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Subjective Information Processing: Its Foundation and Applications

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Abstract: *Subjectivity is inherent characteristics of information processing by/in humans, but almost no researcher has tackled this issue as main theme. Thus, this paper aims to give the readers a framework of subjective information processing (SIP) at first. Moreover, treatment of subjectivity in several natural sciences and relationships of SIP with related fields of engineering are described. Another aim is to show potential of SIP through an example; a model for communicating subjective degree with adverbs of degree.*

Keywords: *Subjectivity, Subjective information, Subjective information processing, Kansei, Adverb of degree*

1. Introduction

Background: In recent year, importance of human's feeling and judgment, namely Kansei, in product design and information processing (IP) has been gradually recognized. Kansei engineering and Kansei information processing have attracted academic researchers and industrial practitioners in various fields. When we consider IP in the field concerning Kansei, words and so on, subjectivity is obviously one of the human's inherent properties that we must treat adequately. Moreover a paradigm of manufacturing is going to shift from mass production of a few brands to less production of many brands. Hence importance of adequate consideration of an individual opinion arises, although consensus in group is still a great deal. From the above viewpoint, methods for handling subjectivity are the key to this new millennium.

Aims of this paper: In this paper, we describe the importance of considering subjectivity adequately when we treat systems of humans' information processing (HIP) and systems included humans. First, transition of treatment of subjectivity in natural sciences and characteristics of HIP are explained in Chapter 2. Then a framework of subjective information processing (SIP) is described in Chapter 3. Furthermore we mention relationships of SIP with related fields in Chapter 4.

Another aim is to show one of the directions of applications in SIP. In Chapter 5, taking communication of subjective degree of objects with words as examples, we exemplify research topics of SIP, directions of study in SIP, and applicability of methods in SIP to real problems.

2. Relationships between IP and Subjectivity

Transition of position of subjectivity: First let us consider transition of treatment of subjectivity in fields of natural sciences. ***Figure 1*** shows that it divide into three stages: exclusion, consideration, and center. Present time is the turning point from consideration to center. Let us describe every stage bellow.

Exclusion of subjectivity: Many scientists in natural sciences attached weight to objectivity of information. Thus, they excluded subjective information (SI) from topics that they treated because they thought that SI was (objective) one that lacks generality and covers only uncertain information. However, adequate treatment of topics closely related to humans now becomes important more and more in these fields. In such situation over-exclusion of subjectivity has brought several problems: e.g., separation of findings derived from theories from real issues, unwanted limitations of the finding in coverage and so on.

Consideration of subjectivity: On the other hands, fuzzy sets theory [1] allows us to treat subjectivity and gives

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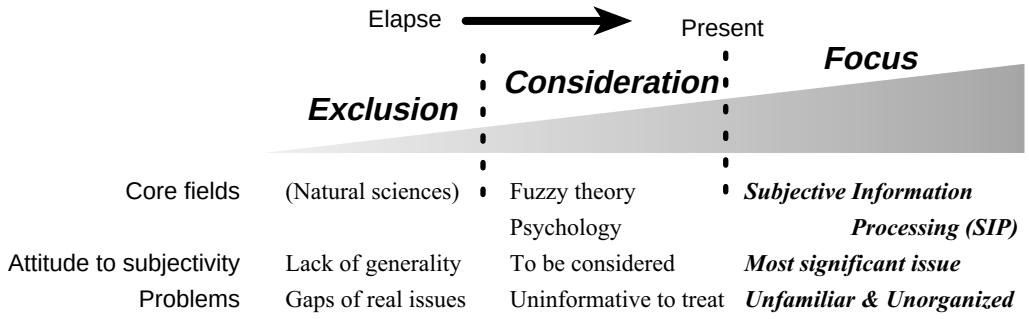

Figure 1: Transition of evaluation of subjectivity in natural sciences

a theoretical framework for considering it. Of course, it gives us effective tools for treating subjectivity, such as methods for quantitatively expressing fuzziness that meaning of word and subjective degree contained. However, it is insufficient to give us knowledge of how to use subjectivity, namely, how to treat subjectivity with the tools and how to apply the finding obtained.

