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Computational Emotion Model for Virtual Characters

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1. Introduction

Computer game is becoming a new computer application field, its one of key technology is to set up intelligent virtual characters. Emotion is of the highest importance in modern computer games. The essence of computer game lies in waking a user's emotion experience; modeling virtual character's emotion is the key goal in computer game. David Freeman pointed out in his best-seller book "Creating Emotion in Games"(Freeman, 2003) : the revolution in the future of computer game is not the technology, but to create emotion experience. Truthfully, many directors of computer game products have already realized that the contents must be full of emotion experience.

Computer game industry needs more clever virtual characters with an intelligent model. Intelligent virtual character is a new research field that integrates artificial life and computer animation together. Artificial life is the research field that tries to describe and simulate life by set-ting up virtual artificial systems with the properties of life. We can get more understanding from the developing history of computer animation. Early computer animation only includes shape and movement of a geometry model, it is very difficult to draw complex natural landscape, and artificial life can help to solve these problems. In a general, an artificial life model is based on bottom-up strategy. Emergence is the key concept of artificial life. It means a complex system is from the simple location interactions of individuals. Another key concept of artificial life is adaptation, which means evolution. In 80 years of the 20th century, many models of computer animation were presented, such as particle models, L-system, kinematics and dynamics, facial animation, etc. In 90 years of the 20th century, artificial life influenced the development of the computer animation greatly (Tu, 1994); Funge presented the cognitive model for computer animation (Funge, 1999), On the basis of the Funge's a cognitive model for computer animation, we can illustrate a virtual character's hierarchy of computer animation in Fig 1. In order to create believable characters, people hope to set up computational emotion models for virtual characters.

There are a lot of relative researches on virtual character and emotion model; we only introduce part of them. Badler et al. use finite state machine to control a virtual character's behavior, personality characteristic was expressed by locomotion parameters (Badler, 1997), they also built a system called Emote to add personality and emotion for virtual characters (Chi, 2000), Ball et al. proposed a Bayesian network-based model of personality for speaking

(Ball, 2000), they only used two traits (dominance and friendliness). Goldberg realized a script-based animation system for virtual characters (Goldberg, 1997), users could add some personality parameters in script file. Rousseau et al. used a value for a personality on social psychology (Rousseau, 1998). The OZ project at CMU made a lot of researches on emotion and personality for believable agents (Bates, 1994; Loyall, 1997; Reilly, 1996). Blumberg in MIT presented a mental model of an autonomous virtual dog with a cognitive architecture (Blumberg, 1997). A virtual dog had a motivation system to express its behavior and personality. Blumberg also presented a learning method of the virtual dog, and his technique was based on Reinforcement Learning (RL)(Blumberg, 2002). Moffat presented a personality frame by emotion theory in psychology (Moffat, 1997), he used Frijda's theory of emotion to illustrate the relation between emotion and personality, but his model is abstract and lacks in mathematical details. N.M.Thalmann suggested that virtual character should not only look visual, they must have behavior, perception, memory and some reasoning intelligence (Thalmann, 1994), D.Thalman presented the concept of virtual character society (Thalmann, 2004; Noser, 1995), which is built according to agent architecture, Musse et al. depicted a crowd model for virtual characters (Musse, 2001). Egges et al. built a multi-layer personality model by the Big Five theory (Egges, 2004), their goal was to create believable virtual avatar that could interact with natural language, emotions and gestures, this personality model set up the relation between personality and emotion by a matrix. Gratch et al. presented a domain-independent framework for modeling emotion, they supposed that people had beliefs about past events, emotions about those events and could alter those emotions by altering the beliefs (Gratch, 2004). Cassell et.al realized a behavior animation toolkit (Cassell, 2001), and Pelachaud et.al presented a method to create facial expression for avatars (Pelachaud, 2002). Human emotion is related to stimulus and cognitive appraisal (Ekman, 1979; Ortony, 1988; Picard, 1997), most of emotion models in psychology are qualitative, there are little researching on formalization of emotion, personality and motivation. On the basis of previous research (Liu, 2002;Liu, 2005), a computational emotion model is presented in this chapter; the goal is to construct virtual characters with the ability of emotion self-control in environment. The emotion model gives a quantitative description for an emotion process; it can integrate emotion, personality and motivation together.

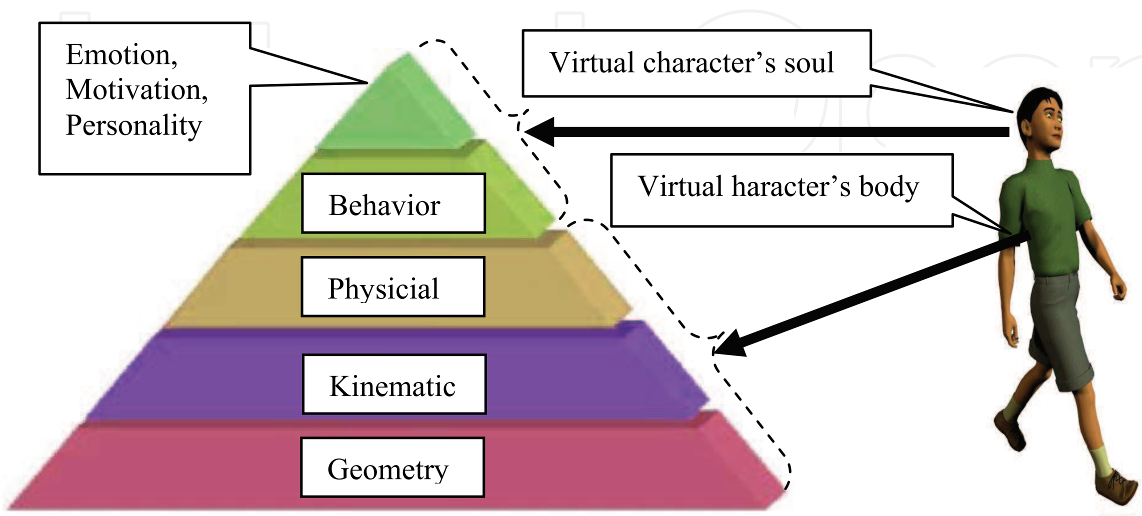


Fig. 1. Intelligent virtual character ’s modelling hierarchy

The remainder of this chapter is organized as follows: In the section 2, mental architecture of virtual character is presented by cognitive model. In the section 3, a formalization model of emotion is set up. In the section 4, animation expression of 3D virtual characters is proposed. In the section 5, an example of the model is introduced, and conclusion is in Section 6.

2. Mental architecture of a virtual character

A virtual character is regarded as an agent with a built-in structure. It should be provided with the mechanism of physical or mental variables that include emotion, personality, motivation and social norm. Based on Freud theory (Bernstein,1997; Satrongman, 2003), ID is the inborn, unconscious portion of the personality where instincts reside, and it operates on the pleasure principle. Libiduo is a source of psychic energy. Ego is responsible for organizing ways in the real world, and it operates on the reality principle. Superego is the rulers that control what a virtual character should do or not. The research is mainly based on behavior animation, and the goal is setting up a mental state-based animation model for 3D virtual character. The cognitive structure of a virtual character is shown in Fig 4:

(1) Sensors module collects environment's information from memory module. In this chapter, we only consider visual sensors, which can read from memory module to get current information of a 3D environment.

