Simulation of Individual Spontaneous Reactive Behavior

Alejandra García-Rojas
Virtual Reality Laboratory
École Polytechnique Fédérale de Lausanne
1015 Lausanne, Switzerland
alejandra.garciarojas@epfl.ch

Mario Gutiérrez*
National Institute for Astrophysics, Optics and Electronics
Luis Enrique Erro #1
Sta. Ma. Tonantzintla
72840 Puebla, México
mgutierrez@ccc.inaoep.mx

Daniel Thalmann
Virtual Reality Laboratory
École Polytechnique Fédérale de Lausanne
1015 Lausanne, Switzerland
daniel.thalmann@epfl.ch

ABSTRACT

The context of this work is the search for realism and believability of Virtual Humans. Our contribution to achieve this goal is to enable Virtual Humans (VH) to react to spontaneous events in virtual environments (VE). In order to reflect the individuality of each VH, these reactions have to be expressive and unique. In this paper we present firstly a model of reaction based on personality traits. The model was defined using statistical analysis of real people reacting to unexpected events. We also consider that the emotional state is involved in the modulation of reactions, thus we integrate a model of emotion update. Secondly, we present a semantic-based methodology to compose reactive animation sequences using inverse kinematics (IK) and key frame (KF) interpolation animation techniques. Finally, we present an application that demonstrates how Virtual Humans can produce different movements as reaction to unexpected stimuli, depending on their personality traits and emotional state.

Categories and Subject Descriptors

I.3.7 [**Computer Graphics**]: Three-Dimensional Graphics and Realism; J.4 [**Social and Behavioral Sciences**]: Psychology

General Terms

Animation, Virtual reality, Cognitive simulation

Keywords

virtual humans animation, semantics, reactive behavior, expressive animation.

1. INTRODUCTION

The lack of believability of virtual humans (VH) is partially due to the fact that we are unable to produce varied animations that are coherent with the context and with the individual traits of each character. A particular situation is when these characters are not able to perform individualized reactions to unexpected events in the environment. We fail on reflecting individuality because in most of the cases VHs are animated with the same animations for one kind of reaction. One solution for individualized and varied animation is to use many animation sequences reproduced by real actors, instead of having a limited selection of movements. This approach is used in the most popular interactive games. However, large animation repositories are difficult to handle and are not enough to achieve the impression of individuality.

Our main goal is to enhance the believability of Virtual Humans by enabling them to produce spontaneous reactions to unexpected events in a VE. In order to verify the hypothesis that reactions are highly dependent on personality traits, we conducted an experiment where we observed how people with different personalities reacted in different ways to similar stimuli. To be able to extract personality traits from people and describe them for VHs, we used Five Factor Model(FFM) [13] of personality. We also consider that not only personality, but also emotional state is involved in the modulation of reactions. In particular, motion speed and certain hand or body gestures that reflect the current emotional state. Therefore, the working principle of our proposal is this: the specific reaction to a given event is defined as a function of personality; perception defines (selects) the basic characteristics of the reaction (general orientation of the gesture: gaze direction, global body orientation, etc.); once the basic characteristics of the reaction are defined, we add emotional clues to the motion to reflect the current emotional state.

In order to produce individual realistic reactions to unexpected events, we propose a model of reactions that is based on individual traits (personality), complemented with a computational model for synthetic characters which simulates changes of the emotional state. We decompose reaction movements in simple movements and describe animations that have emotional content. To organize this information a semantic-based methodology is applied. We created an ontology whose domain is the description of individualized reaction movements in terms of character animation techniques.

For the synthesis of reactive motion we used a run-time methodology that combines two animation techniques: Inverse Kinematics (IK) and Key Frame Interpolation (KF). IK was used to create desired postures for the reaction, and KF was used to enhance animations with expressiveness.

*Work done while at EPFL - Virtual Reality Laboratory

Cite as: Simulation of Individual Spontaneous Reactive Behavior, A. Garcia-Rojas, M. Gutierrez, D. Thalmann. Proc. of 7th Int. Conf. on Autonomous Agents and Multiagent Systems (AAMAS 2008), Padgham, Parkes, Müller and Parsons (eds.), May, 12-16., 2008, Estoril, Portugal, pp. 143-150.

An ontology help us to structure the domain knowledge and serves as a guide to annotate all the data needed form the animation sequences. We describe VH individualities in terms of morphology, personality and emotion. We classify and annotate animations that have expressive meaning by decomposing animations according to the involved body parts. Each sub-sequence is considered as a separated action or body expression. In this way, we can apply different animation sequences to different body parts, accordingly to the individuality description of each character. The information in the ontology is extracted with queries and used by our application.

