An Emotion-Processing System Based on Fuzzy Inference and Its Subjective Observations

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ABSTRACT

The history of the development of emotion psychology, especially the two theories concerning mixed emotions adopted in this research, is briefly explained. Also discussed are the image codes linked to the mixed emotional words and the way to realize a mechanism using fuzzy inference, in which the internal emotion of a simulated person reacts on a sequence of inputted terms and evokes some emotional change. It is shown that the fuzzy inference technique is very useful and applicable even to such a flexible human life system as emotion.

In the next section, the relevant part of the theory for the subjective observation model (Yanaru et al. [1]) to the application of the emotion-processing system is briefly explained. The construction methodology of the system, which has two functions, is described; one function is that the evoked emotion is transitive depending on the observation, and the other is that the aggregated emotion by the several subjective observations settles to the objective emotion.

In conclusion, some attractive results obtained from the simulated emotion-processing system are shown: what kinds of emotions are evoked and how the emotional transition is done by subjective observations, when a poem is used for the input signal.

KEYWORDS: Emotion psychology, emotion processing, mixed emotion, subjective observation model, fuzzy inference

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1. INTRODUCTION

In general, fuzzy inference technology is very effective when it is applied to the object whose strict analysis and formulization are almost impossible [3]. The effectivity was somewhat verified in research concerning the "problem-studying system" (Yanaru et al. [4]). We wanted to apply it to a more flexible human system, such as emotions. We hoped to find the significance of approach from fuzzy set theory even to such complicated systems as "mind-cooperating" emotions and intelligence. We show here, using some poems that contain implicit emotions inside the constructing terms, how fuzzy technology is useful even for such vague subjects as human emotions.

On the other hand, if we focus on the main studies, especially on classification of emotions and basic emotional reactions, we can list the following studies (Matuyama et al. [5]):

1. classification of emotions from the viewpoint of instinct, studied by W. McDougal
2. classification of emotions based on three basal emotions: fear, anger, and acceptance, studied by J. B. Watson
3. classification of emotions focused on recognition, studied by M. B. Arnold
4. classification of emotions based on eight pure emotions, studied by R. Plutchik
5. theory for emotional transition, studied by P. T. Young

In this way, a lot of studies on emotional classification and transition have been done within the psychological field; however, there are almost no studies approached from the engineering facet, especially of fuzzy technology.

Thus, constructing a mathematical model, several emotional reactions are studied here from an engineering viewpoint in two ways, i.e., for general emotional reactions, fuzzy inference technology is applied, and for the transitional emotions evoked from a person's temporal condition, the theory for subjective observation model (Yanaru et al. [3]) is applied.

Let us briefly outline the two psychological theories used in this paper at first.

1.1. Outline of Plutchik's Theory

R. Plutchik proposed a multidimensional model of emotions where the constructive idea came from the analogical inference for the three-dimensional, mixed-color model (Plutchik [6]). The following six postulates are proposed to construct the model:
Postulate 1: There is a small number of pure or primary emotions.

Postulate 2: All other emotions are mixed, that is they can be synthesized by various combinations of primary emotions.

Postulate 3: Primary emotions differ from each other both with regard to physiology and behavior.

Postulate 4: The emotions of daily life are mixed.

Postulate 5: Primary emotions can be conceptualized in terms of pair of polar opposites.

Postulate 6: Each emotion can exist in varying degrees of intensity.

1.2. Outline of Young’s Theory for Emotional Transition

P. T. Young proposed that emotional transition occurs depending on three factors such as sign, intensity, and duration (Young [7]):

1. **sign:** We can find two phases in our activities, i.e., approach and avoidance for the concerned object, corresponding to the sign + and −, respectively.

2. **intensity:** Emotional process is affected by the intensity of inputted signal, and the intensity can be drawn on a continuous coordinate with two poles, + and −.

3. **duration:** Emotion varies and is evoked depending on the duration of excitation of the object.

2. MECHANISM FOR EMOTIONAL VARIATION BY INPUT WORDS

2.1. Image Codes of Words

Taking into account the two theories mentioned above, the mixed emotions are defined by linear combination of eight pure emotions, i.e., joy, sadness, anger, fear, expectation, surprise, hate, and acceptance, which are regarded as no more than classified basic attributes. Then, the values of the image codes are made by five people from our laboratory, taking the image of words in daily life and the intensities of some words shown by Plutchik into account as standard intensities for normalization, because they are the resultant values investigated statistically from the psychological viewpoint (see Table 1). It seems to me that, it is more natural to think that the intensities of words fluctuate depending on the person’s condition. From this viewpoint, the quantitative coded values statistically investigated are not so important but may be valuable in some allowable qualitative
Table 1. A Part of the Image Codes Dictionary for Mixed Emotional Words