Subjectivity has been naturally taken up in psychology. However, its interest focused on describing characteristics of generalized behavior of humans objectively. Therefore, psychologists considered subjectivity as disturbance against general descriptions and models of human behavior, then treated subjectivity to separate it from those descriptions and models clearly.

Necessity to treat subjectivity in IP: Subjectivity exists in various situations where humans are involved. Especially IP executed by/in humans is one of the best examples that contained subjectivity to the most extent. Therefore, consideration of characteristics of HIP is important not only to treat systems that involved humans adequately, but also to utilize excellent IP methods used by humans for improvements of system's performance. Therefore, it is useful to center the subjectivity in HIP and treat adequately it in the field of engineering.

3. A Framework of Subjective Information Processing: SIP

IP by humans: IP by/in humans originates from mutual communication. It associates with some extent of interpretation. Sender and receiver of information are different personalities in most cases. Conceptual disagreement between sender and receiver causes different recognition upon a same word. In other words, a sender intends to include a certain meaning in the word with his/her own vocabulary, while a receiver interprets it on receiver's own criteria. The difference becomes one of sources of subjectivity. In addition, increasing social activity caused by increasing communication methods is growing diversity of subjectivity because it makes numerous senders and the receiver needs to precess a flood of information from them. Under such bad situation, people can adequately process information that involves fuzziness, non numerical information, and incomplete information subconsciously.

Fuzziness in IP: Let us mention fuzziness closely related with subjectivity in order to show a relationship of IP by/in humans with subjectiveness and importance of subjectivity in IP. We need to understand characteristics of IP done by humans to utilize those flexible and excellent functions in HIP for improvement of performance at IP systems. For the sake of this, Nakamura [2-4] has classified characteristics of fuzziness in HIP, then has divided them into the following three characteristics: perspective, flexibility and nonlogicality. ***Figure 2*** shows the relationship among the three categories. Note that nonlogicality was called subjectivity in original literatures of [2-4], but I named it in this paper to avoid confusion.

Now let us explain the characteristics in detail. First, perspective is related to compression of information. That is, a flood of information is compressed by synthesizing and fuzzifying it to process it adequately and effectively. This characteristic, moreover, is divided into following three sub-characteristics: First conceptualization is to group objects based on their similarity. Second approximation is

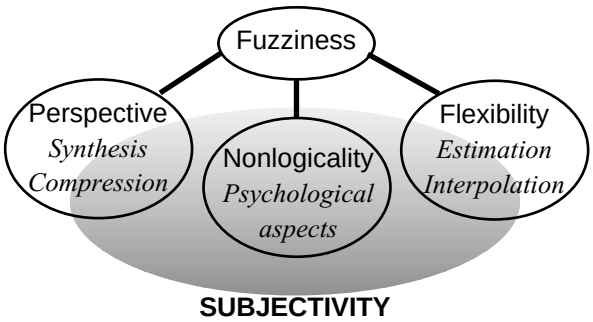

Figure 2: A relationship between subjectivity and fuzziness in IP

to group objects by making their meanings vague. Third summarization is to extract important parts of meanings in order to understand easily.

Second, flexibility is related to interpolation of information. That is, in the case where information required lacks or is uncertain, the information is complemented to treat successfully. This characteristic is also divided into following three sub-characteristics: First elasticity is to allow us to expand meaning depending on contexts. Second plasticity is to adapt gaps from outside using one's experience. Third interactivity is to learn oneself how to treat unknown objects by trial and error.

Finally, nonlogicality is related to psychological aspects of IP. This is, IP is influenced by emotion, motivation, intuition, Kansei, belief and so on. This characteristic is also divided into following three sub-characteristics: First believability is to process information with one's understanding and belief. Second intuitiveness is to process information nonlogically with intuitive inference, association and ellipsis. Third emotionality is that all processing is influenced by emotion.

