A Computational Model Based on Emotion Energy

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***Abstract*—Emotional intelligence plays an important role in the communication between people and computers or robots. Based on psychodynamics, in this paper, the concept of emotional energy is proposed and the emotional energy is quantified as a unified parameter to measure the emotional state. On this basis, the energy distribution description space of the emotional states is established, which is the foundation for further describing the changing state of emotional state. The process of emotional change is regarded as a stochastic process in this paper, and Markov chain is used to describe the spontaneous transfer process of emotional state. The results show that the model can simulate the process of emotional state changes to some extent.**

***Index Term*—artifical emotion, psychological energy, emotion model**

I. Introduction

With the development of science and technology, more and more of our work and life are connected with computers or robots. It has raised an important question, how to make these complex and sophisticated machines can communicate with us more easily, effectively and harmoniously.

The emotional computing model is considered to be a key component of achieving more effective human-computer interaction [1]-[3]. In order for a computer to "have" emotions, first, we must understand how human emotions are produced. Many psychological theories and models attempt to explain this process [4], [5], such as stimulus-response theory, physiological response theory, facial expression theory, motivation theory, subjective evaluation theory and so on.

At present, the most widely accepted emotion theory is cognitive evaluation [6]. According to it, emotions are generated by the evaluation of an event that it considers to be important when the subject experiences an emotional experience. But this evaluation process is subjective and depends on the specific goals, beliefs and norms of the subject. Different subjects have different internal psychological structures, so the interpretation of the same external stimulus may be different, and the resulting emotions will depend on their respective cognitive and subjective evaluations of the stimulus.

The psychodynamics pioneered by Freud and further developed by Jung brings the concept of dynamic law and energy to psychological research, and regards the human psychological system as a dynamic balance system [7]. The concept of psychological energy provides us with a good idea to uniformly measure the emotional states and the changes in different emotional states. From this, it is possible to develop an effective way to establish artificial emotion models. In this context, this paper makes some preliminary research work on the modeling of artificial emotion automatic generation based on psychological energy in psychodynamics, provides a new perspective and a new approach for this problem.

II. Psychodynamics and Psychological Energy

According to psychodynamics, the human mind is a relatively closed system or a self-sufficient energy system. Everyone is given a certain amount of energy at birth, and the energy remains the same. There are two basic forms of psychology energy, a kind of which is free to move and another is constrained, the latter is stimulated by instinctive desires. The constraint of energy is unpleasant, it means that one's needs are not met, and the energy cannot be used for other activities. Different manifestations of psychological energy can be transformed into each other, and the proportion of distribution among various emotional states is also in dynamic change, so that emotions also exhibit different states.

III. Mathematical Description of Psychological Energy

A. Two Basic Forms of Psychological Energy

Psychological energy is the ability to promote individuals to carry out various psychological activities and behaviors. It has two basic forms, namely, free

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psychological energy and constrained psychological energy.

1) Free psychological energy

Denoted by E_f, it is a spontaneously generated energy in an appropriate psychological state, used to guide individuals to engage in activities of interest (tourism, knowledge, exploration, research etc.) and freely express various emotions.

2) Constrained psychological energy

Denoted by E_r, constrained psychological energy is motivated by the satisfied state of the needs based on human instinctive desires, used to guide an individual to engage in activities corresponding to the type of unmet need. If the needs are met, the constrained psychological energy is released and becomes free. If the needs are still unmet, the constrained mental energy will not be released normally, but become the repressed psychological energy.

3) Degree of constraint on psychological energy

$\lambda = E_r / E$ is defined as the degree of psychological energy constraint, $\eta = (1-\lambda)$ is defined as the degree of freedom of psychological energy. These two parameters indicate the relaxation-tension dimension of the emotional states, and they can be given by

$$E_r = \lambda E, E_f = \eta E, \ \eta + \lambda = 1 \tag{1}$$

B. Definition of Emotional Energy

There are two main aspects to the external manifestation of psychological energy. On the one hand, it is embodied to drive individuals to carry out various activities of interest or linked to current needs. On the other hand, it is reflected in various emotional states and emotional expressions according to whether the targets of various activities are achieved or whether the needs are met.