<table>
<thead>
<tr>
<th>Mixed emotional words</th>
<th>Joy</th>
<th>Ang</th>
<th>Exp</th>
<th>Hate</th>
<th>Sad</th>
<th>Fear</th>
<th>Sur</th>
<th>Acc</th>
</tr>
</thead>
<tbody>
<tr>
<td>ecstasy</td>
<td>91</td>
<td>0</td>
<td>30</td>
<td>-30</td>
<td>-91</td>
<td>0</td>
<td>-30</td>
<td>30</td>
</tr>
<tr>
<td>joy</td>
<td>74</td>
<td>0</td>
<td>50</td>
<td>-30</td>
<td>-74</td>
<td>0</td>
<td>-50</td>
<td>30</td>
</tr>
<tr>
<td>happiness</td>
<td>65</td>
<td>0</td>
<td>50</td>
<td>-30</td>
<td>-65</td>
<td>0</td>
<td>-50</td>
<td>30</td>
</tr>
<tr>
<td>pleasant</td>
<td>52</td>
<td>0</td>
<td>30</td>
<td>-30</td>
<td>-52</td>
<td>0</td>
<td>-30</td>
<td>30</td>
</tr>
<tr>
<td>quiet</td>
<td>40</td>
<td>0</td>
<td>10</td>
<td>-30</td>
<td>-40</td>
<td>0</td>
<td>-10</td>
<td>30</td>
</tr>
<tr>
<td>calm</td>
<td>30</td>
<td>0</td>
<td>10</td>
<td>-30</td>
<td>-30</td>
<td>0</td>
<td>-10</td>
<td>30</td>
</tr>
<tr>
<td>pride</td>
<td>55</td>
<td>52</td>
<td>0</td>
<td>-30</td>
<td>-5</td>
<td>0</td>
<td>30</td>
<td></td>
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<tr>
<td>optimism</td>
<td>48</td>
<td>0</td>
<td>48</td>
<td>-30</td>
<td>-48</td>
<td>0</td>
<td>-48</td>
<td>30</td>
</tr>
<tr>
<td>hope</td>
<td>67</td>
<td>0</td>
<td>67</td>
<td>-30</td>
<td>-67</td>
<td>0</td>
<td>-67</td>
<td>30</td>
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<tr>
<td>unhealthy</td>
<td>45</td>
<td>0</td>
<td>30</td>
<td>45</td>
<td>-45</td>
<td>0</td>
<td>-30</td>
<td>45</td>
</tr>
<tr>
<td>rage</td>
<td>0</td>
<td>90</td>
<td>50</td>
<td>0</td>
<td>-90</td>
<td>0</td>
<td>50</td>
<td></td>
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<tr>
<td>anger</td>
<td>0</td>
<td>76</td>
<td>50</td>
<td>0</td>
<td>-76</td>
<td>0</td>
<td>50</td>
<td></td>
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<tr>
<td>perplexity</td>
<td>-45</td>
<td>45</td>
<td>-45</td>
<td>0</td>
<td>-45</td>
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<td>80</td>
<td>80</td>
<td>0</td>
<td>-80</td>
<td>0</td>
<td>80</td>
<td></td>
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<tr>
<td>obstitute</td>
<td>0</td>
<td>55</td>
<td>55</td>
<td>0</td>
<td>-5</td>
<td>5</td>
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<td>78</td>
<td>78</td>
<td>0</td>
<td>-78</td>
<td>0</td>
<td>78</td>
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</tr>
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<td>hostility</td>
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<td>50</td>
<td>50</td>
<td>0</td>
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<td>42</td>
<td>-44</td>
<td>0</td>
<td>-42</td>
<td>4</td>
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<td></td>
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<tr>
<td>expectation</td>
<td>20</td>
<td>0</td>
<td>66</td>
<td>-30</td>
<td>-20</td>
<td>0</td>
<td>-6</td>
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<tr>
<td>anticipate</td>
<td>10</td>
<td>0</td>
<td>61</td>
<td>-35</td>
<td>-10</td>
<td>0</td>
<td>-61</td>
<td></td>
</tr>
<tr>
<td>careful</td>
<td>-10</td>
<td>0</td>
<td>53</td>
<td>-30</td>
<td>10</td>
<td>0</td>
<td>53</td>
<td></td>
</tr>
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<td>posture</td>
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<td>-20</td>
<td>32</td>
<td>-30</td>
<td>0</td>
<td>20</td>
<td></td>
<td></td>
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<tr>
<td>irony</td>
<td>0</td>
<td>0</td>
<td>48</td>
<td>48</td>
<td>0</td>
<td>-48</td>
<td></td>
<td></td>
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<tr>
<td>pessimism</td>
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<td>0</td>
<td>59</td>
<td>0</td>
<td>59</td>
<td>0</td>
<td></td>
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<td>0</td>
<td>63</td>
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<td></td>
<td></td>
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<tr>
<td>anxiety</td>
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<td>-50</td>
<td>50</td>
<td>0</td>
<td>50</td>
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<td></td>
<td></td>
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<td>detest</td>
<td>0</td>
<td>83</td>
<td>0</td>
<td>83</td>
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<td>hatred</td>
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<td>69</td>
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<td>30</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>-30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: Ang, anger; Exp, expectation; Sad, sadness; Sur, surprise; Acc, acceptance.

range. We will report in the near future on the studies concerning dynamic image codes as an expansion of the static code. In this sense, this is the report on the basic study of the model whose image codes are restricted under static codes.