Needless to say, it is certain that subjectivity most appears in nonlogicality among the three characteristics. However, in case where new information is generated by synthesizing several inputs, i.e., in perspective, or in case where one predicts without sufficient information, i.e., in flexibility, there is also subjectivity in the synthesis or inference process of information. As you can see from Figure 2, subjectivity, like fuzziness, is related to various characteristics of HIP. Therefore, it is important that we will consider HIP based on subjectivity, as Nakamura did based on fuzziness.

Subjectivity in IP: We define subjectivity as individual difference in judgment and evaluation of same object. In other words, according to the definition, subjectivity not only indicates mental feature related to such emotion and Kansei, but also includes all individual difference in processing results. It also includes difference in information itself and individual difference in the way to process information mentioned above. Incidentally, subjectivity depends on individuals. Meanwhile, we can find it only in a group because we need to compare with other in order to recognize it.

Subjective information: SI is defined as information that is originated in individual standards concerning judgment, definitions of concepts, and methods for processing information. SI is divided into following two kinds of information: One, containing subjectivity, and the other, precessed subjectively. In a broad sense, any information is classified as SI because any information communicated in the real world is made by humans, as mentioned in next chapter.

Subjective information processing : Therefore, SIP is defined as both analyzing subjectivity in HIP and applying the results to various fields. According to above definitions of SI, SIP is also divided into following two approaches: One is to analyze subjectivity within information and to apply the results to real applications. The other is to analyze methods of IP subjectively done by humans and to apply the results. For examples, the former contains quantifying adverbs of degree, such as "very," with considering both vagueness of them and individual differences in their meanings for each person. For the sake of this, we need to develop standard methods for measuring the subjectivity, such as membership function identification method. Meanwhile, the latter corresponds to analyzing how to choose words, especially adverbs, when one expresses his/her degree within themselves, such as impression and emotion, using words.

4. Relationships of SIP with other regions and fields

SI versus objective information: We define the information that has been treated traditionally and that does not contain subjectivity as objective information (OI) to clarify in this paper. It is likely to think that SI and OI are conceptually opposite. However, we should consider that OI is a part of SI, in which subjectivity is removed from standard of judgment and method for processing information to avoid miscommunication originated from subjectivity. Therefore, it is inadequate to interpret both kinds of information as opposite concepts. ***Figure 3*** shows that intersection of SI among individuals corresponds to OI. Suppose that one expresses subjective degree of tallness of a man, an expression with adverb of degree, such as "very tall," corresponds with SI, thus the expression is affected by individual differences in meanings of the adverbs. To avoid the dependence upon individuals, units, such as "meter" in this example, are introduced and corresponds with OI.

Generally speaking, it is likely to think that OI is global and SI is local. This statement originates from the range that one of information is common to a group. When we

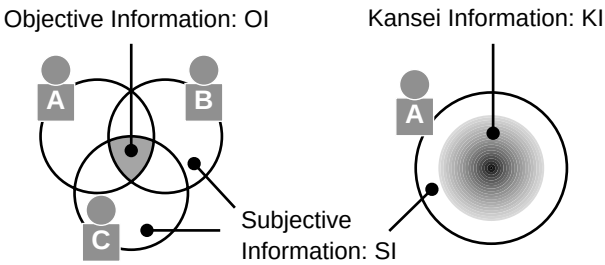

Figure 3: Relationships of subjective information to objective information and Kansei information

limit the relation to an individual, Figure 3 reveals clearly that the contrary relationship holds: All OI perceived by each individual is SI.

