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Estimation of Hierarchical Emotion in Mental State Transition Learning Network

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Abstract — **In general, emotions are often appeared in the facial expressions, voice pitch, exaggerated gesticulation, and so on. They are outward signals of emotions, internal world in order to serve for human communications. Perlovsky described on aesthetic emotions and analyzed their role within joint functioning of cognition and language. This paper proposes the different method from his idea. The method uses Mental State Transition Network proposed by Ren and Emotion Generation Calculations. Moreover, the transition costs in the network are modified according to the stimulus from external world. The simulation results also are reported.**

I. INTRODUCTION

Emotions such as love, hate, courage, fear, joy, sadness, pleasure, and disgust are represented in both psychological and physiological terms. An essential role of emotions in working of the mind was analyzed in philosophy[1-3], psychology[3], neuro-psychology[9], and from the learning and cognition perspective [10-12]. Kant's aesthetics is a foundation aesthetic theory. According to Kant, emotions are closely related to judgments about which individual experiences and perceptions correspond to which general concepts and vice versa. The ability for judgment is a foundation of all higher spiritual abilities, including beautiful and sublime.

In general, emotions are often appeared in the facial expressions, higher voice pitch, exaggerated gesticulation, and so on. They are outward signals of emotions, internal world in order to serve for human communications. [13] described on aesthetic emotions and analyzed their role within joint functioning of cognition and language. The concept in some aspects of the mathematical theory closely followed ideas of Kant, Jung, Grossberg and Levine are similar to internal models of the objects and situations in the worlds. They evolved for satisfaction of the basic instincts, which have emerged as survival mechanisms long before concepts. Instinct operates as internal sensors indicating the basic needs. Instincts are connected to cognition and behavior by emotional neural signals. An important fundamental role of emotions within the mind is emotional signals evaluate concepts for the purpose of instinct satisfaction.

Instincts for food and procreation are one of 'basic instincts.' However, Perlovsky considers the instinct for knowledge, which the fundamental nature of this instinct is related to the fact that our knowledge always has to be modified to fit the current situations. In other words, a mathematical model of the mind will be constructed to make obvious the fundamental nature of our desire for knowledge. Knowledge is not just a static state and it is still in a constant process of adaptation and learning. Therefore, we have an inborn need, a drive, an instinct to improve our knowledge through experiences and impression in our life. Perlovsky call it the *knowledge instinct* and it can be described as a maximization of a similarity measure between concept-models and the world[13].

Perlovsky developed the Modeling Field Theory(MFT) based on the theory of neural modeling fields[14]. The integrated model with the hierarchy of language and cognition has some levels in a hierarchy. At each level, there are integrated cognitive and language model, where the similarities of model and signals are defined. Similarities are integrated as products of cognition and language similarities. However, the model may not realize the diversity in human emotion, because simple emotion such as pleasure/displeasure and complex emotion such as joy, fear are the same, and the calculation of similarity is not the basic idea of brain signal processing.

The Mental State Transition Network has been developed for the basic concept of approximating to human physiological and mental responses[15]. In order to derive transition networks for human psychological states, the assumption of discrete emotion state is that human emotion are classified into some kinds of stable discrete states, called "mental state", and the variance of emotions occurs in the transition from a state to other state by a predefined probability.

Moreover, the assumption is that our model consists of the cognition and language model, inner emotion model, and instinct model. The inner emotion model has three parts which have an advanced processing function from the inside gradually, based on the latest achievements of brain science and psychology. In this paper, we calculate the strength of emotion by Emotion Generating Calculation (EGC) method[16] under the Mental State Transition Network. Especially, we challenge to modify the transition probability according to the input signals.

The remainder of this paper is organized as follows. In the section II, we describe a hypothesis of hierarchical emotion model. The section III explains the EGC method. The section

IV describes the mental state transition learning network. The section V reports the experimental result. In Section IV, we give some discussions to conclude this paper.

II. HIERARCHICAL EMOTION

The cerebral cortex is a structure within the brain that plays a key role in memory, attention, perceptual awareness, thought, language, and consciousness. It constitutes the outermost layer of the cerebrum. The part of cerebral cortex plays the different role and at each part the specified function works respectively.

