprehensive real-time presential study was performed (Figure 4.14). The major findings are:

- The amount of extraversion and emotional-stability that participants attributed to the realistic 3D virtual characters depended on a specified combination of computer generated facial expression, eye gaze, body posture and hand/body gestures that the character's exhibited.

- The real-time interaction adds to the strength of the perception of personality, when comparing its results with the passive video-rating of behaviour (see 4.5). This is a novel finding worth further exploration since most related studies that proposed computational affective models did not evaluate the model, only evaluated it employing static images or videos, or did not compare the results of passive video-rating and real-time interaction [37][45][61][93] [94][96].

- How the channels of behaviour are framed and filtered affects the perception of personality. For the web-based experiments, I found the framing of videos (face only versus neck-down full body) affected the impression formation by reducing the motion cues through filtering out some channels of behaviour. To the best of my knowledge exploring the effect of the framing of the body in forming the user perception of the personality of a virtual character needs further exploration.

1.4. Thesis Structure

In Chapter 1, the research problem and the contribution of the thesis are introduced.

Chapter 2 outlines well-known personality models, studies of the synthesis of behaviour for virtual 3D characters, and behaviour which affect the impression of personality for humans and for virtual characters. In addition, I review the computational architectures exist for creating the impression of emotion and personality in virtual characters.

In Chapter 3, the RealAct hybrid system for generating consistent responsive nonverbal behaviour is proposed. The RealAct's architecture, details of its implementation, the modules of the RealAct system such as the behaviour controllers, the behaviour scheduler, and the sensor module are described.

In Chapter 4, the design and results of four experiments I performed to address the evaluation criteria of the dissertation are described.

Chapter 5, summarizes the results, the conclusion and future work.

Appendix A includes the screenshot of the questionnaires and scales used for the real-time presential experiment. A link to RealAct source code and its documentation is available in Appendix B. The details of the statistical methods used are reviewed in appendix C.

Chapter 2. Related Work

To create a framework for personality expressive nonverbal behaviour for virtual characters, a comprehensive review of various disciplines was conducted. Here first, I explore the personality models used in both psychological studies and computational architectures and review how the impression of personality is formed from human behaviour. The result of this is a comprehensive model that can be said to be on the map between nonverbal behaviour and the formation of personality impression. Secondly, to synthesize the behaviour of the virtual character, common synthesizing techniques for the three main channels of non-verbal behaviour – Gaze, Facial Expressions, and Postures/Gestures – are reviewed. Finally, the related theoretical and computational architectures for expressing personality are reviewed.

2.1. Personality, and Its Relation to Behaviour

Personality is the consistent patterns of thoughts, feelings, and behaviour that distinguish one person from another and persists over time and situations [44][120][63][48]. The science of personality is a controversial domain in the field of psychology. Different theories of personality have emerged by considering the effects of variables such as individual differences, the environment, varying situations, mental skills, and intelligence levels [132] [6] [27] [39]. In this section, I first go over the three important models of personality: The Big Five, BIS/BAS, and Circumplex. Due to the wide usage of Big Five model in both psychological studies and computational architectures, RealAct is designed and implemented using this model. The dissertation reviews the existing empirical psychological data on the map between Big Five personality traits and the channels of behaviour, for both humans and virtual characters.

2.1.1. Personality Models

Personality traits are relatively stable patterns of behaviour over time and are different across individuals. Two general approaches are popular to extract the important personality traits. The first approach is empirically driven and uses factor analysis on a large pool of lexical terms and adjectives (using personality questionnaires), mapping the patterns of covariation among the traits. Both lexical and questionnaire research provide evidence to support the Big Five model of personality [11]. The second approach is theoretically driven and is based on motivational systems. It extracts the traits that are related to variation in the functioning of the motivational systems and focuses on the biological foundation of traits. BIS/BAS is an example of this model that proposed that people differ in the sensitivity of their Behavioural Approach System and Behavioural Inhibition System [39]. These two approaches are beginning to converge since the popularity of personality neuroscience is increasing. Sensitivity to reward and punishment used in BIS/BAS model have been associated with two traits of the Big Five: extraversion and emotional-stability. The following is an introduction to three important and widely used personality models associated with computational modelling: Big five, BIS/BAS, and Circumplex models of personality.

Big Five

The Big Five or Five Factor Model (FFM) [6] is a comprehensive model that has widespread acceptance in psychology and is widely used and validated in several studies [11] [43]. In the Five Factor Model, personality is categorized according to the following traits: Openness to experience (inventive/curious vs. consistent/cautious), Conscientiousness (efficient/organized vs. easy-going/careless), Extraversion (outgoing/energetic vs. solitary/reserved), Agreeableness (friendly/compassionate vs. cold/unkind), and Neuroticism (sensitive/nervous vs. secure/confident). Neuroticism is also referred to in terms of Emotional-Stability, the term used in this dissertation, such that high neuroticism is equivalent to low emotional-stability and vice versa. There are 6 “facets” of personality associated with each aforementioned factor (Table 2.1) [6].

In the context of this research, I narrow my work in this thesis to two particularly important traits: extraversion and neuroticism (low emotional-stability). Extraversion is a measure of how outgoing and social a person is. People who are rated high in extraversion enjoy being with others and participating in social activities; they have more energy and like to engage in physical activity [12]. They also like to express themselves and join conversations. By comparison, introverts are less outgoing, participate less in conversations, and show less engagement in social activities; they seem to demand less stimulation and more time alone [6]. Neuroticism is referred to emotional instability and the tendency to experience negative emotions, such as stress and depression. As a result, some situations can be interpreted as more threatening for neurotics. Neurotics' negative emotional reactions also tend to last for unusually longer periods of time. On the other hand, people with a lower score in neuroticism are more emotionally stable. However, stability does not necessarily equate to positive feelings.

Table 2.1. Five Factor 30 Facets [6]

Openness to Experience	Imagination Artistic Interests Depth of Emotions	Willingness to Experiment Intellectual Curiosity Tolerance for Diversity
Conscientiousness **'Work Ethic'**	Sense of Competence Orderliness Sense of Responsibility	Achievement Striving Self-Discipline Deliberateness
Extraversion	Warmth Gregariousness Assertiveness	Activity Level Excitement-Seeking Positive Emotions
Agreeableness	Trust in others Sincerity Altruism	Compliance Modesty Sympathy
Neuroticism (Low Emotional-Stability)	Anxiety Angry Hostility Moodiness/Contentment	Self-Consciousness Self-Indulgence Sensitivity to Stress

BIS/BAS Model of Personality

The BIS/BAS model proposed by Gray is fundamentally different from the Big Five approach since it is theoretically driven, based on motivational systems, and focuses on the biological foundation of traits. Gray proposed that people differ in the sensitivity of their Behavioural Approach System (BAS, responsible for impulsivity) or Behavioural Inhibition System (BIS, responsible for anxiety) [39]. People with BAS are sensitive to signals of reward and desired events, while those with BIS tend to be more sensitive to moving away from unpleasant events and punishments. Extraversion and neuroticism traits have been associated with Gray's two-dimensional model of impulsivity and anxiety.

Circumplex Model of Personality

A simplified version of the FFM is Wiggins' Circumplex model of personality, that is founded on Affiliation, and Dominance [58]. Circumplex model represents the FFM's extraversion and agreeableness factors in a circumference map. In spite of dimensional models of personality which describe the personality using a set of dimensions which are varying independently of others, Circumplex considers the personality dimensions to be interrelated by a spatial model. By using a combination of two factors—Affiliation and Dominance—result personalities can be distributed on a circle in the following order: warm, exhibitionist, dominant, competitor, cold, shy, submissive, and helper (Figure 2.1) where each point represents a specific personality [27].

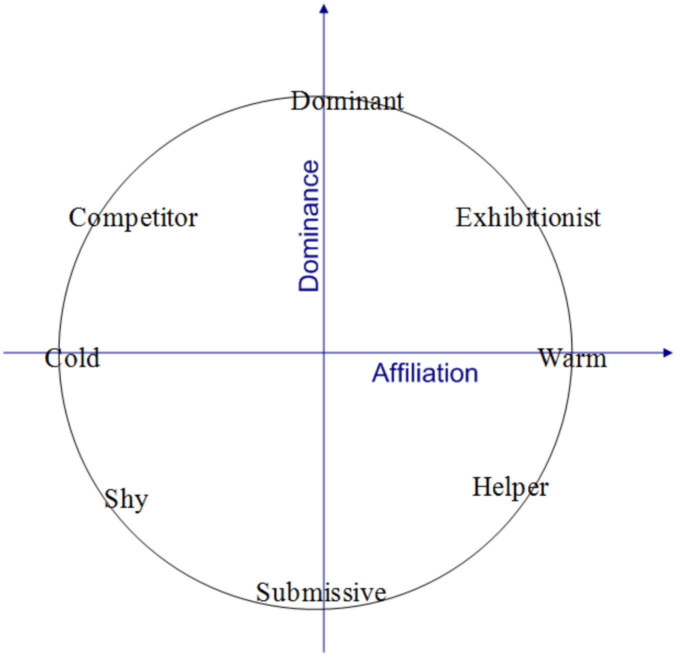


Figure 2.1. Circumplex model of personality figure from [27]

2.1.2. Impression of Personality (Big Five) from Human Behaviour

Psychological studies show a significant correlation between the impression of personality and body movements. Here, I am reviewing some of the reported links between behaviour and traits of the five-factor personality model: extraversion, neuroticism, agreeableness, openness, and conscientiousness [6].

Extraversion

Individuals who score high on the extraversion scale smile often [29], show more body movements and facial activity [40], and exhibit more frequent hand and head movements [29]. They show more gesturing, more head nods, and faster general speed of the movement [29] [30], and tend to position themselves closer to others in conversation and have direct eye contact [8]. Based on Gill and Oberlander's empirical study, extraversion is positively correlated with direct facial postures and eye contacts [38]. In addition, people with a high score in the extraversion scale are sensitive to signals of rewarding and they show heightened emotional reactivity to positive mood induction [32] [41]. In coping situations, they show positive thinking and rational actions [43]. Tankard's study showed that people who looked straight seemed more active than people who looked downwards [14]. Based on the work of Larsen et al., gaze-avoidant women were viewed by others as not extraverted [4]. Extraversion is positively correlated with shorter dwelling time and a higher number of fixations [1].

Emotional-Stability (Neuroticism)

Based on Campbell and Rushton's study, individuals who score high on neuroticism are associated with touching oneself, and an absence of expressive gestures [31]. They show signs of tension or anxiety and express insecurity or sensitivity, hostility, self-pity, and guilt. Moreover, they seek reassurance, behave in a fearful or timid manner, are irritable, and try to sabotage or obstruct interactions [36]. Highly anxious patients generated significantly more stroking, twitches, and tremors. They also maintained eye contact for significantly less time on each gaze. Low-anxiety patients smile more frequently [57] and engaged in more manual signaling. Neuroticism is correlated with sensitivity, nervousness, and low confidence. In Tankard's study, people who looked straight seemed more secure than people who looked downwards [14]. People who have a high score on neuroticism are also sensitive to signals of non-reward and punishment [10][32]. They experience more negative emotions (e.g. anxiety and, guilt) [36]. In coping situations, they show the use of withdrawal, indecisiveness, and passivity [43]. Cook et al. showed that those who maintain lower gaze duration are considered nervous and less confident [17]. Less eye contact is also assigned to anxiety in communication-oriented research [18] [19]. Multiple psychological works also revealed that as the amount of eye contact increases, people are perceived as more self-confident [13] and less anxious [16]. People with higher self-esteem maintain eye contact for a longer period of time, and break eye contact less frequently, as compared to people with lower self-esteem [3].

Agreeableness

Borkenau and Liebler's empirical study showed that people rated high in agreeability have smile often [29]. As shown in on Funder and Sneed's research, they have friendly and self-assured expressions [36]. People rated low in agreeability, on the other hand, show less visual attention but more visual dominance. They also do less back-channeling (short utterances such as 'ok' and behavioural cues such as nodding that synchronize and advance the communication) [54]. Agreeableness is a personality trait correlated with friendliness and, being compassionate vs. cold and unkind. Tankard demonstrated that people who looked straight seemed more receptive than people who looked downwards [14]. With a normal gaze amount of 50%, the eyes are perceived as friendly [9].

Conscientiousness

People who score high in conscientiousness have a predominance of upward looks [35], and high eye contact [36]. They tend to avoid negations, try to control interactions, have high enthusiasm and energy levels, and engage in constant eye contact. They express warmth and show genuine interest in intellectual matters. They appear relaxed and comfortable, and offer advice to conversational partners [36]. Borkenau and Liebler showed that conscientious people do not show fast movements [29], do not have frequent hand movements [29], and do not touch themselves frequently [29]. Conscientiousness is correlated with efficiency and, being organized versus being easy-going and careless. Gaze avoidant women were viewed by others as less conscientious [4].

Openness

Openness is associated with being relaxed and comfortable. Open people tend to fixate their gaze with a mean duration and dwelling time [1], and their eye fixation point increases [2]. They have high enthusiasm and energy levels and seem to enjoy the interaction. They engage in constant eye contact and do not behave in a fearful, timid, reserved, or inexpressive manner [36]. Openness is linked to inventive and curious behaviour vs. consistent and cautious manners.

2.2. Synthesizing Behaviour in Animation Systems

In the previous section, I have reviewed the relationship between non-verbal behavior and personality in humans. To be able to translate these finding to virtual characters, we need to be able to control various aspects of their behavior. In the following, I review a variety of computational approaches used to animate the gaze, gesture, posture, and facial expression of the 3D virtual humans. In addition, the high-level descriptors for body and facial behaviour are introduced. These descriptors categorize the movements based on their specifications and characteristics, using psychological data.

2.2.1. Gaze

To create natural and realistic virtual characters, their gaze should appear natural and consistent with human ocular behaviour. Gaze consists of the behaviour of not only the eyes, but also their coordination with head, and sometimes chest and torso movements. Several studies addressed the simulation of gaze movements' patterns for virtual characters during the social interaction, or specifically during the conversation. Cassell et al studied the rules of eye engagement of virtual characters during the conversation [138]. Andrist et al developed a model of gaze behaviour by exploring the design variables for the gaze that lead to realistic gaze behaviour by drawing on the research in human physiology [144]. Lee et al [100] presented an eye saccade model, called Eyes Alive, which was developed based on empirical models of saccades and statistical analysis of the eye-tracking video. The models reflect the dynamic characteristics of natural eye movement, which include saccade magnitude, direction, duration, velocity, and inter-saccadic interval [141].

Saccades are rapid movements of both eyes from one gaze position to another [142]. Magnitude or amplitude of a saccade is the angle of eyeball rotation. Saccade direction is a 2D axis of rotation, with zero degrees being to the right. Saccade duration is the duration of movement, which is based on the velocity threshold. They also performed a study to evaluate their eye saccade model which showed the model made the face character look more natural. The RealAct character's gaze behaviour is a combination of eye, head, torso, chest, back and blink behaviour. It refines the Eyes Alive model of gaze [100] to create a gaze behavior following the human ocular behaviour. The expression of personality is reinforced by controlling the following gaze parameters: chance of occurrence of averts or mutual gazes, gaze direction, duration of avert and mutual gazes, and speed of head movements (Table 3.2).

There were also attempts to create a model of attention of gaze for virtual characters in a changing and dynamic environment such as the character monitoring the traffic light [139]. Colburn et al. investigated how observers reacted to averted gaze versus mutual gaze of the avatar [140]. Itti et al proposed a neurobiological model of attention in order to create realistic gaze behaviour [143]. They then explored the model by using it to implement a virtual character's head watching a series of visual inputs [143]. Since our focus is a real-time interaction between the virtual character and users, attention to the environment and interaction scenario was crucial. Thus, RealAct simulates two attention types based on the body parts involved: gaze, body. If the attention signal only requires the attentiveness of the gaze, other body parts can continue with their idle behaviour. The same rule applies to the body (see section 3.5).

2.2.2. Gestures and Postures

Procedural 3D computer animation and motion capture techniques are two common approaches to animate the gestures and postures of virtual characters [73]. Procedural 3D animation [74] creates a continuous control over the characters' joints to perform the desired behaviour. It can be difficult to control the behaviour of the 3D character to behave lifelike or realistic. Pre-defined motion capture [75] or hand-key-framed animated motions can be used to produce in very realistic behaviour. On the other hand, animation systems that use a fixed set of pre-defined animations can lead to non-realistic repetitive behaviour, especially in real-time interaction setups. In addition, it can be difficult to maintain environmental constraints such as a foot contacting the ground properly, or a hand grabbing an object from the scene [73].

Moreover, describing nonverbal behaviour solely through low-level parameters such as position or angle of each joint is very time-consuming and does not convey the deep expressive value of nonverbal behaviour. Movement notation descriptors are therefore used as a guide to define high-level movement descriptors. These descriptors categorize the movements based on their specifications and characteristics, using psychological data. BAP and Delsarte's system are two notation systems that are used for describing body movements. BAP (Body Action and Posture) is a theoretical notation system for describing temporal and spatial characteristics of expression of emotion through body movements. It offers 141 behavioural categories for coding actions, postures, and functions of body movements. BAP does not code whole body postures and leg movements, nor does it code dynamic movement characteristics such as velocity, acceleration, and energy [68]. In regard to BAP, I refer to Delsarte, who defines nine laws for the meaning of movements. These laws are altitude, force, motion (expansion and, contraction), sequence, direction, form, velocity, reaction, and extension [69]. Delsarte focuses extensively on microanalysis and does not explicitly provide quantitative measures [69].

Laban is a widely-used movement descriptor that is designed based on structure and expressivity of movements in dance choreography. Its components are Body, Space, Effort (Space, Weight, Time, and Flow), and Shape (Flow, Directional, and Shaping/ Carving). Body indicates which body parts are active during the movement and the sequence of their involvement in a movement. Space defines the space in which the movement is happening as well as the body and body parts' directions. Shape is about dynamic changes in movements. Effort is about inner attitude towards using energy in different specified aspects: Space (a range from Indirect to Direct), Weight (a range from Light to Strong), Time (a range from Sustained to Sudden), and Flow (a range from Free to Bound) [67]. There have been efforts to convert the Laban notation into 3D human figure animation such as Labandancer [128]. Another high-level categorization was introduced by Ekman et al mainly for the movements of the hands. They proposed three classes for interpretation of hand movements' behaviour: emblems, illustrators, and self-adaptors. Emblems are nonverbal signals that can be directly translated to words such as a waving hand instead of saying 'hello'. Illustrators are movements that accompany the speech, for instance, moving the hands to specify the size of an object. Adaptors are behavioural acts such as scratching, or holding the self which is generated in low awareness and usually used to adapt to various communication situations [106].

RealAct proposes the following expressivity dimensions to reflect emotional-stability and extraversion personality traits: 1) Posture-shift behaviour, 2) Self-adaptor behaviour, 3) Leaning behaviour (lean forward, no lean and lean backward) 4) Twitches (true or false) and 5) Spacious gestures (true or false). These dimensions can have three different frequencies (high, mid, low) and three speeds (fast, mid, slow) (Table 3.3). The importance of these dimensions in creating the impression of personality is emphasized in several psychological studies [40][29][30][36][31]. In addition, these dimensions are feasible to synthesize using Smartbody animation toolkit's provided features.

2.2.3. Facial Expressions

Various methods exist to animate the face of a 3D virtual character. Keyframe and morph target animation provides a complete control of the character's face but can be time-consuming. Another approach is to synthesize facial movements from text or speech. In this model, visual phonemes (visemes) are used to animate the face. The Facial Action Coding System (FACS) is another approach that systematically describes facial actions in terms of small Action Units (AUs) such as left-eye-lid-close and jaw-open. Ekman and Friesen proposed the original FACS in the 1970s by verifying how the contraction of each facial muscle (individually and in combination with other muscles) changes the appearance of the face [71]. The goal of proposing FACS was to produce a proper and reliable way to categorize facial actions. They used videos of facial actions to recognize the differences caused by muscles' interactions, and how to detect them.

Studying anatomy, reproducing the appearances, and palpating their faces led Ekman and Friesen to speculate on relationships between appearance modifications and the effects of muscles.

FACS measurements are described in terms of Action Units and, not in the activations of the muscles themselves, since in some cases, each AU is a composition of several muscles activations. Otherwise, some individual muscle movements may not result in recognizable facial changes. Additionally, sometimes one muscle produces an appearance modification that decomposes to two or more AUs in order to show the independent actions of different parts of the muscles. FACS scores are only descriptive. They do not provide any information on the meaning of the face's behaviour. The raw FACS scores can be used for data analysis, or researchers can use available techniques such as FACSAID to translate the FACS scores into psychologically meaningful concepts, e.g., basic emotions. The MPEG-4 system used in my system extended the idea of FACS. MPEG-4 introduces Face Definition Parameters (FDPs) for defining a face by giving measures for its major parts and their related distances and Face Animation Parameters (FAPs), which together encode the movements of these facial features [71]. The RealAct's character's facial animations are controlled through both FACS, as well as visemes (for lip syncing) [101].

Facial animations of virtual characters can correspond to speech or to emotional expressions such as sadness and happiness. Psychological models of emotion have been used to model the emotion. The basic model of emotion claims that emotions are universal and there are mainly six emotions: sadness, fear, happiness, excitement, disgust, and anger. Circumplex model is a circular space with two dimensions: arousal and valence [51]. In this model each emotion such as sadness and anger corresponds to a point on the surface of the circular space. The PAD emotional state model is another psychological model to describe emotional states using three dimensions: Pleasure, Arousal, and Dominance [81]. These models of emotion are mapped to character's facial action units to create the impression of emotions. For instance, Ekman et al mapped the basic emotions to facial action units [34]. Arya and DiPaola (2007) proposed a behavioural model for affective social virtual characters based on parameter spaces Knowledge, Personality, and Mood. Related data from behavioural psychology is used to map the impression of emotion and personality to the facial actions. The list of the tasks to be performed and the decision-making process is stored as an XML-based animation language. MPEG-4 compatible parameters control the facial muscles of the character [122].

Zammitto et al (2008) then used a hierarchical approach to model the FFM personality systems into their facial character system using the XML-based facial language to script the face systems [59]. Next, Arya et al (2009) proposed a method for creating perceptually valid facial expression of mixed emotions. Through a set of user studies, they explored how people combine facial actions to express mixed emotions', and 'how users perceive the emotions of a set of facial actions'. The result of the studies is used to map facial actions to regions in three-dimensional (arousal, valence, and agency) emotion space, and to create a facial expression (called facial expression units) based on the location of the mixed emotion in the emotion space [20]. Boukricha et al, recruited 353 participants to rate randomly generated facial expressions which were modeled following FACS [82]. The result was a repertoire of about 6000 faces arranged in PAD space. Statistical and reverse engineering methods were used on the resulting repertoire to create a control architecture for simulating a virtual human's facial expressions with respect to PAD values. Additionally, an expressive output component for animating the AUs of virtual characters' face was modeled [82]. I adapted Boukricha et al's model to associate the emotional valence and arousal values [82] with facial muscle movements [71]. The impression of personality was created through changing the intensity of emotions, filtering of emotions, and facial twitching (Table 3.4).

2.3. Existing Frameworks for Personality-based Behaviour

In this section, first I review a few influential cognitive architectures designed for modeling affective behaviour. Then, I focus on computational models that specifically address the expression of the personality. Fum and Stocco's developed an extension of ACT-R to reproduce Gambling Task's results [83]. ACT-R stands for Adaptive Control of Thought-Rational [84] [85]. In this model two knowledge representations are used: declarative (consist of facts) and procedural (consist of productions which are knowledge about how humans do things). Productions are matched on perceptions which lead to an action in response to the environment or to change declarative memory. In their model, emotional weight is considered as a risk probability. Emotional strength is added as a parameter to ACT-R memory activation formula. Memories associated with risk have a higher probability of being recalled. Cochran et al.'s ACT-R extension [86] supports arousal and valence model of affect [87]. In this model, an arousal parameter is added to a base activation formula. Base activation decreases gradually if tagged with low arousal and increases if it is tagged with a high arousal. WASABI (WASABI Affect Simulation for Agents with Believable Interactivity) is based on BDI (Believe-Desire-Intention) cognitive theory [88].

BDI hierarchical structures include beliefs about the environment, desires the agent wants to achieve, and intentions the agent plans to perform. On each cycle, the agent decides whether to continue executing its current intention or to select a new intention. In WASABI model, BDI planning processes are affected by emotional states triggered by the PAD-based emotional system. The agent's emotional state limits the set of possible next actions and goals. Thus, emotion is the crucial component of this model. EMA [89] is also designed based on BDI theory. It consists of a series of cognitive operators that explain the emotional changes during a sequence of events. Plan steps are informed by appraisal frames which lead to either emotion derivation or coping (change of strategies, beliefs, desires and intentions). In FAtiMA (Fearnot AffecTIve Mind Architecture) information received from environment update the memory and trigger appraisal process [90]. The result of the process is saved as affective state and influences the action selections. Lim, et al. used FAtiMa as a base for ORIENT (Overcoming Refugee Integration with Empathic Novel Technology) architecture as an interface for interaction between users and 3D virtual agents [42]. In this model, personality is mainly revealed to modulate an emotional framework and the appraisal process. In developing ORIENT, Lim et al. focused on different aspects of designing the character, such as perception, motivation, emotions, memory, learning, and planning [42]. They used the ORIENT as an interface for interaction between users and 3D virtual characters. The game is designed for children between the ages of 13 and 14. The work does not, however, assess the believability of the interaction. In addition, personality is mainly revealed to modulate emotional framework and the appraisal process.

In Soar-Emote [91], emotion is effective on three levels: biological, cognitive and social. On the biological level, it addresses physiology and body emotion system. On the cognitive level, it includes appraisal rules [92], cognitive emotion system and emotion-focused coping. Finally, on the social level problem-focused coping and perception of the external physiology of others are addressed. In this model, knowledge influences but not determines the emotions and feelings. FLAME which stands for "Fuzzy Logic Adaptive Model of Emotions" is based on Ortony et al. [93] and Roseman et al.'s [96] event-appraisal models of emotion [94]. The model uses a fuzzy-logic method to map emotional states to remembered events. The model uses learning algorithms for learning patterns of events. A computer simulation of a pet is used to evaluate the system [94].