In this sense, we refer to the psychological energy expressed in the second form as emotional energy. Because E_f is free-moving, it can be used to express various emotions, whereas E_r is constrained, it can only be used to express a variety of emotions to a certain extent, so emotional energy can be denoted as

$$E_p = E_f + \gamma E_r = (1-\lambda)E + \gamma\lambda E = (1-\lambda+\gamma\lambda)E \tag{2}$$

γ is denoted psychological emotional excitement, which shows the degree of inhibition and excitement caused by psychological factors.

IV. The Distribution of Emotional Energy and the Establishment of Emotional State Description Space

From the perspective of psychodynamics, the process by which individuals produce different emotions is actually the process of dynamic allocation of activated emotional energy E_p among different emotional states. Due to the difference in the static allocation structure of E_p, the dynamic allocation process of E_p also shows a large difference. The allocation of E_p can be described in two ways, either by the absolute value of the emotional energy or by the relative proportion of the emotional energy.

A. Static Allocation Structure of E_p

Supposed $E_p^* = [E_{p1}^*, E_{p2}^*, \ldots, E_{pN}^*]$ is the absolute energy distribution vector of emotional energy. According to the law of energy conservation, here is $\sum_{i=1}^{N} E_{pi}^* = E_p$.

Supposed $e_p^* = [e_{p1}^*, e_{p2}^*, \ldots, e_{pN}^*]$ is the relative energy distribution vector of emotional energy. Here $e_{pi}^* = E_{pi}^* / E_p^*$, $\sum_{i=1}^{N} e_{pi}^* = 1$ can be obtained from $\sum_{i=1}^{N} E_{pi}^* = E_p$.

Where N is the total number of basic emotions, E_{pi}^* or e_{pi}^* is the absolute or relative component of the emotional energy corresponding to emotion i, and vector E_{pi}^* or e_{pi}^* reflects the tendency in E_p to produce a variety of different emotional states.

B. Dynamic Allocation Structure of E_p^α

Supposed $E_p^t = [E_{p1}^t, E_{p2}^t, \ldots, E_{pN}^t]$ is the absolute distribution vector of emotional energy in the actual performance at time t. $\sum_{i=1}^{N} E_{pi}^t = E_p$

Supposed $e_p^t = [e_{p1}^t, e_{p2}^t, \ldots, e_{pN}^t]$ is the relative distribution vector of emotional energy actually expressed at time t.

$e_{pi}^t = E_{pi}^t / E_p$, $\sum_{i=1}^{N} e_{pi}^t = 1$ can be obtained from $\sum_{i=1}^{N} E_{pi}^t = E_p$.

The individual's emotional state at time t can be determined by the relative size of each component in E_p^t or e_p^t.

C. Emotional Energy Distribution Space

According to the discussion above, there are the following equations:

$$E_{p1}^t + E_{p1}^t + \cdots + E_{pN}^t = E_p = (1-\lambda+\gamma\lambda)E \ \ (0 \le E_{pi}^t \le E_p, i = 1,2,\cdots,\mathrm{N}) \tag{3}$$

$$e_{p1}^t + e_{p1}^t + \cdots + e_{pN}^t = 1 \ \ (0 \le e_{pi}^t \le 1) \tag{4}$$

(3) is called the absolute emotional energy distribution equation, (4) is called the relative emotional energy distribution equation, and the corresponding geometric

representation is called the absolute emotional energy distribution space and the relative emotional energy distribution space.

For convenience to analyze the problem, Supposed $N = 3$, $i = 1,2,3$ indicates the three emotional states of happiness, anger and fear respectively, and supposed $x, \mathrm{y}, \mathrm{z}$ represents the E_{p1}^{t} , E_{p2}^{t} and E_{p3}^{t} or e_{p1}^{t} , e_{p2}^{t} and e_{p3}^{t} respectively, then the three-dimensional absolute or relative emotional energy distribution equation can be described as

$$x + y + z = (1 - \lambda + \gamma\lambda)E \quad (0 \le x, y, z \le E_p) \quad (5)$$

$$x + y + z = 1 \quad (0 \le x, \mathrm{y}, \mathrm{z} \le 1) \quad (6)$$

The description space of the three-dimensional emotional energy distribution corresponding to (5) and (6) is shown in Fig. 1.