(2) Perception module is different from sensor module, and a virtual character can perceive the meaning of objects in environment through perception module. The perception module reads and filtrates information from sensor module and collect information of outer stimuli, a simplified attention mechanism can be integrated in perception module. In a dynamic environment, a virtual character needs not focus on all objects in environment. In this chapter, an attention object list can be set up beforehand for different virtual character. If an object is in the scope of perception, and is not in attention object list, character will not perceive the object. Moreover, the perception module reads the memory module to get mental variables, knowledge, and social norm. Meanwhile, perception module can communicate with mental variables by memory module.

In this chapter, we only discuss the visual perception. Synthetic vision is an important method for visual perception, which can accurately simulate the vision from view of a virtual character, the method synthesis vision on PC. When a virtual character needs to observe the virtual environment, the demo system can render the scene in invisible windows with no texture, and get a synthesis vision image. The virtual character can decide what he (she) could see from the values in color buffer and depth buffer. The purpose of using color buffer is to distinguish objects with different color code. The purpose of using depth buffer is to get the space position of a pixel in the window. In order to simulate perception for space, we can use static partition of scene octree that is a hierarchical variant of spatial-occupancy enumeration (Noser, 1995). We partition the static part of the scene in advance and record octree in data base module. We can use octree to solve path searching problem, as scene octree and the edges among them compose a graph, and so the path searching problem can be transformed to the problem of searching for a shortest path from one empty node to another in the graph (See Fig.2). In a complex virtual environment in which there are a lot of virtual characters, synthetic vision will be costly. Furthermore, this method cannot get the detail semantic information of objects. Therefore, we present another efficient method for simulation of visual perception. The visual perception of virtual character is limited to a sphere, with a radius of R and angle scope of θ_{max}. The vision sensor is at point O_{eyes} (the midpoint between the two eyes), and sets up local left-handed coordinate system. O_{eyes} is the origin and X_{axis} is along front orientation (See Fig.3). To determine whether the object P_{ob} is visible, the first step is to judge whether P_{ob} is in the vision scope. If the distance from P_{ob} to O_{eyes} is less than R and the angle between the ray and X_{axis} is less than $\theta_{max/2}$, the object P_{ob} is in the vision scope. The second step is to detect whether other obstacle occlude P_{ob}. We can shoot a ray OP from the O_{eyes} to P_{ob}, cylinders can serve as the bounding boxes of obstacles. In order to check the intersection of OP with an obstacle's bounding box, we can check whether OP intersects with a circle that is a projection of the obstacle's bounding box, and further to check whether OP intersects with the obstacle's bounding box. In a 3D virtual environment, there are a lot of dynamic objects, on which we set up feature points (such as geometric center). If one feature point is visible, the object is regarded as visible. In our demo system, all obstacles are building.

Fig. 2. A* path searching (the left is no obstacle and the right is near a house)

Based on the Gibson's theory of affordances (Gibson, 1986), affordances are relations among space, time and action. A character can perceive these affordances directly. An affordance is invariance for environment. In this chapter, we use the Gibson's theory to guide navigation, affordances of objects hints navigation information. We set up some navigation information in database for special area or objects in the 3D virtual environment. For example, when a character wants to walk across a road, we set navigation information of the zebra crossing is accessible, so that the character will select zebra crossing. We use scene octree to simulate the character's perception for static object in 3D virtual environment. The locations of all dynamic objects are recorded in memory module in animation time step. If an object is visible, we suppose that a virtual character moves on a 2D plane, let D_{ovc} is detection radius, d_{min} is avoiding distance for the character, if $D_{ovc}<d_{min}$, the virtual character will read navigation information of the object from memory. With doing so, when a virtual character wants to move from one place to another. We can set up some navigating points in a 3D environment, and a virtual character can seek the navigating point that is nearest to him and move to it. Usually, a virtual character moves from one navigating point to another. A default plan is a script file that records default-navigating points. If there is no external stimulus, a virtual character walks by a walking plan. When a virtual character perceives an object or events, he may stop walking and make some actions, then he continues walking to the nearest navigating point.

A virtual character has the sensor of detection barrier or stimulus, if a barrier or stimulus is in the fan-shaped region, the character will sense the barrier or stimulus, and read the semantic information for navigation. The navigation arithmetic of a virtual character is as follows(see Fig.3):

Step1: Read first location and goal location, stimulus location, octree of virtual environment, and motion step. Go to **Step2**.

Step2: If the distance from current location to goal location is less than motion step, the navigation is over; or else, go to **Step3**.

Step3: If the virtual character is in a navigation area (the distance from current location to navigation point is less than motion step), he will read the semantic navigation information navigation area from database, the navigation information will guide the virtual character to select a possible motion path; or else, go to **Step4**.

Step4: the virtual character will move along on the road, he will detect any barrier or stimulus by his sensors, if he senses a barrier, he will read the semantic navigation information on the barrier from memory, he will change motion direction and move by navigation information, go to **Step5**. If he senses a stimulus, he will read the semantic interaction information on the stimulus from memory module and knowledge module, in the emergent condition, the virtual character will leave road, he will move in free area and detect buildings by octree. When the emergent behavior is over, he will return to road, go to **Step 5**.

Step 5: the virtual character will move to the next navigation area, go to **Step2**.

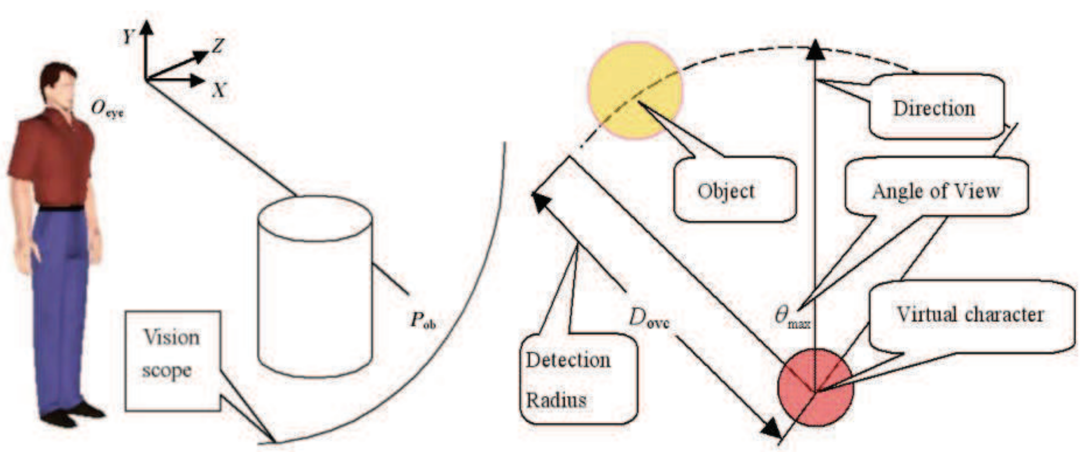


Fig. 3. Visible detection and detection of object's affordance

(3)Plan module executes navigation behavior code by perception model, it also executes a (expressive) behavior code by stimuli, emotion, personality, motivation, norm and knowledge, the detail is in section 3.