In order to realize a system as flexible as possible like humans, under even such static restriction of codes, the theory for the subjective observation model is introduced, which is applicable to the modifiable system connected with the context of the inputted sentence.
It will be important to find out what common words can be derived even from a number of the systems, whose image codes are different from each other depending on the persons who made the codes, and what is conservative to the person's own feature. This novel study may be of value in the near future, in the sense that there will exist a capability to conquer the very difficult present problems, introducing the opposite idea to traditional philosophy, i.e., introducing the methodology to think from a subjective observation toward an objective one.

2.2. Mechanism for Emotion Variation by Inputted Terms: Fuzzy Inference on Each Pure Emotion

The internal emotional state of a person is expressed by aggregation of the eight pure emotional situations. The transition of the internal emotional state is supposed to be caused by the inputted terms, and to be done by fuzzy inference mechanism. That is, it is also supposed that, for each pure emotion as an attribute, fuzzy inference is applied generally in such a way as, e.g.; "the emotional state on a pure emotion is strengthened in proportion to the coded intensity of the inputted term."

Thus, we adopt a very simple system consisting of nine fuzzy rules shown in Figure 1A. The fuzzy inference process based on triangular membership functions is shown in Figure 1B. Where, the support space is taken in the interval $[-100, 100] \times 0.01$ for the fuzzy sets on current emotional states and on inputted terms, and for those of output (new emotional state), the support space is taken in $[-200, 200] \times 0.01$. Thus, after max-min operation, the defuzzified values by center of gravity method (Mamdani's method, for example, Sugeno [8]), are made in the interval $[-100, 100] \times 0.01$ as shown in the figure.

The eight defuzzified values (coefficients on eight-dimensional vectors) can be regarded as an expression of the new emotional state of the simulated person evoked by the inputted terms. Furthermore, the obtained coefficients are applied again for the fuzzy inference as an intensity of the current emotional state, on each pure emotion, respectively.

2. EXPRESSION OF EMOTIONAL TRANSITION BASED ON SUBJECTIVE OBSERVATIONS

2.1. Expression of Emotions by Vectors and Conditional Euclidean Space

Image codes of the mixed emotions $\{x_k\}$ ($k = 1, 2, \cdots, 68$) can be expressed by the vectors consisting of the coefficients on eight attributes (pure emotions) of a normalized rectangular basal coordinate (NRBC).
Figure 1. (A) The nine fuzzy rules on a pure emotion. (B) An example of fuzzy inference process on a pure emotion and defuzzification.
whose system is denoted by $\{e_i\}$ (for $i = 1, 2, \cdots, 8$), inner product, $e_i \cdot e_j = 0$ ($i \neq j$), $e_i \cdot e_i = 1$). (The origin or location of the system is dropped here for simplicity, but it will be introduced later when a number of such systems (frames) must be considered), i.e.;

$$x_k = x_{k1}e_1 + x_{k2}e_2 + \cdots + x_{k8}e_8,$$

where

$$(e_1, e_2, \cdots, e_8) = ([\text{joy}], [\text{anger}], [\text{expectation}], [\text{hate}],$$

$$[\text{sadness}], [\text{fear}], [\text{surprise}], [\text{acceptance}]).$$

It should be noted that, although the vector itself is changeable depending on which attribute corresponds to which coordinate, the relationship between any pair of the two vectors arbitrarily picked up holds constant for all combinations between the attributes and the coordinates. That is, we can expand theory with the expression of Eq. (1) without losing generality.

Furthermore, the image of the terms besides the emotional words is supposedly also defined to be computed two ways; one is to weigh directly the intensity of the pure emotions, and the other is to compute the intensity by linear combination of the image codes of associated mixed emotional words. (Of course, the methodology to automate these two operations is also a very important study.)

In any way, a term $s_k$ (the suffix $k$ means the term in order $k$ in a sequence of terms like a sentence, in general) can be expressed by the image code by expanded fuzzy vector, correspondingly,

$$s_k = s_{k1}e_1 + s_{k2}e_2 + \cdots + s_{k8}e_8, \quad s_{ki} (i = 1 \cdots 8) \in R \text{ (real number)}. \quad (3)$$

Consider a processor $P_1 = (p_{11}, p_{12}, \cdots, p_{18})$ whose function is to transform the inputted signal $\{s_k\}$ consisting of a sequence of image code vectors into the output signal $\{s_{kout}\}$, then we can express each member of the output signal as follows,

$$s_{kout} = \sum p_{1i}(s_{ki})e_i = \sum y_{ki}e_i. \quad (4)$$

On the other hand, if we want to express the output signal of Eq. (4) as appropriate mixed emotional words corresponding to the transformed image code, it is natural to introduce a norm $\|s_{kout} - x_k\|$ (distance between two vectors), and to take out the words in smaller order of the computed norm, i.e., for an assigned constant $\delta$, we can list such words as to hold the following equation,

$$\|s_{kout} - x_k\| = \sqrt{\sum (y_{ki} - x_{ki})^2} < \delta. \quad (5)$$

It is easily understood that, in general, the larger the value $\delta$, the greater the number of terms listed; on the contrary, the smaller the value, the
smaller the number of terms. Sometimes, a case occurs where terms can be
selected, which is analogous to a person’s condition in daily life, e.g., such as expressing internal emotion only with tears, unable to find an appropriate term. We call this selection “soft matching method.”