SI versus Kansei information: Although we do not have common definition of Kansei information (KI) currently [7], we define KI as information that is processed based on feelings and emotions and that contains Kansei. According to this definition, KI corresponds to subsets of SI, as shown in Figure 3. For examples, impression of beautifulness belongs to both KI and SI. Meanwhile, impression of tallness belongs to SI undoubtedly, but it is doubtful whether it belongs to KI. However, if we would stand for the following definition adopted in recent years; Kansei is a series of HIP from senses to cognition and their outputs [7], KI is close to SI. In this case, they differ in weight to consideration of individual differences. In other words, in KI we attach weight to sources of information like emotions or feelings, while in SI we attach weight to processed information like individual differences.

Moreover, there are common parts of KI among individuals, as OI is SI common to different individuals. For examples, they correspond to a consensus of KI formed within a group, such as the smell of writer Mr. X in his works.

Here is one of the reasons why I propose SIP is difficult in treating KI. Although we understand that KI is an attractive issue, it is difficult to analyze and apply because it relates to deeper systems of HIP. Thus, I believe that the following steps are expedient: A part of SI is simpler to analyze than KI. We first study SI, then apply those results of SI to KI and validate these results concurrently.

SIP versus Kansei engineering: Kansei engineering (KE) is an engineering method to translate one's feelings, impressions and emotions into elements to design real products that Kansei is reflected [8]. Taking design of cars as examples, KE aids how to choose their color combinations or forms to design cool or beautiful cars. It is necessary to establish a quantitative measurement for Kansei. KE often utilizes adjectives to measure degree of Kansei, e.g., semantic differential (SD) method, then KE handles world of adjectives, as shown in ***Table 1*** [6]. On the other hands, SIP handles world of adverbs to use for measuring subjective degree, mentioned next chapter. Moreover, people gradually begin to recognize that individual judgments are important in KE because there are individual differences in Kansei [9]. As mentioned previously, SIP focuses on individuals and their differences. Therefore, I believe that findings obtained from studies on SIP are also applicable to KE.

Table 1: Objects treated in the three fields

Field	Objects treated	
AI	Nouns & Verbs	*Objective (logical) information*
KE	Adjectives	*Psychological information*
SIP	**Adverbs**	***Individual information (difference)***

SIP versus Human Interface: Human Interface (HI) is a field of engineering to make good mutuality between humans and environments that surround them [10]. Hence, we need to evaluate the environments by influence upon humans and their behavior, not by physical properties of the environments. For examples of cars, it is important to evaluate them upon easiness to drive and amenity, not upon their top speed and their acceleration. An important characteristic of evaluation of HI is that its measuring instruments are humans themselves. Therefore, subjective judgments, called organoleptic research, play important roles in the field.

Moreover, it is also important for evaluation of HI to handle individual differences, though almost no one recognizes the importance. Let us consider evaluation of a tool on usability for instance. If 999 out of 1000 people would rate the tool at being excellent in usability, the tool remains unusable for the rest. In other word, majoritarianism and denominator make no sense for rating of usability, and only his/her own result is important. From the above viewpoint, we can see the importance of adequate treatment of individual differences, and I believe that SIP can offer us useful methods to aid.

5. Directions of Applicability of SIP

We have mainly described theoretical issues on SIP, such as its frameworks, up to previous chapters. Now we will show directions of applicability of SIP to solve real prob-

lems with some examples for their topics.

5.1 Model for Communicating Subjective Degree with Adverbs of Degree

Structure of model: We here take up expression of subjective degree with adverbs of degree as one of the examples. The reason we take it up is that subjectivity appears clearly in this example and this target is worth realizing.

Two processes in the model: The process is globally considered as a process that transforms multidimensional continuous inputs, i.e., stimuli outside from human, into a one-dimensional discrete output, i.e., a label of adverb of degree. ***Figure 4*** shows that the process consists of following two processes: One is a process in which the multidimensional inputs are combined into one-dimensional degree that sender wants to communicate. The other is a process in which an adequate adverb of degree is chosen to express above degree. We name the former processor unit (PU) and the latter encoder unit (EU). That is, the former combines multidimensional continuous values into an one-dimensional continuous value, and the latter transforms the continuous value into a discrete value.