The application scenario consists in an animation sequence where several virtual humans are able to perceive the environment and react differently to the situations presented. The animation displayed is actually a composition created out of available KF sequences and IK. Changing individuality parameters of a given VH we obtain different reactive animations that indeed give the impression of personalized unique reactions.

This paper is organized as follows, next section overviews previous work on commercial and research projects aimed at producing VH with realistic autonomous behavior. Later we describe our representation of individualities and the proposed models. We continue by describing in detail the formal specification of personality and individuality of VH by means of an ontology. Finally we present an application scenario where we have put in practice the proposed methodology and tools, and our conclusions and future work.

2. RELATED WORK

The successful video game "The Sims" by Will Wright (1998) is a representative example of the state of the art in character animation. This game provides high level of interaction between user and avatar. Interest on the game is kept due to the dynamics of the character's individuality. Personalities are chosen to fit the role you want your *Sim* to play, the virtual characters can be considered semiautonomous. However, animation still looks robotic and the database of movements seems to be limited: repetitive movements. Reactive animations -to express surprise, and other reactions to unexpected events- in general are reduced to a unique motion sequence which is not individualized. However, this system uses personality descriptors (outgoing, playful, neat, active and nice) which drive the character's behavior. Most of the systems that integrate models of behavior include detailed models of personality and emotions [1]. The state of the art in models and methods that cover models of emotion and personality generating expressions and behaviors can be found in [26].

The synthesis of expressive behaviors has been implemented using perceptual parameters (e.g. speed, fluidity) to regulate the dynamics of the agent in different modalities [15]. In [3] authors propose to use Laban Movement Analysis (LMA) to provide parameters of Shape and Effort to generate more natural movements. However, mentioned parameters are not directly labeled with a emotion or personality traits, but they allow the agent to express itself in different manners. In [23], authors used decomposition of body movements for describing important cues of personality to provide hight level control of affective story characters.

Since reactive animations are movements difficult to reproduce by hand due to their specificity and variability, they are usually created from motion capture data. To be able to perform a realistic reaction, a large database of motion capture data is required, together with a search engine to find the most suitable animation. For example, to produce realistic reactive animations out of motion capture data, some authors apply motion blending, dynamic constraints [32] or physical constraints [24]. Komura et al. [10] used motion capture mixed with momentum-based IK. IK was used to keep the balance of the character. On these approaches, authors deal with the passive effect of an impact. In [8], the realism of the reaction was improved by making the arms of the character react in a protective way when falling down. These animations are physically realistic, but not individualized.

Some of the described work that aims at the formal definition of individualities point to the integration of computational models of psychology. Since our approach is similar, in following section we describe the solution we adopted for the representation of our models.

3. DEFINING INDIVIDUALITIES FOR VIRTUAL HUMANS

Individual behavior results from the interaction of three components: (1) personality-based predispositions for behavior, (2) moods/emotions and (3) environmental situations [19]. Personality can be considered as a consistent state in a long period of time, while emotions are short and inconsistent. In this section we will describe models that where used to create individualized reactions.

3.1 Personality Models

To represent personalities there exist several psychological models that provide dimensional representations that go from three up to seven dimensions. One of them is the Big three model [7], which relies on biological basis of socialization-psychoticism introversion-extraversion and neuroticism-stability to describe personality. However, a competing model, the Five Factor Model [13] is the most popular used for computational models is which defines the following dimensions:

Openness refers to how willing people are to make adjustments in notions and activities in accordance with new ideas or situations

Conscientiousness high in Conscientiousness tend to be organized, thorough, and planful.

Extraversion defined as a trait characterized by a keen interest in other people and external events, and venturing forth with confidence into the unknown

Agreeableness measures how compatible people are with other people, or basically how able they are to get along with others

Neuroticism is a dimension of personality defined by stability and low anxiety at one end as opposed to instability and high anxiety at the other end

FFM has been integrated in several models for synthetic characters, e.g. [22] [11]. In the search of modeling individual reactive behavior, we used FFM in an experiment to analyze the influence of each personality factor on the type of reaction, which is explained right after.

3.2 Personality Influences Reactions

For finding out the influence of personalities to a type of reaction, we conducted an experiment where 20 people participated. It consisted in inducing participants to a spontaneous reaction and applying them a test to obtain their personality profile [18]. This test results in the quantification of previously described personality traits in a scale of 0 to 100. The conditions of the experiment were to have the person standing up with the body free of obstacles (like a back-pack or a purse), in front of a computer answering the personality test. After some time, the subject was called from the back and a ball was thrown towards him/her. We obtained different reactions for the same kind of stimuli, such as avoiding the ball, catching the ball, closing the eyes, contracting the upper body (a protective movement), etc. As it is very complex to classify all movements we had to group them to simplify the data analysis. We defined the following types of reactions:

Intercept : to catch the ball or to use the hands to avoid contact with the ball.