The phylogenetically most recent part of the cerebral cortex, the neocortex, is differentiated into six horizontal layers; the molecular layer I, the external granular layer II, the external pyramidal layer III, the internal granular layer IV, the internal pyramidal layer V, and the multiform layer VI. The more ancient part of the cerebral cortex is divided into paleocortex(prepiriform cortex and so on) and archicortex(also called hippocampus and has at most three cellular layers). The paleocortex and the archicortex are called allocortex or heterogenic cortex. The neocortex is called isocortex or homogenic cortex. Moreover, there is the mesocortex between isocortex and allocortex.

Fig.1 shows the concept of hierarchical emotion model. The center of Fig.1 consists of three parts depicted from inside corresponded to archicortex, paleocortex, and neocortex.

The neurologist Paul MacLean has proposed that our skull holds not one brain, but three, each representing a distinct evolutionary stratum that has formed upon the older layer before it, like an archaeological site. He calls it the “triune brain.”[15] Fukuda proposed an evolutionary hierarchical hypothesis that feelings in humans consist of four levels of emotion based on brain structure, brain functions, brain evolution, and emotional evolution[19] under the consideration of “triune brain.”

According to new comparison neurology, however, the fact that vertebrates except the mammal also have the part of homology in mammal’s “Neocortex” is found. The concept of our hierarchical emotion model is conceived the main function in the part of archicortex, paleocortex, and neocortex and a new technological emotion model is developed. The left side in Fig.1 shows the cognition and language model, the center in Fig.1 calculates the emotion from signals and/or instincts, and the right side shows the instincts described in the introduction. Fig.2 shows the primitive emotion, basic emotion, and complex emotion from inner side. This figure is similar to the Hierarchical Hypothesis of Feeling[16], but Fig.2 shows only the relation of primitive emotion, basic emotion, and complex emotion.

Perlovsky said that emotions evaluating satisfaction or dissatisfaction of the *knowledge instinct* are not directly related to bodily needs. Therefore, they are ‘spiritual’ or aesthetic emotions. Not only direct signals from cognition and language model to the primitive emotion and basic emotion, but also stimulus gradually spread in the hierarchical emotion model such as reflection from complex emotion is propagated to the region of Instincts. The Instinct includes basic instincts for food, etc. and aesthetic emotion. However, this paper does not describe the relation between aesthetic emotions and instincts. That is, this paper describes the relation between emotion in brain and cognition and language model. The transitions of emotion are represented by using Mental State Transition Network described in Section IV and the emotion from language model is calculated by EGC described in section V.

Fig. 1 Concept of Hierarchical Emotion

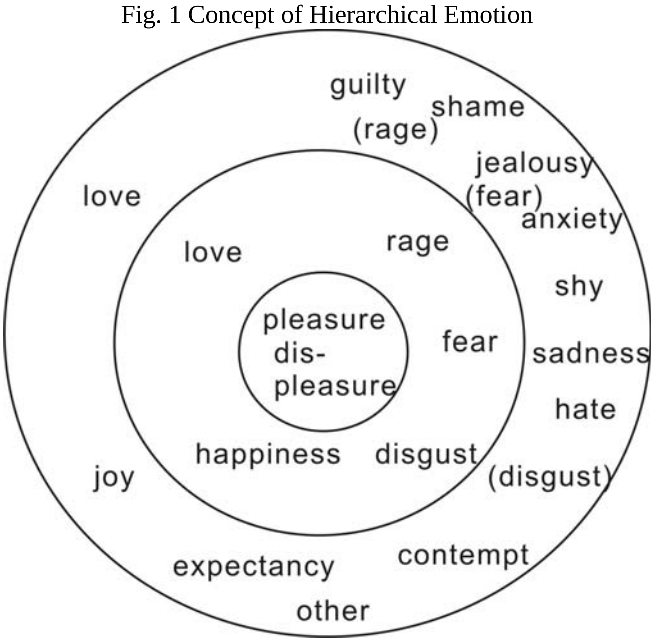

Fig. 2 Classification of Emotions

III. EMOTION GENERATING CALCULATIONS[16]

Initially, the EGCs mechanism is explained briefly. The EGCs extract pleasure/displeasure from an event expressed by the case frame representation. Favorite Values (FVs) which shows the degree of like/dislike for objects are defined according to the results of a questionnaire. The FVs are given a real number on a ratio of [–1.0, 1.0]. Each equation consists of 2 or 3 terms like subject, object and predicate and calculates the emotions in an event based on the relation among the terms.

Then, the system classifies this simple emotion (pleasure/displeasure) into 20 various emotions based on the “Emotion Eliciting Condition Theory.” The theory requires judging such conditions as follows; "feeling for another," "prospect and confirmation," "approval/disapproval" [17].