In this way, when a sequence of image codes of the constructing terms extracted from a poem, \{s_1 \rightarrow s_2 \rightarrow \cdots\} is inputted, the transition of internal state of emotions results in the sequence \{s_{1\text{out}} \rightarrow s_{2\text{out}} \rightarrow \cdots\} and the corresponding sequence of mixed emotion words, \{x_{k1} \rightarrow x_{k2} \rightarrow \cdots\} that are selected from the image code dictionary (see Table 1). It is noted that a number of emotional words, \{x_{ki}\} (or some cases, no word) are selected by an inputted term \(s_k\), in general, but here, they are represented by only a symbol \(x_{ki}\) for simplicity.

For clearer understanding, image of the flow and the process of transformation are illustrated in Figure 2A and 2B, but they are drawn in three-dimensional normalized rectangular basal coordinates frame (NRBCF) in place of the strict drawings in eight-dimensional NRBCF, because drawing them on the plane is essentially impossible.

A physical image of the model for the emotion-processing system is shown in Figure 2A, which consists of the following equipment:

1. the NRBCF that consists of \(\{e_i\}\) corresponding to the attributes \(\{e_i\}\) as a combination, and of the origin \(O_{E_1}\)
2. the layer of the set of mixed emotional words as a set of genetic elements, \(\{x_k\}\)
3. the higher layer for the elements newly produced linear combination of the genetic mixed emotional words, \(\{y_{s}\}\)
4. the processor for transformation, \(E_1\), from symbols to the image code vectors
5. the fuzzy inference processor \(P_1 = \{p_{1i}\} (i = 1, 2, \cdots, 8)\)

Note that suffix 1 of the symbols, \(S_1, S_1, P_1, E_1\) and \(\Omega_1\) in Figure 2, means implicitly further existence of a number of local subsystems (LS) like this model, and the expanded theory concerning the universe constructed by all such subsystems has been reported (Yanaru et al. [1]). Also note that the computer simulations shown later are the results performed under the restriction of only an LS.

On the other hand, the model for the emotion-processing system can be described by mathematical notations as follows:

All of the elements including the newly produced elements can be equivalently drawn on a conditional Euclidean space (or Euclidean subspace) \(X_1, V^8_{1\text{out}}|E_1\) (see Figure 2B), where the condition \(E_1\) is denoted by \((\Omega_1, \{x_k\})\) that is a tuple of NRBCF, \(\Omega_1\), and the genetic elements as an infrastructure \(\{x_{ki}\}\), \(X_1\) is a set of the starting points of the vectors, and \(V^8_{1}\) is a set of eight-dimensional vectors related with innerproduct operation to
each other (usually called inner-product vector space), i.e., \( \Omega_1 = (O_{E1}: e_1, e_2, \cdots, e_8) \), where, \( O_{E1} \) is the origin (location) of the system.

\[
O_{E1} \quad \text{and all of the other starting points of vectors } \in X_1,
\]

\[
\{x_k\}, \{y_k\}, \cdots, \{s_k\}, \{s_{kout}\} \in V_1^8.
\]
Human's find it almost impossible to recognize the absolute meanings of objects or the true relationships among them directly; we usually understand the meanings concerning the objects by dropping the order of dimension and aggregating the observed information from several angles.

Taking this human property into consideration, a specialized two-dimensional Euclidean space for observation is equipped with the model. The model stands on the philosophy that all recognition and understanding can be done only on the observation space, mapping the objects defined on the high dimensional space onto the observation space.

Moreover, if we consider again the concern related to Eq. (5) taking account of the philosophy mentioned above, the direct reverse transformation of the output signals into emotional words on the defined original space may look like nonsense. However, the function for reverse transformation before mapping still remains meaningful for special usage like diagnostics.

Thus, the condition for the observation space $E_o$ can be denoted by,

$$E_o = (\Omega_o, \varepsilon) (\varepsilon \text{ means empty}),$$
and the coordinates frame,

$$\Omega_o \text{ is written as,}$$

$$\Omega_o = \{O_o: o_1, o_2\}.$$  \hspace{1cm} (6)

Consequently, applying affine mapping theory, well-known in the mathematical field (for example, Kawata [9]), to the mapping method of this model, not only all of the vectors for mixed emotions as the genetic members and for the produced elements in higher order, but also transition of the vectors caused by a sequence of the inputted signals and of output signals can be observed on the two-dimensional space (plane) from several angles. And thus, emotional words, depending on the observation, can be taken out by the soft matching method (see Figure 2C).

2.2. Affine Mapping and a Pair of Vectors for Subjective Observation

Let us introduce general theory for affine mapping (Kawata [9]), under supposition of existence of a number of local subsystems (LS) at first.