(4) Behavior module reads plan module and creates action codes for actuator module. There are several behaviors in the same time, for example, a virtual character can have smile behavior , calling to other's behavior and walking to a place behavior. Inhibitory gain and fatigue are time sequence characteristic of behavior. The higher Inhibitory gain, the longer the duration of the behavior is and new behavior is excited only under new stimuli. Fatigue means that behavior with low degree of priority can obtain the chance to carry out, once a certain behavior is carried out, the behavior will stop at some time (Tu, 1994). We can introduce the inhibitory gain coefficient (a real number greater than one) and fatigue

coefficient (a real number smaller than one) to measure inhibitory gain and fatigue correspondingly.

(5) Actuator module executes the behavior in behavior code, it includes inverse kinematics arithmetic to drive locomotion, and read motion capture data from memory module (memory module will read motion capture data in database). When actuator module successful executes a behavior code, it will write to memory module with an action sign that indicate whether the character moves to or executes a behavior code.

(6) Database module includes 3D geometry of virtual environment, original information, such as, the original location and parameters of virtual character, motion capture data, 3D model and location of objects, default motion plan scripts that record some goal location.

(7) Memory module serves as a center of information share among all other modules.

(8) Id module includes gender and need variables, gender variable is related to behaviors. Need variables include physical needs (hungry, etc) and psychic needs(safety). Let GD is a gender variable for a virtual character, $-1 \leq GD \leq 1$. If $GD<0$, the virtual character is a female, If GD>0, the virtual character is a male if $GD=0$, the virtual character is neutral. $|GD|$ is the measure of gender, if $|GD|=1$, the virtual character is a pure female or male. A virtual character can have many needs, Let $\boldsymbol{NED}$ is need vector, $\boldsymbol{NED}=\{ned_1, \ldots, ned_{ne}\}$, ned_i is a need variable, $i \in [1, ne]$, ne is the number of needs, for example, let ned_1 is food energy, $0 \leq ned_1 \leq 1$, if $ned_1=0$, the virtual character is not hungry, if $ned_1=1$, the virtual character is very hungry.

(9) Ego module includes emotion, personality and motivation. This module read external stimuli from memory (the perception module write stimuli information to memory module). Activation of an emotion is relative to external stimuli and inner mental variables. If an emotion is active, this module will create emotion expression, emotion expression code will be sent to behaviour module. Emotion is the core of the module, personality is some stable psychological traits of a virtual character, and motivation variables include some physiology parameters of a virtual character.

(10) Superego module includes norm and knowledge. Norm module includes status, interaction information and interaction rules, it controls the process of a nonverbal social interaction, and knowledge provides the social knowledge for virtual character.

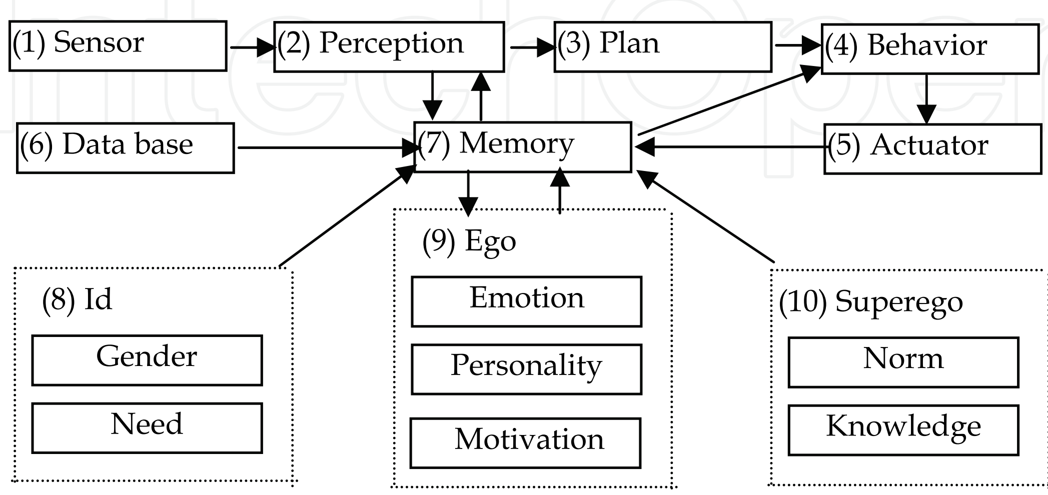


Fig. 4. Virtual character 's cognitive structure

3. Emotion model of virtual character

3.1 Formalization of some relative concepts about emotion

There are some classical research works in emotion model. The theories of emotion in psychology demonstrate that emotion is a cognitive interpretation of those responses to emotional experiences. Emotion associates the environment stimulus with the character personality on the basis of James-Lange theory of emotion and Schachter-Singer theory of emotion, and occurs with motivation simultaneously. In some sense, motivation can intensify emotion, but emotion can also create motivation. Emotion is usually transitory, with a relatively clear beginning and ending, and a short duration. Ortony et al set up an emotion cognitive model that is called OCC model (Ortony, 1988)(see Fig.5 and Fig.6). In the model, emotions are generated in reaction to objects, actions of agents and events. They outlined specifications for 22 emotion types.

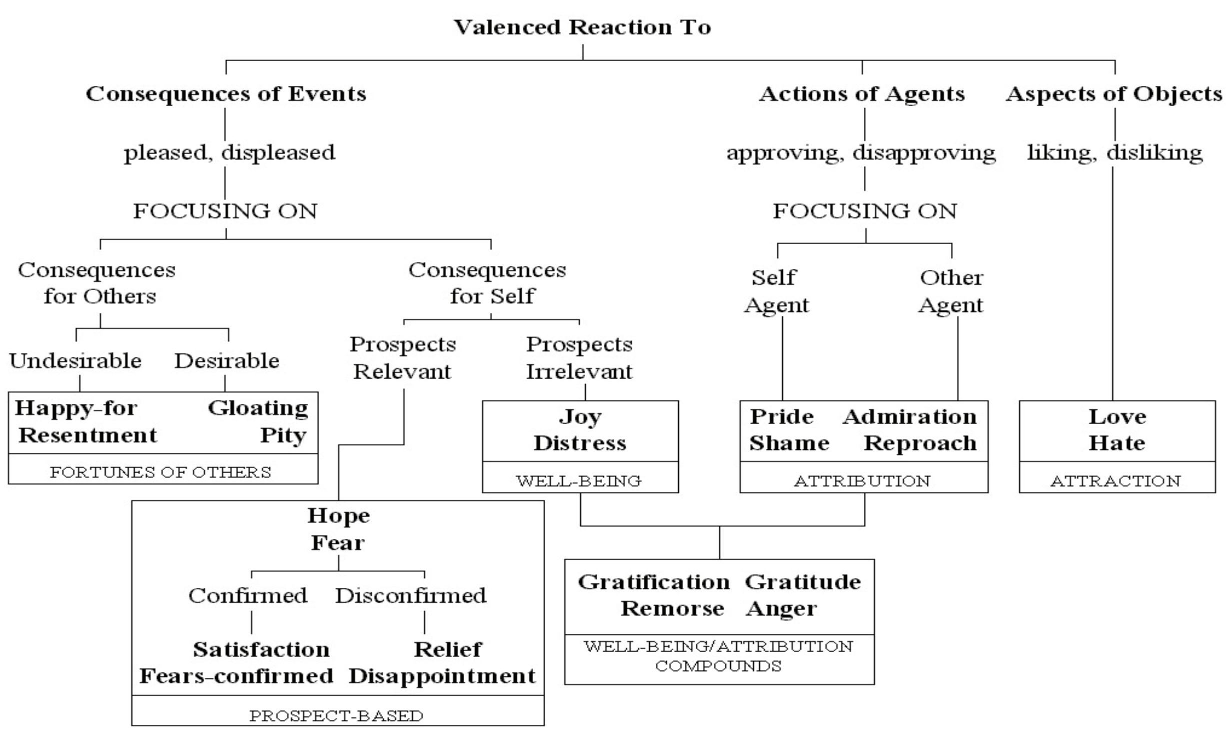
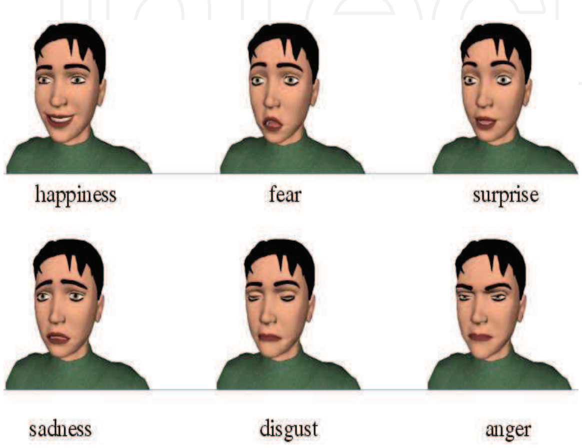