A. Emotion Generating Calculations

We assume an emotional space as three-dimensional space. We classify pleasure/displeasure for an event by judging in which area the synthetic vector exists. Table 1 shows the correspondence between the case elements in the EGC equations and the axis in the three-dimensional model.

f_S	: FV of Subject	f_O	: FV of Object
f_{OF}	: FV of Object-From	f_{OT}	: FV of Object-To
f_{OM}	: FV of Object-Mutual	f_{OS}	: FV of Object-Source
f_{OC}	: FV of Object-Content	f_P	: FV of Predicate

Table 1. Correspondence between the event type and the axis

Event type	f_1	f_2	f_3
V (S) A (S, C) A (S, OF, C) A (S, OT, C) A (S, OM, C) A (S, OS, C) N (S)	f_S	—	f_P
V (S, OF) V (S, OT)	f_S	$f_{OT} - f_{OF}$	f_P
V (S, OM)	f_S	f_{OM}	f_P
V (S, OS)	$f_S - f_{OS}$	—	f_P
V (S, O)	f_S	f_O	f_P
	f_O	—	f_P
V (S, O, OF) V (S, O, OT)	f_O	$f_{OT} - f_{OF}$	f_P
V (S, O, OM)	f_O	f_{OM}	f_P
V (S, O, I)	f_O	f_I	f_P
V (S, O, OC)	f_O	—	f_{OC}
A (S, O, C)	f_O	—	f_P

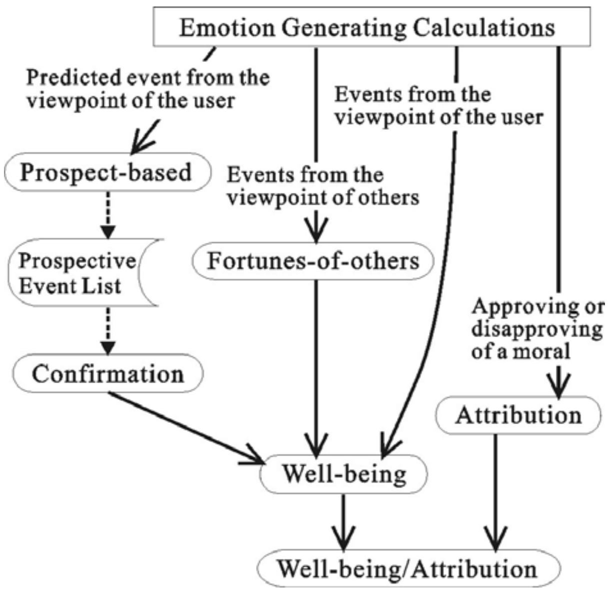

Fig.3 Dependency among emotion groups

B. Complicated Emotion Allocating Method

Based on emotion values calculated by the EGC method and their situations, the pleasure/displeasure is classified into 20 types of emotion. We consider only 20 emotion types as follows. The 20 emotions are classified into an emotional group as follows;, "joy" and "distress" as a group of "Well-Being"; "happy-for," "gloating," "resentment," and "sorry-for" as a group of "Fortunes-of-Others"; "hope" and "fear" as a group of "Prospect-based"; "satisfaction," "relief," "fears-confirmed," and "disappointment" as a group of "Confirmation"; "pride," "admiration," "shame," and "disliking" as a group of "Attribution"; "gratitude," "anger," "gratification," and "remorse" as a group of "Well-Being/Attribution." Fig. 3 shows the dependency among the groups of emotion types.

IV. Mental State Transition Learning Network

A. Mental State Transition Network[18]

The Mental State Transition Network, proposed by Ren[18], has the basic concept of approximating to human physiological and mental responses. He focuses not only information included in the elements of phonation, facial expressions, and speech usage, but also human psychological characteristics based on the latest achievements of brain science and psychology in order to derive transition networks for human psychological states. The assumption of discrete emotion state is that human emotion are classified into some kinds of stable discrete states, called "mental state", and the variance of emotions occurs in the transition from a state to other state with a probability. The probability of transition is called "transition cost" and it is not same. Moreover, with no stimulus from the external world, the probability may converge to fall into a certain value as if the confusion of the mind leaves and is relieved. On the contrary, with a stimulus from external world and/or attractive thought in internal world, the continuous accumulated emotional energy cannot jump to the next mental state and remains in its mental state still. The simulated model of mental state transition network[18] describes the simple relations among some kinds of stable emotions and the corresponding transition probability. The probability was calculated from analysis of many statistical questionnaire data.