Avoid to move the body in the opposite direction from where the stimulus is coming from.

Protect to contract the chest, to protect the body from the impact of the ball, or close the eyes.

There were of course several reactions that could fall in two of the described categories, but as we aim at the decomposition of these movements we had to classify them in the closest description. Unfortunately important movement's characteristics such as the power of the movement, the speed, etc, were not considered because it should take more specialized studies and a statistical classification would be not possible.

We wanted to find out whether there was a correlation between the type of reaction and personality traits, thus we decided to use classification trees. This kind of analysis can predict responses on a categorical dependent variable from one or more predictor variables. Decision trees are easy to understand and easy to convert to a set of production rules. However, these algorithms are unstable because slight variations in the training data can result in different attribute selections and the effect can be significant since attribute choices affect all descendant subtrees. Within the data mining WEKA software [31], we performed a supervised approach for classification called J48 which is an implementation of of Quinlan's model C4.5 [21]. This algorithm works as follows:

1. Choose an attribute that best differentiates the output attribute values.
2. Create a separate tree branch for each value of the chosen attribute.
3. Divide the instances into subgroups so as to reflect the attribute values of the chosen node.
4. For each subgroup, terminate the attribute selection process if:
   (a) All members of a subgroup have the same value for the output attribute, terminate the attribute selection process for the current path and label the branch on the current path with the specified value.
   (b) The subgroup contains a single node or no further distinguishing attributes can be determined. As in (a), label the branch with the output value seen by the majority of remaining instances.
5. For each subgroup created in (3) that has not been labeled as terminal, repeat the above process.

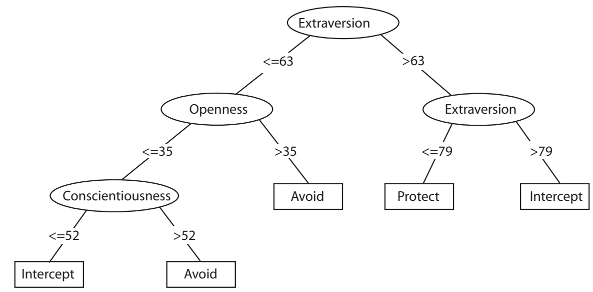

Figure 1: Decision tree for reactive motion.

From this analysis we got a model that could classify correctly the majority of the instances in our data set (17/20).

The decision tree that we obtained (presented in figure 1) is a practical solution to produce different reactions depending on personality descriptors associated to virtual characters. However, one can argue about the coherent signification of the influence of some personality traits in the reaction, which is the case of conscientiousness. From the previous definition of conscientiousness, one can suppose that this trait does not influence spontaneous reactions because there is not much time to think about making a good or bad decision when performing a reaction. On the other hand, from the statistical point of view, there is a relationship between conscientiousness and the reaction. This is one of the problems when working with psychological approaches, personality is a very diffuse concept and the results obtained may not be applicable to other populations. However, for the simulation of an individual reactive behavior, a model like this one will definitely help to improve realism in synthetic characters because it comes out from small but real information.

Next section describes how emotional state is used as modulator of the reaction movements.

3.3 Emotion Models

To describe emotion there are also several models that have different objectives, e.g. Ekman's for face expression [6], OCC [14] largely used for emotion synthesis, Whissel's activation - evaluation space [30] to represent emotions in a continuous space, etc. These models are readily amenable to the intentional stance, and are ideally suited to the task of creating concrete representations of personality and emotions with which to enhance the illusion of believability in computer characters. These psychological models are used to create models that simulate emotions in synthetic characters, such as [12] that describes how characters can copy emotions and change beliefs from appraisal mechanisms; or DER representation [25] that proposes a model to create continuous emotion changes, but does not consider personality as influence of emotion. The model we have considered for implementing in our system is based on a linear implementation of a generic update mechanism, and it is described in the following section.

3.4 Emotion Modulates Motion

The emotion as a dynamic factor in individuals can be used to modulate expressions during the animation. Thus, we needed to implement a model that creates a simulation of emotional change. We derived our implementation from the Generic Personality and Emotion Model (PEModel) presented in [5]. This model proposes to use vectors and matrices to represent the emotion, the personality, and a relation between them. Different vectors are considered: one vector for personality p with a dimension m where m is the number of personality dimensions; one vector for emotions e, with a dimension n where n is the number of emotions; another vector a of dimension m that contains emotion information of a desired change in the emotion, called emotion influence; and a vector w_t for the emotional state history. Therefore the model proposed to simulate emotion is given by the formula:

$$e_{t+1} = e_t + \Psi(p, w_t, a) + \Omega(p, w_t) \qquad (1)$$

The function Ψ, based on the personality p, the current emotional state history w_t and the emotion influence a, calculates the change of the emotional state as a result of the emotion influence. And the function Ω represents the internal change such as decay of emotional state. Given this model the implementation can be made in different ways. For our implementation, we define this as a matrix of dimension $[mxn]$ that we will call *Personality-Emotion Influence Matrix*: P_0. This means that a given personality has associated different emotional states with varying intensities. The matrix P_0 is defined depending on the model of personality and emotion being used. Then, assuming that personality does not change, we can calculate the product of P_0 and p, which will give a vector u indicating the importance of each emotion depending on the personality dimensions. This vector is used to construct the diagonal of the matrix P, thus for each emotion the matrix P contains a value that defines how strong an emotion can be given by the personality p. Thus the function Ψ is defined by:

$$\Psi(p, w_t, a) = P \cdot a \qquad (2)$$

As we wanted to keep it simple, for this implementation we are neither considering the emotion history w_t, nor the internal change decay (Ω function). The impact of not consider this would be a not so realistic performance in a long term in the animation.

The models described in these sections are the basis to create individualized VHs. To be able to practically implement them we have opted to make a formal representation of the knowledge using ontologies. Ontologies fill the gap between the theory and the practice because we can express the described concepts as an ontology and use this as the structure of a database for feeding the required information to our system. Next section describes this semantic layer.

4. SEMANTICS FOR REACTIVE MOTION SYNTHESIS

Personalizing gestures and reactions strongly contributes to the believability of virtual humans. As a consequence of personalization, we obtain more diversity of movements. In order to modify animations to reflect individuality, we must express in a formal language the parameters that define personality and emotional state and how they affect animation. These semantics has been formally represented inside an ontology using Protégé [20] and OWL [27]. The advantage of this semantic formalization is that we can query this knowledge base to retrieve all the descriptions of the VHs and associated animations, and this is application independent. The queries we performed are in SPARQL [28], which is a plug-in for Protégé software.

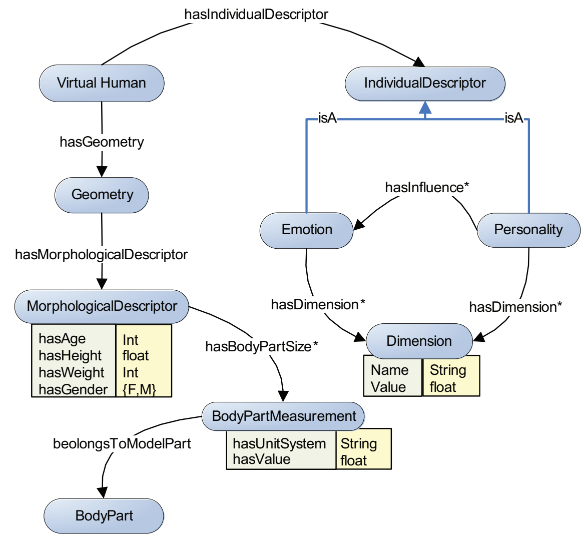

Figure 2: Virtual Human individuality.

4.1 Representation of Individual Virtual Humans

The individuality of a virtual human can be given by visible and not visible aspects. The visible one is the appearance which is described in its morphology; and the not visible is its internal "configuration" described by the personality and emotional state. These aspects provide a semantic definition of virtual humans and should be taken into account at animation-time. Character's morphology constrains the animation in terms of anatomical measurements. Personality traits can determine the action to perform under certain circumstances. The emotional state defines a particular way of performing an action, and can communicate character's feelings. Finally, character morphology confines motion to some physical capabilities.

Individuality depends on personality and emotional state. Personality and emotions can be described in terms of several dimensions. Each dimension represents the tendency of characters to perform some actions. We represent the relationship of influence between personality and emotion. In figure 2, we show the interrelations of the meta-data we just described. The morphology is also represented as description of the shape of the human body; it has properties like: weight, height, gender, age, etc. In the case of 3D VH, the morphology is inherent to the geometry. Moreover, geometry has other features such as skeletal structure and landmarks which are used to drive the animation and set skinning parameters to deform the geometry.

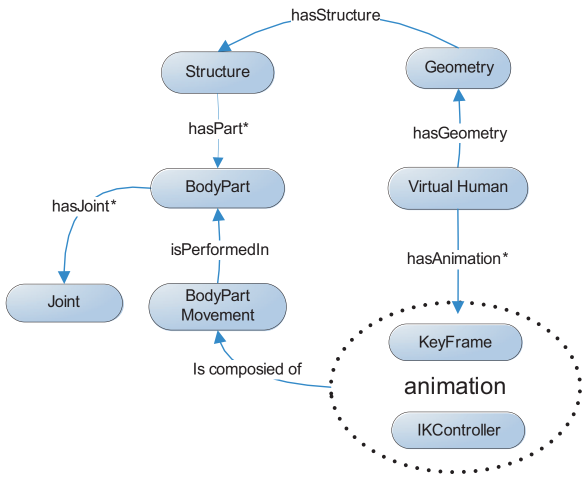

Figure 3: Character Animation Composition.