Fig. 5. Emotion types of OCC model



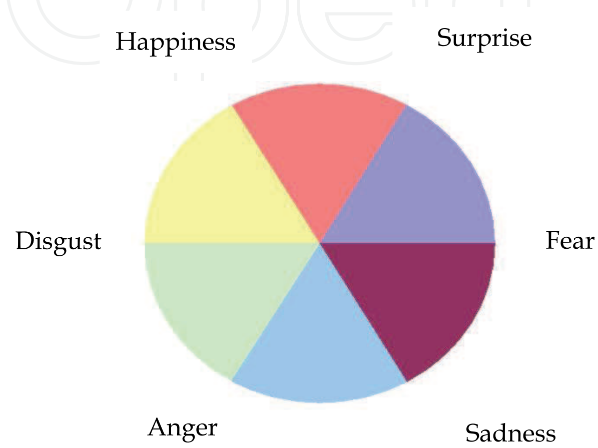


Fig. 6. Six basic emotions expression

Picard gave the concept of affective computing for interface between character and computer (Picard, 1997). In the opinion of Plutchik's emotion classification (Satrongman, 2003), emotion intensity distributes on a "circle" with eight basic categories of emotion that motivate various kinds of adaptive behavior of character. In the center of "circle", emotion intensity is zero, while in the edge of "circle" emotion intensity is one. In this chapter, the simplified Plutchik's emotion classification on face expression is as follows: happiness, surprise, sadness, fear, disgust, and anger. We can integrate OCC emotion model and Plutchik's emotion classification together; a virtual character can have 22 types emotion in OCC model, and six basic face expressions. We can set a function from OCC emotion types to six face expressions in table 1.

Plutchik's types	Emotion types in OCC model
Happiness	Happy-for, Gloating, Joy, Pride, Admiration, Love, Hope, Satisfaction, Relief, Gratification, Gratitude
Disgust	Hate
Anger	Anger, Reproach, Hate
Sadness	Resentment, Pity, Distress, Shame, Disappointment, Remorse
Fear	Fear, Fear-confirmed
Surprise	By context

Table 1. Relation between Plutchik's simplified emotion types and OCC emotion types

In this section, we give some new definitions for describing emotion process of virtual characters.

For a certain virtual character, ***BE*** is a basic emotion set, ***BE***={be_1, …… ,be_N}, $i \in [1, N]$, be_i is a basic emotion (such as happiness). N is the number of basic emotion class. $EI_i(t)$ is the intensity of be_i, $EI_i(t) \in [0, 1]$, t is time variable. $\boldsymbol{be}_i$ is the unit vector of be_i. For example, be_1={1,…,0}, be_N={0,…,1}. Let ES is emotion state, ***E*** is represented emotion vector of ES, the projection length of ***E*** on $\boldsymbol{be}_i$ is $EI_i(t)$. ***E*** can be represented as formula (1):

$$\boldsymbol{E} = \sum_{i=1}^{N} EI_i(t)\, \boldsymbol{be}_i . \quad (1)$$

Let $\boldsymbol{E}_1$ and $\boldsymbol{E}_2$ are two emotion vectors, the synthesis of $\boldsymbol{E}_1$ and $\boldsymbol{E}_2$ is represented as $\boldsymbol{E}_1 + \boldsymbol{E}_2$ in formula (2).

$$\boldsymbol{E}_1 + \boldsymbol{E}_2 = \sum_{i=1}^{N} [\, EI_{i1}(t)\, \boldsymbol{be}_{i1} + EI_{i2}(t)\, \boldsymbol{be}_{i2}\,]. \quad (2)$$

Let ***EP*** is the set of all emotion vectors, if any element of ***EP*** satisfies to formula (1)(2), ***EP*** is called emotion vector space, $\boldsymbol{be}_i$ is called the basic emotion vector.

Let ***PS*** is a personality set, $PS_k(t)$ is the personality variable, ***PS***={ $PS_k(t)$}, Θ [$PS_k(t)$] is the intensity of $PS_k(t)$, *nps* is the number of personality(k=1,…, *nps*), and $0 \le \Theta [PS_k(t)] \le 1$.
MV is a motivation variable set, $MV_m(t)$ is the motivation variable, ***MV*** ={ $MV_m(t)$}, w is the number of motivation variable(m=1,…,w). $\Theta [MV_m(t)]$ is the intensity of $MV_m(t)$, $0 \le \Theta [MV_m(t) \le 1$.

3.2 How an emotion is active

Let $O_j(t)$ is an external stimuli, *no* is the number of stimuli(j=1,…, *no*). $\Theta [O_{ji}(t)]$ is the stimuli intensity function of $O_j(t)$ for emotion be_i , and $0 \le \Theta [O_{ji}(t)] \le 1$.
In a virtual environment, there are a lot of stimuli, a virtual character can express emotion under stimuli or not, any virtual character has the ability of resisting external stimuli, let $C_i(t)$ is the average resistive intensity for emotion be_i. If stimuli intensity is bigger than $C_i(t)$, emotion expression for emotion be_i is active. The weaker $C_i(t)$ of a virtual character is, the more emotion expressive the virtual character becomes to be with emotion be_i, and $0 \le C_i(t) \le 1$.
In a general, a $C_i(t)$ is different for two virtual characters, personality and motivation will influence $C_i(t)$. We can give a simple method to update a $C_i(t)$.
For a certain $C_i(t)$, personality has impact on emotion state, α_{ki} is an impact coefficient from personality $PS_k(t)$ to $C_i(t)$. $NC_i(t)$ is the updating $C_i(t)$ with considering impact from personality $PS_k(t)$, $NC_i(t)=\min[\alpha_{ki} C_i(t),1]$, α_{ki} >=0. If α_{ki} =1, $NC_i(t)= C_i(t)$, personality has no impact on resistive intensity of emotion. $NC_i(t)$ is the updating Ci(t) with considering impact from all personality variable,

$$NC_i(t) = \sum_{k=1}^{nps} \Theta [PS_k(t)]\, NC_{ki}(t) \Big/ \sum_{k=1}^{nps} \Theta [PS_k(t)]. \tag{3}$$