The Mental State Transition Network denotes a mental state as a node, a set of some kinds of mental state $\mathbf{S}$, the current emotional state $\mathbf{S}_{cur}$, and the transition cost $\mathrm{cost}(\mathbf{S}_{cur}, \mathbf{S}_i)$, which is the transition cost as shown in Fig.4.

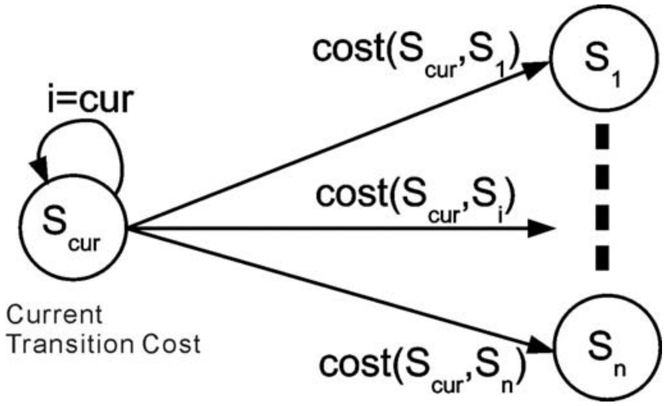

Fig.4 Transition Cost

Table 2. Transition Cost in Mental State Transition Network

next / current	happy	quiet	Sad	surprise	angry	fear	disgust
happy	0.421	0.362	0.061	0.060	0.027	0.034	0.032
quiet	0.213	0.059	0.090	0.055	0.039	0.051	0.042
sad	0.084	0.296	0.320	0.058	0.108	0.064	0.068
surprise	0.190	0.264	0.091	0.243	0.086	0.076	0.048
angry	0.056	0.262	0.123	0.075	0.293	0.069	0.121
fear	0.050	0.244	0.137	0.101	0.096	0.279	0.092
disgust	0.047	0.252	0.092	0.056	0.164	0.075	0.313

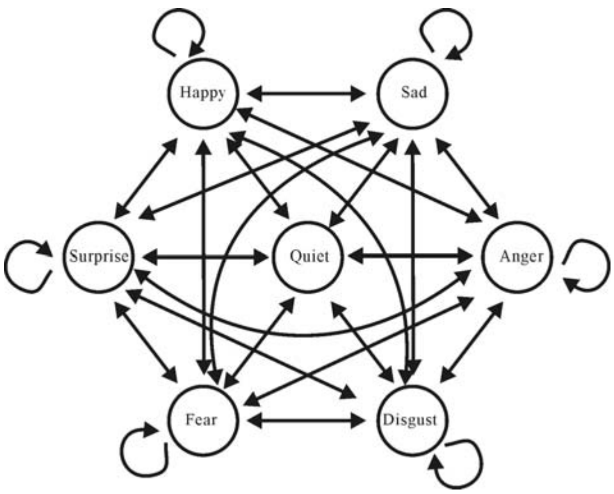

Fig.5 Concept of Mental State Transition Network

In [18], 6 kinds of mental state and quiet state are considered for questionnaire. That is, the transition table of $\mathrm{cost}(\mathbf{S}_i, \mathbf{S}_j)$, $i = 1,2,\cdots,7$, $j = 1,2,\cdots,7$ is prepared. The experiment for participants was examined without stimulus from external world. Each participant fills in the numerical value from 1 to 10 that means the strength of relation among mental states. Moreover, same questionnaire was examined under the condition with the stimulus from external world. 200 participants answered the questionnaire. The numerical values in Table 2 show the statistical analysis results. The transition cost from each current state to the next state is summarized to 1.

B. EGC with Mental State Transition Network

Even if there are no signals from external world, the mental state will change small. In this case, the transition costs represented in Table 2 are adopted to calculate EGC.

In this paper, we assume that the stimulus from an external world is the communication by language and the emotion is calculated as follows.