Consider mapping of the $i$-th LS, $(X_i, V_i^2|E_i)$ onto the observation space $X_o, V_o^2|E_o)$, and suppose that the coordinates frames are denoted by $\Omega_i, \Omega_o$, respectively, i.e.,

$$\Omega_i = (O_{E_i}: e_1, e_2, \cdots, e_n), \quad O_{E_i} \in X_i.$$  

$$\Omega_j = (O_o: o_1, o_2), \quad O_o \in X_o.$$
where, \((e_1, e_2, \cdots, e_n)\) are basal coordinates of \(E_i\), and \((o_1, o_2)\) are particular coordinates for mapping. \(O_{E_i}\) and \(O_o\) are the origins of the frames, respectively.

Thus in general, an affine mapping \((\gamma, \phi)\) is expressed as follows,

1. As for the origins, mapping is performed by a function \(\gamma\) as follows;

\[
\begin{align*}
    f_o &= O_o \gamma(O_{E_i}) = \alpha_{1} o_1 + \alpha_{2} o_2, \\
    (7)
\end{align*}
\]

2. where, \(\alpha_{11}\) and \(\alpha_{12}\) are coefficients depending on the function \(\gamma\) decided by application. (For example, \(\alpha_{11} = \alpha_{12} = 0\), in this model for the most simple case, but as for the advanced model thinking of two emotional subspaces with cross communication, the mapping function with non-zero coefficients will be introduced). As for basal coordinates, mapping is performed by the function \(\phi\) in the following way;

\[
\begin{align*}
    \phi(e_i) &= \begin{pmatrix}
    \epsilon_1 \\
    \vdots \\
    \epsilon_n
    \end{pmatrix} = \begin{pmatrix}
    \delta_1 \\
    \vdots \\
    \delta_n
    \end{pmatrix}
    \begin{pmatrix}
    o_1 \\
    o_2
    \end{pmatrix}, \\
    (8)
\end{align*}
\]

3. As for any vector, \(A \in V^n_i\) constructing the LS, linear transformation by function \(\phi\) is done in the following way;

\[
\begin{align*}
    A &= a_1 e_1 + \cdots + a_n e_n, \\
    \phi(A) &= a_1 \phi(e_1) + \cdots + a_n \phi(e_n) \\
    &= \left( \sum_{i=1}^{n} a_i \epsilon_i \right) o_1 + \left( \sum_{i=1}^{n} a_i \delta_i \right) o_2. \\
    (10)
\end{align*}
\]

On the other hand, let us consider definition of function \(\psi\), and supposed that the two vectors, \((\zeta, \eta)\) are arbitrarily picked up from the LS, i.e.:

\[
\begin{align*}
    \psi(e_i) &= (\zeta \cdot e_i) o_1 + (\eta \cdot e_i) o_2 \quad \text{(for } i = 1, \cdots, n), \\
    (12)
\end{align*}
\]

where,

\[
\begin{align*}
    \zeta &= \xi_1 e_1 + \cdots + \xi_n e_n, \\
    \eta &= \eta_1 e_1 + \cdots + \eta_n e_n. \\
    (13)
\end{align*}
\]
Eq. (12) can be written as,

\[
\begin{pmatrix}
\psi(e_1) \\
\vdots \\
\psi(e_n)
\end{pmatrix} = 
\begin{pmatrix}
\xi_1 & \eta_1 \\
\vdots & \vdots \\
\xi_n & \eta_n
\end{pmatrix}
\begin{pmatrix}
\varphi_1 \\
\varphi_2
\end{pmatrix},
\]

(14)

because, the inner product \( \zeta \cdot e_i \) becomes single coefficient \( \xi_i \) by rectangularity, i.e.,

\[\zeta \cdot e_i = \xi_i \quad \text{(for } i = 1, \cdots, n).\]

(15)

It should be noted that Eq. (14) becomes the same equation as Eq. (8), consequently, the function \( \psi \to \varphi \), and the coefficients \( \zeta_i \to e_i, \eta_i \to \delta_i \), (for \( i = 1, \cdots, n \)), each other. And further, concerning an arbitrary vector \( A \in V^n \), we can define the following function,

\[\psi(A) = (\zeta \cdot A)\varphi_1 + (\eta \cdot A)\varphi_2,\]

(16)

which is made coincident with the formula (11) in the same corresponding way. Thus, we can conclude that any pair of the vectors constructing the LS can be selected and treated as the mapping vectors for subjective observation. Thus, all of the vectors can be mapped on the space \( \Omega_o \), depending on the subjective observation by the pair vectors \( (\zeta, \eta) \).

The way of thinking and the resultant properties are significant not only for the theoretical expansion, but also for various applications.