For a certain C_i(t), motivation has impact on emotion state, β_{mi} is an impact coefficient from motivation variable MV_m(t) to C_i(t). MC_{mi}(t) is the updating C_i(t) with considering impact from motivation variable MV_m(t) , $MC_{mi}(t)=\min[\beta_{mi} Ci(t),1]$, β_{mi} >=0. If β_{mi} =1, $MC_{mi}(t)= C_i(t)$, motivation variable has no impact on emotion. MC_i(t) is the updating C_i(t) with considering impact from all motivation variable, and so:

$$MC_i(t) = \sum_{m=1}^{w} \Theta [MV_m (t)]\, R_m\, MC_{mi}(t) \Big/ \sum_{m=1}^{w} \Theta [MV_m (t)]\, R_m. \tag{4}$$

For a certain $C_i(t)$, motivation and personality has impact on emotion state in the same time, $TC_i(t)$ is the updating $C_i(t)$ with considering impact both from personality and motivation. $TC_i(t)=\min(NC_i(t), MC_i(t))$.
When an emotion be_i is active, emotion expression include three phases as follows:
(1) **Growth phase**: the intensity of an emotion class grows from its minimum value $[EI_{ji}(t)]_{\min}$ to its maximum value $[EI_{ji}(t)]_{\max}$. $[DT_{ji}]_{\text{growth}}$ is the duration time.

(2) **Delay phase**: the intensity of an emotion class is equal to its maximum value $[EI_{ji}(t)]_{max}$. $[DT_{ji}]_{delay}$ is the duration time.
(3) **Decay phase**: the intensity of an emotion class decrease to its minimum value $[EI_{ji}(t)]_{min}$. $[DT_{ji}]_{decay}$ is duration time.
In order to simplify the three phases, for a given be_i, we can give a default duration time for a certain external stimuli $O_{ji}(t)$ with $\Theta\,[O_{ji}(t)]_{max}$=1.The corresponding default duration time of the three phases are indicated by $DT[O_{ji}(t)]_{s\text{-}growth}$, $DT[O_{ji}(t)]_{s\text{-}delay}$ and $DT[O_{ji}(t)]_{s\text{-}decay}$. We suppose the intensity of an emotion changes with linear rule in growth phase or decay phase. The three phases are described as formula (5)-(9):

$$[EI_{ji}(t)]_{min} = [\,\Theta\,[O_{ji}(t)\text{- TCi(t)}]/(1\text{- TCi(t)}). \tag{5}$$

$$[EI_{ji}(t)]_{max} = \Theta\,[\,O_{ji}(t)]. \tag{6}$$

$$[DT_{ji}]_{growth} = [EI_{ji}(t)]_{max}\,.\,DT[O_{ji}(t)]_{s\text{-}growth} \tag{7}$$

$$[DT_{ji}]_{delay} = [EI_{ji}(t)]_{max}\,.\,DT[O_{ji}(t)]_{s\text{-}delay} \tag{8}$$

$$[DT_{ji}]_{decay} = [EI_{ji}(t)]_{max}\,.\,DT[O_{ji}(t)]_{s\text{-}decay} \tag{9}$$

4. Animation expression of 3D virtual characters

4.1 Creating expressive pose animation

In our method, a kinematic chain is used to simulate the pose animation of virtual character (Tolani, 2001), while an analytical method is used to solve inverse kinematics. In general, the kinematic chain can be expressed as: $\Delta\theta = J^{+}\Delta X + (I - J^{+}J)\,\Delta Z$, $\Delta\theta$ is the joint variation vector, I is the identity matrix, J is the Jacobian matrix of the set of cartesian constraints, J^{+} is the pseudo-inverse of J, ΔX is the variations of the set of cartesian constrints, ΔZ is used to minimise the distance to the attraction posture. Numerical algorithms for solving inverse kinematics are too slow to meet the demands of real-time applications. Deepak Tolani presented an analytical method for solving inverse kinematics and more accurate (Tolani, 2001). In his opinion, human limb kinematic chain can be expressed as Fig 7. Let T_1 denote the rotation matrix from the proximal to the distal site of S_1 as function of θ_1, θ_2, θ_3. T_2 similarly represents the rotation matrix from proximal to the distal site of S_2 as function of θ_5, θ_6, θ_7, and T_y is the rotation matrix produced by revolute joint F as a function of θ_4, let A is transformation matrix from proximal of F to distal S_1, B is transformation matrix from proximal S_2 to distal of F, G is the goal matrix of end effector. The kinematic chain can be denoted as: $G=T_1 A T_y B T_2$, and so θ_1, θ_2, θ_3, θ_4, θ_5, θ_6, θ_7 can be solved.
Motions of whole virtual character body can be realized in the motion capture data process software, and can accumulate a motion library M. Let $M=\{m_i\}$, i=1,....,L, L is the number of motion in M, m_i is a motion capture data including the three dimension rotation of a joint of body, m_i is stored as BVH format file. We can blend motion capture data to create an emotional walking pose.

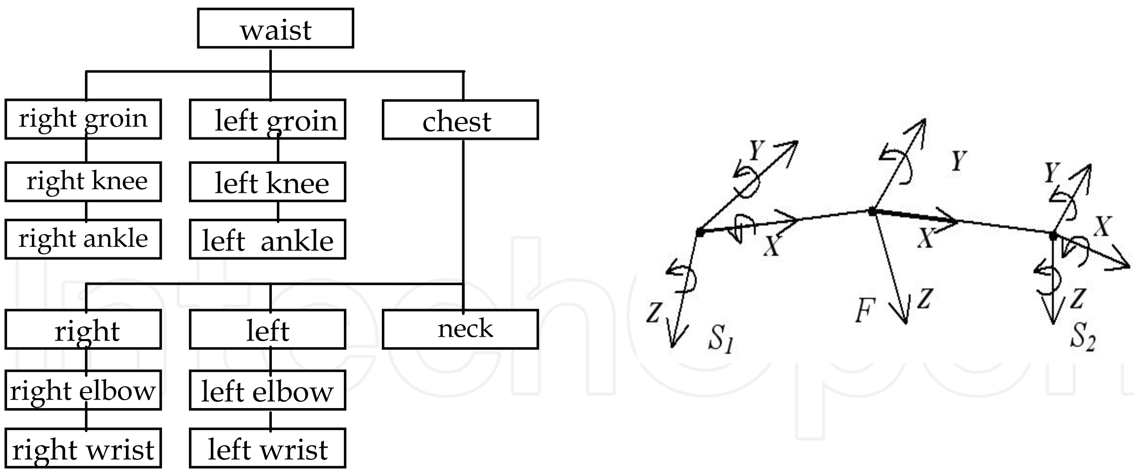


Fig. 7. Skeleton of virtual character and kinematic chain with seven degree

We can blend motion capture clips to create an emotional walking pose (see Fig. 8 and Fig. 9). The target of motion blending is to support motion concurrency. Motion concurrency means the avatar performs multiple motions at the same time. It is quite natural in our life. For example, we can greet to others while walking and we can lift a bag by one hand while making a phone call by the other hand. Motion concurrency results in different limbs performing different actions. Take greeting while walking: legs perform walking motion and arms perform greeting motion. Motion blending is to embed one motion into another and to simulate the effect of motion concurrency. We use signal interpolation to solve the problem of transition between two motions (Kovar, 2002; Lee, 2002). To calculate the phasing of each motion, generic time is needed. A motion signal can be represented as:

$$A_i = \{\theta_{ij}(T), K_m, P_s, P_e, \mid j=0,\ldots,numDof\text{-}1,\ m=0,\ldots,num\text{Keytime-}1\}$$