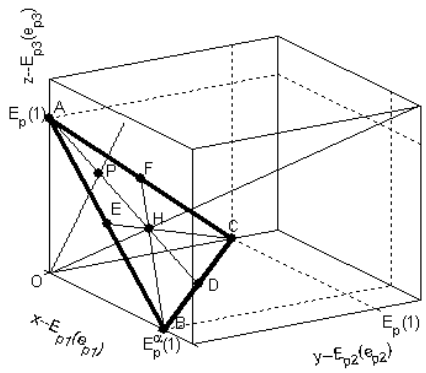


Figure 1. Distribution description space of emotional energy.

As can be seen from Fig. 1, the emotional state points determined by equations (5) and (6) are always within the range of the equilateral triangle ABC (including the boundary) in Fig. 1, and the transition of the emotional state is also limited to this range.

Equation (4) expresses the proportion of emotional energy distribution between different emotions from the perspective of energy distribution. We can also regard e_{pi}^{t} as a probability and $P^t = [p_1^t, p_2^t, \ldots, p_N^t]$ as the emotional state probability distribution vector. $p_i^t = e_{pi}^t$. p_i^t indicates the probability of being in emotional state i at time t , and the emotional state of the individual can also be determined according to the relative size of each component in P^t .

D. The Division of Emotional States and the Changing Process of Emotional States

According to the theory of psychology, the emotional state refers to the certain emotions exhibited by the individual in a certain period of time under the influence of the external environmental stimulating event. According to the different levels of emotional stimulation, emotional state can be divided into three situations: equilibrium state, mood state and emotional state.

The definition of emotional intensity: $p_{i\Delta} = p_i - 1/N, \quad i = 1,2,\ldots,N$ is called emotional intensity, and $p_{i\Delta}^{(t)}$ is called emotional intensity at time t .According to the probability space of the emotional state, we can accurately divide three different emotional states:

1) Absolute Equilibrium state: When $p_{i\Delta}^{(t)} = 0, \quad i = 1,2,\cdots N$, the emotional state is called to be in an absolute equilibrium state, corresponding to the H point in Fig. 1;

2) Relative equilibrium state (i.e., Mood state): When $0 < \left|p_{i\Delta}\right| \le \delta \ (i = 1,2,\cdots,N)$, δ is a relatively small constant, the emotional state is called to be in a relative equilibrium state, corresponding to a relatively small area centered on H in Fig. 1.

3) Emotional activation state: When $\left|p_{i\Delta}\right| > \delta \ (i = 1,2,\cdots,N)$, the emotional state is called to be in an excited state.

Different emotional states are actually determined by the uniformity of the distribution of emotional energy E_p . Under certain conditions, the distribution relationship of E_p in various emotions will change under the constraint of equation (3) or (4), resulting in the transition of emotional state in these three situations, as shown in Fig. 2.

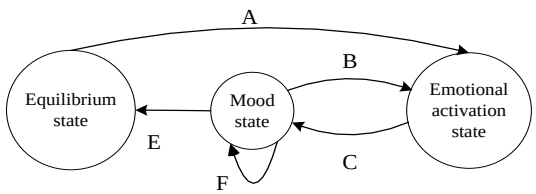


Figure 2. Transfer of emotional state.

Due to different conditions, the transfer of emotional state can be as follows:

1) Emotional state stimulation transfer: Under the stimulation of external events, the emotional state is transferred from the equilibrium state or a certain mood state to the emotional activation state of a certain level of stimulation, represented by two lines A and B.

2) Mood state stimulation transfer: Under the stimulation of a specific external event, the mood state will drift within a certain range centered on the equilibrium state, represented by the line F.

3) Spontaneous transfer of emotional state: When the external stimuli are over, a certain emotional state will spontaneously transfer from a stimulating state to a certain mood state within a certain period of time, indicated by the line C.

4) Spontaneous transfer of mood state: In the absence of external stimuli, a certain emotional state will spontaneously shift to equilibrium state within a certain period of time, indicated by the line E.