$\#(S_i \to S_j)$ is the number of transition from an mental state S_i, $1 \le i \le 7$ to S_j, $1 \le j \le 7$. The transition cost is calculated by using the total of $\#(S_i \to S_j)$ for all mental state. Eq.(1) means that the higher transition cost is, the less transition occurs.

$$\mathrm{cost}(S_i, S_j) = 1 - \frac{\#(S_i \to S_j)}{\sum_j^7 \#(S_i \to S_j)}, \tag{1}$$

Eq.(2) calculates the next mental state from the original mental state $S_{cur} \subset \mathbf{S}$ by using the emotion vector.

$$next = \arg\max_k \left(\frac{e_k}{\mathrm{cost}(S_{cur}, S_i)} \right), \ 1 \le k \le 9 \tag{2}$$

The emotion vector consists of 9 kinds of emotion group which are classified 28 kinds of emotions as shown in Table 3. Fig.6 shows the mental state transition network by using EGC. The circled numbers in Fig.6 are the number in the left side of Table 3. The e_k is the strength of emotion group k and e_k ($1 \le k \le 9$) is the maximum value of elements belonged in the each set e_k as follows.

$$e_1 = \max(e_{gloating}, e_{hope}, \cdots, e_{shy})$$
$$e_2 = \max(e_{joy}, e_{happy\_for})$$
$$\vdots$$
$$e_9 = \max(e_{suprise})$$

The emo in Eq.(3) calculates the maximum emotion group k according to the transition cost between current state and next state.

$$emo_k = \arg\max_k \left(\frac{e_k}{\mathrm{cost}(S_{cur}, next(S_{cur}, k))} \right), \ 1 \le k \le 9 \tag{3}$$

, where $next(S_{cur}, k)$ is next mental state from the current state by selecting emotion group k.

Table 3 Classification of Generated Emotion

	Emotion
1	gloating, hope, satisfaction, relief, pride, admiration, liking, gratitude, gratification, love, shy
2	joy, happy_for
3	sorry-for, shame, remorse
4	fear-confirmed, disappointment, sadness
5	distress, perplexity
6	disliking, hate
7	resentment, reproach, anger
8	fear
9	surprise

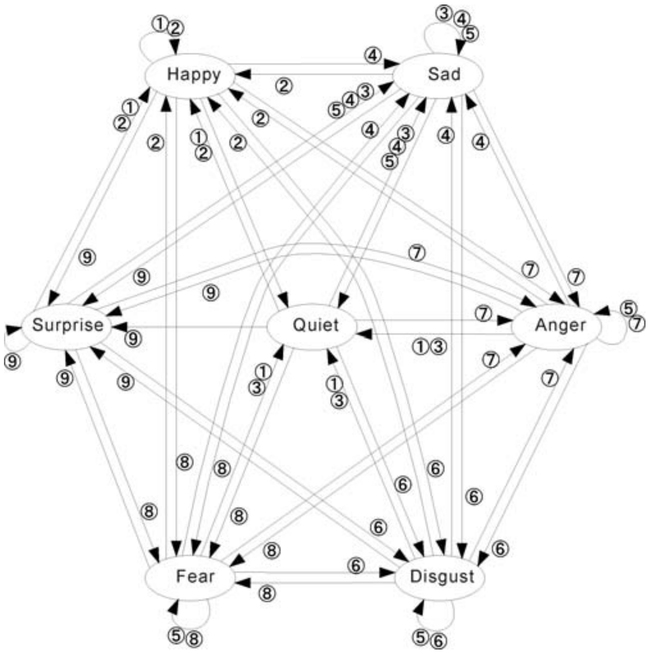

Fig.6 Mental State Transition Network with EGC

C. Mental State Transition Learning Network

Mental State Transition Network may meet the distortion by inputted the signals from external world. For such a case, it might be natural to adjust the transition cost. Eq.(3) is useful for the change of transition cost, because it can select only an emotion among 9 kinds of emotion group. Then if human feels strong emotion, the effect of the emotion remains in their minds although they will forget its event that the emotion occurred. Therefore, if e_k is larger than the threshold value, the modification of e_k, which takes the maximum value of emotion, is required as follows.

$$Modify\_m_i = \alpha_i[t] \times e_k$$

$$Modify\_otherwise = \frac{1}{6}\alpha_i[t] \times e_k \quad (4)$$

, where $\alpha_i[t]$ is a decay or amplifier parameter depending on mental state i and time t. The dependency between i and k is determined by the relation on the map in Fig. 6. '6' means current state to i and itself were excluded from 7 kinds of mental states.

Fig.7 shows the example of when the current state is "Quiet" and the next state is "Sad." If the $Modify\_m_i$ for mental state i is a positive number, the mental state transition learning network decreases $Modify\_otherwise$ from the current transition cost connected with the dot lines and adds $Modify\_m_i$ to the current transition cost with the normal line.