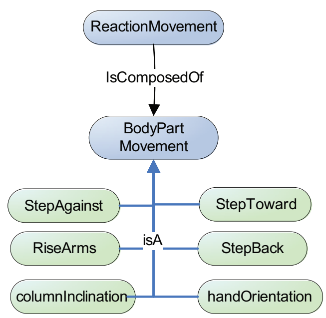

Figure 4: Semantics for Reactive synthetic movement using IK.

4.2 Representation of Expressive Reaction Movement

The way we relate individual reactions and expressiveness in the animation is by using two different animation techniques: Inverse Kinematics (IK) and Key Frame interpolation (KF). The VH's geometry is driven by a skeletal structure, which has joints that act as articulations. The Skeleton can be segmented in body parts, and each body part has their own joints (i.e. the arm has shoulder, elbow and wrist joints). In each body part, we can apply transformations from one of the two animation types: IK or KF. This is illustrated in the diagram of figure 3.

We decided to use IK for specific postures, for example to put the hands in a desired position. These postures are function of anatomical measurements (e.g. to synthesize a step backwards we need to know the legsŠ length in order to compute for example how much the root should move). IK will produce a rough version of the intended animation. In figure 4, we describe the simple movements (*StepAgainst, StepToward, etc*) that compose a reactive movement, a detailed implementation of IK and these movement can be found in [9]. As IK-based animation tends to be very robotic, we try to enhance the expressivity and realism by using KF animation to control other body parts different from the ones affected by IK.

The KF animations are firstly classified in motion categories: Locomotion, Interaction, Communication and Emotional Gestures. In order to be able to enhance synthetic animations with emotional expressiveness, we annotated existing animation sequences that contain specific motions with emotional meaning. How emotions are performed through the body started to be studied by Darwin [4], who said that there are specific movements in human beings that are performed depending on a specific emotional state. This approach has been supported by experimental research in body expression [29]. In table 1, there is the description we used to define body part movements and their relation with emotion. Therefore, we have segmented animations on body parts: face, head, upper body, lower body and hands. By observing the movement of each part, we established a relationship: *KeyFrameAnimation isComposedOf* an *AnimationSegmentDescription* that *hasBodyPartMovement* that *describesEmotion*. An example of this relationship could be where a *ConversationAnimation isComposedOf HandsAnimation* that *hasBodyPartMovement HandsClosed* that *describesEmotion Angry*. Figure 5 presents the ontology diagram of the segment description of animation segments.

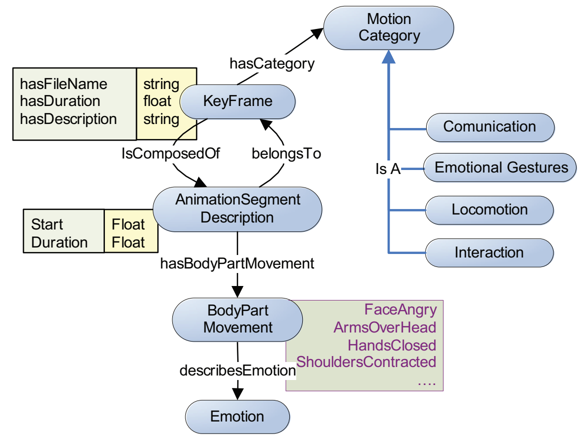

Figure 5: Description of emotional expressions using FK.

Next section shows how we put these ideas into practice. We implemented a virtual environment where VH are characterized by a specific personality and emotional state, which will define the way they react to different stimuli.

5. APPLICATION SCENARIO

The scenario we present aims to illustrate the different reactions that VHs can perform accordingly to individual traits. The description of this individuality is by means of the FFM personality model and we consider six emotional states: Sad, Angry, Happy, Disgust, Fear and Surprised. For each character we used arbitrary values to define their individuality and stored them in the ontology. This ontology contains also information about animations as described in section 3.2. To retrieve this information from the ontology we used Protégé software [20] that allows us to make queries using SPARQL [28]. An example of a query is to extract the body part animations that have been annotated with a given emotion. The query results also include the file name where the animations are contained, the start time and the duration. Query results are parsed by the 3D application which also extracts and uses the data.

. Emotion	Head	Upper Body	Hands	Movement Quality
Sad	Down, hanging	Contracted	-	Slow, passive
Angry	Erect	Expanded, rigid	Opening and closing	High movement
Happy	Up	Erect	-	
Disgust	Downward	Contracted, Arms crossed, rise shoulders	-	No expansive movements
Fear	-	Arms over the head, rise shoulders, arms against chess	Opening and closing	-

Table 1: List of emotions associated with specific body part movements.