2.3. How to Estimate the Objective Coefficients of Vector by Several Subjective Observations

Consider the relationship by innerproduct operation between a vector \( A \) and a basal coordinate \( e_i \), which are arbitrarily picked up from a certain LS. That is,

\[A = a_1 e_1 + \cdots + a_n e_n,\]

(17)

\[R(A, e_i) = A \cdot e_i = a_i.\]

(18)

It is easily noticed that, the coefficient \( a_i \) on the basal coordinate \( e_i \) can be computed by the relationship of innerproduct. Then in the same way, we can define the relationship between the mapped vectors by innerproduct operation, under the condition that the mapped origin is made coincident with the origin of the observation space, as follows,

\[R_o(\phi(A), \phi(e_i)) = \phi(A) \cdot \phi(e_i).\]

(19)
Substituting a pair of the vectors \((\zeta, \eta)\) for the mapping function \(\phi\), and using Eqs. (12), (16), and (19) can be written as,

\[
\phi(A) \cdot \phi(e_i) = \{(\zeta \cdot A) o_1 + (\eta \cdot A) o_2\} \cdot \{(\zeta \cdot e_i) o_1 + (\eta \cdot e_i) o_2\} \tag{20}
\]

\[
= (\zeta \cdot A) \zeta_i + (\eta \cdot A) \eta_i \tag{21}
\]

\[
= \left( \sum_{j=1}^{n} \zeta_j a_j \right) \zeta_i + \left( \sum_{j=1}^{n} \eta_j a_j \right) \eta_i. \tag{22}
\]

On the other hand, as mentioned previously, in order to realize the objective observation of the coefficients by aggregating the information obtained from several subjective observations, i.e., selecting the several pairs of vectors \((\zeta, \eta)\), Eq. (26) must hold:

At first, regarding the value in Eq. (22) as a pseudo coefficient by a subjective observation, it can be written as follows,

\[
a'_i = \left( \sum_{j=1}^{n} \zeta_j a_j \right) \zeta_i + \left( \sum_{j=1}^{n} \eta_j a_j \right) \eta_i \quad \text{(for } i = 1, 2, \ldots, n), \tag{23}\n\]

and the pseudo vector \(A'\) can be expressed by,

\[
A' = a'_1 e_1 + a'_2 e_2 + \cdots + a'_n e_n. \tag{24}\n\]

Then,

\[
E(a'_i) = E\left( \left( \sum \zeta_j a_j \right) \zeta_i + \left( \sum \eta_j a_j \right) \eta_i \right) \tag{25}\n\]

\[
= a_i, \tag{26}\n\]

where, \(E(\cdot)\) means expectation of \(\cdot\). \(a'_j, \zeta_j, \xi_i, \eta_j, \text{ and } \eta_i\) are all random variables corresponding to \(a_i', \zeta_j, \zeta_i, \eta_j, \text{ and } \eta_i\), respectively. The reason is that the meaning of several observations is equivalently regarded as the procedure to replace \(a'_i\) (consequently \(A'\)) to random variables \(a'_j\) (consequently \(A'\)), which is also equivalent to replace the coefficients, \(\xi_j, \xi_i, \eta_j, \eta_i\) to the random variable, \(\xi_j, \xi_i, \eta_j, \eta_i\), respectively. Consequently, Eq. (26) can be written as,

\[
\sum_{j=1}^{n} a_j E(\zeta_j \xi_j) + \sum_{j=1}^{n} a_j E(\eta_j \eta_j) = a_i, \tag{27}\n\]

Taking \(a_i\) outside,

\[
\sum_{j=1}^{n} a_j \left[ E(\xi_j \xi_j) + E(\eta_j \eta_j) \right] + a_i E(\xi_i^2 + \eta_i^2 - 1) = 0. \tag{28}\n\]
Consequently, in order that Eq. (28) will always hold for any of the vectors $A$, all of the coefficients concerning \{a_i\} (i = 1,\cdots, n) must become zero, i.e.,

$$E(\xi_i \xi_j) + E(\eta_i \eta_j) = 0 \quad \text{for} \quad (j = 1, 2, \cdots, n \ j \neq i),$$

and

$$E(\xi_i^2 + \eta_i^2 - 1) = 0.$$  

Thus, Eqs. (29) and (30) are regarded as the necessary condition for Eq. (26). On the contrary, let us consider the condition that the mapped NRBCs ($\phi(e_i)$, $i = 1, 2, \cdots, n$) distribute uniformly around a unit circle without grouping. The following equations are thought to be a definition holding the above condition,

$$E(\xi_i) = E(\eta_i) = 0,$$

$$E(\xi_i^2 + \eta_i^2) = 1,$$

$$E(\xi_i \xi_j) = E(\eta_i \eta_j) = 0 \ (i \neq j),$$

(or, equivalently, $\text{cov}(\xi_i, \xi_j) = \text{cov}(\eta_i, \eta_j) = 0 \ (i \neq j)$, because of Eq. (31), where, the notation $\text{cov}$ means covariance).

It will become clear by the following explanation that the definition is natural. Figure 3 shows the reason for Eqs. (31) and (32).

Further, Eq. (33) represents the condition that each of the random variables $\xi$ (or $\eta$) distributes in weak independence of the other variables $\xi_j$ (or $\eta_j$) ($j \neq i$) ($i = 1, 2, \cdots, n$).

On the other hand, it is clear that Eqs. (32) and (33) hold Eqs. (29) and (30), respectively. Consequently they also hold Eq. (26).

Thus, Eqs. (31), (32), and (33) are regarded as sufficient condition to hold Eq. (26). In other words, the strategy to see the true coefficients of original vector is to make several mappings so that the mapped coordinates distribute uniformly around a unit circle without grouping.