Three kinds of information related to the processes: When the input information is processed in both units, following two sources relate besides it: One is information that is stored within an interior part of humans, such as knowledge, experiences, Kansei, vocabulary, and so on. We name this information *reference information* since they are referred as standard and norm of processing. The other is information that affects outside from humans, such as environments, contexts, and so on. Since they affect the two units and *reference information* temporary, we name it *modification information*. Lastly, outputs from each unit are fed back to sources of the *reference information* to revise them. Therefore, we name the information *revise information*. In this model, physical stimuli as inputs and a label of verbal expression as an output do not contain fuzziness. On the other hand, we need to describe as fuzzy sets subjective degree, i.e., output of PU and degree of adverbs of degree used in EU because boundaries of their meanings are vague.

Aim to construct the model: As you may be noticed, the model for expressing subjective degree in Figure 4 does not exactly simulate physiological functionality of humans. The aim, however, is to describe a series of the processes as a format easy to use it for real applications, not to construct a precise model of this functionality. Hence, we may accept that the model is apart from the real process in interior structure and details only if similar results are obtained from the model.

Explanation of the model with concrete examples: Let us explain above model in detail, taking impressions of fatness versus thinness that Mr. A feels as an example. Here input information is a height and width of Mr. B. PU combines information of his height and width, then transforms it into subjective degree of fatness versus thinness based on his knowledge and experience of proportion. Suppose that Mr. A meeting Mr. B after ten years no see is surprised at how Mr. B is fat and looks like other people. In this situation, *the reference information*, i.e., feeling and knowledge, and *the modification information*, i.e., context, in-

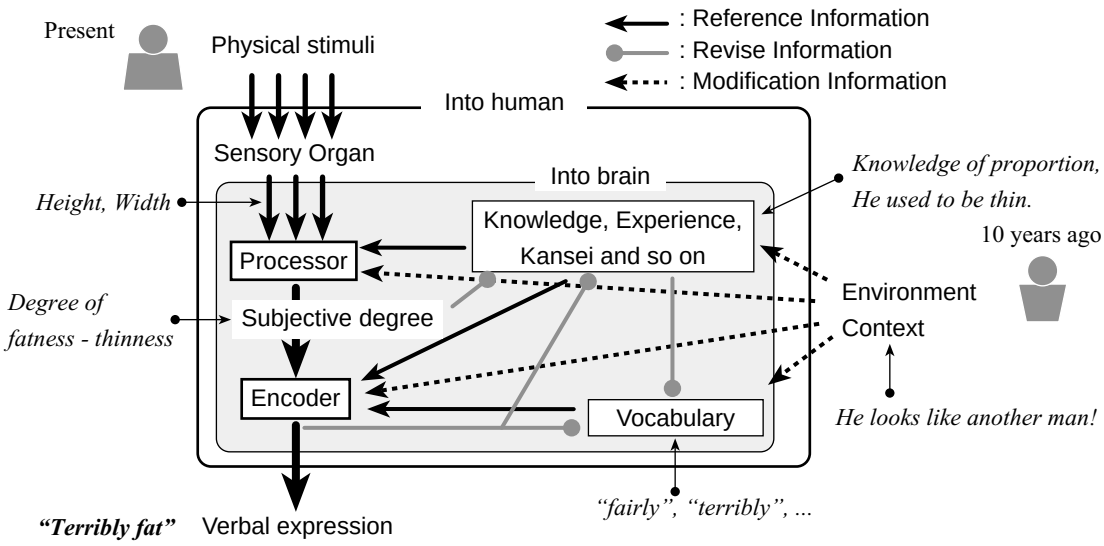

Figure 4: A model for expressing degree of object with advebs of degree

crease degree of impression of fatness.

Meanwhile, EU chooses adverbs of degree suitable to express the degree of fatness versus thinness, comparing the fuzzy set for the degree with those for adverbs of degree. In above situation that Mr. B is fatter than ever, EU chooses the adverb in standard that can express the degree of Mr. B's fatness adequately, besides Mr. A's surprise and unexpectedness due to his feeling and context [11].