Figure 6: Simulation of view, hearing and touch sensors with bounding boxes.

Figure 7: Initial scene.

We have used the 3D development kit [16], where we can visualize and animate H-Anim compliant characters. To simulate perception, we developed basic perception sensors that let characters perceive events and interact with nearby objects. In the Figure 6 we present the sensors using bounding boxes attached to a specific joint: vision is the trapezoid, audition is the circle, and touch is the yellow rectangle. For the collision detection and physical simulation of some objects we used Aegia Physics Software [17].

To animate the characters we use two animation libraries, a Key Frame player, and an Inverse Kinematics controller [2]. Using IK we create the reactive animation to perform (intercept, avoid, etc.), and with the KF we play any action and expressive animations according to the emotional state of the character. When characters are not reacting, they perform a predefined stack of actions: walk, talk, wait, etc, which are defined using the motion category. These actions can be also composed with expressive movements (animation segments that have emotional meaning).

The animation composition consist in having one main animation (KF or IK) in the Upper and/or Lower body and secondary animations segments (KF) in the hands, head and face. The secondary animations are for performing those animations that were annotated with emotional content. We have annotated 120 animations considering the six emotional sates. The main issue to solve when playing different animations in parallel is the coordination and synchronization -duration- of animations. Thus we take as main duration the one of the main animation. When blending the two kinds of animation: KF and IK, there is no problem of coordination, it is possible to set a transition value from the actual posture to the final posture of the IK.

Spontaneous reactions happen when unexpected events - stimuli- occur in the environment. Each VH has a reactive controller, which performs the following sequence:

1. perceive an event, turn the head to look at it;
2. get a type of reaction depending on its personality using the decision tree model described in section 3.2;
3. compute the reaction posture according to the stimulus position and set the end effectors of the arms and/or legs (body parts affected by IK);
4. update emotional state with the intensity of the predominant emotion depending on the personality of the VH, as described in section 3.4;
5. get expressive KF animations for the remaining body parts according to the current emotional state.

In our scenario we have 4 virtual humans (see figure 7): Helena, Peter, Brian and Lydia (from top left to bottom right); they have different personalities and emotional states. The ideal[1] scenario is presented in figure 8. The animation starts when Peter comes behind Helena (a) and screams to say "hi!" to her (b). She reacts and becomes angry, turns away from Peter and kicks a pot on the roof (c). The pot falls down. As Brian and Lydia hear something they look up and realize that a pot is falling over them (d). Brian gets surprised and tries to catch the pot (e). Lydia feels fear and tries to protect her self (f).

[1]"Ideal", because it does not happen like this all the time. VH actions depend on their current personality and emotion configurations

To create a continuous animation we defined a list of actions to be performed during the sequence while any reactions are performed. For every animation, including the reaction, we complement them with expressiveness by adding secondary expressive animation segments, where selected segments correspond to the actual emotional state.

By changing the personality values we are able to obtain different reactions. Moreover, as the stimulus comes from a different direction, the reaction simulation looks different every time.

6. CONCLUSION AND FUTURE WORK

In this paper we proposed to improve believability of VH by enabling characters to display a reactive behavior to unexpected events. VH reactions are individualized by using a reaction model that consist on a decision tree based on a statistical analysis of real people reacting. Moreover, we considered an emotion update model to increase expressiveness to VH's reactions. The synthesis of the reaction is the combination of two animation techniques Key frame interpolation and inverse Kinematics. IK was used to produce reaction postures: intercept, avoid and protect; and KF was used to enhance animation with expressiveness in the body parts that were not used by IK. We use an ontology to annotate animation segments that contained emotional meaning, and to describe the individualization of characters.

The reactive model presented is good enough to provide a simulation of different personalized reactions. However, the actual reaction types and animation sequences should be validated by psychology theories. The animation synthesis sometimes produced weird postures due to the IK, this could be fixed by adding more constraints to each type of movement. So far, we have annotated key-frames animations in a subjective way, depending on author's personal judgment. Animation annotation resulted to be a very exhaustive work, thus we plan to be able to annotate and classify animation sequences in a semi-automatic way. This may require pattern recognition techniques and the definition of specific criteria to qualify movements. However results were quite appealing. This work provides a generic platform that can be further parameterized to better fit different psychological models; and render virtual characters more and more expressive and to some extent, unpredictable.

Acknowledgements

We would like to thanks to Etienne Roesch for its value comments in the psychological aspects of this paper. This research has been funded by the EC and the Swiss Federal Office for Education and Science in the framework of the European Networks of Excellence IST-HUMAINE (http://emotion-research.net) and IST-AIM@SHAPE (http://www.aimatshape.net).