Our proposed architecture is not developed as a part of any previous cognitive architecture. However, I found some similarities between how it is structured and ORIENT architecture [95]. Similar to my work in this thesis, they considered using a hybrid structure as a combination of reactive versus deliberative systems. However, I mainly focus on the realistic behaviour of 3D humanoid characters [161] [162]. Additionally, in our design, personality not only directly affects behaviour; but also it affects the generation and expression of emotion and the copying behaviour of the agent. Few works exist that specifically investigate the role of personality in the cognitive model and how to generate various personality impressions for humanoid 3D characters. In addition, many of the mentioned architectures are not used in an actual real-time scenario in which a virtual agent is interacting with humans and is reactive to the changes in the environment. In a few of the architectures that are empirically tested, the focus is not to create a believable and human-like behaviour for the virtual agent. Thus, it is still a necessity to increase the ability of 3D character agents to behave displaying consistent bodily and facial behaviour while interacting with users in real-time. This dissertation addresses this gap by performing a set of studies on our designed personality model. A combination of high-resolution body and facial expressions are used to enhance the expressiveness of the 3D virtual agent.

In addition to the above-mentioned cognitive architectures, several computational systems have been designed that considered personality traits as weighting parameters for generating the impression of emotion and personality. Amaya, et al. addressed the issue of generating realistic emotional expression of the body by using data from a motion to modify the emotional content of another movement by changing the timing and intensity of movements [28]. Andre et al. [63] developed computational models of emotions and personality for children's virtual puppet theaters, virtual sales presentations, and virtual guides for internet websites to make the interaction more enjoyable and closer to communication styles in human-human conversations. PERSEED is an architecture which was developed using a socio-cognitive perspective to build a model of personality for 3D virtual characters, with a focus on how the situation may affect any personality behaviour exhibited [78]. No experiment has been performed, however, to reveal the application of this model in the social and situation-based interaction.

McRorie et al.'s [44] work is part of a European project (SEMAINE) with the aim of developing a system that facilitates human interaction with conversational and Sensitive Artificial Listeners (SAL) characters. They designed an architecture in which personality affects the character's non-signaling gestures during speech and appearance. The main focus of this research is the content of the conversation and behaviour during the conversation. The study empirically examines how users rate videos and images of 3D virtual characters' expressive behaviour, but no real-time interaction between humans and the character is tested. Read et al. [66] proposed a neural network model of structure and dynamics of personality based on research about the structure and neurobiology of human personality. Differences in the sensitivities of motivational systems, the baseline activation of specific motives, and inhibitory strength are used to model the given personality traits. The model is designed for portions of behaviour such as "Tease and Make Fun of", "Gossip and Talk about Others" and "Ask for Date" as well as for situational parameters such as "At Home" and "In Conference Room". Neff et al. [45], limited their study to investigate the correlation between FFM's neuroticism trait and changes in conversations and nonverbal behaviour. They found that the presence of self-adaptors (movements that often involve self-touch, such as scratching) made characters look more neurotic.

ALMA (A Layered Model of Affect) [37] is designed to provide a personality profile with real-time emotions and moods for 3D virtual characters. ALMA is part of the

‘VirtualHuman’ project, which creates interactive 3D virtual characters with conversational skills. Appraisal rules and personality profiles are specified in an XML-based affect modeling language. The emotions and moods are computed based on the appraisal of relevant inputs. The concentration in this study is on modulating the appraisal process, but there is no mapping between nonverbal behaviour and personality traits. Alternatively, Kshirsagar and Magnenat-Thalmann [61] devised a personality model of emotional 3D virtual characters. They used Bayesian Belief Networks and a layered approach for modeling personality, moods, and emotions. They also integrated the system into a chat application in which the developer is able to design and implement personalities, and in which users can interact with the character. The focus in this work was also only on emotional personality. Similarly, Su et al. [62] designed a system to control affective story characters with parameters for personality and emotion. They developed a hierarchical fuzzy rule-based system to control the body language of a story character with personality and affect. In this system, story designers specify a story context with personality and emotion values with which to drive the movements of the story characters. Likewise, Poznanski and Thagard [49] developed a neural network model of personality and personality change: SPOT (Simulating Personality over Time). Personality-based predispositions for behaviour, moods/emotions, and environmental situations specify the output behaviour. In their model, personality develops over time, which is in turn based on the situations encountered. The focus of the study is on modeling personality change, with nine behaviour mapped to personality via output tags, e.g., “talk” or “avoid help”.

Reviewing the state of the art shows that there is still a necessity to increase the ability of 3D character characters to behave in consistent bodily and facial behaviour while interacting with users in real-time. My work addresses this gap by performing a study on my designed architecture. High-resolution facial models are used to display expressive movements properly. In addition, a combination of body and facial expressions are used to enhance the expressiveness of the 3D virtual character. Interacting dynamically with a 3D virtual character able to express unique personality, creates a rich and effective experience for users and adds to the character’s believability.

Chapter 3. RealAct – A Computational System for Real-time Expressive Behaviour

RealAct is designed to generate plausible, consistent, and dynamic behaviour for the 3D virtual humanoid character in response to the human user's inputs in real-time [163][164]. It is a hybrid system, in the sense that it exhibits a combination of event-based and continuous behaviour. RealAct's hybrid structure is designed to support both a 1) logical behaviour of the virtual character moving through states of a human interaction, and 2) continuous updates of the emotional expressions of the virtual character depending on feedback from interactions with the human. Matlab Stateflow [125] and Matlab Simulink [126] are selected to implement respectively Event-based and Emotionally-Continuous behaviour of the RealAct [124].

This chapter begins with a high-level overview of the design (sections 3.1 and 3.2) and implementation (section 3.3) of the RealAct system. Next, I discuss the design and implementation of important sub-systems of the RealAct (3.43.9). The sensing module receives input from several real-time bio sensors (devices that convert biological responses to electrical signals), gesture, and movement sensors which are tested, installed and implemented to ensure that the 3D virtual character appears to sense the user's feedback. By processing the environment's input streams, the attention module directs the attention of the character to people and objects in the environment in a believable and human-like manner. Further, the character's emotional responses are generated as a linear function of immediate perceptual features and interaction scenario inputs. Finally, the behaviour controllers generate behaviour commands for three modalities: facial expressions, postures/gestures, and gaze movements, which are prioritized and sent to the animation engine.

3.1. RealAct Architecture

To create smooth and responsive behaviour, the architecture combines continuous and event-based components for behaviour, generation using two modules: an Emotionally-Continuous system and an Event-based system (Figure 3.1). In conjunction, these two components provide an ideal structure for the RealAct system to generate gestures, postures, and facial expressions for the 3D character that are smooth and responsive to environment inputs. Because of the discrete and turn-based nature of face to face communication implicit in our Event-based system, this component is implemented using the finite state machine provided by Matlab Stateflow [125]. I programmed the Emotionally-Continuous system using Matlab Simulink [126]. Interaction configurations and rules are set at the beginning of the interaction and determine the rules specific to the scenario of the interaction such as the desired coordination of the user in the environment. Goals and strategies of the interaction are hard-coded in this version of the system to narrow the work (Figure 3.1). The environmental inputs are fed to the Event-based system through the sensors. The Attention controller module makes the 3D character attentive to sudden environmental changes in the interaction.

The Emotionally-Continuous sub-system contains an emotion generation module which is responsible for continuously calculating the facial expressions of the 3D virtual character by comparing the character's goals with inputs such as the user's actions. In addition to facial expressions, the Emotionally-Continuous system also affects the quality of the gestures and how they are expressed. For example, an angry head nod is generally faster than a sad head nod. To limit the scope of the work, in this dissertation I only explore the effect of personality on behaviour. Three kinds of triggers are used to elicit emotional valence and arousal [51]: 1) triggers activated during interaction with the user and environment, 2) triggers regarding the interaction scenario, and 3) internal triggers when no external event is taking place. The Event-based system is responsible for the logic and flow of the interaction, and contains the behaviour controllers and behaviour scheduler. Behaviour controllers generate commands for controlling the gaze, postures/gestures, and facial expressions of the character. The behaviour scheduler prioritizes and selects an action from multiple behaviour requests generated by behaviour controllers and sends the one with the highest priority to the animation engine.

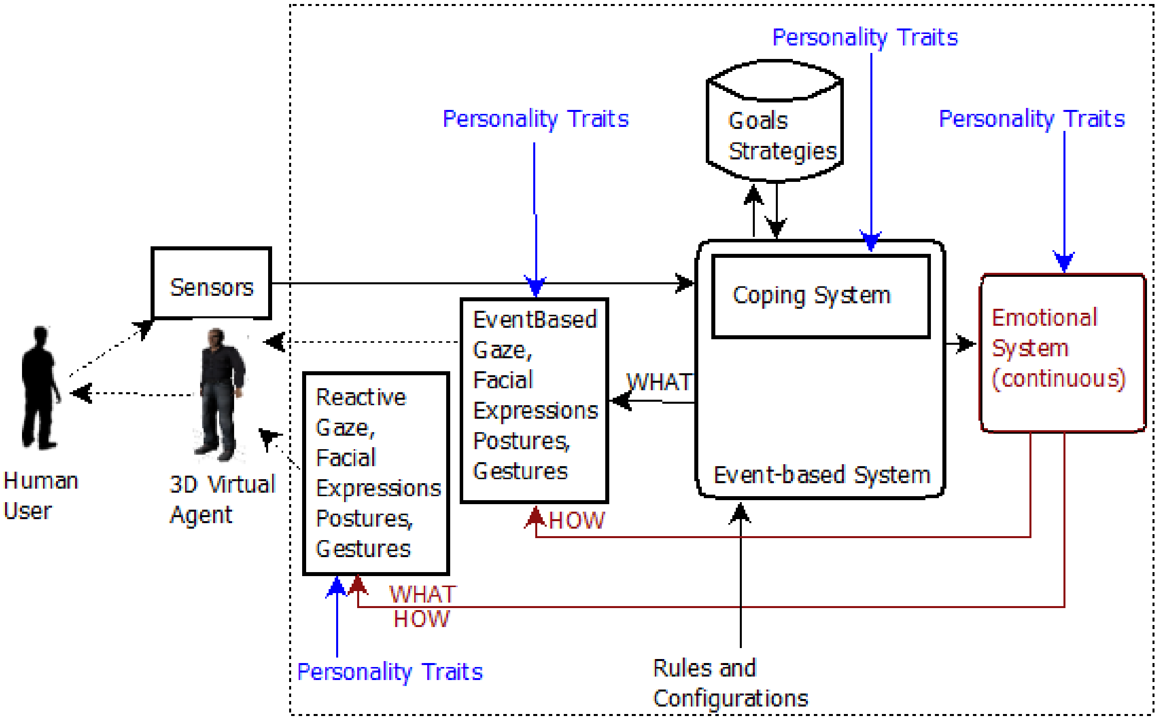


Figure 3.1. **The RealAct architecture and how personality impacts its different modules. (Personality traits affect four parts of the architecture: 1- Gestures, e.g., extraversion correlates with showing faster hand and head movements; 2- Facial expressions e.g. extraversion is correlated with filtering less and showing more facial emotions; 3- Coping mechanism e.g. low stability is correlated with withheld coping strategy; 4- Emotional reactions e.g. low stability is associated with more negative emotions in general.)**

The expression of personality (emotional-stability and extraversion traits) is reinforced by controlling the behaviour through carefully selected expressivity parameters. For gaze behaviour, the following parameters are proposed: chance of occurrence of averts or mutual gazes, gaze direction, duration of avert and mutual gazes, and speed of head movements. The ‘postures and gestures controller’ proposes the following expressivity dimensions to reflect emotional-stability and extraversion personality traits: 1) Posture-shift, 2) Self-adaptor behaviour, 3) Leaning (lean forward, no lean and lean backward) 4) Twitches (true or false) and 5) Spacious gestures (true or false). For facial expressions, the impression of personality is created through changing the intensity of emotions, filtering of emotions, and facial twitching (Table 3.4).

Personality can be tuned by the designer at the beginning interaction or dynamically during the interaction between the 3D character and the user. The outputs of the RealAct system are behaviour commands sent to the animation engine for three modalities: facial expressions, postures/gestures, and gaze movements. These commands are dynamically fed to the animation engine, and performed by the virtual character during the simulation. To promote future use by other researchers, I programmed the RealAct system as a set of modular, encapsulated and reusable blocks.

3.2. Hybrid Structure of the System

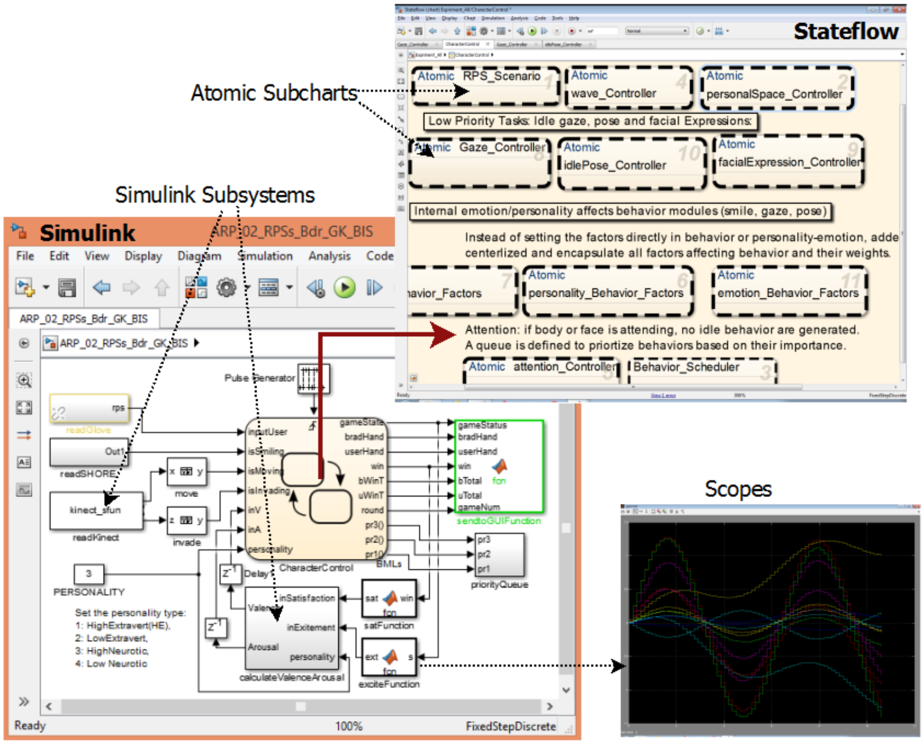
A hybrid behavioural computational architecture is designed to model the character's personality. It consists of two components: an 'Event-based' component, and an 'Emotionally-Continuous' component. The Event-based component mainly generates the character's gestures/poses based on different states of the interaction and the user's feedback. The character's facial expressions are controlled by the Emotionally-Continuous component. Emotions are continuously updated based on internal and outside status. Since Event-based system has a discrete and turn-based nature, it is implemented using the finite state machine (FSM). A state machine is a set of input events, output events, and states. The FSM is in one state at a time. The state a FSM is in at any given time is called the current state. The machine can change from one state to another (which is called a transition) when an event or condition is triggered. A FSM is defined by a list of states, and triggering condition for each transition [72]. The state machine in the model determines what are the character's gestures and gaze behaviour correspond to the events, conditions, goals and strategies. In addition, the FSM controls the turn-taking behaviour of the interaction. Based on the interaction scenario the turn-taking behaviour can be synchronized using users' actions or environment inputs. For example, turn-taking between the character and the user can be synced using the coordination of the user in the space. It is the character's turn to act only if the user is standing still (her coordination is not changing). In the FSM, specific events or information triggers corresponding gestures from the character. For instance, if the character wants to guide the user to move to a place, he points to the location and gazes at the user to encourage her. Based on the predefined goals for the scenario of the interaction, and inputs the character gets from the environment, he decides what state he should transfer to and what gestures he need to express in response to the user. For example, if the goal is to lead the user to a specific coordination (and if, based on the sensor value, the user is not yet in that coordination), the character's next action is to convince the user to move there by pointing. If the user does not comply and move to the desired place, the character may try different strategies, or give up, depending on the selected coping strategy.

The coping mechanism is an important aspect of behaviour which functions differently for different personalities. Due to its importance, I considered the copying behaviour in the design of the RealAct system. Coping is a mechanism of dealing with problems while trying to minimize conflict [64]. The effectiveness of a coping mechanism depends on the circumstances of the events and the individual's personality. [64]. Therefore, when environmental feedback is not compatible with the character's goals, the character strategizes and acts accordingly. If the feedback does not change regardless of the character's effort, the character may become distressed and deal with the situation in a personality-specific manner. In RealAct, coping is part of the Event-based system. Based on the situation and personality of the character, the character picks a specific coping mechanism. As explained in the previous sections, coping mechanisms are different for different personalities. Extraversion is corrolated with thinking positively and reacting rationally. In addition, individuals who score low on the emotional stability tend to withhold and disengage from the interaction and become passive. Although, I considered the coping mechanism in the design of, RealAct, coping behaviour is not implemented in this version of RealAct system.

The Emotionally-Continuous component is for controlling emotional reactions to the environment. Emotions are updated continuously and are not necessarily based on specific events. Event-based gestures are only triggered based on specific states of the interaction so they are independent of how much time has passed. Emotional valence and arousal, on the other hand, change based on how long the character has been in a specific state. For example, if the character is continuously receiving negative feedback from the environment, its disappointment can continue to increase. If he cannot find a way to avoid the negative feedback, after a certain amount of time, he may start finding a way to cope with this situation.

3.3. MATLAB (Simulink/Stateflow) as RealAct's Platform

Because of the discrete and turn-based nature of face to face communication, the Event-based system is implemented using the finite state machine provided by Matlab Stateflow [125]. Stateflow is an environment for modeling and simulating combinatorial and sequential decision logic based on state machines and flow charts. The state machine in my system determines the character's gestures and gaze behaviour in response to events, conditions, goals and strategies. I used Stateflow's authoring environment to program behaviour and responsive states. In addition, FSM controls the turn-taking behaviour of the interaction. Based on the scenario the turn-taking behaviour is synchronized using users' actions or environment inputs.



Low Priority Tasks: Idle gaze, pose and facial Expressions:

Internal emotion/personality affects behavior modules (smile, gaze, pose)

Instead of setting the factors directly in behavior or personality-emotion, adde
centerlized and encapsulate all factors affecting behavior and their weights.

Attention: if body or face is attending, no idle behavior are generated.
A queue is defined to priortize behaviors based on their importance.

Set the personality type:
1: HighExtravert(HE),
2: LowExtravert,
3: HighNeurotic,
4: Low Neurotic

Figure 3.2. **Screenshots of the system (Matlab Simulink/Stateflow)**

The Emotionally-Continuous system is implemented using Matlab Simulink [126] which facilitates a real-time continuous framework. Programming with the Simulink platform allowed me to give RealAct the possibility of interactively simulating while continuously viewing the results of the selected variables of the system using scopes and graphical displays. Simulink also allowed me to use integration algorithms that compute system dynamics over time.

Within the RealAct system, Simulink sends data to Stateflow and receives data in return. The personality type selected by the software designer, sensor data and emotional valence and arousal generated in the Emotion Generation module flows from Simulink into a chart, dynamically during the simulation, via input ports on the chart. Output data, such as interaction phase and status of the interaction, flows from a chart into Simulink via output ports on the chart (Figure 3.2). I took advantage of Simulink data stores memory blocks to create global variables across the Simulink and Stateflow such as Behaviour Markup Language (BML) strings [129] created in behaviour control modules and sent to animation engine from Behaviour-Scheduler module (section 3.8).

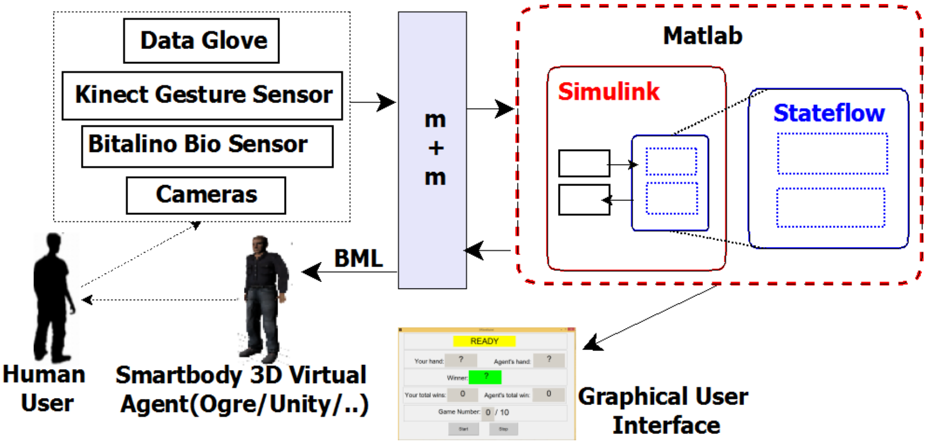


Figure 3.3. (a) Matlab Simulink/ Stateflow is depicted as an implementation tool for the hybrid structure of the system (m+m [167] stands for Movement and Meaning framework is explained in section 3.10). For the subsystems inside the Simulink and Stateflow see the next figure.

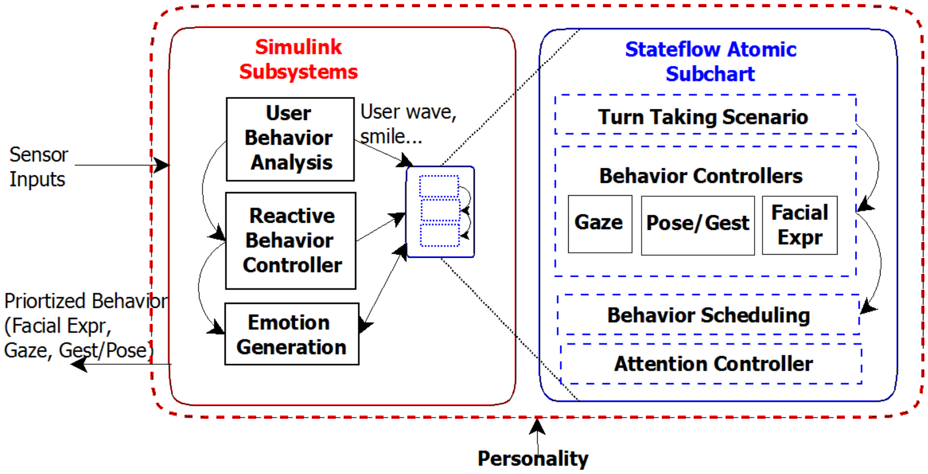


Figure 3.3. **(b) Detailed structure of the components of Simulink and Stateflow (Note: The User-Behaviour-Analysis module is not supported in this version, but is suggested here as an important module to be implemented in future. However, the current system supports a few simple functionalities such as understanding and mimicking user's smile and wave gesture).**

As depicted in Figure 3.3.a, the inputs of the system are received from sensors installed in the environment. The character reacts dynamically and in real-time to these inputs. The outputs of the system are facial expressions, postures, and gestures of the 3D virtual character, which are dynamically generated and fed to the animation toolkit before being displayed to the user. Figure 3.3.b demonstrates that event-based behaviour of the character is dynamically generated and scheduled in the Event-based component of RealAct. On the other hand, facial expressions and reactive gestures of the character are controlled continuously and based on the continuous feedback from the environment in the Emotionally-Continuous component. Parameters such as personality traits can be defined by the designer at the beginning of the interaction or dynamically tuned during the interaction. The behavioural scope of the architecture is limited to strategic turn-taking interaction between the character and the user.

3.4. Sensors Module

For a virtual character to come across as responsive and emotive in real-time, it must appear to first sense the user's movements, facial expression, hand gestures, and even intent (via say in a rock-paper-scissors game), and then process those sensory signals. To do this I designed, implemented, and tested several sophisticated real-time bio, gesture, and movement sensors in our RealAct system. The inputs of the RealAct system are continuously received from sensors installed in the environment. Various sensors, such as a Kinect 3D camera [127] and overhead cameras were used to send streams of input such as users' coordination in the space, users' heights or environmental information such as noise and light. The character reacts dynamically and in real-time to these inputs. The SHORE application developed by Fraunhofer research center [97], was used to receive the input stream from a webcam and forward information such as emotional expression of the user's facial expressions (and age, sex) to RealAct. The electromyography (EMG) sensor [98] was used to measure activity of the facial muscles to detect the user's smile in real-time [99]. A Microsoft Kinect 3D camera was used to locate the user's head to guide the virtual character's gazes [127]. A data glove sensor is used to capture the user's hand gestures. More detailed information on the multiple sensor setups and scenarios for the sensors were used in are discussed in section 4.5.

3.5. Attention-Controller Module

A virtual humanoid character needs to be able to direct its attention to people and objects in the environment in a believable and human-like manner [139]. In most of behavioural computational models, an attention module is employed for controlling the characters' gaze to attend a person or an object [139] [143]. In RealAct, the attention module prevents idle behaviour from disrupting more deliberate and at times immediate reactive and communicative behaviour. Idle behaviour must be paused if an event that requires immediate attention occurs. There are two types of events that require immediate attention: sudden environment changes, and events regarding the interaction. For example, if the user starts to wave at the character, the character cannot gaze idly or avert its head. As another example, during the RPS game, it does not make sense if the character averts its gaze when playing a hand.

If a behaviour command for a specific joint of the character enters the animation engine right after another command for the same joint, the resulting movement will blend both animations. For example, if the character is showing the rock hand gesture and a scratching head gesture comes after that, the rock gesture blends with the head scratch. This is not desirable. The attention module is designed to avoid such unwanted blending. The Attention-Controller module attempts to balance the realism of blended natural, ongoing, complex behaviour with more deliberate reactionary behavior.

The attentive body parts in the RealAct's Attention-Controller can be gaze based, body based, or both. If the attention signal only requires the attentiveness of the gaze, other body parts can continue with their idle or ongoing behaviour. The same rule applies to the body. Similar to Sidner et al.'s work, the design leads to three phases for attention: establishing, maintaining, and ending attention [146]. When attention-seeking, events occur, establishing the attention occurs by triggering a flag for gaze, body or both. During the maintaining phase, the FSM time-based attention flag continues for a fixed period of time and then turns off automatically (closing) unless another attention-request is received. In the maintaining phase, depending on whether it is the gaze or body attention flag that is in the on position, their corresponding idle behaviour pauses until the flag turns off.

3.6. Emotion Generation Module

The RealAct design goal is to facilitate real-time, natural and human-like non-verbal behaviour which is responsive to the input streams from multiple sensors. As a result, in the RealAct system emotional responses are associated directly and as a linear function of immediate perceptual features and interaction scenario inputs, rather than responses based on the appraised interpretation of events which is of potential interest to models of strategic decision-making and action selection such as in [86][89][90].

In the current version of RealAct, three kinds of triggers elicit emotional valence and arousal: 1) triggers activated during interaction between the user and environment, 2) triggers regarding the interaction scenario, and 3) internal triggers when no external event is occurring. Several psychological studies indicate that emotion is contagious [155]. Thus, the positive valence of the character increases if they sense a user's positive emotion [155]. Moreover, a signal of potential gains increases valence while the signal of potential losses decreases valence [171][172]. In the RPS scenario, I assume satisfaction is increasing as the character wins and decreases as he loses in each round. Thus, on one hand, positive feedback from the user (such as waving and smiling), and positive feedback regarding the interaction scenario (such as winning in the RPS game) increase the desirability of the interaction and generated valence. On the other hand, negative feedback from the user and interaction scenario decreases the desirability of the interaction and generated valence.