V. Mathematical Model of Spontaneous Transfer Process of Emotional State

A. Emotion Transition Matrix

According to the previous discussion, the change of emotional state can be regarded as a stochastic process, so that the theory of stochastic process can be used to further study the changing rule of emotional state.

Based on the basic theory of Markov chain [8], the basic equation of the spontaneous transfer process of emotional state can be denoted as $P^{t+1} = P^t \bar{A}$ or $P^t = P^0 \bar{A}^t$. Here $\bar{A}$ denotes N*N's emotional state transition matrix, t is the sampling time. $P^0 = [p_1^0, p_2^0, \ldots, p_N^0]$ is the emotional state probability distribution vector at the initial moment, $P^t = [p_1^t, p_2^t, \ldots, p_N^t]$ is the emotional state probability distribution vector at time t .when $N = 3$, The form of the transfer matrix $\bar{A}$ as follows:

$$\bar{A} = \{q(i,j)\}_{3\times 3} = \begin{bmatrix} \frac{\theta\pi_1^* - 2}{\theta\pi_1^*} & \frac{1}{\theta\pi_1^*} & \frac{1}{\theta\pi_1^*} \\ \frac{1}{\theta\pi_2^*} & \frac{\theta\pi_2^* - 2}{\theta\pi_2^*} & \frac{1}{\theta\pi_2^*} \\ \frac{1}{\theta\pi_3^*} & \frac{1}{\theta\pi_3^*} & \frac{\theta\pi_3^* - 2}{\theta\pi_3^*} \end{bmatrix} \tag{7}$$

$\bar{\pi}^* = [\bar{\pi}_1^*, \bar{\pi}_2^*, \ldots, \bar{\pi}_N^*]$ is the Limit probability distribution of $\bar{A}$, that is , $\lim_{t\to\infty} P^t = \bar{\pi}^*$. It indicates the state of mood when it is stable. Here θ can be used to adjust the speed of the spontaneous transfer process of emotional state.

B. High-Order Transition Probability and Its Limit Probability Distribution

when $\pi_1^* = \pi_2^* = \pi_3^* = 1/3$, $L_1 = L_2 = L_3 = L = \theta/3$, The characteristic equation of $\bar{A}$ is:

$$|\bar{A}(\lambda)| = |\lambda I - \bar{A}| = (\lambda - 1)(\lambda - \frac{L-3}{L})^2 = 0 \tag{8}$$

The characteristic root of $\bar{A}$ is:

$$\lambda_1 = 1, \lambda_2 = \lambda_3 = L - 3/L = \delta \tag{9}$$

From

$$q_{ij}^{(n)} = \sum_{l=1}^{N} \frac{\lambda_l^n A_{ji}(\lambda_l)}{\prod_{\substack{m=1 \\ m\neq l}}^{N} (\lambda_l - \lambda_m)}, \quad i,j = 1,2,\ldots,N; n = 1,2,\ldots. \tag{1.0}$$

The equation (11), (12) can be got:

$$\Delta q_{ij} = \begin{cases} \frac{2}{3}\delta^k = \frac{2}{3}(\frac{L-3}{L})^k = \frac{2}{3}(\frac{\theta-9}{\theta})^k, & i = j \\ -\frac{1}{3}\delta^k = -\frac{1}{3}(\frac{L-3}{L})^k = -\frac{1}{3}(\frac{\theta-9}{\theta})^k, & i \neq j \end{cases} \tag{11}$$

$$\bar{A}^k = \begin{bmatrix} \frac{1}{3} + \frac{2}{3}\delta^k & \frac{1}{3} - \frac{1}{3}\delta^k & \frac{1}{3} - \frac{1}{3}\delta^k \\ \frac{1}{3} - \frac{1}{3}\delta^k & \frac{1}{3} + \frac{2}{3}\delta^k & \frac{1}{3} - \frac{1}{3}\delta^k \\ \frac{1}{3} - \frac{1}{3}\delta^k & \frac{1}{3} - \frac{1}{3}\delta^k & \frac{1}{3} + \frac{2}{3}\delta^k \end{bmatrix} \tag{12}$$