7. REFERENCES

[1] E. Andre, M. Klesen, P. Gebhard, S. Allen, and T. Rist. Integrating models of personality and emotions into lifelike characters. *Proceedings International Workshop on Affect in Interactions. Towards a New Generation of Interfaces*, 453, 1999.

[2] B. L. Callennec and R. Boulic. Interactive motion deformation with prioritized constraints. *Graph. Models*, 68(2):175–193, 2006.

[3] D. M. Chi, M. Costa, L. Zhao, and N. I. Badler. The emote model for effort and shape. In K. Akeley, editor, *Siggraph 2000, Computer Graphics Proceedings*, pages 173–182. ACM Press / ACM SIGGRAPH / Addison Wesley Longman, 2000.

[4] C. Darwin. *The Expression of the Emotions in Man And Animals*. Digireads. Com, 2005.

[5] A. Egges, S. Kshirsagar, and N. Magnenat-Thalmann. Generic personality and emotion simulation for conversational agents. In *Journal of Computer Animation and Virtual Worlds*. John Wiley and Sons, Ltd., 2004.

[6] P. Ekman. Facial expression and emotion. *Am Psychologist*, 48:384–392, 1993.

[7] H. Eysenck. *Handbook of personality: Theory and research*, chapter Biological dimensions of personality, pages 244–276. New York: Guilford., 1990.

[8] P. Faloutsos, M. van de Panne, and D. Terzopoulos. The virtual stuntman: dynamic characters with a repertoire of autonomous motor skills. *Computers and Graphics*, 25(6):933–953, 2001.

[9] A. Garcia-Rojas, F. Vexo, and D. Thalmann. Individualized reaction movements for virtual humans. In *GRAPHITE '06: Proceedings of the 4th international conference on Computer graphics and interactive techniques in Australasia and Southeast Asia*, pages 79–85, New York, NY, USA, 2006. ACM Press.

[10] T. Komura, E. S. L. Ho, and R. W. H. Lau. Animating reactive motion using momentum-based inverse kinematics: Motion capture and retrieval. *Comput. Animat. Virtual Worlds*, 16(3-4):213–223, 2005.

[11] S. Kshirsagar and N. Magnenat-Thalmann. Virtual humans personified. In *AAMAS '02: Proceedings of the first international joint conference on Autonomous agents and multiagent systems*, pages 356–357, New York, NY, USA, 2002. ACM Press.

[12] S. Marsella and J. Gratch. A step toward irrationality: using emotion to change belief. In *AAMAS '02: Proceedings of the first international joint conference on Autonomous agents and multiagent systems*, pages 334–341, New York, NY, USA, 2002. ACM Press.

[13] R. McCrae and O. John. An introduction to the five-factor model and its applications. *Journal of Personality*, 60(2):175–215, 1992.

[14] A. Ortony, G. Clore, and A. Collins. *The cognitive structure of emotion*. Cambridge University Press., Cambridge, UK, 1988.

[15] C. Pelachaud. Multimodal expressive embodied conversational agents. In *MULTIMEDIA '05: Proceedings of the 13th annual ACM international conference on Multimedia*, pages 683–689, New York, NY, USA, 2005. ACM Press.

[16] A. Peternier, D. Thalmann, and F. Vexo. Mental vision: a computer graphics teaching platform. In *Edutainment 2006*, Technologies for E-Learning and Digital Entertainment. First International Conference, Edutainment 2006. Proceedings (Lecture Notes in Computer Science Vol.3942), pages 223–232, 2006. Virtual Reality Lab., Ecole Polytech. Fed. de Lausanne, Switzerland.

[17] A. PhysX. Ageia physx system software.