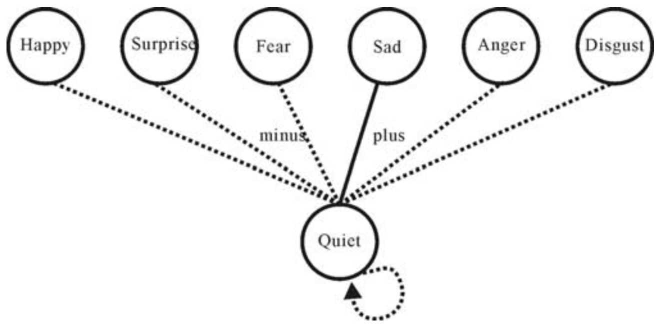

Fig. 7 Concept of leaning in MSTN

Although the value of $\alpha_i[t]$ depends on mental state i, we can see the continuousness of emotion in Table 2. That is, the emotion is not easy to change and remains in its situation, because human emotion may be stored in the memory. As shown in Table 2, the values of transition cost from i to i, $\text{cost}(\mathbf{S}_i, \mathbf{S}_i)$, and that from i to "Quiet", $\text{cost}(\mathbf{S}_i, \mathbf{S}_{quiet})$ are higher than other transition costs. Therefore, for such cases, $\alpha_i[t]$ is set to high as if the emotion remains still. However, the $\text{cost}(\mathbf{S}_{cur}, \mathbf{S}_i)$ cannot exceed 1. Therefore, we set the threshold θ to the maximum value of $\text{cost}(\mathbf{S}_{cur}, \mathbf{S}_i)$. On the contrary, even if there is no stimulus from external world, the strength of emotion will decrease gradually depending time t. The phenomenon resembles to forgetting curve which Hermann Ebbinghaus[20] discovered the exponential nature of forgetting: $R = e^{-t/s}$, where R is memory relation, S is the relative strength of memory, and t is time.

V. EXPERIMENTAL RESULTS

EGCs calculate emotions from events which are contained in the input utterance. Firstly, our proposed method extracts the events from the input sentence based on reasoning and inference. Next, EGCs are applied into the extracted events and emotions are calculated. Then, the present mental state moves to the next mental state considering intensities of aroused emotions and transition costs.

We show an example of mental state transition as follows;

1. (from quiet state…)
2. The sentence "He felt sorrow by suddenly said good-bye from his girlfriend." is inputted.

3. From the sentence, two events "He believed to be able to stay with her," "She left him" are extracted from the utterance.
4. EGCs calculate emotions aroused in him from the two events. "Distress" and "disappointment" are aroused and their intensities are 0.8.
5. Because "disappointment" belongs to the emotion group 5 at mental state transition network, the strength of emotion value 5 is 0.8 and the strength of the other emotion groups are 0.
6. Based on Eq.(2), next mental state will be "sad."
7. For most cases of the transition from "quiet" to "sad", the transition to other mental state may not change if it doesn't take long time. Therefore, the transition cost to self-loop remains a high value.

VI. Coclusive Discussion

The Mental State Transition Network with modification of transition cost has been developed for the basic concept of approximating to human physiological and mental responses. The EGCs extract pleasure/displeasure from an event expressed by the case frame representation. By the relation between emotion in brain and cognition and language model, the concept of Hierarchical Emotion depicted in Fig.1 were discussed for the use of EGCs and Mental State Transition Network. However, the mechanism in the model is insufficient for the relation between the inner emotion and *knowledge instinct*. Moreover, the transition costs in Mental State Transition Network are asymmetry, because the change of mental states is not stable. Therefore, the stable transition costs are required by some training algorithms.

The application of the model is considerable for the field of the counseling of pet loss, grief and so on. The loss of a pet or an animal to which one has become emotionally bonded can be an intense loss, comparable with the death of a loved one. Pet illness and loss is gradually becoming recognized as similar to other forms of sickness and death of a loved one. Such person has become emotionally bonded can be an intense loss. Their people experiences and expresses grief in their own way. Grief counseling becomes necessary when a person is so disabled by their grief, overwhelmed by loss to the extent that their normal coping processes are disabled or shut down.

We expect that our proposed method can detect the emotionally bounded and the counseling system to avoid such difficult mental condition will be developed in future.

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