Likewise, generated arousal is a linear function of user and interaction scenario feedback. For example, when a user invades the personal space of the character, this will increase the arousal of the interaction. Uncertain cues, competition, challenges, reward and punishment typically increases arousal [16][57]. In addition, increasing the difficulty of the game leads to a higher arousal [157][57]. Since arousal is in direct relationship with the difficulty of the game, in the RPS game scenario, I am assuming the character's excitement increases as it gets closer to the "Go" state and decreases as it gets to the "Wait" state (more information about the procedure of the RPS game is discussed in section 4.5.1). Since psychological data shows that repeating the game again and again decreases the experienced arousal [156][158], during the RPS game the repetition of the game cycles have a negative effect on the character's emotional arousal.

Additionally, depending on how important a trigger is in satisfying the character's needs, it can have different types of impacts on generated arousal and valence. Based on Maslow's "hierarchy of needs", three categories of input triggers are defined: self-esteem, love/belonging and safety [123]. Based on work from [123], in RealAct I make the assumption that the triggers related to safety have more impact on arousal and valence changes than inputs related to love and belonging, and they both have higher importance than inputs regarding the self-esteem. For example, a user invading the personal space of the character jeopardizes the need for safety and has the highest impact on arousal while smiling back at the user corresponds to the need for being loved, which has a lower importance. The values for the factors are specified merely to differentiate between the effects of different inputs. The impact is specified by multiplying a set of pre-defined weights to each trigger (Figure 3.4).

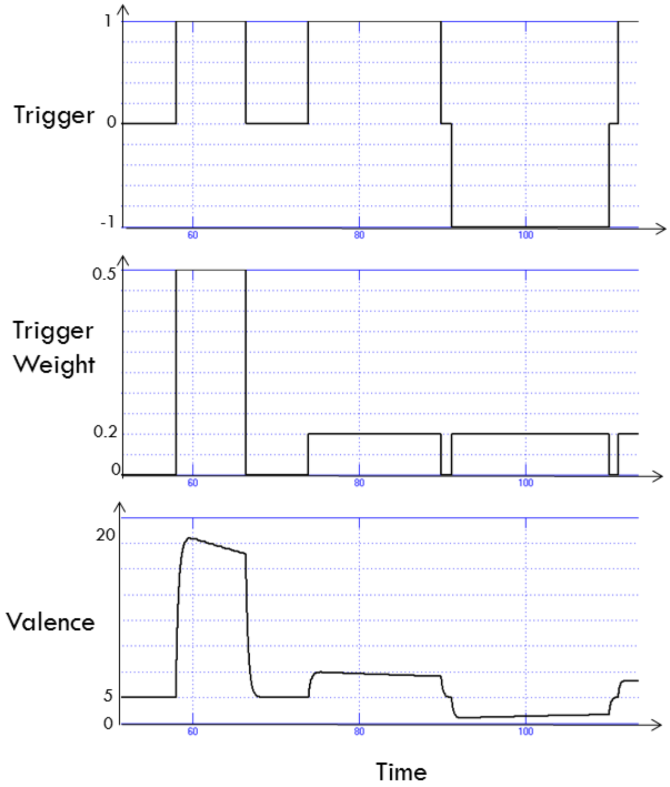


Figure 3.4. **The generation of valence over time is a function of triggers that have different weights.**

Figure 3.4, shows the temporal change of input triggers, the weight of each trigger and the resulting valence change, using a Simulink Scope block. The Simulink Scope block allows us to view signal data during simulations while grouping data, in this case triggers, weights, and valence signals.

The RealAct Emotion-Generation module is designed such that future designers can add their desired input triggers and weights easily. More details on the complete list of triggers implemented can be found in Appendix B. In the current version of the emotion generation module, emotional reactions are only considered to be self-centered. For example, the character gains positive valence when winning and negative valence when losing the game.

3.7. Behaviour Controllers Modules

The virtual character's behaviour is controlled by modular controllers for three modalities: facial expressions, postures/gestures, and gaze movements. For each of the three modalities, three kinds of behaviour are defined: 1) idle, 2) communicative and 3) reactive. The idle and communicative behaviour is generated in the Event-based system, while reactive behaviour is controlled with the Emotionally-Continuous system (Figure 3.1). The idle behaviour is mainly a dynamic set of animation sequences that involves subtle movements of all the body parts such as gaze, head and hand movements. It is defined to ensure that the character does not look motionless while standing and doing nothing. People tend to keep moving their body even if they are doing nothing, e.g., they shift their body, scratch their body parts or move their head around. For the virtual character, an idle behaviour is a behaviour the character exhibits when not following any goal or not responding to any environment change.

The communicative behaviour is triggered in response to goals (usually goals dictated by the interaction scenario) such as character showing the rock hand gesture (e.g. throwing out their hand in a fist position) in a rock/paper/scissors game (RPS). The communicative behaviour has a higher priority than idle behaviour and will replace it if they are triggered at the same time. Reactive behaviour is usually in response to a sudden or unexpected change of environment and an automatic or not planned behaviour. For instance, if the user gets too close, the character automatically moves back and adjusts her personal space [165]. The reactive behaviour has the highest priority. For the full explanation of the defined priorities and the logic behind them see section 3.9. Moreover, the character's idle, responsive or communicative behaviour is influenced by his personality. This sophisticated and lifelike hierarchy of prioritized and integrated behaviour, which can be dynamically augmented by personality type and reaction to long term and immediate user and environmental events, is the main contribution of my research and the RealAct system. If for example, a character is an extravert, its idle behaviour consists of faster gestures, postures, and head movements. In addition, Gaze, Pose/Gesture, and Facial Expression controllers are developed in the way that can be used separately. For instance, researchers can use the gaze module without getting involved in the rest of the system.

What follows is a general description of RealAct's main behaviour channels (gaze, pose/gesture, and facial expression), how they function, and their implementation details. All of the behaviour channels (Gaze, Pose/Gesture, and Facial expressions) have their own Matlab functions and Truth-table functions. Stateflow's Truth-tables are used to implement combinatorial logic design behaviour to categorize and select the behaviour control commands. Each of the decision columns combines an outcome for each condition (usually specified based on personality type) with a logical AND into a compound condition that is referred to as a decision. The term 'decision' refers to the selection and performance of one or multiple BML commands to control behaviour. Prioritizing and sending behaviour commands are centralized in the Behaviour-Scheduler module. All these sub-systems are designed separately from and in the same hierarchical order as the scenario of interaction. Some of these sub-charts include inner sub-charts of their own. For instance, gaze consists of two sub-charts executed in parallel to control the character's eyes and head.

3.7.1. Gaze Controller

Gaze behaviour is a combination of movements of the character's eyes, head, chest, back, and torso, dynamically controlled by the system. Blink frequency of the character is also controlled as a part of gaze behaviour. To make the character's gaze behaviour appear natural, the gaze module produces eye movements that are consistent with human ocular behaviour. Head movements are implemented based on empirical, psychological, and statistical data on human head movement behaviour, and how it is affected by personality. Personality affects gaze behaviour on multiple dimensions: head speed, blink frequency, type, direction, frequency, and duration of the gaze (see 3.8.2).

In RealAct's design, three categories of gaze behaviour are utilized: 1) reactive, 2) communicative, and 3) idle behaviour (Figure 3.5). The reactive category is when the gaze responds to user's movements and in general environment feedback. The communicative category addresses gaze behaviour that communicates meaning to the user, or is triggered by a change in the state of the interaction. For instance, in a rock-paper-scissors game, the character gazes at the graphic user interface (GUI) which has real-time updates of the game statistics, to create the impression the character is checking the ongoing results of the game.

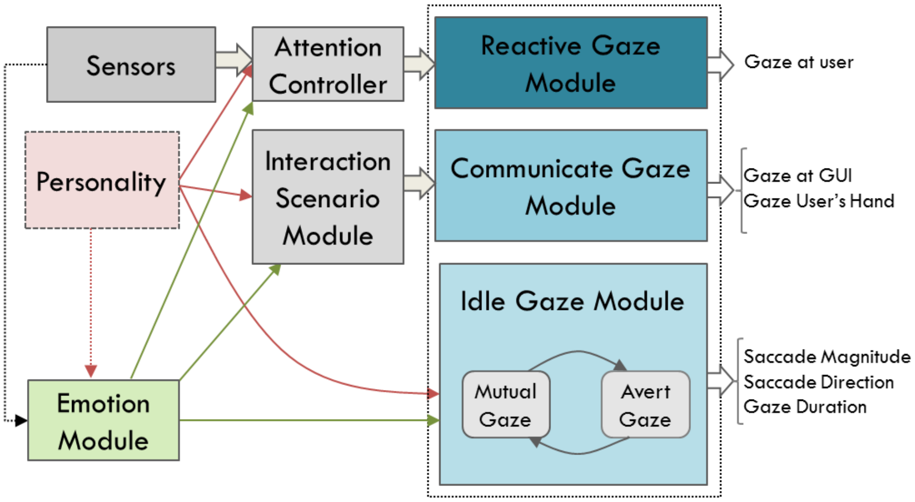


Figure 3.5. **The hierarchical structure of gaze behaviour is affected by generated emotion and selected personality for the virtual character. Reactive gaze has a high level in the hierarchy and is responsive to environment changes. Communicative gaze is responsive to character's goal and scenario of the interaction. Idle gaze has a low level of importance and other gaze behaviour will overwrite them.**

The idle category is employed for the gaze behaviour when the character is doing nothing. These categories are prioritized so the higher-level behaviour overwrites lower level behaviour. The highest priority gaze movement is reactive gaze. People, regardless of what they are doing, tend to look at unpredicted movements they notice in the environment. Thus, gaze at unexpected environment changes and feedback, such as a sudden loud noise, is always in a higher priority than communicative gaze and will overwrite it if they are triggered at the same time. The idle gaze behaviour has the lowest priority and happens if no other gaze behaviour is triggered.

To incorporate the kinematic characteristics of the idle eye movement, the RealAct gaze module adapted and updated Lee et al model of gaze (Eyes Alive) [100]. Lee et al developed an eye behaviour model which is derived from statistical models of eye-tracking data and is consistent with human ocular behaviour (see 2.2) [100]. In the Eyes Alive model, two states of the gaze are defined: 'avert' and 'mutual'. The mutual gaze is when the character gazes at the user, while avert is when the character is looking away. The character’s gaze rests at one of these states for a period of time and then moves to the other state. Additionally, idle gaze behaviour in Eyes Alive model is calculated as a function of 1) saccade magnitude, 2) saccade direction and 3) saccade duration. I am using the same terminology in my gaze model: ‘Saccades’ are defined as rapid movements of eyes [142]. The ‘magnitude’ of a saccade is the rotation angle of the eyeball. Saccade ‘direction’ is the position of the eye based on polar coordinates. Saccade ‘duration’ is the duration of an eye movement.

Eye movements are usually followed by a head rotation in the same direction. A natural gaze is usually not more than 15 degrees [102]. Head and eye movements are synchronous [103]. Thus, to control idle head movements in RealAct’s design, if the generated amplitude is more than 15 degree, a head movement in the same direction as the eye is generated. Smartbody’s procedural eye model supports realistic eye and head coordination. When the head rotates to a new position, eye movement is automatically generated and layered on top of the head and torso movement [101]. However, Smartbody characters’ head and eyes do not coordinate perfectly when the speed and magnitude of the head rotation are high (more than 25 degrees). Thus, I re-coded the head movements to limit the movements and speed to achieve more natural behaviour.

Reactive gaze behaviour is implemented to be responsive to sensor inputs. The character’s gaze follows the user as they move into the space in front of the character. Microsoft Kinect [127] and an overhead camera are used to feed the user’s position to the system. The character’s head and eyes are then moved to give users the impression that the character’s gaze is responsive to the users’ movement. While generating this reactive gaze behaviour, I encountered an issue referred to as the ‘Mona Lisa gaze effect’ in the literature [121]. Since the virtual environment the character exists in is two-dimensional, looking at the character in the TV monitor from any direction gives users the feeling that the character is looking at them. This makes it hard to implement the impression of the character following the user moving in the room. On the one hand, a small rotation of the character’s head creates a drastic change of direction in the real world (e.g., if the head of the character moves 10 degrees to the left, it looks like the character is looking approximately 90 degrees to the left in the real world). On the other hand, if the character’s head does not move, it looks like he is unresponsive. To solve this problem, I coded the system to primarily move the torso and chest of the character in response to movement of the user, while the eyes and the head make a subtle movement in the same direction. The communicative and reactive gaze behaviour was not the main focus of the implementation, so a minimum functionality was implemented to maintain believability and smoothness of interaction. However, they need to be explored in more detail in the future.

3.7.2. Gestures and Postures Controller

Similar to gaze behaviour, gestures can be reactive, communicative or idle (Figure 3.6). Reactive gestures are responsive to the environment, such as a 3D virtual character waving back at a user when that user waves first at them. Communicative gestures and poses are generated based on the scenario of the interaction, such as rock hand gesture in a rock-paper-scissors game. Same as the idle gaze, idle poses and gestures are performed while the character is not performing any specific task, which is at idle.

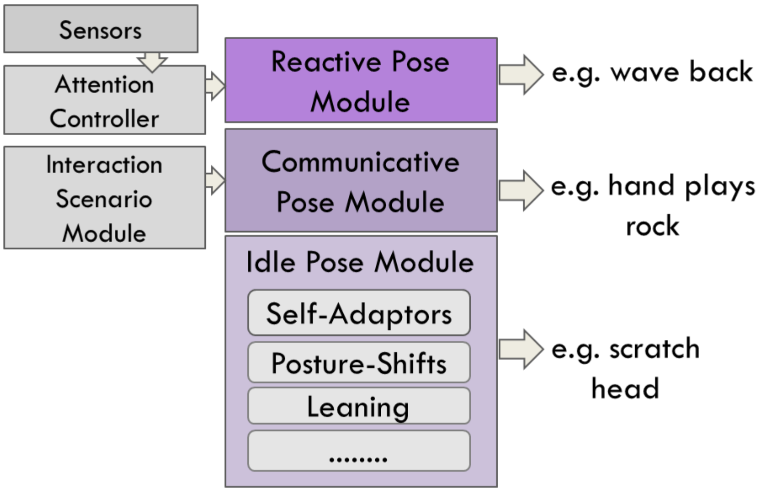


Figure 3.6. Gestures are categorized into three types: reactive, communicative and idle gestures and poses.

Reactive gestures/poses are tested in a simple scenario in which the character was mainly mimicking the behaviour of the user.

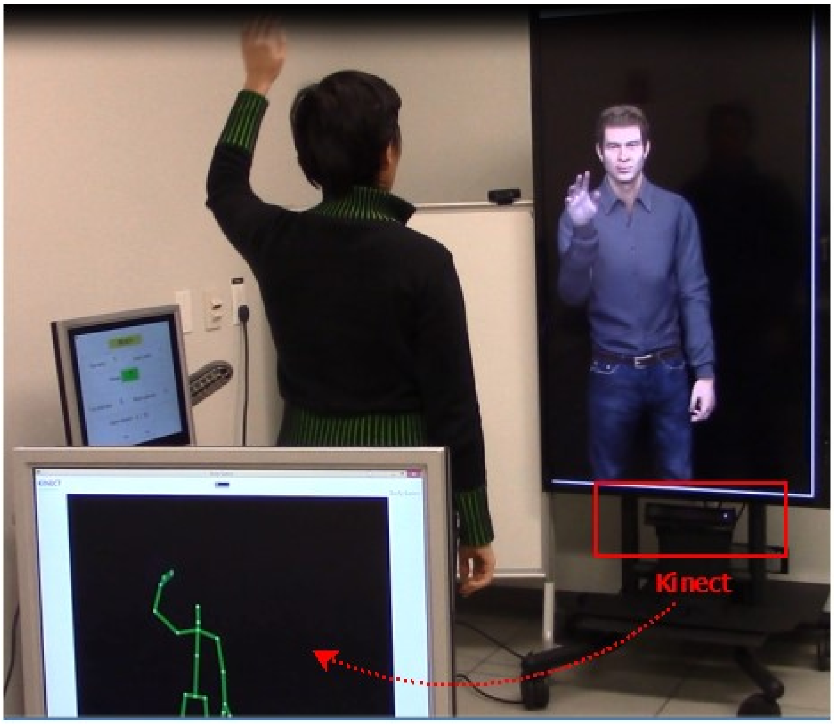


Figure 3.7. **Using a Kinect sensor [127] the user's waving hand gesture is recognized by the system, at which time the character responds with a wave back.**

The scenario was only designed as a proof of concept and to show the flexibility of the system for the range of different scenarios. For instance, using the Kinect sensor [127], a user's hand gestures such as waving is recognized by the system (Figure 3.7), at which time the character responds with a gesture such as waving back (more details on section 4.5.1).

Communicative gestures/postures are usually responding to social scenarios such as rock hand gesture in the RPS game (Figure 4.14). With these types of gestures, strong emotional reactions can be accompanied by a set of emblems (for nonverbal signals that can be translated to words, see section 2.2.2). For example, if the character is very angry, he positions his hand into a fist while making frowning facial expression. Emblems, illustrators, and self-adaptors are proposed by Ekman et al's as three classes for hand movements' behaviour [106] (see2.2.2 for more details). Ekman et al presented a theatrically based categorization for interpretation of hand movements. Since my focus was on non-verbal behaviour, illustrators (used for dialog based conversation) are not addressed in the RealAct gesture/postures categorizations. Self-adaptors such as "scratching the head" and "holding two hands together" are also used in the RealAct.

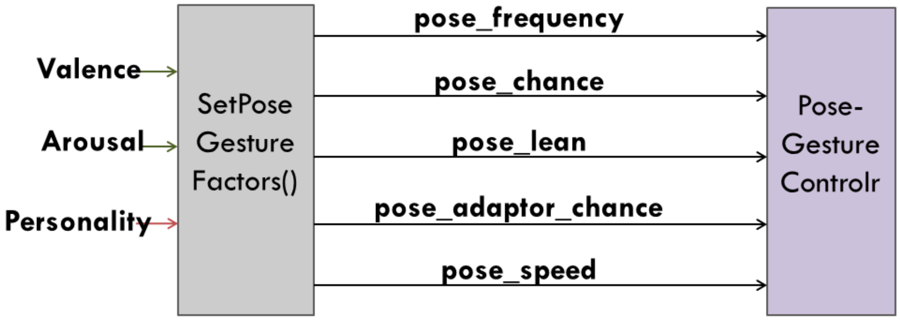


Figure 3.8. Drawing on psychological research, emotional state (valence-arousal) and personality of the character (extravert or stable) affects several dimensions of gesture and poses behaviour such as if the poses are occurring, their frequency occurrences and their speed [154][29][30][152].

The chance of selecting each of the gestural/postural animations from the mentioned categories is a function of 1) the simulation time, 2) emotional state of the character (valence-arousal) and 3) personality of the character (extravert or stable). These three parameters can specify if the pose is occurring, if it is either fast or slow and how frequent the occurrences of a category of gestures are (Figure 3.8).

A significant part of the research in this thesis was building a simple and implementable computational model of these mentioned categories into believable and verifiable dynamic and real-time gestural/postural animations in the RealAct responsive character. The character's hand movements, body gestures, and poses are controlled by pre-defined key-framed 3D parameterized animations. In order to synchronize multiple animations, Behaviour Markup Language (BML) provides sync-points and timing constraints which can be used to order the behaviour [129]. A subset of the animations used in the RealAct is selected from my animation toolkit's default animations. The rest were created by an animation team we recruited from undergraduate students in the iVizLab, Simon Fraser University. In addition, we recruited an actor and recorded him playing a list of scenarios that needed to be animated (Figure 3.9). I divided the recorded videos into small portions, 3 to 5 seconds and sent them to 3D animators as a guideline alongside the 3D character's skeleton. I worked with the 3D animators on integrating better animations for the system and built in the parameterization that made the animations dynamic (parameters such as speed of the movement). Cinema 3D and Poser were used to create the animations. Finally, I used the fbx converter [101] to convert the animations received from animators back to the fbx format and tested them in the system. The fbx format is a standard format and can be used by other animation toolkits.

Figure 3.9. We recruited an actor and recorded him playing a list of scenarios needed to be animated. The recorded videos then were divided into small portions, 3 to 5 seconds used by 3D animators as a guideline. The right figure is a screen shot of the actor playing a wave. Left figure is a screen shot of a created animation for waving.

3.7.3. Facial Expression Controller

For humans, emotions are activated by external or internal effects and each last for a short period of time [22][25][24][26]. Similarly, to perceive virtual humans as more natural and believable, it is crucial that they show proper facial expressions with respect to affective states which are recognizable by users [166]. Achieving this level of believable expressive realism on a real-time and responsive 3D character is still a source of ongoing research [44][76][133][136]. In the RealAct system, the rich dynamics of emotional changes, triggered by external and internal stimuli, are continuously generated in the emotion generation module. The generated emotions then are expressed through facial expressions. For generating an emotion (internal), I am using the Circumplex model of affect in which each emotion can be understood as a linear combination of valence (pleasure) and arousal [51]. For the emotions that are revealed externally through our character’s face to the user, generated values of valence and arousal were mapped to Ekman’s Action Coding System to generate facial expressions.

To map the valence and arousal and facial action units, I used the data of Boukricha et al’s study [82]. They applied reverse-engineering methods and statistical calculations to simulate a virtual human’s facial expressions with the Pleasure-Arousal-Dominance models values. Their work is built around the data they gathered from 353 participants rating a set of generated facial expressions. While I was able to use the Boukricha et al work as a foundation of the RealAct emotional facial mapping algorithm, I needed to extend the work as well as test its validity in several areas. Since my system used the animation toolkit and open standards system of BML/Smartbody, it was important to extend the work so the valence and arousal parameters worked for the different facial action set of the SmartBody system including reinterpreting Boukricha et al’s defined face visemes (face movements defined for the speech) for use in expression for SmartBody conversation. In addition, for some of the action units, the mapping values for intensities were not high enough to be visible in the Smartbody character’s face. Thus, I tuned some of the parameters used in Boukricha et al’s mapping [82] to generate higher intensity values for some action units. To test the validity of created emotions and make sure users perceived the same impression of the synthesized emotions as desired, I performed an experiment study in which 20 participants rated the valence and arousal of 9 still images generated from captured real-time output based on my updated emotional mapping (details are discussed in section 4.2).

3.8. Personality as a Parameter Influencing the System

In the previous section, I have explained how the behaviour generation for three modalities in RealAct. In the following, I discuss how this behaviour creates an impression of personalities ‘extraversion’ and ‘emotional-stability’ (traits from the Big Five). Extraversion and emotional-stability traits are widely used in affective computing [6] and have a biological basis [47]. In addition, there is empirical evidence regarding the link between them and nonverbal behaviour [29] [31]. As depicted in Figure 3.1, personality traits affect different parts of the RealAct system. People with different personalities tend to filter their emotions differently e.g. extraversion is correlated with expressing the feelings more easily and do less filtering of the emotions. In addition, personality affects the gestures, postures, and expression of facial emotions. Another aspect through which personality is revealed is the coping mechanisms and emotional reactions of the characters to users' behaviour. To limit the scope of the research, this aspect of personality is not implemented in the current version of the RealAct.

The RealAct's hierarchical parameterized structure (see Figure 3.1) facilitates the encapsulation and separation of the emotion generation, behaviour controllers, and personality parameters. Thus, the designer of the system can choose to incorporate the effect personality in the behaviour modules, or not. Likewise, the designer can determine whether the emotion is affected by the personality or not. How the emotion generation and behaviour controller modules work were explained in the previous section. Here, I review how I implemented the effect of personality traits on emotion generation and behaviour controllers (i.e. gaze, pose, gesture, and face). As a combination of two traits —extraversion and emotional-stability— four personality types are considered: High Extraversion-Low Stability (HELS), High Extraversion-High Stability (HEHS), Low Extraversion-Low Stability (LELS), and Low Extraversion-High Stability (LEHS).

3.8.1. Personality Influence on Emotion Generation

The emotional reaction to the degree of extraversion and stability in characters depend on the coping mechanism and reaction to positive and negative feedback. Table 3.1, lists differences between the fours personalities, implemented in RealAct, in terms of generation of valence and arousal. For instance, highly extravert-highly stable characters are highly responsive to positive stimuli [32], and experience more positive emotions in general [41]. Extraverted individuals' coping mechanism involves acting rationally and thinking positively [43]. Moreover, a low stable coping mechanism is to withhold and be passive [43]. A coping mechanism is not mentioned in the table since it is not implemented in this version of the RealAct. However, RealAct's encapsulated framework, with hierarchically-interconnected and well-defined modules, facilitates an incorporation of future components such as the copying controller.

Table 3.1. **Summarizing the findings from psychology, five dimensions for the effect of personality parameters on the valence and arousal are defined (for emotional valence, initially experienced value of emotion, frequency of chance of valence and reaction to stimuli; and for emotional arousal, initial value and arousal change in response to positive and negative stimuli)**

	VALENCE			AROUSAL	
	INITIAL VALUE	REACTION TO STIMULI	CHANGE FREQ	INITIAL VALUE	REACTION TO STIMULI
HELS	0 [41]	High to positive & negative [32]	High [36]	Positive [36]	High [36]
HEHS	Positive [41]	High to positive [32]	Low [36]	Negative [36]	Low [36]
LELS	Negative [41]	High to negative [32]	High [36]	Positive [36]	High [36]
LEHS	0 [41]	Low to positive & negative [32]	Low [36]	Negative [36]	Low [36]
NEUTRAL	0 [41]	Normal to positive & negative [32]	Low [36]	0 [36]	Normal [36]

Figure 3.10, shows a Simulink Scope Block which compares the emotional valences generated by the RealAct's emotion generation module for four personalities. Since, extraverts show stronger emotional responses to the positive feedback (for example, when the character is winning in a game), when the feedback is positive, extraverts' valence curve has a high exponential rise. However, individuals who score high in extravertion are not typically sensitive to negative feedback, so when feedback is negative, the valence decreases more slowly. Low stables, on the other hand, typically show a stronger response to negative stimuli than positive stimuli [32]. Therefore, valence decreases with a higher rate of response to negative feedback. Low stables experience more negative emotions in general [36].