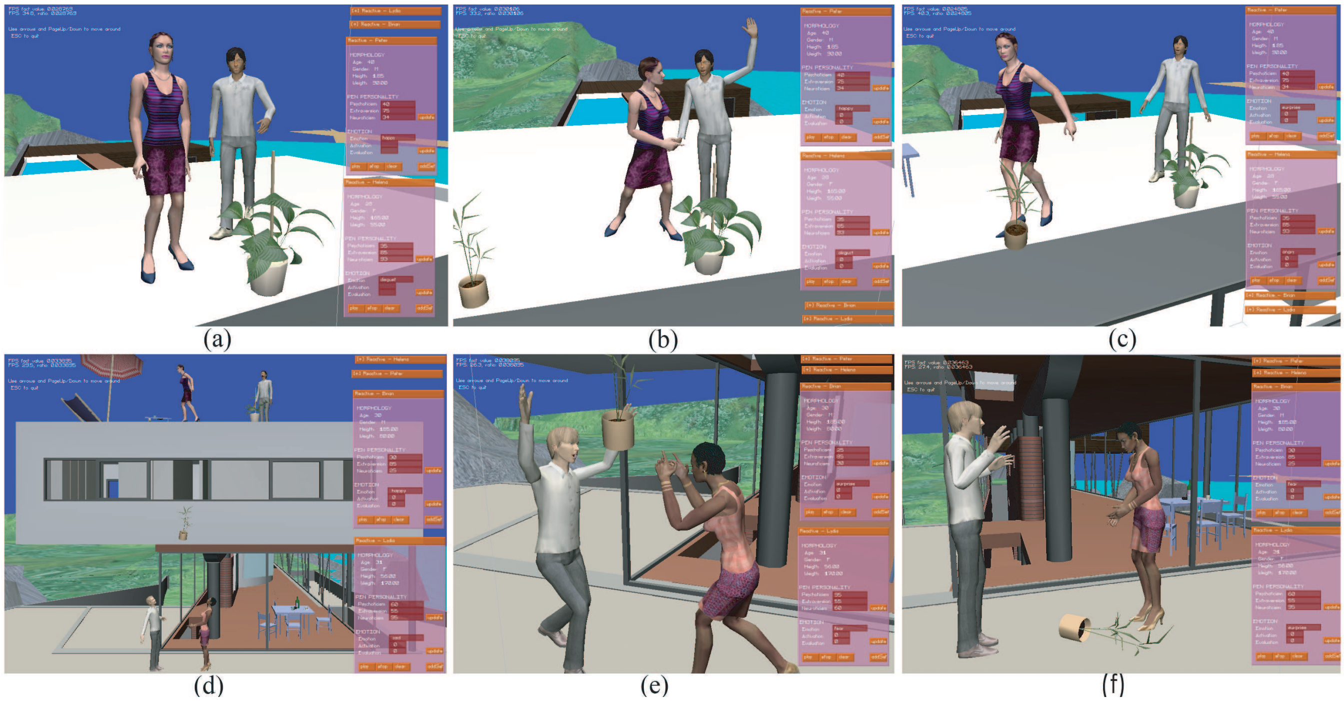

Figure 8: Reactive scenario sequence.

http://www.ageia.com/drivers/drivers.html.

[18] J. Potter. The big five personality test. http://www.outofservice.com/bigfive/, (c) 1996-2007 Atof Inc.

[19] M. Poznanski and P. Thagard. Changing personalities: towards realistic virtual characters. *J. Exp. Theor. Artif. Intell.*, 17(3):221–241, 2005.

[20] Protégé. (c) 2005 stanford medical informatics. http://protege.stanford.edu/index.html.

[21] J. Quinlan. *C4. 5: programs for machine learning.* Morgan Kaufmann Publishers Inc. San Francisco, CA, USA, 1993.

[22] D. R. D. Silva, C. A. Siebra, J. L. F. Valadares, A. C. Frery, J. R. Falcão, and G. L. Ramalho. Synthetic actor model for long-term computer games. *Virtual Reality*, 5:1–10, 2001.

[23] W.-P. Su, M.-B. Pham, and M.-A. Wardhani. Personality and emotion-based high-level control of affective story characters. *IEEE Transactions on Visualization and Computer Graphics*, 13(2):281–293, 2007.

[24] B. Tang, Z. Pan, L. Zheng, and M. Zhang. Simulating reactive motions for motion capture animation. In *Advances in Computer Graphics, LNCS 4035*, pages 531–537. Springer, 2006.

[25] E. Tanguy, J. J. Bryson, and P. J. Willis. A Dynamic Emotion Representation Model Within a Facial. Animation System. *The International Journal of Humanoid Robotics*, 2006.

[26] V. Vinayagamoorthy, M. Gillies, A. Steed, E. Tanguy, X. Pan, C. Loscos, and M. Slate. Building expression into virtual characters. In *Eurographics Conference State of the Art Reports*, 2006.

[27] W3C. Owl web ontology language. http://www.w3.org/tr/owl-features/.

[28] W3C. Owl web ontology language. http://www.w3.org/tr/rdf-sparql-query/.

[29] H. G. Wallbott. Bodily expression of emotion. *European Journal of Social Psychology*, 28(6):879–896, December 1998.

[30] C. M. Whissel. *The dictionary of affect in language R. Plutchnik and H. Kellerman (Eds) Emotion: Theory, research and experience: vol 4, The measurement of emotions.* Academic Press, New York, 1989.

[31] I. Witten and E. Frank. *Data Mining: Practical Machine Learning Tools and Techniques with Java Implementations.* Morgan Kaufmann, 1999.

[32] V. B. Zordan and J. K. Hodgins. Motion capture-driven simulations that hit and react. In *SCA '02: Proceedings of the 2002 ACM SIGGRAPH/Eurographics symposium on Computer animation*, pages 89–96, New York, NY, USA, 2002. ACM Press.