Where A_i represents the ith motion signal, θ_{ij} represents the jth freedom of A_i, Kim represents the m th key time of A_i, Ps is the starting phasing and Pe is the end phasing. Rose defines the mapping from real time T to uniform t as follows (Rose , 1998):

$$t(T)=\left(m+\frac{T-K_m}{K_{m+1}-K_m}\right)\frac{1}{N_k-1} \tag{10}$$

Where m=max (i | K_i<T) and N_k is the number of key times.

As walking is the most frequent motion, so we do phasing calculation based on one walking cycle. For each motion signal, we find the most similar time point in the walking signal and use the generic time of this time point as the phasing value. This can be done by hand. But to be more accurate and efficient, we can use some frame mapping algorithms (Kovar, 2002; Lee, 2002). Signal interpolation is actually signal fade-in and fade-out mechanism. We define a function:

$$f=(1-\cos(\alpha\pi))/2 \tag{11}$$

In the transition time, we use (1-f) and f as the coefficients to do interpolation between the two motion signals and generate the transition motion.

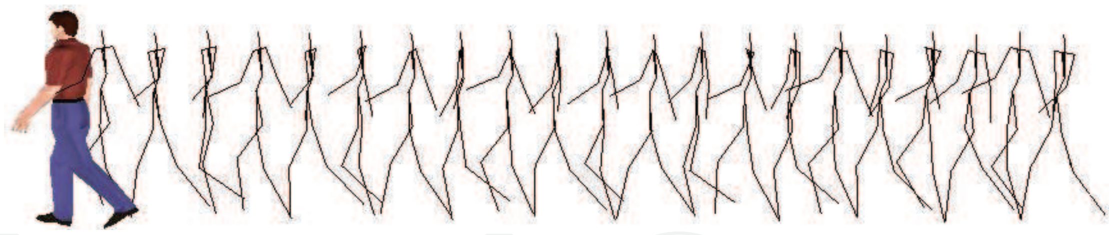


Fig. 8. Skeleton of natural walking

Fig. 9. Skeleton of sad walking (blend sad motion capture data to natural walking)

4.2 Facial animation

A face's geometry model is described by polygons, the location of any vertex can be represented as vector v_k , $k \in [0, L]$, L is the number of all vertex. Let $\boldsymbol{V}$ is a vector for all vertex, $\boldsymbol{V}$ is called expression vector. $\boldsymbol{V}$ is represented as formula (12).

$$\boldsymbol{V} = (v_1 ,\ldots\ldots,v_L) . \tag{12}$$

There are two rulers on $\boldsymbol{V}$:

1) For two expression vector $\boldsymbol{V}_1$ and $\boldsymbol{V}_2$, $\boldsymbol{V}_1$=(v_{11} ,……,v_{L1}) , $\boldsymbol{V}_2$=(v_{12} ,……,v_{L2}) , the synthesis of $\boldsymbol{V}_1$ and $\boldsymbol{V}_2$ is represented as formula(13):

$$\boldsymbol{V}_1 + \boldsymbol{V}_2 = (v_{11} + v_{12} ,\ldots\ldots,v_{L1}+ v_{L2}). \tag{13}$$

2) For any real number C, the multiplication of expression vector by C is represented in formula (14):

$$\mathrm{C}\boldsymbol{V} = (\mathrm{C}v_1 ,\ldots\ldots, \mathrm{C}v_L). \tag{14}$$

Let $\boldsymbol{E}_1$ and $\boldsymbol{E}_2$ are two emotion vectors, if an emotion vector changes from $\boldsymbol{E}_1$ to $\boldsymbol{E}_2$, the corresponding expression vector changes from $\boldsymbol{V}_1$ to $\boldsymbol{V}_2$. In order to describe the process of facial expression, let λ is interpolation function, $\lambda \in [0, 1]$, $\boldsymbol{FV}$ is a expression vector generated by interpolation of $\boldsymbol{V}_1$ and $\boldsymbol{V}_2$, $\boldsymbol{FV} = (fv_1 ,\ldots\ldots, fv_L)$, fv_k is the corresponding vertex vector, $k \in [0, L]$, fv_k is calculated by formula(15):

$$fv_k = \lambda\, v_{k1} + (1- \lambda)v_{k2}. \tag{15}$$

The formula (15) can be transformed to formula (16):

$$\boldsymbol{FV} = \lambda\, \boldsymbol{V}_1 + (1- \lambda)\, \boldsymbol{V}_2 . \tag{16}$$

There are some expression vector, pn is the number of expression vector, $\boldsymbol{V}_i$ is an expression vector, $i \in [0, pn]$, λ_i is the corresponding interpolation function of $\boldsymbol{V}_i$, $\boldsymbol{FV}$ is an expression vector generated by interpolation among different $\boldsymbol{V}_i$, $\boldsymbol{FV}$ is calculated by formula (17):

$$\boldsymbol{FV} = \sum_{i=1}^{N} \lambda_i \boldsymbol{V}_i. \quad (17)$$

All ***FV*** is in formula (17) is called expression vector linear space, *pn* is called the dimension number of ***FV***, $\boldsymbol{V}_i$ is called a base expression vector.In general, there are some expression vector, *pn* is the number of expression vector, $\boldsymbol{V}_i$ is an expression vector, $i \in [0, pn]$, SY is an synthesis function among all $\boldsymbol{V}_i$, ***FV*** is calculated by formula (18):

$$\boldsymbol{FV} = SY(\boldsymbol{V}_1, \ldots\ldots, \boldsymbol{V}_{pn}). \quad (18)$$

All ***FV*** is in formula (18) is called expression vector space.In general, ***EP*** is emotion vector space, ***FV*** is called expression vector space, *T* is a function from ***EP*** to ***FV***, for any $\boldsymbol{E} \in \boldsymbol{EP}$, $T(\boldsymbol{E}) \in \boldsymbol{FV}$.In general, $\boldsymbol{be}_i$ is a unit vector, $i \in [1, N]$, $\boldsymbol{T}(\boldsymbol{be}_i)$ is called base expression vector. If $pn=N$, ***FV*** is calculated by formula (19):

$$\boldsymbol{FV} = SY(T(\boldsymbol{be}_1), \ldots, T(\boldsymbol{be}_N)). \quad (19)$$

In order to simplify the formula (19), let SY is linear function, $\lambda_i = EI_i$, ***FV*** is calculated by formula (20):

$$\boldsymbol{FV} = \sum_{i=1}^{N} (EI_i)\, T(\boldsymbol{be}_i). \quad (20)$$

A demo of synthesis on expression by formula (20) is realized on PC, the programming tools are Visual c++ language and Direct3D API. In the demo, six basic facial expressions are selected in Fig.6, some of synthesis results are shown in Fig.10. For example, in Fig.10(1), "1/2 happiness+1/2 sadness" is represented the synthesis of happiness and sadness, each basic emotion intensify is equal to 1/2.