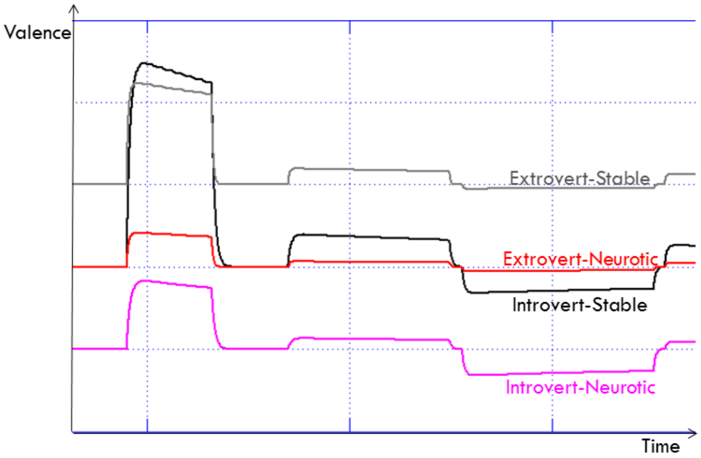


Figure 3.10. **Comparison between the RealAct's generated Valence for four different personalities**

To confirm that the resulting valence and arousal for four personalities are compatible with the psychology literature, I compare the results with Heller Adaption of Heller & Eysenck Model [159], which offers a map between valence-arousal and Personality traits Extraversion and Neuroticism (emotional instability) (Figure 3.11). To be able to compare, I plotted the RealAct's temporal changes of valence and arousal for four personalities using Simulink 2D plots with x dimension as valence and y dimension as arousal (Figure 3.12).

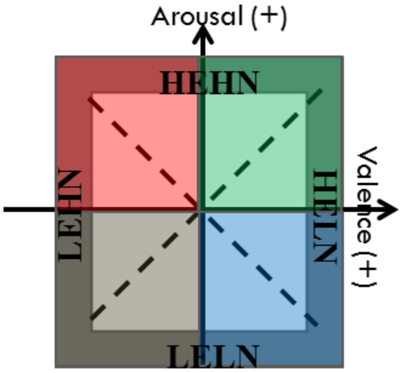


Figure 3.11. **An adaption of Heller & Eysenck Model (a map between valence and arousal and personality traits extraversion and neuroticism [159])**

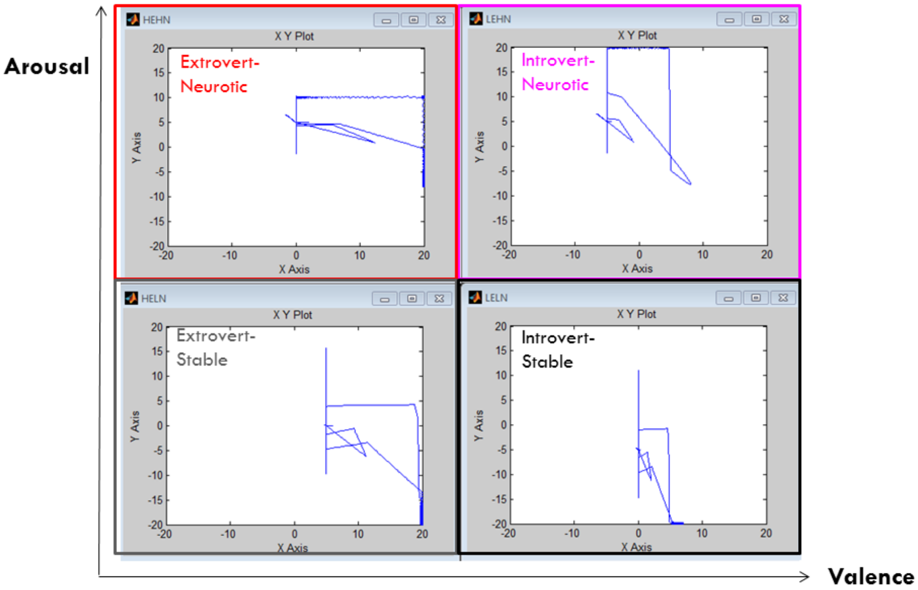


Figure 3.12. **Temporal valence changes of different personality types (Gray: Extravert-Stable, Black: Introvert-Stable, Red: Extravert-Low Stable, Pink: Introvert-Low Stable) using Simulink 2D plots. For all of the plots x dimension is valence and y dimension is Arousal. (need a better figure)**

The RealAct system generated valence and arousal appeared to be compatible with Heller's model in terms of the regions Extraversion and Emotional-stability cover in valence-arousal dimensions. For instance, highly extravert-highly stable individuals seem to experience mostly positive valence and a combination of negative and positive arousal.

3.8.2. Personality Expressive Gaze

A set of factors were added to the gaze model to control the impression of personality. Due to two distinct natures of gaze behaviour, the personality factors change the parameters of the gaze in one of these ways: 1) some of the factors are multiplied with the parameters of the gaze, to continuously impose the effect of personality on the behaviour, 2) some of the personality factors update the gaze parameters, only once, when the personality is changed (specified by 'personality-changed' and 'VA-changed' flags in Figure 3.13). For instance, the system constantly generates new amplitudes and duration to gaze at a new coordination for a short duration of time. Therefore, a personality factor is multiplied by the duration of gaze each time to increase or decrease the duration based on personality type specified on that time of the simulation. On the other hand, blink frequency is only specified one time and in the start of the simulation. Thus, it is enough to multiply the blink frequency value by a factor if the personality changes during the simulation. Moreover, emotional changes (how aroused or pleased someone is) have definite effects on the gaze behaviour.

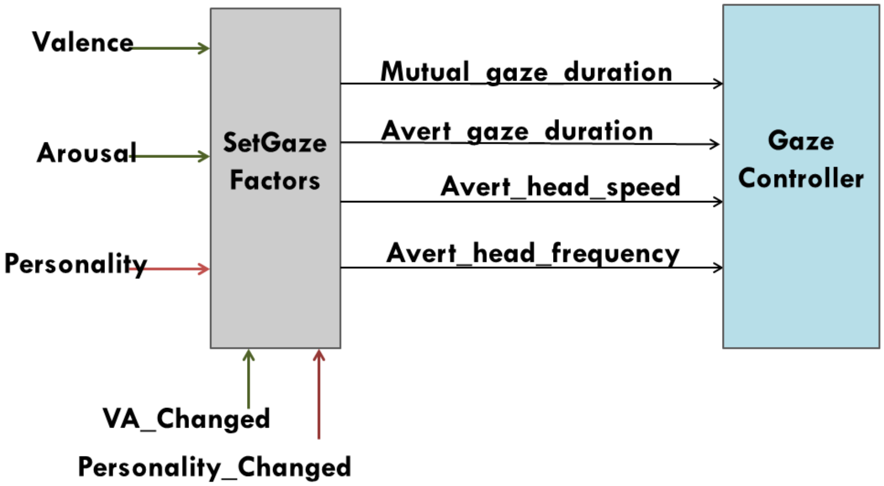


Figure 3.13. Personality and emotional state can affect various dimensions of gaze behaviour such as duration, direction and speed of the gaze (To limit the scope of the research, in this version of RealAct's implementation, effect of emotional valence and arousal on gaze is not implemented. However, in future it will be added to the system.)

The following, statements 1 to 5, are used in RealAct to calculate gaze parameters. The basis for the most of these statements is the Eyes Alive model [100]. However, I adapted and updated the formulas to be responsive to personality changes, and characteristics of Smartbody animation toolkit. In the Eyes Alive model, Saccade magnitude, (statement 1), is an inverse of an exponential fitting function of a chance of occurrence (P). I defined animation_engine_factor variable so the resulting magnitude maps the character gaze's degree of freedom (since for the original P value some of the magnitudes were too small to be seen).

$$\text{Magnitude} = -6.9 * \log\left(\frac{\pi}{15.7}\right) * \text{ animation\_engine\_factor } (1)$$

Percent chance of no change from the mutual state (mutual_cont_chance) and the percent chance of staying in averting gaze (avert_cont_chance) are polynomial fitting functions of elapsed time and are respectively estimated by formula 2 and 3. I used the same second-degree polynomial curves defined in Eyes Alive models to calculate the chance of no change while adding factors to reinforce the expression of personalities. Factors ‘mut_freq_facor’ and ‘avert_freq_facor’ are set dynamically based on specified personality type. For example, introversion is correlated with a higher chance of staying in an avert gaze state. Thus, if the character is highly introverted, avert_freq_facor will automatically set to a higher value by the system, which led to a higher chance of continuing the averted gaze. In addition, the amount of time passed affects the chance of mutual and avert in Eyes Alive gaze model (t). In RealAct, t is set to the current time of simulation.

$$\text{Mutual\_cont\_chance} = \ 0.0003t^2 - 0.18\ t + 32 * \text{mut\_freq\_factor}\ (2)$$

$$\text{Avert\_cont\_chance} = \ -0.0034t^2 - 0.23\ t - 6.779 * \text{avert\_freq\_factor}\ (3)$$

In my implementation, a Matlab function named ‘GazeFunction’ accepts the calculated gaze parameters as inputs and returns gaze behaviour commands. In the updated Eyes Alive model, saccade direction (named gaze_dir in 4 and 5) is assumed to be one of the following eight directions: Up, Down, Left, Right, Up-Left, Up-Right, Down-Left, and Down-Right. There is 15% chance of pure directions (Left, Right, Up and Left) and 8% chance of others. In RealAct, I manipulated the chance occurrence of the directions based on the personality type, utilizing two factors ‘avert_gaze_dir_chance’ and ‘mut_gaze_dir_chance’. For instance, since the literature shows a correlation between introversion and the higher chance of looking down, down-left and down-right [4], I increase the chance of occurrence of Down, Down-Left, and Down-Right, and decrease the chance of Up, Up-Left, and Up-Right.

Duration of the gaze is calculated using the formula 4. Similar to Eyes Alive model, D is assumed to be 2.4 milliseconds per degree and D0 is assumed to 25. Using variables ‘avert_gaze_duration_factor’ and ‘mut_gaze_duration_factor’, Personality affects the duration of averting and mutual gazes. For example, related psychological studies show a correlation between the extraversion and higher duration of the mutual gaze which is set to a higher value of ‘mut_gaze_duration_factor’.

$$\mathrm{avertDur} = (\mathrm{D}_0 + \mathrm{D} * \mathrm{magnitude}) * \mathrm{avert\_gaze\_duration\_factor}\ (4)$$

$$\mathrm{mutualDur} = (\mathrm{D}_0 + \mathrm{D} * \mathrm{magnitude}) * \mathrm{mut\_gaze\_duration\_factor}\ (5)$$

Table 3.2. This table summarizes the findings from psychology on the expression of two personality traits through the gaze behavior. The columns of the table are Idle (for neutral personality) and four different personalities: Highly Extravert-Low Stable (HELS), Highly Extravert- Highly Stable (HEHS); Low Extravert- Low Stable (LELS); Low Extravert- Highly Stable (LEHS). Six dimensions of gaze behaviour are addressed: head speed, blink frequency, type, direction, frequency and duration of gaze. U, D, C, L, R respectively stand for Up. Down, Center, Left, and Right.

	GAZE TYPE	GAZE DUR	GAZE FREQ	GAZE DIR	BLINK FREQ	HEAD SPEED
HELS	Both Mutual & Avert [4][3]	Long to Short[16][15]	High to Low [17]	U/C/L/R [14][9][1][38]	High [105]	High [5] [29]
HEHS	More Mutual [4][3]	Long to Med[16][15]	High to Med[17]	U/C/L/R [14][9][1][38]	Low [105]	High [5] [29]
LELS	More Avert [4][3]	Short [16][15]	Low [17]	D/L/R [14][9][1][38]	High [105]	Low [5] [29]
LEHS	Both Mutual & Avert [4][3]	Short to Med [16][15]	Low to Med [17]	D/L/R/C [14][9][1][38]	Normal [105]	Low [5] [29]
IDLE	Both Mutual & Avert [100]	Normal [100]	Normal [100]	U/D/L/R/C [100]	Normal [104]	Normal [100]

Table 3.4, gives a detailed description of all the gaze parameters set, to generate different gaze behaviour, for a different type of personalities. The direction, duration, frequency of the gaze, and speed of the head movements are controlled to give different impressions of personality. For instance, if the character is low extravert-low stable, it averts its gaze more frequently [17], but for short periods of time [16], mostly gazes down left and right [14][9] and moves its head with a low speed [29].

For the blink behaviour in RealAct system, I used statistical data for human blink behaviour and how emotional state and it is affected by personality. Based on Itti et al [104], people blink 11.6 times per minute. Highly aroused people tend to blink more frequently [105]. Thus, as with other parameters of the gaze, I defined a factor to change the blink frequency, during the simulation, based on changes in the personality. Communicative gaze is triggered based on the scenario of interaction. Although these behavioural acts do not contribute to the expression of personality, they are necessary to have an active realistic interaction. For instance, right after playing the hand in RPS game, the character looks at the hand of the user to see what they played, or looks at the GUI to see and confirms the result.

3.8.3. Personality Expressive Poses and Gestures

Compiling the related psychological and embodied research material I reduced the human-based data for computational use by extracting expressivity parameters for describing the physical realization of gestures and poses. For instance, high extravert-low stable character shows a high frequency of self-adaptors, shows twitches, moves its body parts faster, and shows more gestures and poses in general [154][29][30]. The data indicated that leaning forward communicates a positive attitude and leaning backward communicates a negative attitude [152][153]. Highly stable individuals lean backward reclining while head leans sideway or down. Posture-shifts are more frequent in the beginning of the interaction and decrease in later interactions [107].

I introduce five dimensions for expressive idle gestures and posture in the RealAct system: 1) Posture-shift behaviour, 2) Self-adaptor behaviour, 3) Leaning behaviour (lean forward, no lean and lean backward) 4) Twitches (true or false) and 5) Spacious gestures (true or false). These five dimensions can have three different frequencies (high, mid, low) and three speeds (fast, mid, slow). The map between these dimensions and personality types is mentioned in details in Table 3.3. For instance, highly extravert-low stable characters show idle poses and gestures more frequently and faster. Highly extravert characters tend to lean back more and use more space when gesturing and posing [107]. Unstable characters twitch and their poses and gestures are jerky [31]. These five expressivity dimensions for gestures and poses were chosen since 1) these dimensions are important in creating the impression of personality, 2) these dimensions have in general or in parts been used in several studies on affective computing and for creating the impression of personality and emotion [44][45][131][137], and 3) it was feasible to synthesize these dimensions using my animation toolkit's provided features.

Table 3.3. This table summarizes the findings from psychology on the expression of personality through gestures and poses. Eight dimensions for gestures/postures are proposed: Frequency of gestures and postures in general, Leaning behaviour, Posture-Shifts behaviour frequency and speed, self-adaptors behaviour frequency, and speed and whether twitching and spacious poses and gestures are present. In order to differentiate the four modelled personalities, the above expressivity parameters are used to adjust the behaviour.

	GEST/POSE FREQ	LEAN	W.S. FREQ	W.S. SPEED	S.A. FREQ	S.A. SPEED	TWITCHES	SPACIAL EXTEND
HELS	High [154][131]	Back [152][153]	10% [107] [30]	High [5][29]	90% [45][31]	High [29][30]	Yes [57]	Yes [152][131]
HEHS	Low [154][131]	Fw [152] [153]	90% [107] [30]	High [5][29]	10% [45][31]	High [29][30]	No [57]	Yes [152][131]
LELS	High[131] [154]	Back [152] [153]	10% [107] [30]	Low [5][29]	90% [45][31]	Low [29][30]	Yes [57]	No [152][131]
LEHS	Low [131] [154]	Fw [152] [153]	90% [107] [30]	Low [5][29]	10% [45][31]	Low [29][30]	Yes [57]	No [152][131]
NEUTRAL	Norm [154][131]	Norm [152] [153]	60% [107] [30]	Norm [5][29]	40% [45][31]	Norm [29][30]	No [57]	No [152][131]

3.8.4. Personality Expressive Face

As shown in Table 3.4, in the RealAct process flow, personality affects the expression of emotion in three ways: intensity of emotion expressed, how much emotion is filtered out, and if the character shows facial twitching. For instance, extravert individuals tend to express their emotions more freely and do less filtering [38]. On the other hand, there is a correlation between low stability and the presence of involuntary face twitches and head jerkiness [57].

Table 3.4. Based on the personality type of the character, the amount for activated action units are adjusted. In addition, based on personality type, if the amount assigned to an action unit is less than a threshold it will be filtered out (considered as internal and not expressed emotional states).

	ACTION_UNIT_AMOUNT	FILTER THRESHOLD	FACE_TWITCHES
HELS	High [57][36]	Low [38]	Yes [57]
HEHS	High [57][36]	Low [38]	No [57]
LELS	Low [57][36]	High [38]	Yes [57]
LEHS	Low [57][36]	High [38]	No [57]
NEUTRAL	Normal [82]	Normal [38]	No [57]

3.9. Behaviour-Scheduler Module

In daily life, people tend to pursue various goals e.g. having a well-paid job, buying a house, have an intimate relationship etc. Based on the urgency of the goals and availability of external and internal resources, people tend to prioritize these goals. Each of these main wants and needs can be a source of several compound goals and behaviour. Additionally, some of the goals can be pursued in parallel or in coordination (e.g. finding a job and buying a house), some the goals compete for the same resources (e.g. working or spending time with the loved ones) and some of the goals are in conflict (e.g. avoid rejection and create closeness and intimacy). These different types of complex goals create various tendencies in us which lead to a request for corresponding behaviour (e.g. being hungry requests for eating behaviour while a need for finishing a book requires studying). Humans prioritize and choose between these various requests for behaviour, based on their internal state (e.g. how hungry we are) and my past experiences [173][174][130]. Similarly, for virtual characters, various modules generate multiple behaviour requests and some of these requests can occur at the same time. Therefore, there is a need for a mechanism for prioritizing and selecting proper behaviour, based on the research we understand of humans' behaviour selection [160][130]. Some of the requested behaviour can be performed in parallel (e.g. head avert to a point and scratching the neck) while some are competing for the same body joints (e.g. waving for the user and scratching the chest). As shown in Figure 3.14, I defined four possible ways different behaviour can overlap: sequentially, switching, parallel and interrupting. In the sequential condition, one behaviour is finished before the start of the next one. People also switch to another behaviour, especially if the behaviour is short, and then come back to the current activity. Some of the behaviour can be performed in parallel (e.g. head avert to a point and scratching the neck) while interrupting behaviour occurs when joints are competing for the same body joints (e.g. waving for the user and scratching the chest).

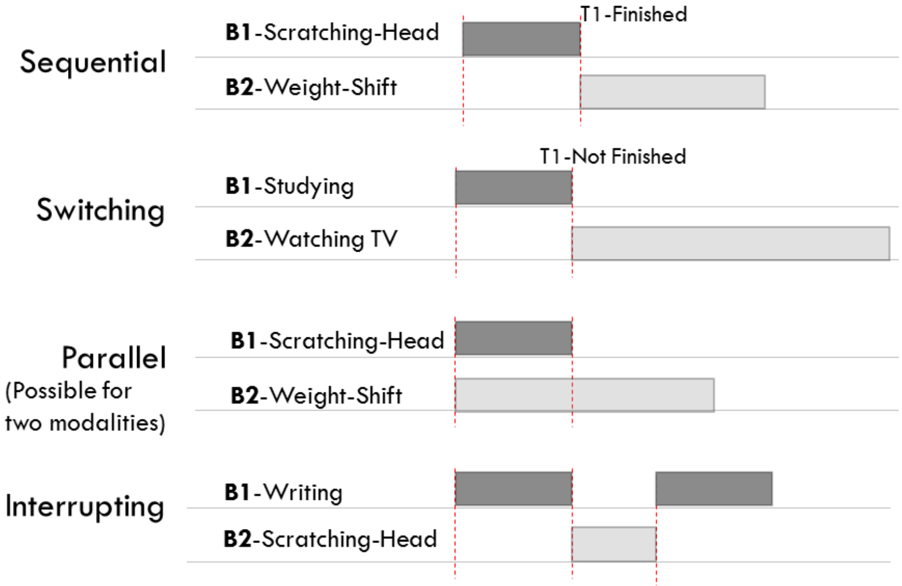


Figure 3.14. The four possible ways different behavioural acts overlap: sequentially, switching, parallel and interrupting. In the sequential condition, one action is finished before the start of the next one. People also switch to another behaviour, especially if the behaviour is short, and then come back to the current activity. Some of the behaviour can be performed in parallel (e.g. head avert to a point and scratching the neck) while interrupting behaviour happens when joints are competing for the same body joints (e.g. waving for the user and scratching the chest).

Sending two behaviour requests which share some of the joints to the animation engine can lead to ignoring one of the behavioural acts or blending the acts in an undesired way. This can be problematic especially for behaviour which is time-based and crucial. To elaborate more, consider the scenario of a virtual character playing the rock-paper-scissor game with a user. Several modules are sending behaviour commands to the animation engine. For example, a module responsible for idle poses and gazes generates random poses e.g. head scratch at random times of the interaction. If this occurs at the time the user and the character want to play the hand, the idle module will send a head-scratch command and this command can overwrite the RPS hand gesture in which case the character will scratch her head instead of playing the hand! Such an unfortunately synced coincidence can negatively affect the believability of the experience.

To avoid problems like these and control the overlapping behaviour with different priorities four techniques have been designed and implemented: if two behavioural acts have different priorities, the one with a higher priority will be selected. If a higher priority task is followed by a lower priority task, RealAct's attention module will assure that the lower priority task does not affect or blend with the higher priority behaviour. If a low priority behaviour is followed by a higher priority/ or low priority behaviour, it will blend to the new behaviour (Figure 3.15).

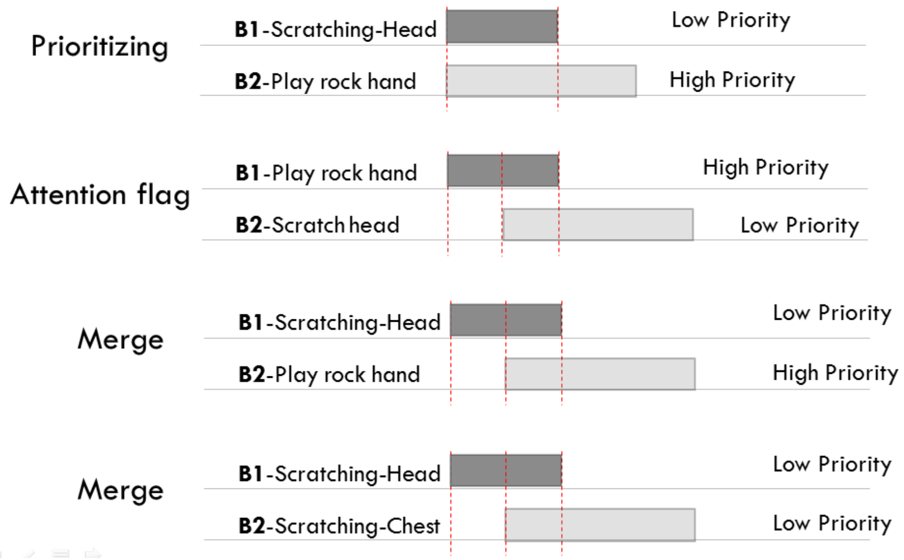


Figure 3.15. The four possible ways behaviour with different priorities can overlap and how they are managed in RealAct: if two actions have different priorities, the one with a higher priority will be selected. If a higher priority task is followed by a lower priority task, the RealAct's attention module makes sure the lower priority tasks does not affect or blend with the higher priority behaviour. If a low priority behaviour is followed by a higher priority/ or low priority behaviour, it will blend to the new behaviour.

When synchronizing and prioritizing the behavioural acts of the character, RealAct is responsive to external events while considering the physical constraints of the 3D character. For instance, whenever the user smiles or waves at the 3D character, the character smiles back or waves. In addition, the character's behaviour stays physically reasonable. For instance, body parts do not move too fast or slow and different channels of behaviour behave in synch.

The RealAct system includes three priority queues for high, mid and low priority behaviour (Figure 3.16). High-priority behavioural acts need to be performed immediately after the generation. They are usually behaviour responsive to the environment and the user inputs or immediate reactions needed to the interaction scenario. For mid-priority behaviour, even if the behaviour cannot be scheduled to the specific time, it still needs to be scheduled as close as possible. The low-priority behaviour is usually idle behaviour which does not correspond in a synced way to any outside events so their delay or removal will not affect the perceived experience. Behaviour is inserted to the corresponding queues in multiple behaviour controller modules. The Behaviour-Scheduler then sends the selected behaviour (with the highest priority) to the animation engine. The Behaviour-Scheduler module is responsible for deciding which behaviour is selected. It will check the behaviour queues by order of their priorities. The low-priority queue is checked, only if the high-priority queue is empty (Figure 3.17).

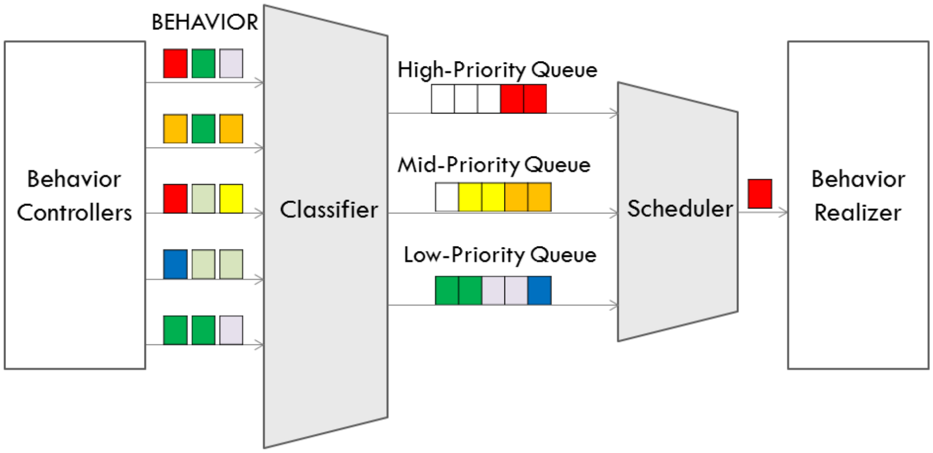


Figure 3.16. **The RealAct system includes three priority queues for high, mid and low priority behaviour. Behaviour is inserted to the corresponding queues in multiple behaviour controller modules. The Behaviour-Scheduler then sends the selected behaviour (with the highest priority) to the animation engine.**

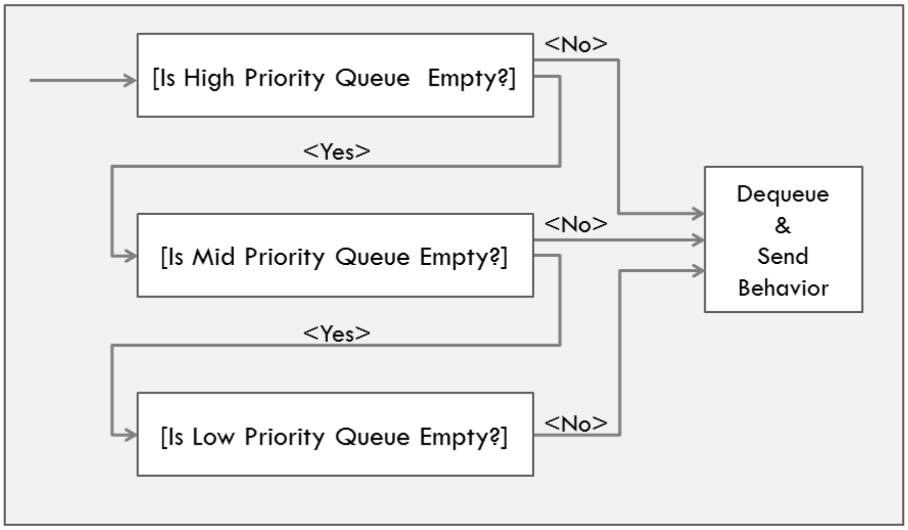


Figure 3.17. A demonstration of RealAct's Behaviour-Scheduler design (first high-priority queue, then mid and at last the low-priority queue is checked for behaviour commands. If each of the higher queues is empty, the lower priority queue is checked.)