Existence of subjectivity in the model: Following two kinds of subjectivity are found out in the model: One is in processing methods, and the other is in the degree and structure of information. The former is found out in PU and EU. For examples, in PU, there is subjectivity in methods for combining and weighting multidimensional inputs eclectically. In EU, there are individual differences in methods for estimating the compatibility between the integrated subjective degree from PU and adverbs of degree and in influences one's nuances upon selection of the adverbs. On the other hand, the latter is found out in *the reference information*, *modification information*, *revise information*, subjective degree as outputs from PU, and verbal expressions as outputs from the whole system. As seen from this example, subjectivity appears in this model everywhere.

5.2 Applications of the Model

Simplification of the model: We have now seen that various elements relate complexly and organically in the simple transformation process from external stimuli into an adverb of degree as mentioned above. Thus, it is difficult to consider all elements in the model from the start. Therefore, we simplify the model as follows: First, we can consider that *modification information*, such as influences of environment and context, is fixed and stable. Second, we suppose that *the revise information* is not fed back temporally. Consequently, we can remove both *the modification information* and *revise information* from the model. The simplified model is applicable to following three directions.

Intelligent information integration (I3) system: First, we can make an I3 system using functionality of transforming multidimensional inputs into one-dimensional output in PU. ***Figure 5*** shows that this system utilizes *the user's reference information* and integrating method, in which the user's subjectivity is reflected. Therefore, the one-dimensional information integrated is easier to understand for the user. Especially, this mechanism is valuable to improve

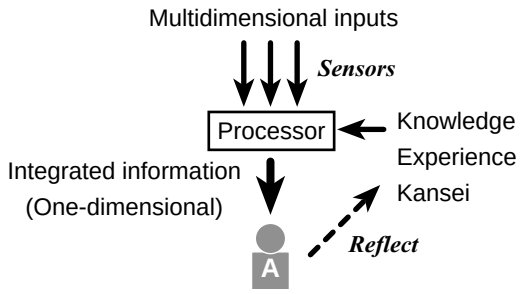

Figure 5: A schema of I3 system

HI of systems that display a flood of information. However, we need to overcome many difficulties to realize it.

Applications to verbal approximation system: Verbal approximation, we treat here, is to transform degree described as fuzzy sets into adverbs of degree. This system, for examples, is expected to apply for many directions: To translate outputs of systems displayed in fuzzy numbers into adverbs of degree makes the users easy to grasp the outputs. When there are individual differences in meaning of same adverbs of degree between a sender and a receiver, we can avoid to mislead a receiver, in order to translate the sender's adverb into another receiver's adverb close to the degree of the sender's adverb. Indeed, some applications have already been tested [12].

Conventional verbal approximation methods are insufficient to treat following issues: One is subjectivity of meaning of adverbs, and the other is relationships between subjective judgment of similarity and similarity indices calculated from fuzzy set operators necessary to approximate. If we adopt a model of the encoder in ***Figure 6***, then above two issues originate in 1) subjectivity of vocabulary and 2) evaluation method of similarity between the input and adverbs in the EU.

We interpret the latter as a comparison between subjective judgment of similarity of fuzzy concepts and similarity indices calculated from fuzzy sets that correspond to the concepts. Zwick et al. [13] and Yoshikawa [14, 15] have already executed this topic. Especially Yoshikawa