2.4. Theory for Time-dependent Subjective Observations

"The mixed emotions of a person are transitive (or evoked) depending on the duration and the repetition of his touching a certain object" (Matuyama and Hama [5]).

In order to take this psychological phenomena into our model, the obtained pseudo vector $A'$ from the real vector $A$ in Eq. (24) by a subjective observation is used again as the pair of vectors for subjective observation instead of $\xi$, replacing $\xi$ to $\eta$. That is in general, the obtained
Figure 3. Diagram for intuitive understanding of the meaning of Eqs. (31) and (32).

PDF: Probability Density Function

pseudo coefficient after $t$-times repetition, which are denoted by $\zeta_i(t)$ ($i = 1, 2, \ldots, n$), can be written by the following recursive equations,

$$a_i(t)' = \zeta_i(t)'$$

$$= (\sum \zeta_j(t-1)'a_j)\zeta_i(t-1)' + (\sum \eta_j(t-1)'a_j)\eta_i(t-1)'$$

$$\eta_i(t)' = \xi_i(t-1)'$$

$$\zeta_i(0)' = \zeta_i, \eta_i(0)' = \eta_i \text{ (for } i = 1, 2, \ldots, n),$$

$$A(t)' = a_1(t)'e_1 + \cdots + a_n(t)'e_n,$$

$$\xi(t)' = \zeta_1(t)'e_1 + \cdots + \zeta_n(t)'e_n,$$

$$\eta(t)' = \eta_1(t)'e_1 + \cdots + \eta_n(t)'e_n.$$
It should be noted that Eqs. (34) and (35) construct a system for nonlinear (two-dimensional, in this case) recursive equations that are regarded as a discrete system of nonlinear derivative equations.

Consequently, the behavior of \((\xi(t)', \eta(t)')\) will be very complicated depending on the initial pair of vectors for subjective observation, \((\xi(0)' = \xi, \eta(0)' = \eta)\). That is both of the pair vectors behave toward the same vector of convergence in some initial cases, but they may fall in divergence, in oscillatory behaviors, or in chaotic ones in the other cases. In any way, these complicated behaviors evoked from Eqs. (34) and (35) will be interesting subjects not only from a mathematical viewpoint but also from a psychological viewpoint.

Let us consider the special cases in convergence on the basis of Eqs. (34) and (35). That is, \(\eta_i(t)' \rightarrow \xi_i(t)'(= a_i(t)') \rightarrow \xi_i'(= A_i') \) (for \(i = 1, 2, \cdots, n\)), consequently, also for vectors, \(\eta(t)' \rightarrow \xi(t)' \rightarrow \xi'(= A')\). Then in this case, Eq. (34) can be written as,

\[
\sum \xi_{iic} a_i = \frac{1}{2}.
\]

Eq. (40) is an equation for \(n\)-dimensional superplane whose crossing points on the coordinates are \(\{1/2a_i\} (i = 1, 2, \cdots, n)\). Then the vector converges to a certain point on the plane.

Figure 4 is an image of the plane where \(n = 3\) for the simplicity of drawing and the converged vector \(\xi' = A'\), and shows some vectors \(\{x_k, x_l, x_m\}\) linked to the emotional words and the original vector for object \(A\), those which are scattered in the globe around \(\xi' = A'\) with radius \(\delta\), written by

\[
\left\{ \|A' - \xi\| = \left\{ \sqrt{\sum (a'_{ic} - \xi_i)^2} \right\} < \delta \right\}.
\]

Consequently, the only mixed emotional words \(\{x_{ki}\}\) linked to the vector \(\{x_{ki}\}\), holding the equation,

\[
\|A' - x_{ki}\| < \delta,
\]

can be selected. And further, whether the selected emotional words are appropriate to express the vector for the object in consideration depends on how the extracted emotional vector approaches the location near to the vector \(A\) in the process of subjective observations. In other words, how the mapped coordinates \(\phi(e_i, t) (i = 1, 2, \cdots, n)\) by \((\xi(t), \eta(t))\) distribute around a unit circle without grouping during the process time until convergence, as mentioned in the paragraph 2.3.

The interesting results by computer simulation will be shown later.
3. COMPUTER SIMULATION AND THE RESULTS

3.1. Experiments for Objectivity on the Selected Mixed Emotional Words Notwithstanding Some Quantitative Difference of Image Codes

Let us consider the following Japanese poem as an example (Yanase [10], Yanaru et al. [3]).

A raindrop fell on a cheek
Suddenly as it betrays gently
the tear having borne.

The meaning translated in English may contain a nuance somewhere between the original in Japanese and the translated version. For this reason, it may be necessary for the native speaker to make the image code
dictionary. However, the nuance is no more important than the research for finding the capability to construct a person-oriented system responsive to such a poem.