Smartbody animation toolkit is used as the RealAct animation engine [101]. Behaviour Markup language (BMLs) is used to send behaviour commands to the Smartbody character [129]. I am using two approaches for controlling Smartbody character's behaviour: 1) procedural control: involved joints will maintain their position until a new behaviour is sent to the character and 2) animations: involved joints return to default pose when the behavioural acts run their course. For example, since Smartbody's gaze behaviour is procedural if a character is asked to gaze at a certain target, the gaze will stay on the moving target until the new gaze behaviour command is sent to the animation engine. In order to synchronize multiple acts together, I align sync-points provided by BML [129]. Additionally, BML also provides timing constraints which can be used to order the behaviour.

3.10. RealAct's Modular Structure

Simulink facilitates component-based modeling and modular design of RealAct. Each component of the system can be simulated and verified independently. All of the sub-systems are saved in a library as separate components to promote the future use by other researchers. In addition, the RealAct system is based on Movement + Meaning (m+m) architecture, which acts as a communication's interface between different components (Figure 3.18). m+m [167] is a software platform that supports the capture, recognition, control and semantic representation of movement data. The architecture of the m+m is based on the YARP (Yet Another Robot Platform) middleware which has a broad international user community and is based on established libraries and standards (http://mplusm.ca).

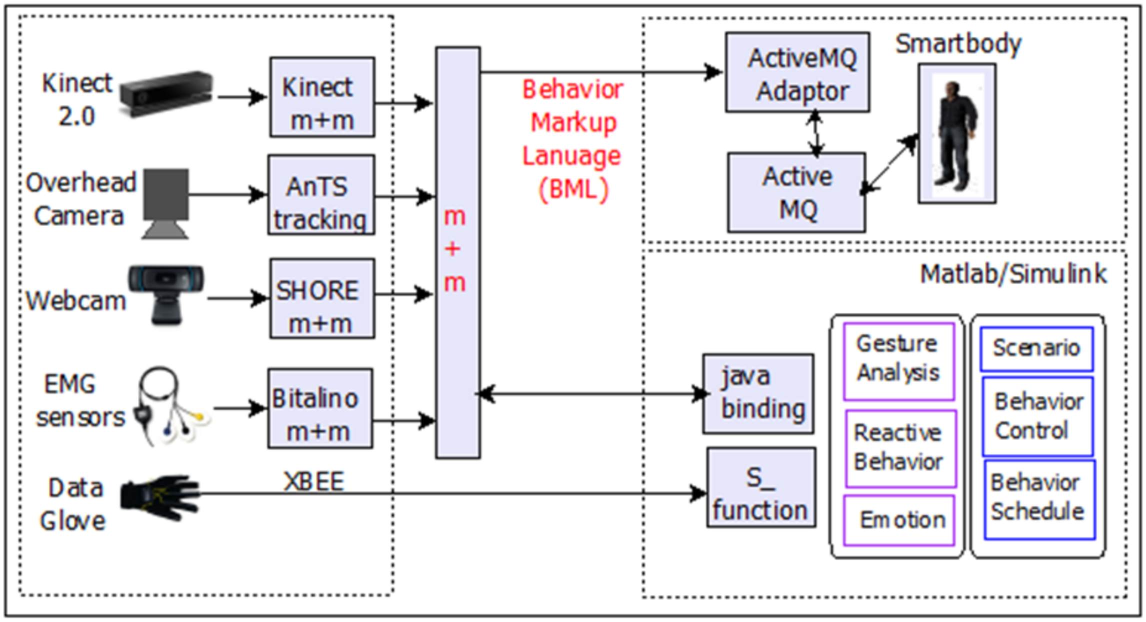


Figure 3.18. Modular structure of the system

This project is part of my lab's, iVizlab, avatar research. The system will benefit the iVizLab's active research areas: namely, Health and Autism research, human movement research, 3D character believability research [http://ivizlab.sfu.ca] In addition, this work is built as a part of SFU SSHRC / Canarie research projects: the Moving Stories and Movement and Meaning projects and will benefit their research [http://mnm.hplustech.com/]. In conjunction with the above projects, my research partners are internationally international movement researchers. By providing a strong real-time affective character system within the open source Smartbody system from USC [101], (and eventually other systems) this project will allow human movement researchers worldwide to use my system for their research. The code for the implemented system will be shared online for the researchers to further test and use. It can also be beneficial for educational systems, therapy systems, virtual museum guides, virtual receptionists, games, story-telling systems and interactive dramas.

Chapter 4. Evaluation and Experimental Results

The previous chapter outlined the underlying concepts, structure, and implementation of the RealAct architecture. To evaluate the effectiveness of the system in conveying personality, I ran a set of experiments. RealAct was used as the main apparatus for these experiments. Therefore, these experiments provided a means of validating both RealAct, and our overall computational model for non-verbal communication using 3D real-time characters. The RealAct system provides a possibility of real-time interaction between a virtual character and human users while creating consistency in behaviour (interpreted by participants as personality traits). The system implements a combination of two personality traits (extraversion and emotional-stability). In this chapter, first, I review the details of design, tasks, and procedure of each of the experiments. Then, I review and discuss the results of the experiments.

4.1. Experimental Design

To evaluate the RealAct system, four experiments were performed. 130 participants in total took part in these four experiments. Each participant was only involved in one of the experiments. As well, each participant fully completed the experiment rating all the stimuli. I used regression for the statistical analysis of the results. In general, Anova (analysis of variance) and regression both can be applied for statistical analysis. In analysing the effect of a variable on an outcome, regression on indicator variables is equivalent to Anova. To apply Anova, the investigator categorizes the data into two or more groups, calculates the outcome variable's mean for each group, and investigates if the means are statistically different. To analyse the same problem with regression, a researcher creates indicator variables to represent each category and applies regression of outcome variables on an intercept and all the indicator variables excluding a reference group. The intercept in this regression represents the outcome variable's mean for the reference group and each indicator variable's coefficient represents the mean difference in outcome variable between the associated group and the reference group. While both approaches are used quite often in psychological, cognitive, and HCI studies and can be extended to multivariate cases [1][2][3][4][5], the author found regression more general and easier to implement in this study.

I specifically used a linear regression technique (fixed effect linear model), using R-studio. This model was used to control for any unobservable but fixed individual effect that might influence the respondents rating of 3D agents' characteristics. As a participant rates several questions, the fixed effect model uses the multiple observations for each respondent to assign different intercepts to the regression line for different respondents. For example, the fixed effect model takes into account that some people assign higher/lower rating to agents' characteristics relative to average [175][176]. In addition, before running the models the following tests were performed to assure the assumptions of multiple linear regression were met: linearity of residuals, homoscedasticity, normal distribution of residuals, autocorrelation or independence of residuals, multi-collinearity, and linear relationship of IVs and DVs. For the details on the statistical methods used (including software package, functions, regression assumptions, and full statistical results) please see appendix C.

The first experiment was conducted to ensure the emotions people perceive from the facial expressions generated by the RealAct system are consistent with the intended emotions. The video-based and presential experiments evaluated the four hypotheses of this dissertation. Hypothesis *S#1* and hypothesis *S#2*, assert that the amount of extraversion and emotional-stability that subjects attribute to a character depends on a specified combination of behaviour (gaze, facial expressions, gestures, and postures) it exhibits. During the two-passive video-based and one presential experiment, participants rated a virtual character who was designed to portray the physical mannerisms of someone who is an extravert, introvert, emotionally-stable or not emotionally-stable. In the video-based experiments, people rated the videos of the idle behaviour of a virtual character captured from running the simulation by setting different personalities as input parameters. The second video-based experiment was designed using feedback from participants in the first experiment. The web-based experiments evaluated the system in a smaller scope and free from complexities of the presential experiment such as scenario of the interaction and response to the environment inputs. In the presential interactive experiment, participants interacted with the virtual character and rated their personality, following a scenario of the interaction. I designed a rock/paper/scissors game (RPS) game as a scenario of a nonverbal interaction. The behaviour of the character was generated in real-time and responsive to the environment, participants and specified personality.

Hypothesis S#3 asserts that the real-time interaction between human and virtual character should strengthen the impression of extraversion and enhance the perception of emotional-stability for the virtual character. I investigated this by evaluating the difference of the presential interactive user interaction experiment with the web-based experiments, in participants' perception. The last hypothesis is that the framing of the character's body (complete frame versus partial frame), should affect the overall impression of personality. This was explored in the two video-based experiments. I mainly used two measures through the all of the experiments: The Self-Assessment Manikin (SAM) scale and Ten Item Personality Measure (TIPI) scale. I also performed a short semi-structured interview and a presence questionnaire for evaluating the general experience of participants in the presential experiment.

4.2. Effectiveness of Facial Expressions to Convey Affect

The first experiment was conducted to evaluate and maintain the consistency of the emotions people perceive from the facial expressions generated by the RealAct system, and the intended emotions. The results of the first experiment showed a significant positive correlation between the intended and perceived emotional valence and arousal.

Independent variables (IV) of the first experiment were intended valence and intended arousal both with five levels (low, medium-low, medium, medium-high, and high). By intended, I mean the valence and arousal amount I set before the simulation to generate the nine combinations of facial expressions: (high valence, medium arousal), (medium-high valence, medium-high arousal), (medium valence, high arousal), (medium-low valence, medium-high arousal), (low valence, medium arousal), (medium-low valence, medium-low arousal), (medium valence, low arousal), (medium-high valence, medium-low arousal), and (medium valence, medium arousal). Dependable variables (DV) were valence and arousal perceived by participants from these nine generated facial expressions.

4.2.1. Participants

20 students participated in the first experiment for course credit. The participants were graduate students of Simon Fraser University (SFU) and The University of British Columbia (UBC), aged between 23 and 46 with an average age of 34. Fourteen participants were female and six were male.

4.2.2. Measurements

The Self-Assessment Manikin (SAM) is used to evaluate the valence and arousal emotional values of still images generated by the RealAct system.

The Self-Assessment Manikin

The Self-Assessment Manikin (SAM) is a non-verbal picture-based assessment tool that measures three emotion elements: pleasure, arousal, and dominance associated with a person's affective reaction [145]. SAM is based on the PAD emotion model of Mehrabian [81]. In the first experiment, the SAM scale is used to evaluate how participants perceive emotional valence and arousal of screen captured still images of the virtual character facial expressions generated by the RealAct system. In addition, I used the SAM scale in my first web-based experiment to investigate if participants attribute the behaviour of the virtual character to being submissive or dominant. However, feedback from participants showed that having TIPI and SAM questionnaires together made the experiment for some of them cumbersome and confusing. I believe since SAM scale is a pictorial and TIPI was a set of paired adjectives measured using a Likert scale, shifting back and forth between them was hard for some subjects. Moreover, to explain both of the scales instruction section of the experiment was probably long and hard to follow. Thus, in the second web-based experiment, I replace the SAM with a Likert scale with a range from Dominant-Controlling to Submissive-Controlled which had the same structure as TIPI.

SAM scale consists of 3 sets of 7 figures, each arranged along a continuum. The figures are used to rate how participants felt while viewing each picture. The first set is the happy-unhappy scale. One extreme of the scale is for feeling pleased, contented, and satisfied. The other end of the scale is for feeling annoyed and unsatisfied. The excited vs. calm dimension is the second type of feeling displayed. One extreme of the scale is for feeling stimulated, excited, and aroused. The other extreme of the scale is for feeling relaxed, sleepy, and unaroused. The third scale is the dimension of controlled versus in-control. At one end of the scale, there are feelings characterized as completely controlled, influenced, and submissive. At the other extreme of this scale, there are feelings of controlling, influential, in control, and dominant (Figure 4.1) [145].

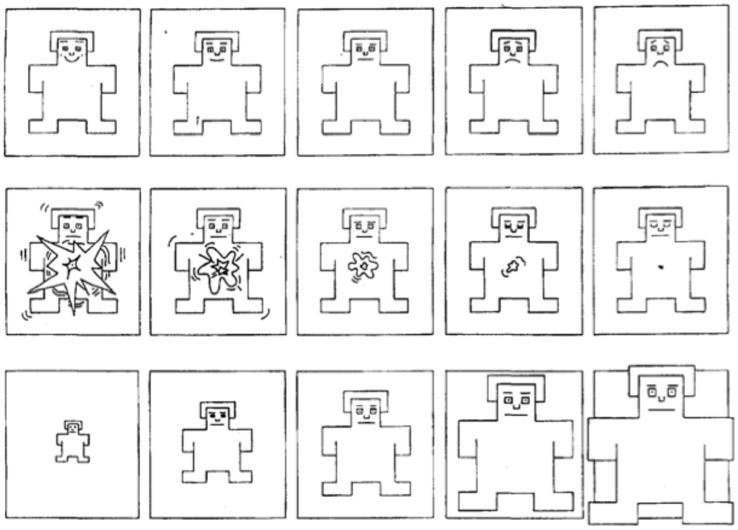


Figure 4.1. The Self-Assessment Manikin (SAM) is used to measures three affective elements of valence (top panel), arousal (middle panel), and dominance (bottom panel).

4.2.3. Procedure

The first experiment was performed to evaluate and ensure the emotions people perceive from the facial expressions generated by the RealAct system are consistent with the intended emotions. To generate facial expressions of the virtual character, I adapted Boukricha et al's proposed map between emotional valence and arousal and facial muscle movements, discussed in 2.2 [82] As it is a common practice in evaluating the association between emotional valence and arousal and facial muscle movements (action units), I picked nine points in the Valence-Arousal space and generated the corresponding facial expressions. These nine points were the combination of three values for valence (neutral, mid, high), and three values for arousal (neutral, mid, high), and are (high valence, medium arousal), (medium-high valence, medium-high arousal), (medium valence, high arousal), (medium-low valence, medium-high arousal), (low valence, medium arousal), (medium-low valence, medium-low arousal), (medium valence, low arousal), (medium-high valence, medium-low arousal), and (medium valence, medium arousal). For example, an image was generated for (medium valence-high arousal) facial expression (Figure 4.2) and another was generated for (medium valence, low arousal) expression. For the figures and list of all generated images please check Appendix B.

Figure 4.2. Two examples of still images of facial expression of the virtual character, generated by the RealAct system, used for the experiment: Left figure is employed for a highly aroused and neutral valence. The right figure is for a neutral arousal and high valence. The intention was to create human-like facial expressions that people show on a daily basis, not extreme ones.

Participants were provided with the link to the experiment which was running on a server on the Simon Fraser University, Surrey campus using jsPsych [168]. jsPsych (http://www.jspsych.org) is a free and open-source software package that simplifies the process of creating a web-browser-based experiment. Using jsPsych, I assembled the experiments by defining a set of plugins for displaying the consent form, instruction forms, showing the stimuli and collecting responses via the keyboard. These plugins are programmed using JavaScript. PHP script was used to save the experiment's result. Participants first read an instruction page that described their task and explained the SAM scale. Then the nine images were presented to participants one at a time, in random order followed by the SAM scale, explained in 4.2. In each page of the experiment, participants saw one of the nine images and three sets of seven figures, each arranged along a continuum to rate how they felt (happy vs. unhappy, excited vs. calm and controlled vs. in-control) while viewing each picture (Figure 4.1). They looked at the pictures and rated each picture in terms of how it made them feel while viewing it. Using a within-subjects design, all participants rated all of the nine images.

4.2.4. Results

A multiple regression analysis was used to test if the intended emotional valence, with the control for intended arousal for the 3D character significantly predicts participants' ratings of the valence. The results of the regression indicated the predictor explained 50% of the variance (R2=.5, F (3,176) =60.96, p<.001). It was found that intended valence significantly predicted the scored emotional valence for the 3D character (β = .7, SD=.05, t (176) =13.25, p<.001) where β represents the coefficient of the intended valence. Rated valence and arousal were coded with a five-point Likert scale with the values between 0 and 4. Figure 4.3, shows the mean and standard error for participants' scores on five intended valences (high, medium-high, medium, medium-low, and low).

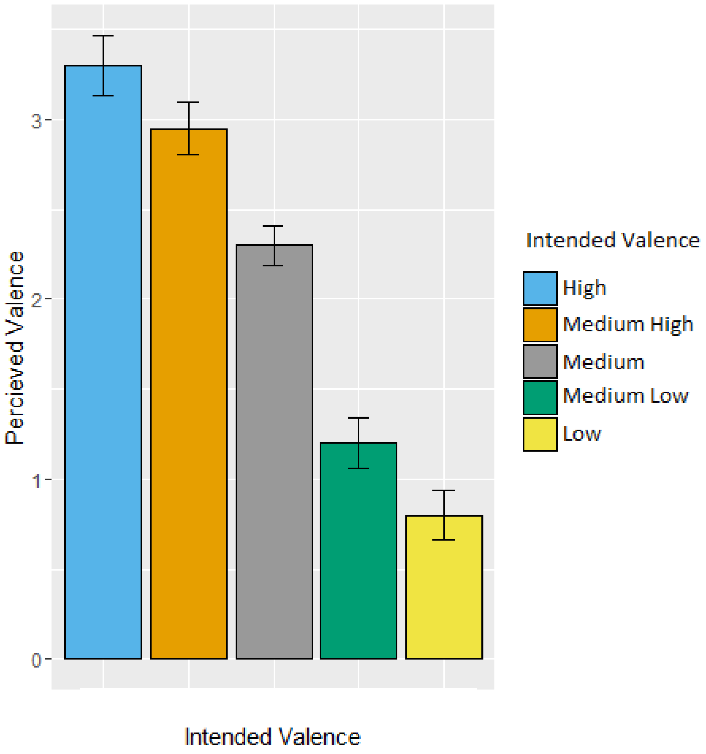


Figure 4.3. **This figure compares the mean and standard error for participants' scores on five intended valences (high, medium-high, medium, medium-low, and low). Five-point Likert scale with the values between 0 and 4 were used to measure each of the intended valences.**

In addition, a multiple regression analysis was used to test if the intended arousal, with the control for intended valence for the 3D character significantly predicts participants' ratings of the arousal. The results of the regression indicated the predictor explained 36% of the variance (R2=.36, F (3,176) =33.37, p<.001). It was found that intended arousal significantly predicted the scored emotional arousal for the 3D character (β = .55, SD=.06, t (176) =8.6, p<.001) where β represents the coefficient of the intended arousal. Rated valence and arousal were coded with a five-point Likert scale with the values between 0 and 4. Figure 4.4, shows the mean and standard error for participants' scores on five intended arousal values (high, medium-high, medium, medium-low, and low). Again, a five-point Likert scale with values between 0 and 4 was used to measure each of the intended arousals.

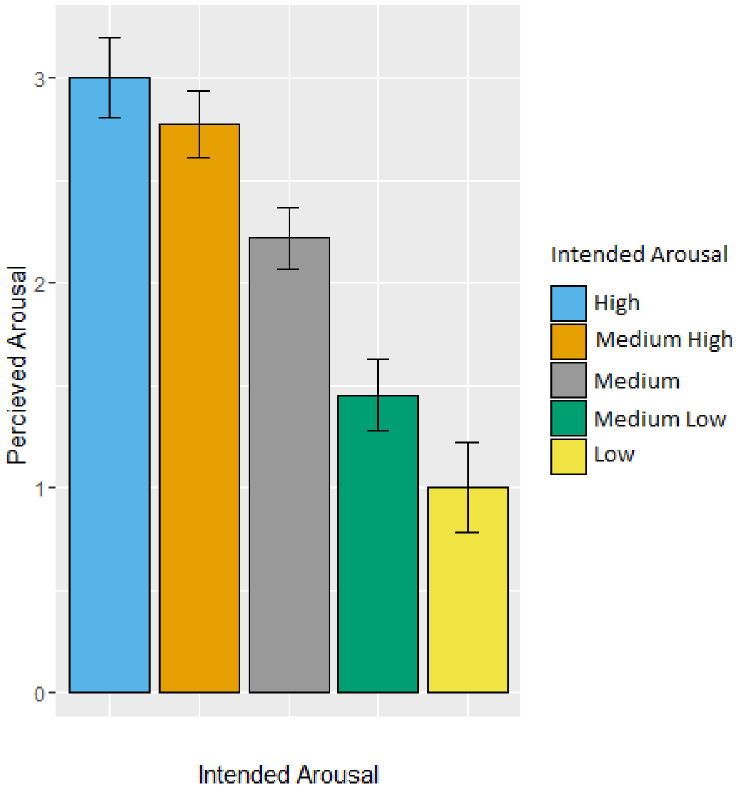


Figure 4.4. **This figure compares the means and standard errors for participants' scores on five intended arousal values (high, medium-high, medium, medium-low, and low). Again, five-point Likert scale with the values between 0 and 4 were used to measure each of the intended arousals.**

4.3. Effectiveness of Behaviour to Convey Personality, 1st Passive Evaluation

After analyzing the result of the first experiment which showed consistency between the perceived and intended emotional facial expressions generated by RealAct, I proceeded to my first video-rating experiment. The online video-rating experiment is a popular method among cognitive scientists since it facilitates the fast collection of generally high-quality data and reduces biases of the experimenters [169] [170]. The two web-based experiments were developed to evaluate the system in a smaller scope and free from complexities of the real-time presential experiment. For instance, during the presential experiment, there is a need for a scenario of the interaction between the virtual character and participants, and the virtual character need to be responsive to the environment inputs. Additionally, since in the real-time presential experiment the actual presence of participants in a specific time in the place is required, possible errors and bugs in the system can damage the whole experiment. Thus, the video-rating experiments helped to fix the bugs and problems of the system prior to running the real-time experiment. During these experiments, each participant rated all of the possible conditions- to avoid carry-over effects.

Independent variables (IV) of experiment one were 1) intended extraversion with two levels (low and high), 2) intended emotional-stability with two levels (low and high), and 3) framing of the body with two levels (partial frame: neck-up or neck-down, and complete frame of the body). By intended, I mean the personality trait that is set as the input parameter of the RealAct system. As discussed in 3.7, the selected input parameter then controls the behaviour of the virtual character by affecting different modules of the system such as controllers of gaze, facial expressions, postures, and gestures. In addition to my main question is if the participants can perceive these personality traits, I also explored the effect of the framing of the videos in how participants perceive the personality traits. Dependent variables (DVs) of all the experiments are perceived extraversion and perceived emotional-stability.

4.3.1. Participants

23 individuals participated in the first web-based experiment in return for course credit. The participants were graduate and undergraduate students of Simon Fraser University and University of British Columbia, aged between 22 and 45 years old. 15 of participants were female and 8 were male.

4.3.2. Measurements

In addition to TIPI test to evaluate the personality of the virtual character, SAM scale is used to evaluate if participants perceived the character as dominant or submissive (using the third dimension of SAM scale). For the details of SAM scale please see 4.2.2.

Ten Item Personality Measure

Drawing on the personality literature, I adapted a method of testing my system that is frequently used by psychologists to measure the individual differences between people [108]. Ten-Item Personality Measure (TIPI) [108] is used to capture the Big Five personality traits: openness, conscientiousness, extraversion, agreeableness and emotional-stability [109]. There is a broad literature which confirms that personality ratings based on TIPI are reliable and repeatedly consistent between raters and can demonstrate strong positive correlations between raters and self-reported personality [108]. The ten item TIPI measure can be found in Appendix A.

After recording the ratings of the 10 scales of the TIPI questionnaire, it is a common practice to analyze the result to average the scores for the positive poles (e.g., Extraversion) with the reverse scores for the opposite pole (e.g., Low Extraversion) to merge the ten scales down to five [108]. The result is five values for dimensions of Big Five.

4.3.3. Procedure

In the web-based experiment 1, participants first read an instruction page that described the process. Next, they were presented with fourteen videos of a physically identical male virtual character showing different personalities through idle behaviour such as rotating head, weight-shift and scratching the body parts. The videos were created as every combination of gesture extraversion level (High, Low), and gesture emotional-stability level (High, Low) and framing (neck-up, neck-down and complete body frame) yielding 12 total clips (2x2x3), in addition to two neutral clips for use in the experiment. Each video took 30 seconds which was short enough to not make the participants tired. In addition, based on psychological data 30 seconds was long enough to make an impression about the personality [50][60][30]. The videos were presented in a random order. After each video, participants were asked a set of 11 questions (10 TIPI questions and one question about the dominancy of the character), with a 7-point Likert scale about the personality of the character. Specifically, they rated the clips in a form that said: "*I see the character as...*", followed by "*1- Extraverted, enthusiastic" (Disagree*

Strongly/Agree Strongly) and “2- Reserved, quiet” (Disagree Strongly/ Agree Strongly) and so forth.

Two partial frames (neck-up and neck-down) and one whole-body frame were used to explore if the framing of the whole body versus a part of the body affects the impression of personalities. For the neck-up frame, the video was zoomed into the face of the character and did not show the neck down. For the neck-down video, the face was neutral and did not have any facial expression. At the end of the experiment, participants were asked a general question about the experiment. The experiment ended with a self-questionnaire in which participants rated the extent to which the pair of traits applied to them. The experiment took, on average, approximately 30 minutes to complete. The subjects were not allowed to replay the videos and return to previous videos to maintain consistency between all the subjects. The stimuli appeared in a random order for each subject. I designed and ran the experiment 1 using jspsych [168]. Python framework was used to save each participant's data as a CSV file on the server. The experiment ran on a server on the Simon Fraser University, Surrey campus.

4.3.4. Results

The following is the result of analysis of data gathered from the first web-based experiment. As discussed in 4.3, during this experiment participants rated the videos of the nonverbal behaviour of the virtual character. These videos were generated by the RealAct system by setting four different personalities for the character. Effects of two kinds of framings in the perception of personality were explored (partial vs. complete). The partial framing is when a part of the character body is expressive while the complete frame is when the whole body is expressive (for details see 4.3).