The equation (13) and (14)can be got from $P^{(k)} = P^{(0)}\bar{A}^k$

$$p_i^{(k)} = \frac{1}{3} + (p_i^{(0)} - \frac{1}{3})\delta^k \tag{13}$$

$$p_{i\Delta}^{(k)} = p_{i\Delta}^{(0)}\delta^k ; p_{i\Delta}^{(k)} = p_i^{(k)} - 1/3 ; p_{i\Delta}^{(0)} = p_i^{(0)} - 1/3 \tag{14}$$

Emotional state probability distribution $p_i^{(k)}(i = 1,2,3)$ and emotional intensity $p_{i\Delta}^{(k)}(i = 1,2,3)$ at any time k can be calculated by equation (13) or (14).

VI. Simulation Results

A. Coordinate Transformation

In order to facilitate displaying emotional states and setting related parameters in the emotional state space, we need to transform the emotional state triangle probability space shown in Fig. 1 onto a two-dimensional plane. The new coordinate takes H point as the coordinate origin, and $\overrightarrow{AD}$ is taken as the axis x^* and $\overrightarrow{Gk}$ is taken as the axis y^* . First, the original coordinate system $O - xyz$ is transformed to $\bar{O} - \bar{x}\bar{y}\bar{z}$, and then rotated to $O^* - x^* y^* z^*$.

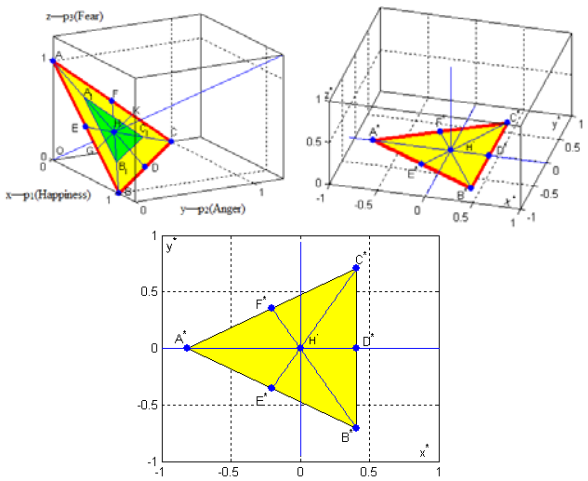


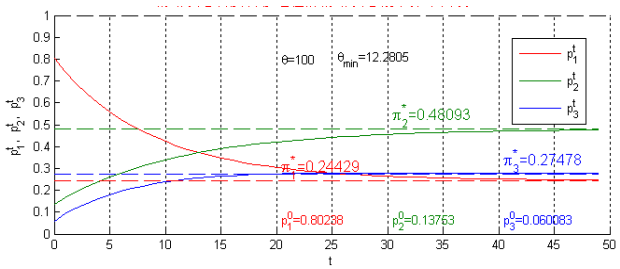
Figure 3. Process of coordinate transformation

B. The Basic Trend of Emotional Spontaneous Transfer

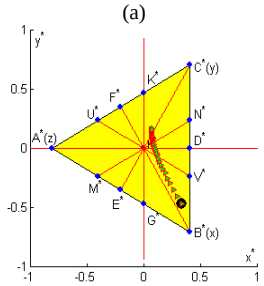
Fig. 4(a) shows the variation of the emotional state probability distribution P^t with t . The basic trend is that P^t is infinitely close to the limit probability distribution π^* of the transfer matrix A^* as the initial distribution P^0 increases with t , i.e., $\lim_{t\to\infty} P^t = \pi^*$ or

$\lim_{t\to\infty} p_i^t = \pi_i^*(i=1,2,3)$; In a psychological sense, when an individual is stimulated by an external stimulus to produce an emotional state, the emotional state will gradually return to a certain mood state as time goes by.

The variation of the emotional state probability distribution point corresponding to the simulation curve in Fig. 4(a) is shown in Fig. 4(b).



(a)



(b)

Figure 4. Emotional state spontaneous transfer process change trend and changes in the probability distribution points of emotional states.