4.3 Norm and social knowledge of virtual characters

Virtual characters live in a virtual society; a believable virtual character should have the ability of social interaction to other virtual characters with verbal and nonverbal manner. In this section, we give a method to construct norm and social knowledge.

For a certain virtual character, a status is a social degree or position. In general, a virtual character may own many status, let $ST(CA)$ is a status set for virtual character CA, $ST(CA)=\{st_1, \ldots, st_{NS}\}$, $i \in [1, NS]$, st_i is a status (such as mother or son).NS is the number of $ST(CA)$.

Status plays an important role in a social interaction. For example, in a virtual office, there are two kinds of social status altogether, namely the manager and staff member. The manager's status is higher than the status of the staff member. In general, a person will control emotion expression by one's status.

For two certain virtual characters CA_1 and CA_2, let $FD(CA_1/CA_2)$ is friendliness value from CA_1 to CA_2. If $FD(CA_1/CA_2)=1$, CA_2 is a friend of CA_1; If $FD(CA_1/CA_2)=-1$, CA_2 is an enemy of CA_1; If $FD(CA_1/CA_2)=0$, CA_2 is a stranger of CA_1; If $FD(CA_1/CA_2)=2$, CA_2 is a lover of CA_1; If $FD(CA_1/CA_2)=3$, CA_2 is a mother or father of CA_1; If $FD(CA_1/CA_2)=4$, CA_1 is a mother or father of CA_2.

A virtual character judges others with friendliness value. In general, a virtual character will not interact with a stranger unless in some exceptive conditions (calling help in danger etc.).

For two certain virtual characters CA_1 and CA_2, let ET_1 (CA_1/CA_2) is default-ending time of interaction from CA_1 to CA_2, let ET_2 (CA_2/CA_1) is default-ending time of interaction from CA_2 to CA_1, and ET is the time from beginning to ending in interaction.

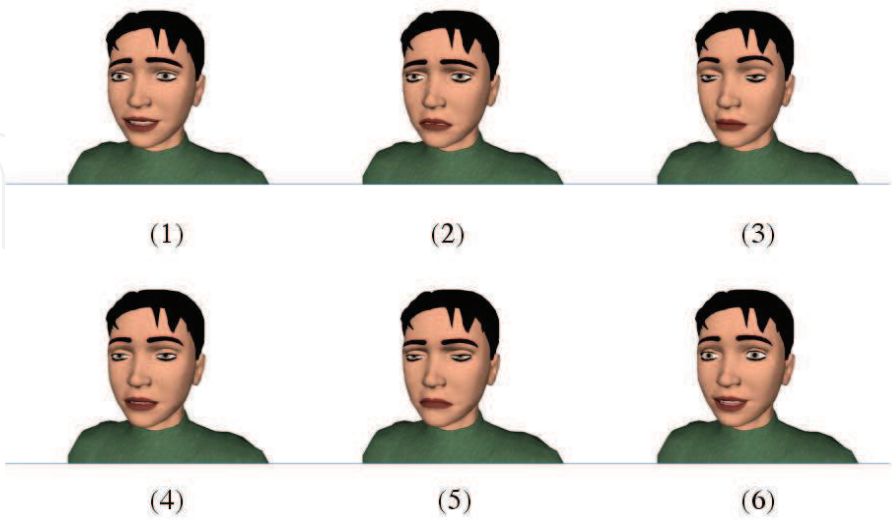


Fig.10. Some synthesis of expressions :(1) "1/2happiness+1/2sadness"; (2) "1/2sadness+1/2anger";(3)"1/2surprise+1/2disgust";(4)"1/3happiness+1/3fear+1/3disgust";(5)"1/3sadness+1/3disust+1/3anger";(6)"1/3happiness+1/3sadness +1/3 anger ".

In general, if ET $\geq$ min (ET_1 (CA_1/CA_2), ET_2 (CA_2/CA_1), the interaction will end. For two certain virtual characters CA_1 and CA_2, let IR (CA_1/CA_2) is interaction radius of CA_1 to CA_2, let DS (CA_1/CA_2) is distance from CA_1 to CA_2. In general, if DS (CA_1/CA_2)> IR (CA_1/CA_2), CA_1 will not make interaction to CA_2; if (CA_1/CA_2)$\leq IR$ (CA_1/CA_2), CA_1 may make interaction to CA_2.

In default condition, when two agents encounter together, interaction radius is critical distance of interaction triggering.

For two certain virtual characters CA_1 and CA_{12}, let PN (CA_1, CA_2) is priority value of social interaction between CA_1 and CA_2. If PN (CA_1, CA_2)=0, CA_1 first interact with CA_2, CA_1 is initiator; If PN (CA_1, CA_2)=1, CA_2 first interact with CA_1, CA_2 is initiator; If PN (CA_1, CA_2)=2, CA_1 and CA_2 interact each other at the same time.

In general, a virtual character acts different status with interaction to others. For instance, there are three virtual characters CA_1, CA_2 and CA_3, CA_2 is mother of CA_1, CA_3 is a student of CA_1, when CA_1 meet CA_2 or CA_3, CA_1 usually first interact with CA_2, CA_3 usually first interact with CA_1, and PN (CA_1, CA_2)=0, PN (CA_1, CA_3)=1.

For two certain virtual characters CA_1 and CA_2, let INS ($CA_1 \leftarrow CA_2$) is an interaction signal set from CA_2 to CA_1, INS ($CA_1 \leftarrow CA_2$)=$\{ins_1, \ldots ,ins_N\}$, ins_i is a nonverbal interaction signal (such as "calling help pose"), $j \in [1, NI]$, NI is the number of INS ($CA_1 \leftarrow CA_2$).

In a virtual environment, when two virtual characters begin to interact each other, Each of them is supposed to be able to know interaction signal. In a practical demo system, interaction signals are sent to memory module by social norm module.

For a certain virtual characters CA, let IR (CA) is an interaction rule for virtual character CA, IR control the manner of interaction, IR include some production rulers.

A high-level algorithm can illustrate how to construct IR, which is related to context. There are two virtual characters CA_1 and CA_2 in a virtual environment. The algorithm procedure of emotion social interaction is as follows step:

Step 1: The procedure gets current emotion state and social norms (status, all friendliness degree, default-ending time of interaction, all interaction radius, and all priority degree of social interaction).

Step 2: The procedure judge whether a character can interact with others according to the current emotion state and social norm. If a character can interact with others, go **Step 3**; else go **Step 4**.

Step 3: Interaction signals are transferred between CA_1 and CA_2. If one of interaction signal is "ending interaction", then go to **Step 4**.