Impression of Extraversion

For the first web-based experiment, a multiple regression analysis was used to test if the intended extraversion for the 3D virtual character significantly predicts participants’ rating of the extraversion. The effect of intended emotional-stability, framing of videos, and participants’ individual effect, and their associated interaction terms with intended extraversion were controlled. Participants’ individual effect verifies if an individual tends to rate the videos higher or lower, in general, it would not affect the results. The individual effect also captures the effect of participants' sex, and participants' self-rate extraversion. The result of the regression indicates that the predictors explained 36% of the variance (R2=.36, F (5, 248) =19.74, p<.001). I find that intended extraversion significantly predicted the scored extraversion for the 3D character (β = 1.08, SD=.22, t (248) =4.81, p<.001) where β represents the coefficient of the intended extraversion. Rated extraversion, rated emotional stability, and participants' self-rate for extraversion were coded with a seven-point Likert scale with the values between 0 and 6. Participants' sex had the value of 0 for male and 1 for female. Framing of the video had the value of 0 for partial and 1 for complete frame of the body.

Impression of Emotional-Stability

In addition, a multiple regression analysis was used to test if the intended emotional stability for the 3D virtual character significantly predicts participants' rating of the emotional stability. The effect of intended extraversion, framing of videos, and participants' individual effect, and their associated interaction terms with intended emotional stability were controlled. The participants' individual effect captures the effect of participants' sex and participants' self-rate emotional stability. The result of the regression indicates that the predictors explained 53% of the variance (R2=.53, F (5, 248) =37.21, p<.001). Intended emotional stability significantly predicted the scored emotional stability for the 3D character (β = 1.33, SD=.22, t (248) =5.94, p<.001) where β represents the coefficient of the intended emotional stability. Rated extraversion, rated emotional stability, and participants' self-rate for extraversion were coded with a seven-point Likert scale with the values between 0 and 6. Participants' sex had the value of 0 for male and 1 for female. Framing of the video had the value of 0 for partial and 1 for complete frame of the body.

Effect of Framing

In the first experiment, the results of the regression show a significant correlation between the framing of the character's body (e.g. how much of the body of the character is visible to the participants) and the perception of the extraversion (β = .78, SD=.3, t(248) = 2.58, p<.005) where β represents the coefficient of the framing of the body.

Based on the results of the regression, there was a significant positive correlation between the complete frame of the body and the perception of extraversion which supports hypothesis 4, see 1.2. This result was expected since seeing the whole body of the character provided the participants with more channels of information (both facial expressions and hand and body gestures and postures) which leads to a stronger perception of the personality.

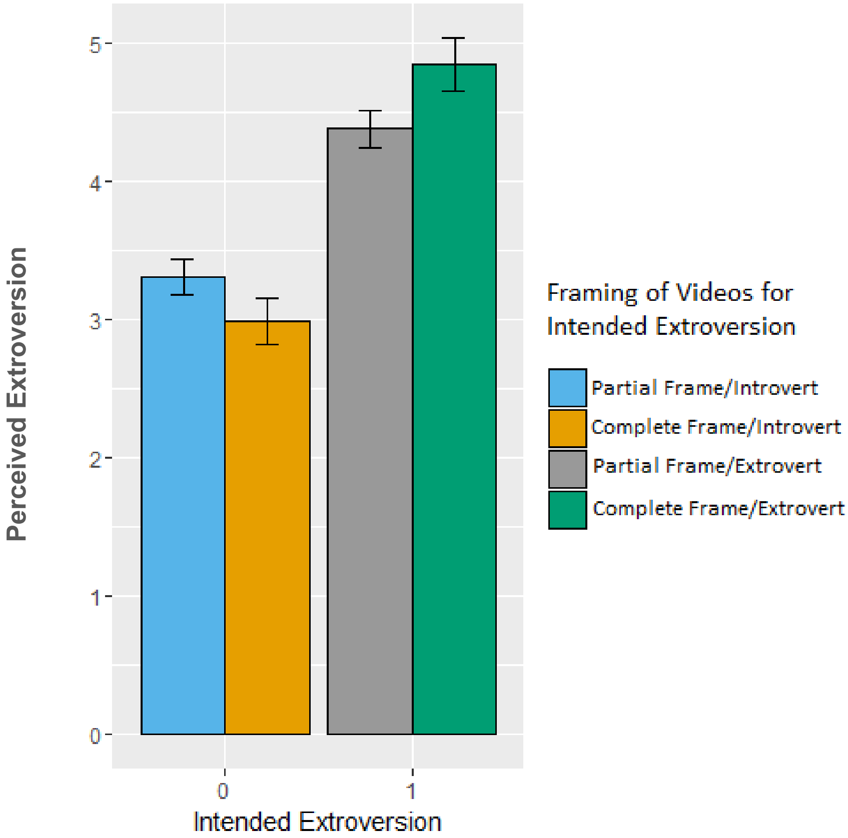


Figure 4.5. **This plot shows the effect of framing, in the first web-based experiments on the perception of the extraversion for the intended extraversion (see hypothesis 4). Partial-Frame refers to showing parts of the body (either only facial expression or focusing on the hand gestures and torso movements). Complete-Frame refers to framing the whole body in the videos. The y-axis shows the perceived value of extraversion by the participants rated using a 7-point Likert scale (1 is used for "disagreeing strongly with the character being an extravert" and 7 is "agreeing strongly"). The x-axis is the intended extraversion, generated by RealAct through nonverbal behaviour, with two values '0' for Low (low-extravert) and '1' for High (highly-extravert).**

Figure 4.16, shows the difference between how participants interpreted the low and high extraversion for two types of the framing of the body. The plot shows that participants rated the extraversion stronger for the complete frame in comparison with the partial frame.

Additionally, the complete frame of the body had a significant positive effect on impression of emotional-stability (β = 0.63, SD= 0.3, t value (248) =2.11, $p<0.05$) where β represents the coefficient of the framing of the body. Figure 4.16, emphasizes the difference between how participants interpreted the low and high emotional-stability for two types of the framing of the body. The plot shows that participants rated the emotional-stability stronger for the complete frame in comparison with the partial frame.

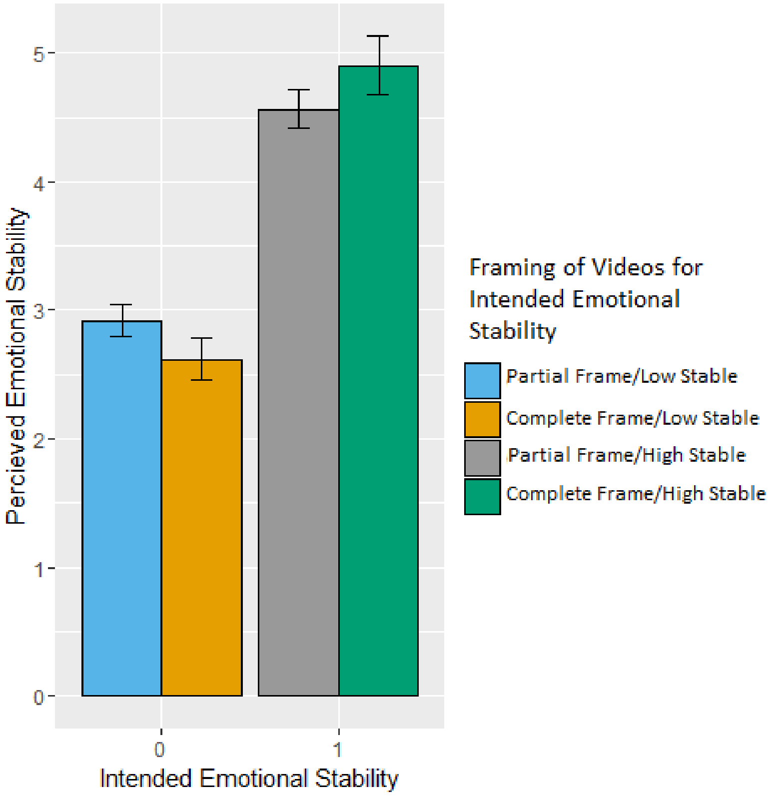


Figure 4.6. **This plot shows the effect of framing, in the first web-based experiments on the perception of the emotional-stability for the intended emotional-stability (see hypothesis 4). Partial-Frame refers to showing parts of the body (either only facial expression or focusing on the hand gestures and torso movements). Complete-Frame refers to framing the whole body in the videos.**

4.4. Effectiveness of Behaviour to Convey Personality, 2nd Passive Evaluation

The second web-based experiment was designed using the feedback I received from participants during the first experiment. In the first experiment, for some of the videos, the face did not have any expression but was visible. Since leaving the emotionless face in the videos could be misleading, and affect the impression of personality, the face was filtered out from the videos for the neck-down frame condition by using a Perl script [148] to simply position an image of a gray rectangle, as a mask, over the face of the character in the videos. In addition, having SAM scale and TIPI at the same time seemed to be cumbersome and confusing for participants. Thus, I replaced the SAM scale with one question with a Likert scale with a range from Dominant-Controlling to Submissive-Controlled which had the same structure as TIPI. Same as the first experiment, IVs of the experiment two were 1) intended extraversion with two levels (low and high), 2) intended emotional-stability with two levels (low and high), and 3) framing of body with two levels (only face, only torso down, the complete frame of body). In addition, DVs of the experiment were the perceived extraversion and emotional-stability.

4.4.1. Participants

A total of 46 participants participated in the second web-based experiment in return for an extra course credit. The participants were graduate and undergraduate students of Simon Fraser University and University of British Columbia, aged between 22 and 45 years old. Thirty of participants were female and sixteen were male.

4.4.2. Measurement

Similar to experiment 1, TIPI measure was used to evaluate the impression of personality through 10 questions. For details of the TIPI test please see section 4.3. In addition, a question was added to evaluate the impression of dominance. Same as TIPI questions, I used a 7-point Likert scale for the range of answers. I also used the same structure of TIPI by using two pairs of adjectives in two ends of the scale: Dominant-Controlling to Submissive-Controlled.

4.4.3. Procedure

The procedure of experiment 2 was similar to experiment 1, except mainly two improvements performed based on feedback received during the first experiment First, a filter was applied to the face of the characters for the neck-down frame condition. In the first experiment, the face did not have any expression but was visible. An emotionless face combined with the emotionally-expressive body gestures could have been perceived as an unnatural behaviour. To solve this problem in the web-based second experiment, in the videos that I wanted to have a partial frame of the body I blurred out the faces. Figure 4.7, shows a snapshot from a video with the face of the character being blurred out (The covered faces helped to avoid the confounding influence of facial expression).

Figure 4.7. A snapshot of the web-based experiments' videos: in four of the clips participants watched, the face was blurred and the focus was on the neck-down nonverbal behaviour of the character similar to the figure above.

Secondly, feedback from some of the participants showed that having TIPI and SAM questionnaires together made the experiment confusing for them. Thus, I replaced the SAM with one question about dominance. Same as TIPI questions, I used a 7-point Likert scale for the range of answers. I also used the same structure of TIPI by using two pairs of adjectives in two ends of the scale: Dominant-Controlling to Submissive-

Controlled. Thus, participants were shown 14 videos of a character and were asked a set of 11 questions about the personality and dominance of the character.

As experiment 1, at the end of this experiment, participants were asked a general question about the experiment, followed by a self-questionnaire in which they rated the extent to which the pair of traits applied to them. In addition, jspsych and PHP script were respectively used to execute and save the experiment's result [168]. The experiment was running on a server on the Simon Fraser University, Surrey campus.

4.4.4. Results

As discussed in 4.4, during this experiment similar to the first experiment, participants rated the videos of the nonverbal behaviour of the virtual character generated by the RealAct system. The videos showed a partial or a complete frame of the body. In experiment 2, filters were used to cover the face when it did not have any emotional expression. The face was blocked out by the gray square to encourage subjects to attune to the character's body movement.

Impression of Extraversion

For the second web-based experiment, a multiple regression analysis was used to test if the intended extraversion for the 3D virtual character significantly predicts participants' rating of the extraversion. The effect of intended emotional-stability, framing of videos, and participants' individual effect, and their associated interaction terms with intended extraversion were controlled. Participants' individual effect verifies if an individual tends to rate the videos higher or lower, in general, it would not affect the results. The individual effect also captures the effect of participants' sex, and participants' self-rate extraversion. The result of the regression indicates that the predictors explained 45% of the variance (R2=.45, F (5, 501) =63.36, p<.001). I find that intended extraversion significantly predicted the scored extraversion for the 3D character (β = 1.25, SD=.15, t (501) =8.3, p<.001) where β represents the coefficient of the intended extraversion. Rated extraversion, rated emotional stability, and participants' self-rate for extraversion were coded with a seven-point Likert scale with the values between 0 and 6. Participants' sex had the value of 0 for male and 1 for female. Framing of the video had the value of 0 for partial and 1 for complete frame of the body.

Impression of Emotional-stability

For the second web-based experiment, a multiple regression analysis was used to test if the intended emotional stability for the 3D virtual character significantly predicts participants' rating of the emotional stability. The effect of intended extraversion, framing of videos, and participants' individual effect, and their associated interaction terms with intended emotional stability were controlled. The participants' individual effect captures the effect of participants' sex and participants' self-rate emotional stability. The result of the regression indicates that the predictors explained 45% of the variance (R2=.45, F (5, 501) = 67.85, p<.001). Intended emotional stability significantly predicted the scored emotional stability for the 3D character (β = 1.48, SD=.17, t (501) =8.64, p<.001) where β represents the coefficient of the intended emotional stability. Rated extraversion, rated emotional stability, and participants' self-rate for extraversion were coded with a seven-point Likert scale with the values between 0 and 6. Participants' sex had the value of 0 for male and 1 for female. Framing of the video had the value of 0 for partial and 1 for complete frame of the body.

Effect of Framing

In the second experiment, the results of the regression show a significant correlation between the framing of the character's body (e.g. how much of the body of the character is visible to the participants) and the perception of the extraversion (β = .66, SD=.16, t (501) = 4.05, p<.001) where β represents the coefficient of the framing of the body. Based on the results of the regression, there was a significant positive correlation between the complete frame of the body and the perception of extraversion which supports hypothesis 4, see section 1.2. This result was expected since seeing the whole body of the character provided the participants with more channels of information (both facial expressions and hand and body gestures and postures) which leads to a stronger perception of the personality. The bar plot, demonstrated in Figure 4.8, shows the difference between how participants interpreted the low and high extraversion for two types of the framing of the body.

Additionally, the complete frame of the body had a significant positive effect on impression of emotional-stability (β = 0.66, SD= 0.16, t value (501) =4.05, p<.001) where β represents the coefficient of the framing of the body. Figure 4.9, shows the difference between how participants interpreted the low and high emotional stables for two types of the framing of the body.

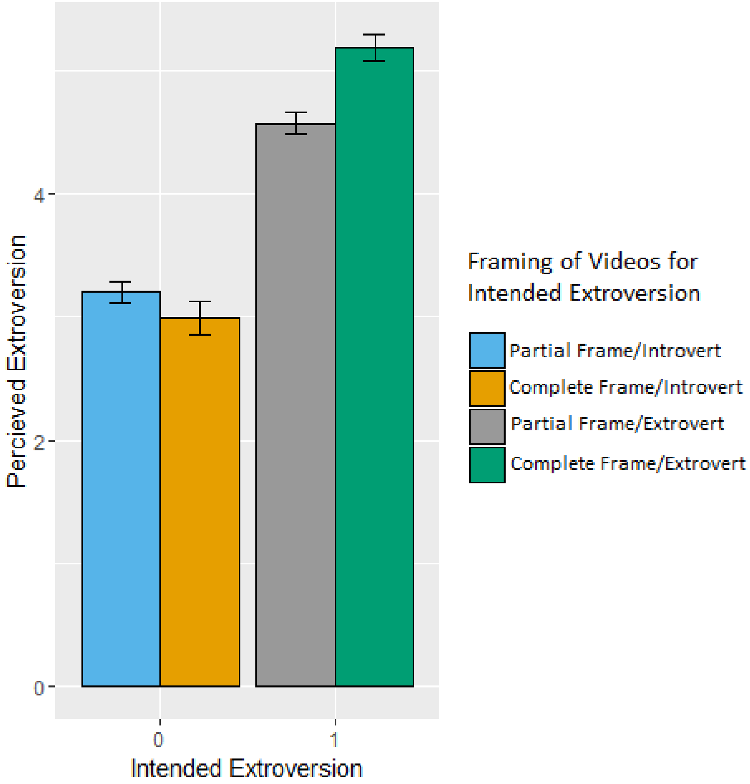


Figure 4.8. **Effect of the framing, in the web-based video rating experiments, on the perception of the extraversion for the intended extraversion (H4): In the plot, LE and HE respectively stand for Low Extravert and High Extravert. Partial-Frame refers to showing parts of the body (either only facial expression or focusing on the hand gestures and torso movements). Complete-Frame refers to framing the whole body in the videos.**

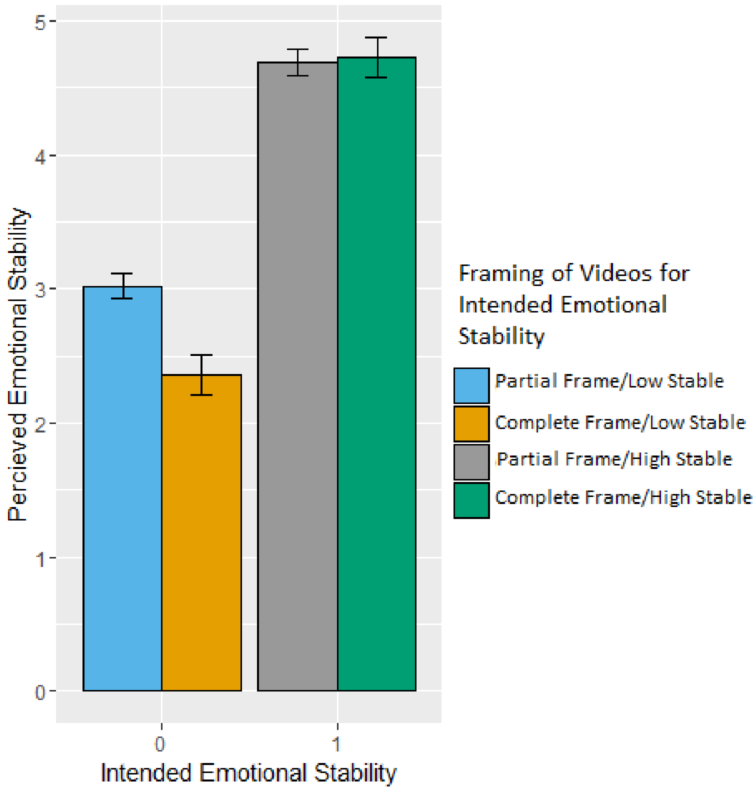


Figure 4.9. **Effect of framing, in the web-based video rating experiments, on the perception of the emotional-stability of the intended emotional-stability generated by the system (H4): Partial-Frame refers to showing parts of the body and Complete-Frame refers to framing the whole body in the videos.**

4.5. Effectiveness of Behaviour to Convey Personality, Comprehensive Interactive Evaluation

Using the feedback received from the experiment 1 and 2, the RealAct system was continuously refined and errors and bugs of the system were fixed. Based on the participants' feedback, some of the animations of the virtual character's behaviour were jumpy, did not look realistic, or were not played at a realistic speed. I adjusted the speed of animations and removed the unrealistic ones. Additionally, I realized since the rate of behaviour commands sent to the animation engine from multiple controllers (gaze, pose, gestures and facial expressions) were high, some of the animations were filtered out automatically by the animation engine. For the presential experiment, there are a lot of high priority animations which are responsive to the scenario of interaction or environment inputs and not playing them can affect the experience dramatically (e.g. during the rock/paper/scissors game, at a certain point the character should play his hand). To avoid this problem, I developed a behaviour scheduler explained in section 3.9.

During the presential experiment participants dynamically interacted with the virtual character which behavioural acts were continuously controlled by the RealAct system. The RealAct system is designed in the way where it attempts to generate proper behaviour for the character to be able to maintain a natural interaction with users. One of the steps along this line has been to develop some scenarios that allow users to interact with the character. During the interaction following the story of the scenario, we can see if the character sustains an interaction with a user and how users judge the experience. The designed test case scenario reduces the problem set while developing and testing the system. Additionally, to create a better impression of personality traits, an interactive environment is a strong help. The goal was to create an easy-to-learn and engaging scenario that provides an interactive environment with no speech. The reason to avoid the speech was to concentrate only on the nonverbal behaviour of the character. Several interaction scenarios were explored to choose a proper interaction story which is based on nonverbal behaviour and is engaging for participants. In this section, you can find a review these scenarios followed by a detailed description of the process of the presential experiment.

4.5.1. Test Case Scenarios

The RealAct system focuses on dynamic interaction with users because I believe an interactive environment is a necessity in creating a stronger perception of personality traits. The test case scenarios were designed to reduce the problem set while developing and testing the RealAct system. The goal was to create an easy-to-learn and engaging scenario that provides an interactive environment with a minimum dialog. The first scenario of interaction I designed was a minesweeper. Although the minesweeper facilitated the nonverbal setup I required for the experiment, the emotional exchange during the game was not adequate. Thus, I explored the rock/paper/scissors game (RPS) for the scenario of interaction. Since RPS provided a more engaging scenario and involved more emotional reactions during different steps of the game, I selected RPS as the scenario of interaction for evaluation of the system. Nevertheless, these two scenarios are only examples of possible applications of the system and are designed for my specific needs. The system's modular design facilitates replacing the scenarios, and future researchers can use the system to test their own designed scenarios by doing small adjustments to the system.

Minesweeper Scenarios

Three types of minesweeper like scenarios were designed to investigate the best way to provide an infrastructure for revealing personality through nonverbal behaviour. The first version involved having the character as a passive observer of users' movements in a field while showing emotional reactions to what the user does. In the passive version, no gestures were involved. The second version of the scenario involved interactive, cooperative 3D virtual characters that used pointing and gestures to help the users meet the goal of the interaction. In the third version, the character was randomly selected to be not cooperative. In that case, the character guided the user to fail (Figure 4.10).

Figure 4.10. In the passive scenario, the character is a passive observer of users' actions while showing emotional reactions to what the user does. In an interactive scenario, the character uses pointing and other gestures to help the users meet the goal of the interaction.

During the minesweeper game, the player starts from a specified point. The human player will be positioned in a field before the monitor. The monitor shows the character from the torso and up (Figure 4.11). All the possible destinations are marked. One of these marks is specified as the target, and several of them are specified as mines. The positions of the target and mines are known to the character but not to the player. The player knows that the positions of the mines and the target are revealed to the character. The player's objective is to reach the target while avoiding the mines. The character tries to guide the player in this field using gestures such as pointing. The player can choose to trust the character and follow the guides or ignore the character's directions. The user wins the game if she reaches the target.

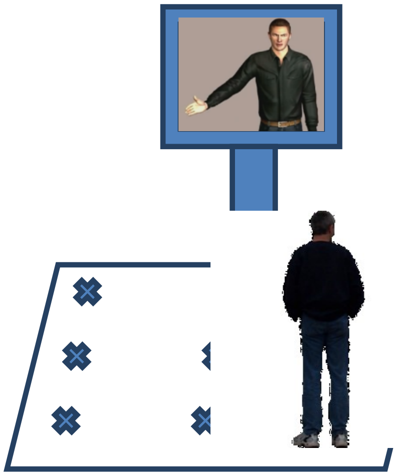


Figure 4.11. The user's objective is to reach the target while avoiding the mines. The character tries to guide the user in the field using gestures such as pointing. All the possible destinations for the user are marked.

A prototype using the scenario with human-human interaction is performed first, to evaluate the scenario and extract the range needed for motion capture and 3D animation. I designed a prototype in which I recorded the interaction of two humans instead of a 3D virtual character and a human. The recorded human behavioural acts were analyzed and used as a reference for generating the 3D virtual characters' nonverbal behaviour. Different scenarios are prototyped with humans and compared to investigate which one is the best candidate for the actual experiment (Figure 4.12).

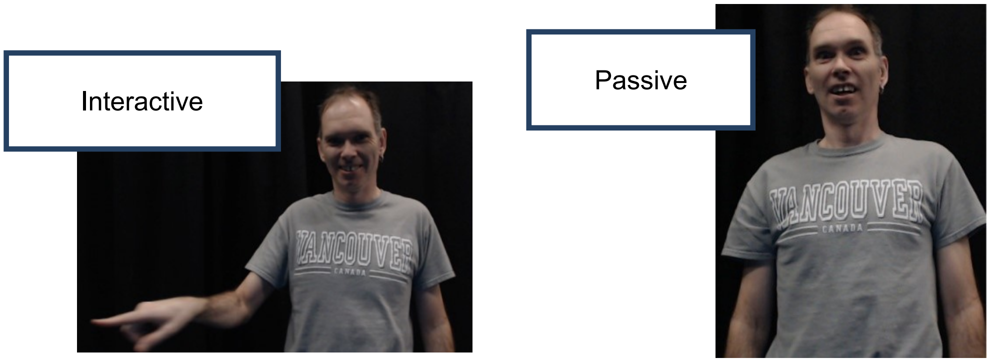


Figure 4.12. Prototype of a passive character versus an interactive character

Analyzing the videos from the prototype led to the following results: a list of possible gestures for the motion capture session was extracted from the videos. This helped to limit the number of possible movements. One problem that occurred in the minesweeper scenario pilot is that guiding the users with pointing limits other hand gestures like self-touching. To solve this problem more time for idle behaviour before the start of and during the interaction will be specified. The videos recorded from the interaction of two humans in pilot gave us some direction on the parameters of behaviour such as speed, space, and repetition.

Rock/Paper/Scissors Game Scenarios

The rock-paper-scissors (RPS) game scenario was designed to provide a chance for interaction between a user (biological human) and a virtual human in real-time with no need to conversation (Figure 4.14). The turn taking nature of the interaction is controlled by the RPS game module. During the game, the virtual character plays multiple rounds of the rock-paper-scissors game with the user. A GUI (graphical user interface) is used for synchronizing the RPS game. GUI is updated based on the states of the interaction (Ready, Go, Hands, Result) (Figure 4.13). In the “Go” state, a random hand gesture is generated for the character.

READY

Your hand: ?

Agent's hand: ?

Winner: ?