First, we make a sequence of image codes of the keywords constructing this poem based on the indirect way as shown in Table 2, under supposition that the constructing words (terms) have already been extracted by some lexical analysis. The mixed emotional words related with the constructing words were picked up by five male and five female students in our laboratory in a questionnaire on what mixed emotional words are associated, less than three words from each student. Then the image code of the constructing words was made by computing the linearly combined values of the selected words in Table 2. Table 3 shows the results based on three kinds of image codes on [male], [female], and [male-female], respectively. Especially in the right-hand column in Table 3, the evoked mixed emotional words, which are selected by soft-matching method, are listed. The words are arranged in the order of smaller values by the equation,

\[ \| s_{out} - x_k \| < 0.6. \]

It should be noted that the common word “calm” is evoked last in all cases, even though the values of image codes differ quantitatively depending on the cases, e.g., shown in Figure 5 for the word, “raindrop.”

The phenomenon mentioned above is very interesting from a psychological viewpoint, and is thought to be an analogy such that, corresponding the resultant image code to a person’s physical or psychological intensity impressed by the poem, he or she usually says a few words or sentences to express the internal complicated emotion, if a single appropriate word to express the emotion does not exist in his or her mind. In other words, a number of people can communicate only by the common words understandable to each other. In this sense, the last extracted common word, such as “calm” in this experiment, is called an “objective emotional word.”

3.2. Experiments for Emotional Transition on Time by Several Subjective Observations

Figure 6 and Figure 7 show the results for emotional transition on time by subjective observations based on the image codes in the case of [male-female] in Table 2. Figure 6 shows the results for a simulated person whose current emotion (or maybe the person’s nature) is supposed to be [curiosity, optimism] before reading the poem, whose image codes are used for the pair of vectors for subjective observation. In fact, a student related to our laboratory, whose personal nature is optimistic and curious, said to us “I was impressed by the poem with some emotion released from mental
Table 2. Associated Mixed Emotional Words from the Key Words Constructing the Poem

<table>
<thead>
<tr>
<th>Sex</th>
<th>Mixed Emotional Words</th>
<th>Joy</th>
<th>Ang</th>
<th>Exp</th>
<th>Hate</th>
<th>Sad</th>
<th>Fear</th>
<th>Sur</th>
<th>Acc</th>
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<td>male</td>
<td>sadness, discouragement, dislike</td>
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<td>10</td>
<td>-13</td>
<td>40</td>
<td>41</td>
<td>-10</td>
<td>13</td>
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<tr>
<td>female</td>
<td>meditation, uneasiness</td>
<td>-20</td>
<td>-31</td>
<td>31</td>
<td>10</td>
<td>20</td>
<td>31</td>
<td>-31</td>
<td>-10</td>
</tr>
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<td>56</td>
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<td>-13</td>
<td>40</td>
<td>56</td>
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<td>13</td>
<td>-10</td>
</tr>
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<td>0</td>
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<td>-43</td>
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<td>0</td>
<td>-58</td>
<td>43</td>
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<td>40</td>
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<td>0</td>
<td>0</td>
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<td>fate</td>
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<td>-2</td>
<td>6</td>
<td>-37</td>
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<td>female</td>
<td>joy</td>
<td>47</td>
<td>0</td>
<td>58</td>
<td>-30</td>
<td>-47</td>
<td>0</td>
<td>-58</td>
<td>30</td>
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<td>male-female</td>
<td>joy, pleasant</td>
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<td>30</td>
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<td>-46</td>
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Abbreviations as in Table 1.
Table 3. Process of Evoked Emotions by the Inputted Poem

<table>
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<tr>
<th>Constructed Words</th>
<th>Joy</th>
<th>Ang</th>
<th>Exp</th>
<th>Hate</th>
<th>Sad</th>
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<td>-7</td>
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Abbreviations as in Table 1.
stress." The sequence in Figure 6 shows that the emotion converges very quickly into the objective. On the other hand, the emotional transition process of the person who has fallen in such the emotion [fear, irony] for some reason, just before reading this poem, converges into the objective emotion seven times as shown in Figure 7.

Besides these results, we could obtain several interesting results that behaved in chaotic or oscillatory mode. These phenomena may be very interesting, even from the psychological viewpoint, although they cannot be shown here for lack of space.

4. CONCLUSION

We applied the basic theory for a subjective observation model, including a fuzzy inference technique that we recently created (Yanaru et al. [3, 11]), to an emotion processing system. And we have verified that the resultant emotional words that are processed and selected by the simulated person (system) fairly resemble a real person, notwithstanding the simple mechanism based on very simple fuzzy inference and affine mapping method. That is, one of the very similar features is that common emotional words are included among the selected words by the soft matching method, even if the image codes of the inputted terms differ depending on those of the simulated person. These are very similar to our human activities; they can communicate only the common words for a certain object, even if almost all of the physical intensities reacted by the
object differ on each of them. And the same thing will occur, even if the genetic image codes of the mixed emotions differ or fluctuate in some allowable range. At present we are studying this subject.

Another attractive result is that we could realize a simulated system that
Figure 7. An example of the emotional transition process when the initial pair vector for subjective observation is [fear, irony].

reacts on the observation space like a human’s conscious field, in such a way as does chaotic movement.

In any event, this is a novel study, and a lot of subjects for research remain. Perhaps, it will be useful to create some new types of processing systems, including emotional function, in the near future.
References