Step 4: Ending interaction.

5. An example of the model

A virtual town is set up on PC, we can use this example to illustrate the above method, all the 3D geometry models of objects in the town are drawn by 3D software and stored in Microsoft DirectX format files. There are dynamic objects (vehicles) and virtual characters; Tom, John and Mary are three virtual characters in the demo system. They can move from one place to another, and can express their emotions. We can suppose John is a friend of Tom, when Tom meets to John, Tom will smile to John, and we can construct the social norm for Tom in a script file as follows:

```
Status (Tom):={a worker};
GD=1; //Gender of Tom is male.
Social relationships:=(John is friend, no enemy)
Friendliness value (to John)=1;
Friendliness value (to others)=0;
Default-ending time of interaction (to John)=1 minutes;
Default-ending time of interaction (to others)=0.1 minutes;
Interaction radius (to John)= 3 meter;
Interaction radius (to others)= 5 meter;
Priority value of social interaction( to John)=0;
Priority value of social interaction( to others)=1;
Interaction signal set=(angry, calling help, happy,…….., );
Emotion Interaction rules of sending information to others
{If Friendliness value=-1 then Emotion to other = angry
        Else
          If other  GD=-1;//other person's gender is female.
          Emotion to other =happy;
          End
        Emotion to other =Null; //no any emotion to others
        End
}
Emotion Interaction rules of receiving information from others
{If Emotion from friend= sad then Emotion to friend=sad
        Else
        Emotion to friend=happy
        End
End }
```

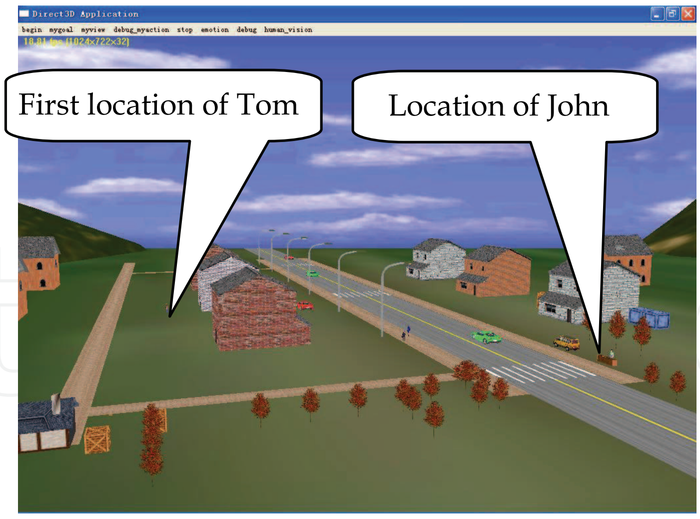


Fig. 11. A bird view of virtual environment

Fig. 12. Tom can move from one place to another

Fig. 13. Tom communicates with John with hand moving and facial expression

Let Mary is a female virtual character, she is watching TV in a room, a TV program is a stimulus, if a TV program is interesting, Mary will be happy on face. We can suppose some parameters for Mary:

1) Mary has six basic emotions (Happiness, Disgust, Anger, Sadness, Fear, Surprise).
2) Let a virtual character may have five personalities: agreeableness, openness, conscientiousness, extraversion, and neuroticism. If Mary's personality is agreeableness, PS_1 is agreeableness, and Θ $[PS_1(t)]$ =1(all other intensity of $PS_k(t)$ is equal to 0). If Mary's personality is conscientiousness, PS_3 is conscientiousness, and Θ $[PS_3(t)]$ =1(all other intensity of $PS_k(t)$ is equal to 0).
3) On the basis of Maslow's theory, human can have five motivations (Physiological, Safety, Affiliation, Achievement, Self-Actualization). In a certain environment, we suppose a virtual character only has one motivation. In the example, Mary only has Affiliation motivation, all R_m are equal, Θ $[MV_3]$ =1,
4) Let O_j ={TV program}, in a certain time, the number of stimulus is one, Θ $[O_{11}]$=0.8, other Θ $[O_{ji}]$ =0.
5) Let $C_i(t)$=0.7 (i=1,…,6), we can define a rule for $NC_i(t)$ and $MC_i(t)$. If a character's personality is agreeableness, $NC_1(t)=C_1(t)$, $MC_1(t)$= min$[1.2\times C_1(t), 1]$; if a character's personality is conscientiousness, $NC_1(t)$=min$[1.2 \times C_1(t),1]$, $MC_1(t)$=min$[1.2\times C_1(t), 1]$.

Fig. 14. Mary's personality (1) agreeableness (2) conscientiousness

6) If Mary's personality is agreeableness, $TC_1(t)$=0.7, Θ $[O_{11}]>TC_1(t)$, the emotion "Happiness" is active. If Mary's personality is conscientiousness, $TC_1(t)$=0.84, the emotion "Happiness" is not active. Mary's expressions are in Fig.14.

6. Conclusion

Emotion is related to stimulus and cognitive appraisal. Emotion is very important for modern computer game. Emotion model of virtual characters is a challenging branch of computer science. A believable character should be provided with emotion and perception. In general, a virtual character is regarded as an autonomous agent with sense, perception, emotion behavior and action. A computational emotion model of virtual characters is presented in this chapter. The method is to construct virtual characters that have internal sensor and perception for external stimuli. First, architecture of a virtual character is set up by cognitive model; Second, emotion model is proposed by a formalization method, some new concepts are presented with a general mathematical model, the model integrates emotion, stimuli, motivation, personality, and social knowledge together. As a result, an emotional animation demo system of virtual character is implemented on PC.

7. Acknowledgements

The work described in this chapter was co-supported by the National Grand Fundamental Forepart Professional Research (grant no: 2005cca04400) and the Natural Science Foundation of NingBo City(grant no:2007A610038) .

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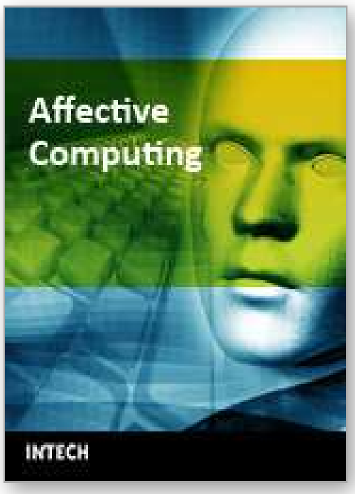

Affective Computing
Edited by Jimmy Or

ISBN 978-3-902613-23-3
Hard cover, 284 pages
Publisher I-Tech Education and Publishing
Published online 01, May, 2008
Published in print edition May, 2008

This book provides an overview of state of the art research in Affective Computing. It presents new ideas, original results and practical experiences in this increasingly important research field. The book consists of 23 chapters categorized into four sections. Since one of the most important means of human communication is facial expression, the first section of this book (Chapters 1 to 7) presents a research on synthesis and recognition of facial expressions. Given that we not only use the face but also body movements to express ourselves, in the second section (Chapters 8 to 11) we present a research on perception and generation of emotional expressions by using full-body motions. The third section of the book (Chapters 12 to 16) presents computational models on emotion, as well as findings from neuroscience research. In the last section of the book (Chapters 17 to 22) we present applications related to affective computing.