Your total wins: 0

Agent's total win: 0

Game Number: 0 / 10

Figure 4.13. **Graphical User Interface for synchronizing the rock-paper-scissor game played between a user (biological human) and a virtual human in real-time**

Gestures and poses used in Rock Paper Scissor Scenario are mainly pre-defined animations that can be grouped, blended and partially dynamically controlled. Some of the poses and gestures used are provided by Smartbody animation toolkit and some are generated by iVizlab's animation team. Some of the parameters of the animations such as speed, starting and ending time of the movements can be controlled dynamically in the simulation. Personality type, which is an input parameter to this module, affects the speed of the gestures. For example, a highly extravert character shows faster rock, paper, and scissors hand gestures.

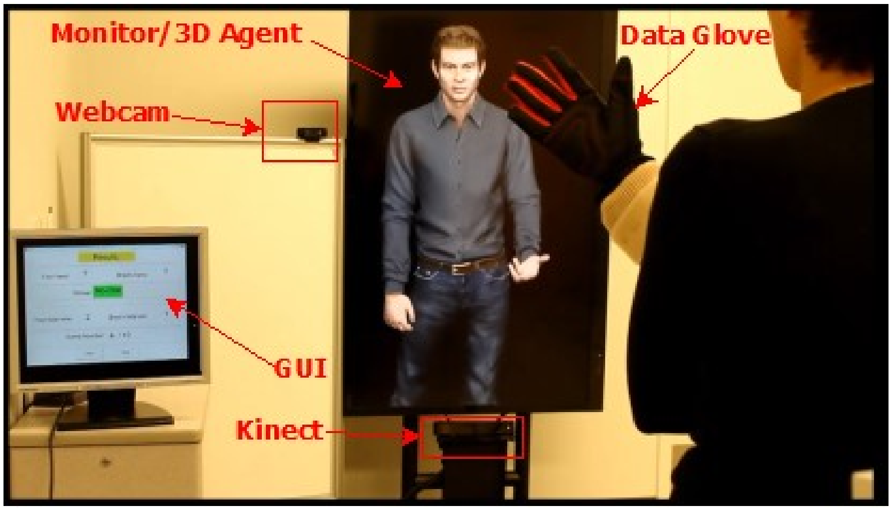


Figure 4.14. **Experiment setup**

In addition to minesweeper and RPS scenario, I developed a few simple scenarios, as a proof of concept for a large range of possible applications of the RealAct system. I developed a set of modules in RealAct to receive streams of inputs of sensors such as Kinect [127], an overhead camera, camera, EMG (muscles facial electromyography) [98], and data from SHORE application [97]. SHORE, developed by Fraunhofer research center [97], receives the input stream from a webcam and forward information such as emotional expression of the user's facial expressions. Using these inputs, the virtual character can react to the facial expressions and gestures of the users such as adjusting his personal space with the user knowing user's location in the space.

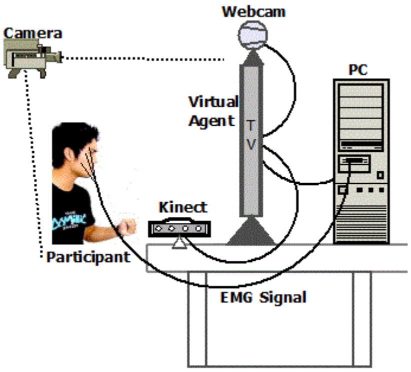


Figure 4.15. A participant plays with the virtual character (right) which behaves based on commands in receives from the RealAct system. A video camera records the interaction of both sides.

In this real-time user interaction experiment, I investigated if a virtual character that shows contingent smile behaviour will create an impression of low social status. Using EMG sensors or SHORE emotional face recognition inputs the system recognized the smile of the users. In the Responsive session, the virtual character mimics the smile of the human participants and in Non-contingent session, the character provides random smiles that are unsynchronized with the human participant's smile. After each of these sessions, the user evaluates the social status of the character (Figure 4.15).

Independent variables (IV) of the presential experiment were 1) intended extraversion with two levels (low and high), and 2) intended emotional-stability with two levels (low and high). By intended, I mean the personality trait that is set as the input parameter of the RealAct system. The selected input parameter then controls the behaviour of the virtual character by affecting different modules of the system such as controllers of gaze, facial expressions, postures, and gestures. Dependent variables (DVs) of all the experiments are perceived extraversion and perceived emotional-stability. In addition to these main dependent variables, I also investigated the correlation between the IVs and other TIPI items (Openness, Conscientiousness, and Agreeableness), and dominance. I like to explore if participants will attribute other personality traits to the gestures, postures and facial expressions of the virtual character, generated by the RealAct system.

4.5.2. Participants

A total of 41 participants participated in the presential real-time experiment in return for an extra course credit. The participants were graduate and undergraduate students of Simon Fraser University and University of British Columbia, between 22 and 45 years old. 25 of participants were female and 16 were male.

4.5.3. Measurement

A paper version of TIPI measure was used to evaluate the impression of personality through 10 questions. For details of the TIPI test please see section 4.3. As experiment 2, one question was added to evaluate the impression of dominance using two pairs of adjectives in two ends of the scale: Dominant-Controlling to Submissive-Controlled.

Presence Questionnaire and Semi-structured Interview

After completing the presential interaction experiment, I asked the participants two open-ended questions to evaluate their overall experience: '*How was the experience?*' and '*Did you enjoy the experience in general*?' The entire process of playing the game and interviews was video-captured with participants' permissions and is available for future research. I gave participants an adapted version of Sanchez-Vives and Slater's questionnaire designed for evaluating a sense of presence [147]. The questionnaire was originally developed to investigate the sense of presence in a virtual reality environment. I adapted the questionnaire to my scenario (real-time interaction between the virtual character and participants) to measure how participants evaluated their presence and how believable they found the experience in comparison with playing the game with a human. I mainly asked two questions. The first question was "*Please rate your sense of playing with Brad, on the scale from 1 to 7, where 7 represents your* *normal experience of playing with a human*.”, followed by “*I had a sense of being there in the field: 1. not at all ... 7. very much.*”. The second question was “*When you think back about your experience, do you think of the game more as images that you saw from a computer-made character or more as a game you played with someone?*” followed by “*Please answer on the following 1 to 7 scale: The game seems to me to be more like... 1. images that I saw of a computer-made character...7. a game I played with someone”*.

4.5.4. Procedure

Experiment 3 was run after applying the feedback received from the two web-based experiments (see 4.5). The rock/paper/scissors game (RPS) discussed in 4.5, was designed and implemented for the real-time presential experiment, as an easy-to-learn and engaging scenario with a minimum need for the conversation. The experiment started by asking participants to review and sign the consent form. Then, they answered the TIPI questions to rate their own personality. Next, they wore a data glove and did a practice round of the RPS game with the character, during which I explained the process and the designed graphical user interface (GUI). Player’s hand gestures were captured using a data glove and were fed to the system. The data glove which was developed in our lab specifically for the RealAct system included three sensors which measured if hand’s fingers are bent. The participants stood in front of a 60-inch TV monitor demonstrating approximately realistic sized, from the knee-up virtual character (see Fig. 6). After performing a practice round, participants started with the experiment. The experiment consisted of 5 sessions of the RPS game for 5 different personalities. The behaviour of the virtual character was controlled by the RealAct personality model. In the five sessions, a combination of four different personalities and a neutral behaviour (no personality parameter in effect) were applied to the character. As a result, there were five distinctive behavioural acts for the combination of extraversion (high and low), emotional-stability (high and low) and a neutral behaviour. In each of these sessions, 5 rounds of rock/paper/scissors game were played to give participants enough time to make an impression about the character. Each session of the game took approximately 2 minutes which psychological research shows that is enough time to make an impression about the personality [60][149]. The GUI displayed on a separate smaller monitor in view of the user was designed in Matlab to facilitate and synchronize the game. The game starts with GUI announcing and demonstrating ‘Ready…Go’ (Figure 4.13). Then, the 3D virtual character and the participant both simultaneously showed a rock, paper or scissor hand gesture while the GUI was updated. The character’s choice of hand gesture was random from the three possibilities. The winner of the game and total wins so far were calculated and updated in GUI. Participants went through the sessions with different orders to avoid the order effect. Finally, after the five sessions of the game, I did a short semi-structured interview with participants asking about their general experience. For instance, I asked them if they enjoyed the experience. I video-captured most of the interaction of the participants with the virtual character and the interview I had with them, with their permission. In addition, I gave them a questionnaire about the sense of presence during the interaction with the virtual character (see section 4.5). Example videos are archived with permission online (see Appendix B).

4.5.5. Results

The results of the two web-based experiments appeared to confirm that the nonverbal behaviour generated by the RealAct system creates an impression of both extraversion and emotional-stability personality traits for the 3D virtual character. The presential real-time experiment explored if the system is able to maintain the impression of personality during a real-time dynamic interaction between the virtual character and human participants, and if having the real-time interaction amplifies this impression.

Impression of Extraversion

For the first web-based experiment, a multiple regression analysis was used to test if the intended extraversion for the 3D virtual character significantly predicts participants’ rating of the extraversion. The effect of intended emotional-stability and participants’ individual effect, and their associated interaction terms with intended extraversion were controlled. The individual effect captures the effect of individual, participants’ sex, and participants’ self-rate extraversion. The result of the regression indicates that the predictors explained 78% of the variance (R2=.78, F (3, 120) =123.6, p<.001). I find that intended extraversion significantly predicted the scored extraversion for the 3D character (β = 2.93, SD=.2, t (120) =14.05, p<.001) where β represents the coefficient of the intended extraversion. Rated extraversion, rated emotional stability, and participants' self-rate for extraversion were coded with a seven-point Likert scale with the values between 0 and 6. Participants' sex had the value of 0 for male and 1 for female.

Table 4.1. Regression results for the correlation between the intended extraversion with perceived extraversion, using complete frame of the character (vs partial frame), and being in the real-time presential experiment (vs. the web-based experiments) are highly significant

Significance level: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

	Estimate (β)	**Std. Error**	**t value**	**Pr(>|t|)**
Extraversion	2.92683***	0.20838	14.046	>0.001

Figure 4.16, shows the distribution of participants' extraversion scores for the character with an intended low extraversion vs. intended high extraversion. The y-axis shows the perceived value of extraversion by the participants rated using a 7-point Likert scale (1 is employed for "disagreeing strongly with the character being an extravert" and 7 is "agreeing strongly"). The x-axis is the intended extraversion, generated by the RealAct through nonverbal behaviour, with two values low-extravert and highly-extravert. The plot shows a clear difference between the participants' extraversion score of the intended low extravert character (with means of approximately 2.5), and the intended highly extravert character (with the mean of approximately 5.5).

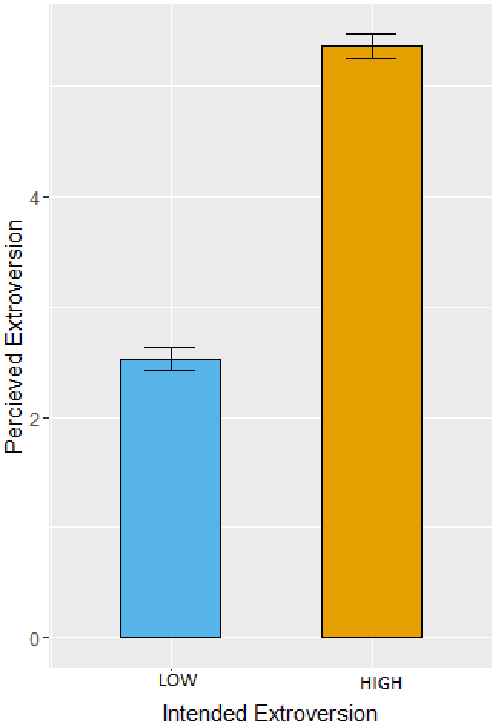


Figure 4.16. **The bar plot shows the scores for intended extraversion and perception of the extraversion (addressing hypothesis 1).**

For the intended extraversion, there was no main effect of the participants' sex, implying that the ratings of the personality were consistent across male and female participants. Furthermore, I tested for a correlation between the participant's own personality ratings and their ratings of character on the same scales. Regression results showed that subjects' own personality does not affect how they evaluate the personality of the virtual character as well.

Impression of Emotional-Stability

In addition, a multiple regression analysis was used to test if the intended emotional stability for the 3D virtual character significantly predicts participants' rating of the emotional stability. The effect of intended extraversion, participants' individual effect, and their associated interaction terms with intended emotional stability were controlled. The participants' individual effect captures the effect of participants' sex and participants' self-rate emotional stability. The result of the regression indicates that the predictors explained 70% of the variance (R2=.7, F (3, 120) =73.13, p<.001). Intended emotional stability significantly predicted the scored emotional stability for the 3D character (β = 2.56, SD=.25, t (120) =10.42, p<.001) where β represents the coefficient of the intended emotional stability. Rated extraversion, rated emotional stability, and participants' self-rate for extraversion were coded with a seven-point Likert scale with the values between 0 and 6. Participants' sex had the value of 0 for male and 1 for female (Table 4.2 and Figure 4.16).

Table 4.2. Regression results for the correlation between the intended emotional-stability and perceived emotional-stability, using complete frame of the character (vs partial frame) and being in the real-time presential experiment (vs. web-based experiment)

Significance level: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

	Estimate(β)	Std. Error	t value	Pr(>|t|)
Emotional-stability	2.56098***	0.24569	10.42	>0.001

In addition, the distribution of participants' perceived emotional-stability for the character for the two levels of emotional-stability (low and high) is plotted in Figure 4.17. The y-axis shows the perceived value of emotional-stability by the participants rated using a 7-point Likert scale (1 is employed for disagreeing strongly with the character being emotionally-stable and 7 is to agree strongly). The x-axis is the intended emotional-stability, generated by RealAct through nonverbal behaviour, with two values low emotional-stability and high emotional-stability. The plot shows a clear difference between the participants' emotional-stability score of the intended low emotional-stable character (with the median of approximately 3), and the intended highly emotional-stable character (with the median of approximately 5.1).

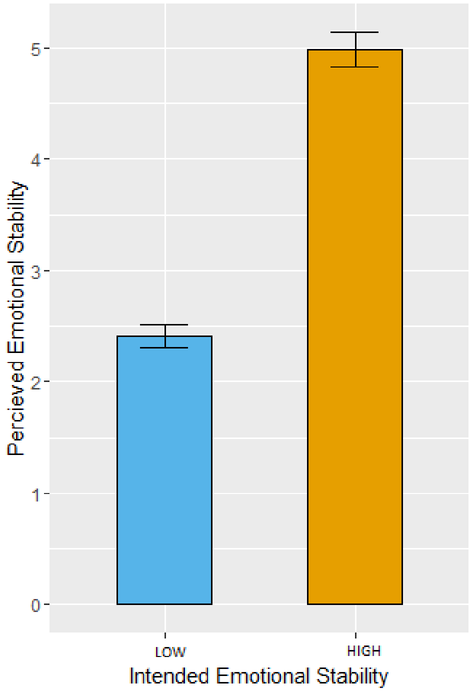


Figure 4.17. The y-axis of the bar plot shows the perceived value of emotional-stability by the participants rated using a 7-point Likert scale (1 is for disagreeing strongly with the character being emotionally-stable and 7 is for agreeing strongly). The x-axis is the intended emotional-stability, generated by the RealAct through nonverbal behaviour, with two values low emotional-stability and high emotional-stability (hypothesis 2).

As for the extraversion, for the intended emotional-stability, there was no main effect of participants' sex or participants' own personality, implying that in general, the ratings of personality were consistent across male and female participants with different personality types. I also explored the interaction effects between the intended extraversion and intended emotional-stability. It is important to note that emotional-stability had absolutely no effects on judgments of extraversion. I also examined the interaction effect of intended extraversion and intended emotional-stability on the perception of emotional-stability. The result showed that intended extraversion had also no effect on the perception of emotional-stability. Therefore, I had a sharp distinction between the perception of extraversion and emotional-stability.

Presential results in Comparison with Other Experiments

The bar plot, demonstrated in Figure 4.18, depicts the difference between how participants interpreted the low and high extraversion for the presential versus the web-based experiments. The plot shows that participants rated the extraversion stronger for the presential experiment (for the intended low-extravert (LE), presential scores were lower, and for the intended highly extravert (HE) presential score were higher). This result is aligned with our third hypothesis.

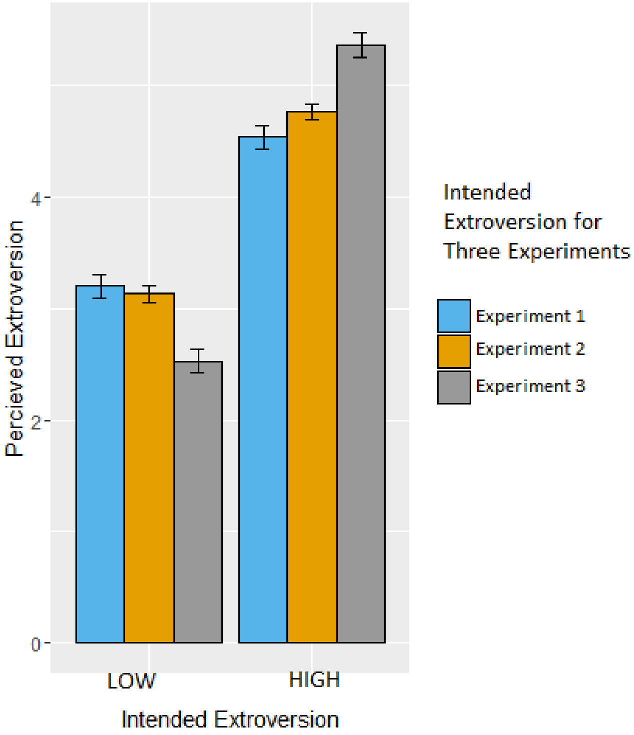


Figure 4.18. The plot shows the effect of real-time interaction on the perception of the extraversion of the character (addressing hypothesis 3). In the x-axis of the plot, LE and HE respectively stand for intended Low Extravert and High Extravert. Presential refers to real-time presential experiment while Web-based refers to the two versions of web-based video-rating experiments.

Figure 4.19, depicts the difference between how participants interpreted the low and high emotional-stability for the presential versus the web-based experiments, For the intended low emotional-stability (LS), presential scores were lower and for the intended high emotional-stability (HS), presential scores were higher.

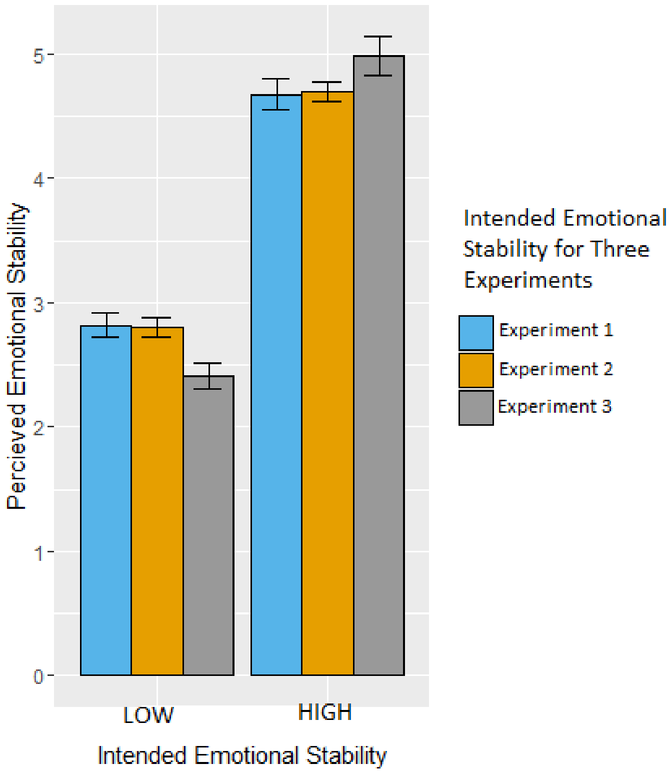


Figure 4.19. Effect of real-time interaction on the perception of the emotional-stability of the character (H3-b): In the x-axis of the plot, LS and HS respectively stand for intended Low emotional-Stability and High emotional-Stability. Presential refers to real-time presential experiment while web-based refers to the two versions of web-based video-rating experiments.

Since the structure and procedure of the web-based experiments are different with the real-time interactive experiment, thus there may be other factors involved in the enhancement of the recognition of personality traits rather than just the real-time interaction. However, mentioned results encourage further investigation of the effect of real-time setup in the perception of the personality of 3D virtual characters and emphasizes the usefulness and general accuracy of the RealAct system in providing a novel responsive character apparatus for these experiments.

Results for the Sense of Presence

Compared to other cognitive science-based research systems using 2D and 3D virtual characters, RealAct was setup and technically based on a highly realistic 3D computer virtual character. That is realistic in geometry, texture mapping and 3D animation quality compared to other academic computer graphic systems. It was the goal of the research to build a system with this level of realism. Some 3D characters that move and look very much like real humans are considered creepy by participants (the uncanny valley effect [55]).

During the presential real-time experiment, in addition to the set of TIPI questions participants answered after each game, at the end of the experiments I had a short interview with them asking about their general experience by asking ‘how was the experience in general’, ‘how did you feel during the experience’. In general, our participants did not discuss the character being creepy looking in the post discussion interview, and they described their experience with positive words such as enjoyable and fun. Forty participants described the experiment as a positive experience with answers including ‘they enjoyed it’, ‘it was fun’, and ‘I liked it’ and one participant rated it as ‘it was ok’. The short interview is video captured and documented as a resource for the experiment (see Appendix B). Finally, I gave them an adapted version of Sanchez-Vives and Slater’s questionnaire [147] to measure how participants evaluated their presence and how believable they found the experience in comparison with playing the game with a human, discussed in 4.5. Figure 4.20, shows bar plots of participants’ score for the two presence questions. The first question was to rate the sense of playing with the character, on the scale from 1 to 7, where 7 represents the normal experience of playing with a human (left plot). The second question was if they thought of the game more as images that they saw from a computer-made character or more as a game they played with someone, where 7 represents playing with someone. Median value of participants scores for both questions were more than average (about 5 in the scale of 1 to 7) which shows they saw the experiment as more close to playing to normal human than a computer made character, and they thought of the experience more as a game they played with someone rather than character. Nonetheless, the general experiences of the participants were positive, I am aware that evaluating their feeling and sense of presence warrants a further investigation.

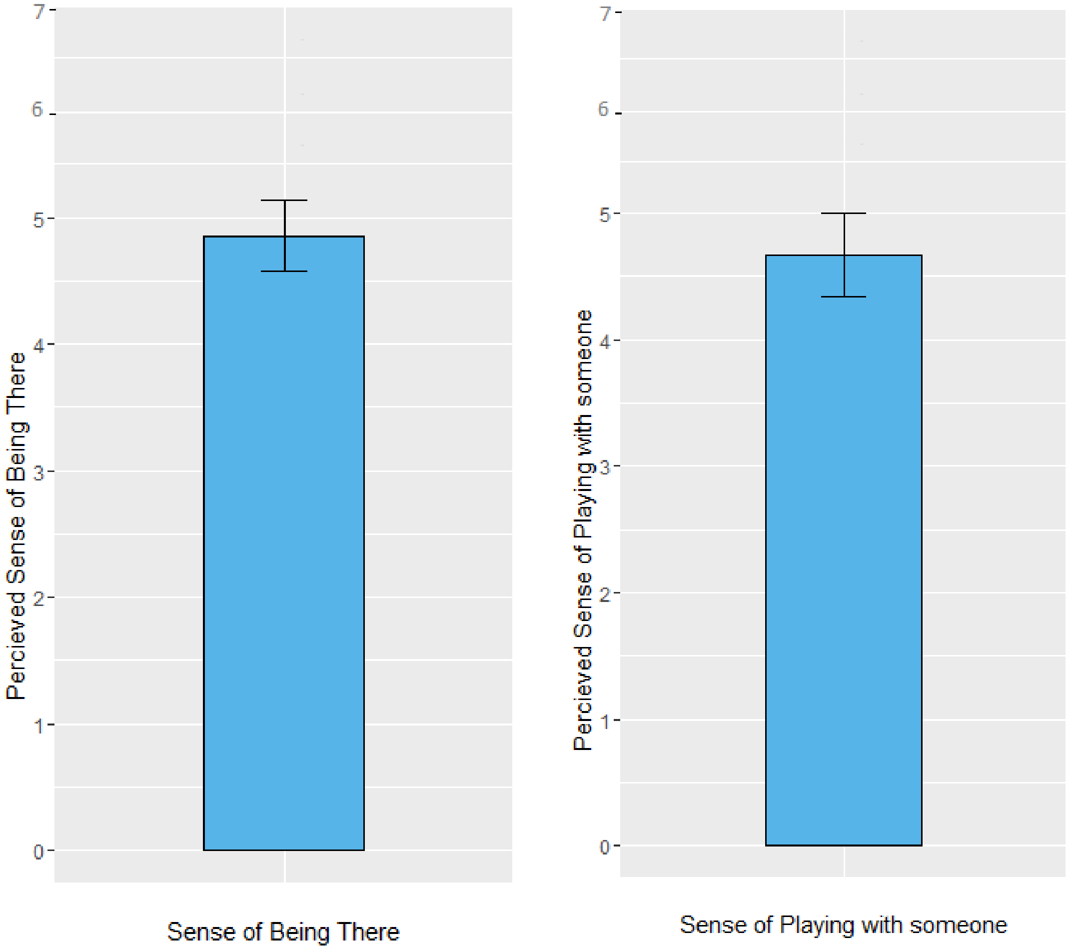


Figure 4.20. **The bar plot for the two questions on sense of presence of the participant when interacting with the virtual character: the left plot is used for rating the sense of playing with character, on the scale from 1 to 7, where 7 represents a normal experience of playing with a human, and the right plot is for investigating if participants think of the game more as images that they saw from a computer-made character or more as a game they played with someone, where again 7 represents playing with someone.**

Results for other Big Five Traits

In addition to asking participants to rate the extraversion and emotional-stability of the character, I inquired what their perception about the other traits of five factor personality (openness, conscientious, agreeableness) and dominance was for all the experiments. I was interested to see if the combination of the behaviour that was generated by the RealAct system to represent extraversion and emotional-stability will also be interpreted as openness, conscientious, agreeableness or dominance. There were no significant correlations between the intended extraversion behaviour and the perception of openness, conscientious, agreeableness, or dominance. This means participants did not attribute any other trait other than extraversion to the behaviour such as high frequency of direct gaze vs avert gaze used to express extraversion. On the other hand, intended emotional-stability had a significant positive correlation with agreeableness, see Table 4.3. This appears to show that the behavioural acts corresponding to emotional-stability were also seen as agreeableness. The result of the regression indicates that the predictors explained 30% of the variance (R2=.30, F (3, 120) =7.17, p<.005). However, the effect of correlation was much lower for agreeableness (β = 0.71, SD=.3, t (120) =2.37, p<.005) than emotional stability (β = 2.56, SD=.25, t (120) =10.42, p<.001). I assume especially low-stability behaviour such as ‘scratching self’ or ‘twitches’, in addition to low emotional-stability, caused the perception of low agreeableness. This is an important result if I consider that some of the behaviour correspond to emotional-stability such as duration of mutual and avert gazes, twitches, frequency of scratches, showing positive vs. negative facial expressions, and frequency of blink can also be used to express the personality trait agreeableness. There were no significant correlations between the intended emotional-stability behaviour and the perception of openness, conscientious, or dominance.