C. The Effect of $\bar{\theta}$ on Changes in Emotional State

Fig. 5 is a simulation curve when $\bar{\theta}=50$ (other conditions are unchanged). Compared with Fig. 4(a), it can be seen that the larger $\bar{\theta}$ is, the slower the transfer speed is. So $\bar{\theta}$ reflects the speed characteristics of spontaneous transfer of individual emotional state.

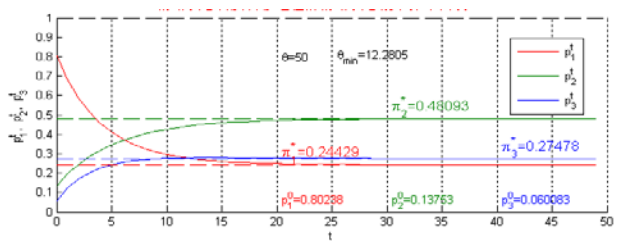


Figure 5. when $\bar{\theta}$ =50, Emotional state spontaneous transfer process.

D. The Principle of Determining The Value of $\bar{\theta}$

It should be made that the elements on the diagonals of the matrix $\bar{A}$ are not less than the other elements of the same row, that is

$$\bar{q}_{ii} \geq \bar{q}_{ij}, (i \neq j, i=1,2,\cdots,N; j=1,2,\cdots,N) \quad (15)$$

The minimum threshold value obtained by (15) is:

$$\bar{\theta}_{\min(i)}\bar{\pi}_i^* - (N-1) = 1; \bar{\theta}_{\min(i)} = N / \bar{\pi}_i^* \quad (16)$$

Then the value of $\bar{\theta}$ is: $\bar{\theta}_{\min} = [\bar{\theta}_{\min(i)}]_{\max}(i=1,2,\cdots,N)$.

When $\bar{\theta} < \bar{\theta}_{\min}$, the elements on the main diagonal of $\bar{A}$ will not satisfy the condition $\bar{q}_{ii} \geq \bar{q}_{ij}$, and the curve of the corresponding emotional state component p_i^t will oscillate. (As shown in Fig. 6, $\bar{\theta}=8$)

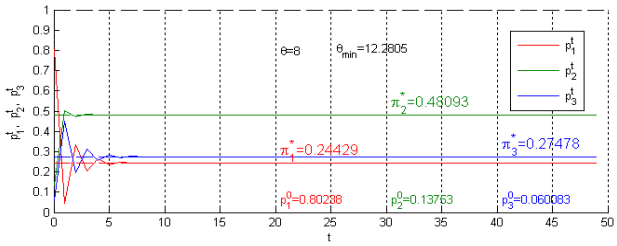


Figure 6. when $\bar{\theta} < \bar{\theta}_{\min}$,Emotional state spontaneous transfer process.

Maximum value: As $\bar{\theta}$ increases, the number of calculation steps required to reach steady state (should meet certain error requirements) is also larger, so $\bar{\theta}$ should be less than a certain maximum value, i.e., $\bar{\theta} \leq \bar{\theta}_{\max}$. Supposed the sampling time interval is Δt, the total number of steps is n, and the total time is $n\Delta t$. The error when reaching steady state after n steps should satisfy with (17):

$$\left| p_i^n - \pi_i^* \right| \leq \delta(\delta > 0) \quad (17)$$

After Δt, n, and δ are determined, $\bar{\theta}_{\max}$ can be determined according to (17).

In the actual choice of $\bar{\theta}$, in addition to satisfying the condition $\bar{\theta}_{\min} \leq \bar{\theta} \leq \bar{\theta}_{\max}$, different values should be selected according to different individuals to reflect the different characteristics of the spontaneous transfer process of different individuals.

VII. Conclusion

Emotion intelligence plays a critical role in increasing the believability of robot or other intelligent agent. In this paper, the basic idea of artificial emotion modeling based on psychodynamics and emotional energy was presented, and the basic framework of emotion model was built. Human emotions and emotional phenomena are very complicated. It is undoubtedly a very challenging subject to establish an artificial emotion model that conforms to the laws of human emotions. This paper uses the energy perspective to study and quantify human emotions, and provides a new perspective and a new exploration path for the study of the automatic generation of artificial emotion.

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