Table 4.3. Regression results for the correlation between the intended emotional-stability and the perceived agreeableness are significant.

Significance level: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

	Estimate (β)	Std. Error	t value	Pr(>|t|)
Perceived Agreeableness for intended Emotional-stability	0.71951*	0.30302	2.374	<0.005

Despite the stronger effect of this behaviour on the perception of emotional-stability, results in both trials (web-based and presential) and for all the individuals, both sexes and with all personality types are similar, thus suggesting that experiment type, sex or personality of the participants does not alter the way my set of nonverbal cues was interpreted. This result reflects my expectations, even though I did not formulate a hypothesis beforehand since I had limited my work to two traits extraversion and emotional-stability. It is very interesting that similar research dealt with agreeableness explored with behaviour parameters such as jerkiness of gestures, or smile expression also experienced the same result as in my experiment. For instance, Liu et al found a correlation between low emotional-stability and low agreeableness [76]. They created the low emotional-stability through gestures such as 'jerks added to motion path', 'rounded vs. sharper gestures' and 'hand position in respond to the body'. I think that, in addition to impact the virtual character's community, this result has also implications in the study of human social psychology. It worth mentioning that empirical psychological data also indicates many personality traits are often inter-correlated. For instance, those who are low on emotional-stability may also be low on agreeableness [76][150][151].

In addition, for the presential experiment, the comparison between the mean values of scores for five-factor traits and dominance, for intended extraversion and emotional-stability, are presented in Table 4.4. The comparison shows for the presential experiment, participants mean scores for intended emotional-stability changes from 2.4 for low stability to 4.98 for high stability and the mean value of the scores shows a change from 2.53 for the low extraversion to 5.36 for the high extraversion.

Table 4.4. In the presential experiment comparison of the means of perceived traits and dominance for the intended low emotional-stability, intended high emotional-stability and intended low and high extraversion shows a clear difference in means of scores of extraversion and emotional-stability for intended low and high emotional-stability and intended low and high extraversion. Extra., Emo St., Consci., Agree., Domin. and Open respectively stand for extraversion, emotional-stability, conscientiousness, agreeableness, and dominance)

	Extra.	Emo St.	Consci.	Agree.	Domin.	Open
Intended Low Extra.	**2.53**	3.68	4.25	3.75	3.86	4.02
Intended High Extra.	**5.36**	3.7	4.23	3.92	4.57	4.39
Intended Low Emo St.	3.96	**2.40**	3.96	3.35	4.06	4.09
Intended High Emo St.	3.93	**4.98**	4.52	4.31	4.37	4.32

4.6. Summary of the Evaluation Results

In order to test whether personality traits affect the perception of extraversion and emotional-stability, I first established that each of the factors: intended extraversion (High, Low), intended emotional-stability (High, Low), experiment type (Presential, Web-based and framing (Complete, Partial) significantly affects each of the two dependent variables: perceived extraversion, and perceived emotional-stability. A linear multivariate regression for all factors showed a statistically significant impact of all of them on the perception of extraversion and emotional-stability. Thus, I found that the amount of extraversion and emotional-stability that participants attributed to RealAct's virtual characters depended on a specified combination of facial expression, gaze and posture and gestures that they exhibited. In particular, characters showing fast and spacious gestures, frequent and long mutual gazes, and frequent intensive positive emotions were judged as extraverted while slow movements, short duration of mutual gaze and frequent and long periods of averting gaze and not strong emotions (filter) were correlated with introverts. Additionally, characters showing frequent scratches, twitches, blinks, and frequent and strong negative emotions were judged as emotionally unstable where lack of twitch and scratch and lack of expression of strong negative emotions were associated by emotional-stability.

In addition, when I looked at the relationship between the framing of the videos of the character and participants' interpretations of personality, I found interesting trends supporting that framing acted as a moderator. The contribution of each of the factors (intended extraversion, emotional-stability, and framing) was analyzed. For the perception of extraversion, intended extraversion had the highest effect, in comparison with the framing. For the perception of emotional-stability, intended emotional-stability had the highest effect, in comparison with the framing. As mentioned before, these judgments were regardless of participants' sex and personality. Furthermore, the presential experiment seemed to enhance the impression formation. I do not know of any previous studies that examine and evaluate the effect of the presential real-time interaction experiments, in comparison with video-rating experiments. I believe this result shows that having a real-time setup and have a realistic 3D virtual character in front of the participants can add to the experience and create a feeling of presence in comparison with a web-based expressive which includes a passive activity watching a video and rating the character. I think the actual presence of participants in the environment and direct interaction with a virtual character in the front of them is the main reason for the increase in the recognition of intended personalities. I believe the highly significant positive results for impression of personality traits in the real-time setup, in comparison with a passive rate of a video of character emphasizes the effectiveness of my real-time system. Similarly, to the best of my knowledge, previous studies did not evaluate the effect of the framing of the body, in the video ratings, in the impression of the personality. Highly significant results for the evaluation of both emotional-stability and extraversion show the importance of framing of the body in impression formation through watching the nonverbal behaviour of the character. In addition, participants rated the two post questions on presence ("how believable they found the experience in comparison with playing the game with a human", and "if they thought of the game more as images they saw from a computer-made character or a game played with someone?") with a median value of scores for both questions more than average (about 5 in the scale of 1 to 7) which suggests they saw the experiment as more close to playing to normal human than a computer made character, and they thought of the experience more as a game they played with a real person rather than a character. Surely this level of realism affected all aspects of the technical complexity of the RealAct development but I felt it was an important design goal. It is left to future studies to see how the use of this level of realism affected the experiment data, say compared to a 2d cartoon looking character or a less realistic 3D character (in rendering and movement).

The results of all the main experiments are controlled for the individual effect so if a participant tended to rate all the stimuli higher or lower, in general, it did not affect the results of the experiments. In addition, for all the scales, there was no main effect of participants' sex, implying that in general, the ratings of personality were consistent across male and female participants. Furthermore, I tested for a correlation between the participant's own personality ratings and their ratings of character on the same scales and found no correlation, implying that in my experiment the sex and the personality of the participant did not affect their ratings of character personality. Each participant rated all of the possible conditions of the experiments to avoid carry-over effect and to provide a larger number of judgments for all stimuli.

The results are limited by the statistical significance of the results for the specific population obtained. Ideally the set of participants would be a balanced population with high cultural variety, sex, and personality equally distributed in all the groups for each trait. However, it worth mentioning that to some extent my sample population covered different ages (22 to 45), various cultures (although mostly students in BC, Canada) and both sexes (84 females and 46 males), and I controlled my result for the individual differences, effect of gender and personality of the participants. Further, although I used a large set of movement parameters for all channels of behaviour, there are still many factors such as fluidity and smoothness of gestures that merit further investigation. In addition, although this behaviour is correlated with the users' impression of personality, identifying the relative contribution of each movement factor would also be valuable. Moreover, more exploration on the sense of enjoyment and presence in the real-time interaction setups for humans and virtual characters is a future need. Finally, a same male virtual character was used through all the experiment. Due to time constraints, the complexity of developing for a realistic 3D character, and not enough available animations for my female character, I decided not to use the female character, and instead worked on the animations of the male character to make it more human-like and smooth. Therefore, it will be a reasonable next step to evaluate the system using several characters, both male and female, and with various appearances. However, since the same character, with the same appearance and clothing, was rated differently in different conditions, it appears that the participants' impressions were merely made based on the behaviour of the character.

Chapter 5. Conclusion, Contribution, and Future Work

3D human-like virtual characters are computer models of humans that can be designed to autonomously sense, perceive, and react to their surroundings [46][23]. To perceive virtual humans as natural and believable, it is crucial that they show consistent facial expressions, gaze behaviour, gestures, and postures (described by psychology as personality) which are recognizable by users. Achieving this level of believable expressive realism on a computer based real-time and responsive 3D character is still a source of ongoing research [7][44][76][133][136].

5.1. Contribution

Comprehensive empirical, psychological and statistical data on biological humans' behaviour and personality were explored and reduced to categorized and structured material for the design of the RealAct computational model. In fact, one of the contributions of this work is this repository which can be useful for cognitive and affective computing researchers. Founded on this repository, an event-based, emotionally-continuous hybrid system (RealAct) was designed, developed, refined, and used to facilitate and maintain consistency and credibility of the behaviour of the virtual characters through conveying personality during the interaction with the environment.

A significant part of the research in this thesis was building the RealAct system as a set of six encapsulated and reusable blocks available in the RealAct library: **1)** the gaze controller which refines the Eyes Alive model of gaze [100] to create a gaze behavior following the human ocular behaviour. The novelty of this module is in reinforcing the expression of personalities by controlling the following expressivity parameters: chance of occurrence of averts or mutual gazes, gaze direction, duration of avert and mutual gazes and speed of head movements, **2)** the postures and gestures controller which enforces the impression of personality through the expressivity posture-shifts, leaning, self-adaptors, body twitches and spacious gestures, **3)** the facial expressions controller which adapts Boukricha et al's model [82] to associates the emotional valence and arousal values with facial muscle movements [71] where the impression of personality is created through changing the intensity of emotions, filtering of emotions, and facial twitching, **4)** emotion generation module which elicits valence and arousal when emotional triggers are activated for instance by the user or environment feedback where personality affect the type and impact of these triggers, **5)** attention controller module which makes the 3D character attentive to events proposing two attention types for gaze and body e.g. if the attention signal only requires the attentiveness of the gaze, other body parts can continue with their idle behaviour, **6)** behaviour scheduler which prioritizes and selects a behaviour with the highest priority from multiple behaviour requests using three priority queues for high, mid and low priority behaviour.

These reusable and separate blocks saved in the RealAct library promote the future use by other researchers. In addition, since RealAct uses Behaviour Markup language [129] open standard system for sending behaviour commands to the animation toolkit, the framework can be used by other animation engines rather than Smartbody. The RealAct system and its documentation are freely available online (see Appendix B). The sophisticated and lifelike hierarchy of prioritized and intergraded behavior layers which is dynamically augmented by personality type and reaction to long term and immediate user and environmental events are the main contributions of my research and the RealAct system. Generating 3D characters with human qualities that show consistent patterns of behaviour, thoughts, and emotions can lead to the wider use of virtual characters in various faculties such as educational systems, therapy systems, games, training systems, museum guides, story-telling and interactive dramas.

The RealAct system is designed to express extraversion and emotional-stability through different channels of dynamic responsive behaviour (gaze, pose/gestures, and facial expressions). Each of these channels has multiple dimensions which are all affected by the personality parameters. For instance, highly extraverts show more frequency and duration of mutual gaze, and faster head movements expresses more positive emotions (through facial expressions) and shows more spacious gestures (e.g. limbs spread wide from the body). Thus, to evaluate the RealAct system, I checked what personality virtual characters conveyed, where the characters were programmed to display introversion versus extraversion and high versus low emotional-stability.

We designed four experiments to test, and refine different aspects of the RealAct system. In the first three experiments, I evaluated how users perceived still images of facial expressions and videos of the behaviour of 3D character generated by the RealAct. Then, by refining the RealAct system using the feedback received from the users, a comprehensive real-time presential experiment was performed. The major findings of these experiments showed that the amount of extraversion and emotional-stability that participants attributed to the realistic 3D virtual characters depended on a specified combination of computer generated facial expression, eye gaze, body posture and hand/body gestures that the character's exhibited. This suggested that empirical data extracted from psychology literature on the perception of personality (extraversion, and emotional-stability traits) based on nonverbal behaviour can be translated to the context of human and virtual character interaction.

This dissertation reports the results of a set of experiments analyzing the expression of extraversion and emotional-stability using nonverbal behaviour of a computer-based virtual character. The goal of this work is to contribute to a broader domain of controlling the expressivity of virtual characters. Considerable works exist with the focus on expressive behaviour such as the system developed by Neff et al with the focus on both verbal and non-verbal factors impacting the perception of personality [131]. In most of these systems, personality is manifested only through behavioural characteristics, and not through other layers such as emotion and coping responses. Additionally, most of these systems are not designed for the real-time interaction between humans and the virtual character and are only evaluated using videos or still images [37][94][96]. Finally, to the best of my knowledge, they did not explore the effect of framing the body in the perception of personalities.

In addition, participants rated the two post questions on their sense of presence which suggested they saw the experiment as more close to playing to normal human than a computer made character, and they thought of the experience more as a game they played with someone rather than character. Surely this level of realism affected all aspects of the technical complexity of the RealAct development but I felt it was an important design goal.

Moreover, two potentially beneficial theories worthy of further exploration are point out by this thesis. First, the findings indicate that how the channels of behaviour are framed and filtered affects the perception of personality. For the web-based experiments, I found the framing of videos (face only versus neck-down full body) affected the impression formation by reducing the motion cues through filtering out some channels of behaviour. Exploring the effect of the framing of the body in forming the user perception of the personality of a virtual character needs further exploration. Secondly, a real-time interaction, when virtual characters are responsive to what human do, comparing to passive video-rating of behaviour adds to the strength of the user's perception. This is a novel finding worth further exploration since most of the related studies which proposed computational affective models did not evaluate the model, only evaluated it employing static images or videos, or did not compare the results of passive video-rating and real-time interaction [37][45][61][93] [94][96].

5.2. Conclusion and Future Work

This thesis presents the design, implementation, and evaluation of the RealAct to control and maintain consistency the non-verbal behaviour of virtual characters. To make the virtual characters behave in an expressive and consistent manner, the system controls non-verbal behavior of the 3D virtual character to give the impression of a specific personality type. The design and development of different modules of the RealAct system is directly modelled from existing behavioural and computational literature. In addition to the core modules for controlling the behaviour of the 3D virtual character, the RealAct system contains a library of modules that are specifically geared toward real-time behavior control needs such as sensory inputs, scheduling of behaviour, and controlling the attention of the character.

Creating believability and consistency in the behaviour of virtual characters and maintaining that during a long period of interaction with users is a very complex task involving different disciplines. Therefore, it was necessary to limit the domain of work by concentrating on some aspects of personality and some nonverbal behaviour. I believe the next step is to add new personality traits to the system. In addition, due to the limit in time and resources, the number of animations used for the character was limited. A new and more variant set of pre-defined and procedural animations can add to the believability of the experience. Another future step that is already started in the iVizlab research group is to use the whole of part of the RealAct system for other scenarios of interaction, and by adding other sensory inputs to explore its possible usages. Finally, although I concentrated on the nonverbal behaviour of the character, adding the verbal content to the interactions and how it affects the quality of the interaction need to be explored.

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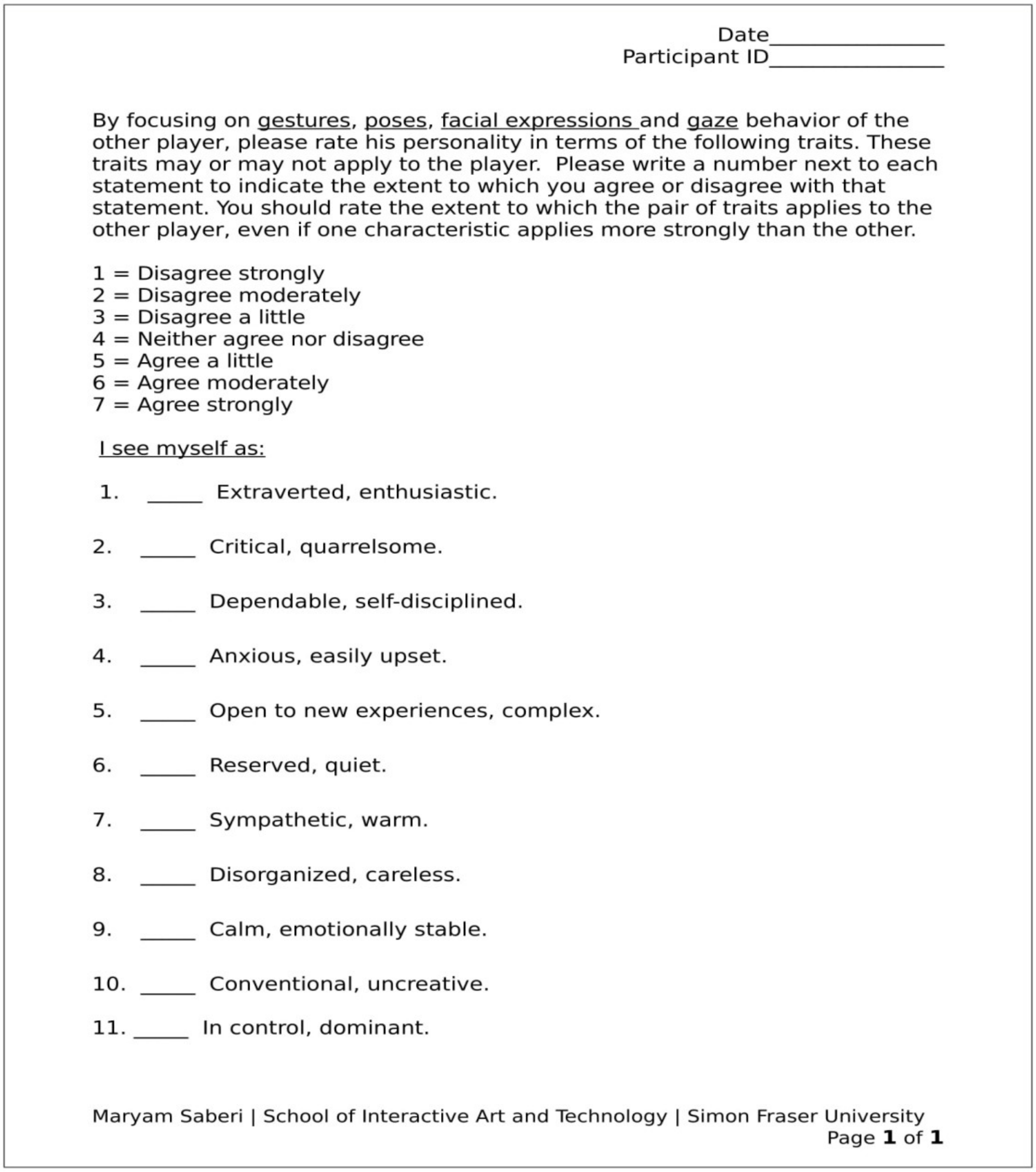
Appendix A.

Measurements used for the Real-time Experiment

The following are the screen shots of TIPI measurement and the adapted presence questionnaire used in the real-time presential experiment:



Date________________
Participant ID________________

By focusing on gestures, poses, facial expressions and gaze behavior of the other player, please rate his personality in terms of the following traits. These traits may or may not apply to the player. Please write a number next to each statement to indicate the extent to which you agree or disagree with that statement. You should rate the extent to which the pair of traits applies to the other player, even if one characteristic applies more strongly than the other.

1 = Disagree strongly
2 = Disagree moderately
3 = Disagree a little
4 = Neither agree nor disagree
5 = Agree a little
6 = Agree moderately
7 = Agree strongly

I see myself as:

1. _____ Extraverted, enthusiastic.
2. _____ Critical, quarrelsome.
3. _____ Dependable, self-disciplined.
4. _____ Anxious, easily upset.
5. _____ Open to new experiences, complex.
6. _____ Reserved, quiet.
7. _____ Sympathetic, warm.
8. _____ Disorganized, careless.
9. _____ Calm, emotionally stable.
10. _____ Conventional, uncreative.
11. _____ In control, dominant.

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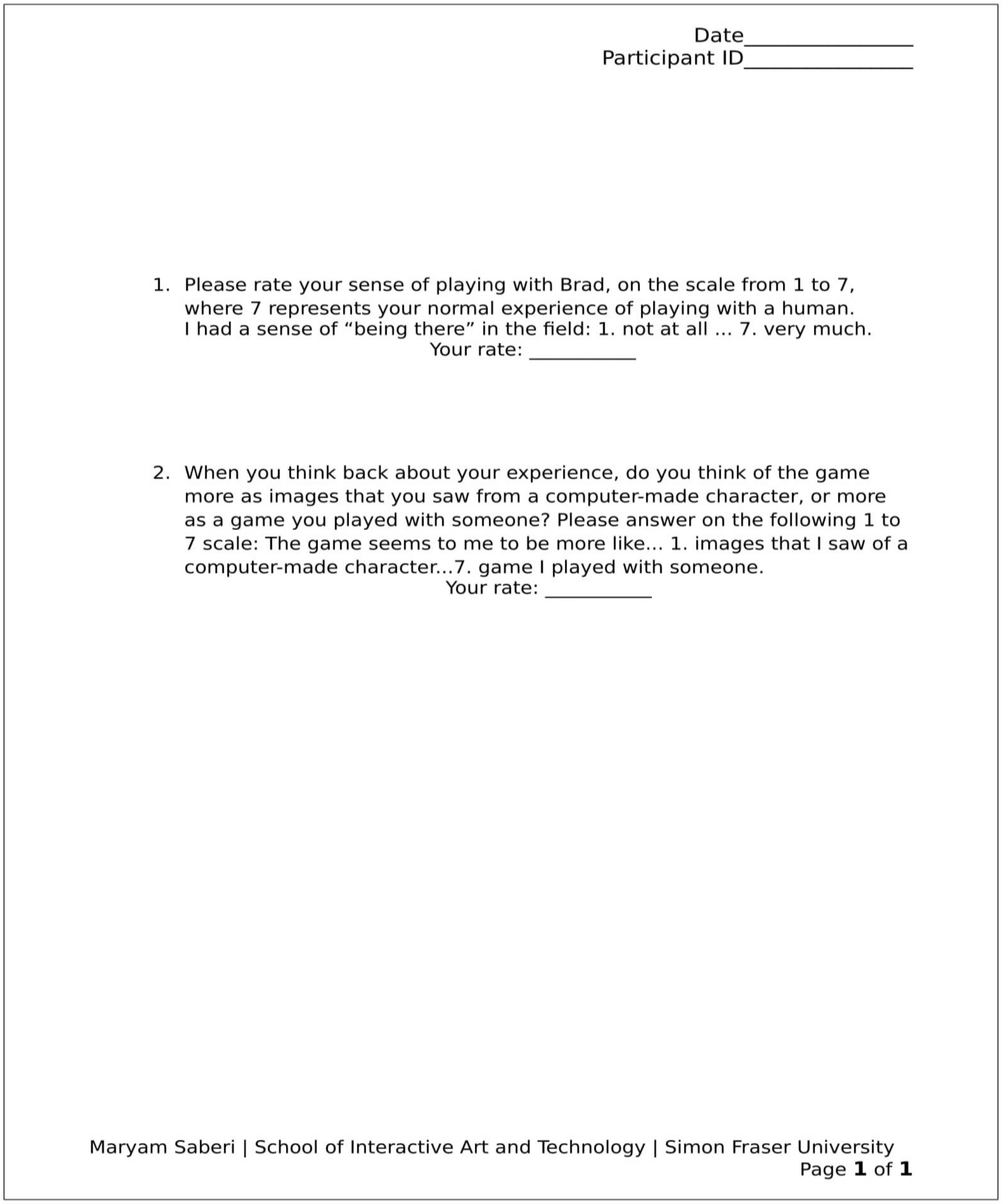
Figure 5.1. TIPI scale was used for measuring the personality of the virtual character



Date_______________
Participant ID_______________

1. Please rate your sense of playing with Brad, on the scale from 1 to 7, where 7 represents your normal experience of playing with a human. I had a sense of "being there" in the field: 1. not at all ... 7. very much.
   Your rate: __________

2. When you think back about your experience, do you think of the game more as images that you saw from a computer-made character, or more as a game you played with someone? Please answer on the following 1 to 7 scale: The game seems to me to be more like... 1. images that I saw of a computer-made character...7. game I played with someone.
   Your rate: __________

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Figure 5.2 Presence questionnaire was adapted from [147], and used to measure the sense of presence of the participants

Appendix B.

RealAct's Archived Open Sourced Output

The qualitative cognitive data on human social behavior is analyzed, simplified and categorized to a set of definitive parameters using tables, figures, and diagrams useful to computer model researchers. Then, the RealAct system is designed and developed using these parameterized data. To promote the future use by other researchers, I programmed the RealAct system as a set of encapsulated and reusable blocks saved in the open source RealAct library. Finally, the system and assumptions are evaluated through four still, video and interactive experiments.

The archived open sourced output of this research consists of parametrized data on expressive nonverbal behaviour, and a refined system for generating expressive behavior for 3D virtual characters.

The RealAct framework and its documentation are available online at: [ivizlab.sfu.ca/research/thesis/saberi]

Appendix C.

Statistical Analysis Details for the Experiments

Software Package

To analyze the data software package RStudio, version 3.2.4 (http://www.rstudio.com/) was used.

Packages used in R-Studio

- ‘MASS’, ‘car’, and ‘lfe’
- For drawing the plots packages ‘gplots’, ‘ggplot2’, ‘RColorBrewer’, and ‘reshape2’ were used.

Functions Used in the Analysis

- plot(X,Y) was used to produce a scatterplot of the variables X and Y with X on the x-axis and Y on the y-axis.
- summary() command was used to get the regression coefficients and other info needed.
- lm(X,Y) was used to run a linear regression of Y on X where Y is your dependent variable and X is your independent variable.
- felm was used to run a fixed effect linear regression to control for the individual effect.

  Thus, my models take the form:
  model <- felm (DV ~ IV1+ IV2 + G(as.factor (ind)) , data=data)

  Fixed effect linear model was used to control for any unobservable but fixed individual effect that might influence the respondents rating of 3D agents' characteristics. As a participant rates several questions, the fixed effect model uses the multiple observations for each respondent to assign different intercepts to the regression line for different respondents. For example, the fixed effect model takes into account that some people assign higher/lower rating to agents' characteristics relative to average

Testing Regression Assumptions before Running the Model

Before running the models, the following tests were performed to assure the assumptions of multiple linear regression were met: linearity of residuals, homoscedasticity, normal distribution of residuals, autocorrelation or independence of residuals, multi-collinearity, and linear relationship of IVs and DVs.

The details of testing process for the assumptions are available online in ivizlab space:

[ivizlab.sfu.ca/research/thesis/saberi], in the ‘Experiments Statistics’ section.

Full RStudio Outputs

The full results from running the models in R studies are available in ivizlab space:

[ivizlab.sfu.ca/research/thesis/saberi], in the ‘Experiments Statistics’ section.