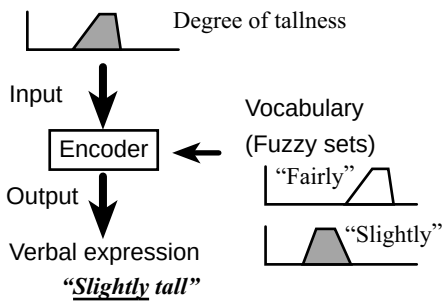

Figure 6: A schema of verbal approximation system

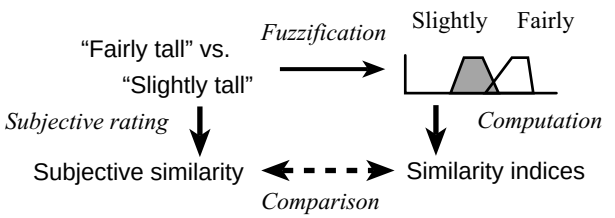

Figure 7: A relationship between subjective similarity and similarity indices

had his subjects identify membership functions (MFs) for verbal tallness, such as "very tall" and had them rate degree of similarity for pairs of two expressions. Then, he calculated 30 candidates for similarity indices from the MFs obtained, and compared their values with the degree of similarity that the subjects rated directly (***Figure 7)***. The 30 candidates are divided into following two categories: One is of indices obtained from t-norm operators, such as height of logical product set. These indices, which have been used often in several applications, show an overlap between two fuzzy set. The other is of distance between two fuzzy set along with element axis, such as distance between gravity centers of fuzzy sets. The correlation coefficients between the calculated similarity indices and the rated degree of similarity over all subjects indicate the latter corresponds to the rated degree of similarity than the former, i.e., overlap measures which are often used.

Meanwhile, the former, i.e., treatment of subjectivity of vocabulary, results in identification of MFs for adverbs of degree. Although some researchers have already proposed several MF identification methods [16-19], there is no standard method up to now. Since MF identification methods play important role in quantification of subjectivity, we need to improve the standard methods immediately.

Applications to psychological scaling: Psychological scaling utilizes EU in opposite direction against the verbal approximation, as shown in ***Figure 8.*** Psychological scaling is a method for quantifying subjective degree measured with adverbs of degree as ticks, for examples, questionnaire data rated at "very tall" and so on. One of the well-known methods is the method of successive categories (MSC) [20]. However, this method contains some significant defects. One of the most considerable defects is that the MSC cannot handle subjectivity from individual differences in meaning of adverbs of degree [21].

Outline of the method of fuzzy categories: To ameliorate the defect, Yoshikawa proposed a new method considering EU as follows: EU decides an adverb of degree to

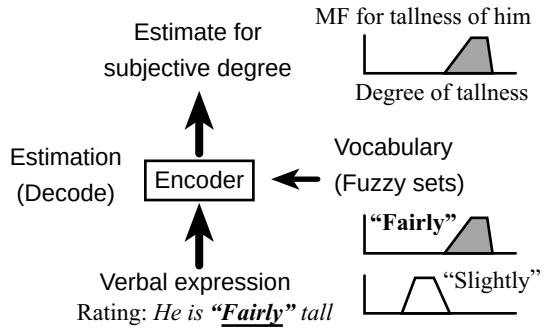

Figure 8: A schema of psychological scaling with the model (Method of fuzzy categories)

express the subjective degree based on compatibility degree. It is calculated with truth qualification, i.e., to what degree each MF of adverb well expresses MF of the subjective degree [22]. The MF of the adverb used as the answer does not necessarily agree with the MF of subjective degree absolutely, because the subjective degree is continuous while the adverbs as ticks are discrete. However, supposed that the two of degree agree with absolutely, an estimate of the subjective degree is obtained from the MF for the adverb, which each answerer identifies. In other words, we first have each answerer identify MFs for all adverbs of degree used in the rating scale prior to the rating, then we can estimate the subjective degree of the object as the MF for the adverb at which the answerer rates the object. This psychological scaling method is called the method of fuzzy categories (MFC) [23].

Three features of the MFC: The MFC has the following features: The first is that it adequately estimates subjective degree for each answerer considering individual differences in meanings of adverbs of degree, which are neglected in the MSC. The second is that it does not require repeated rating that the MSC requires necessarily. The third is that it allows to quantify rating categories, i.e., adverb of degree in rating scale, prior to rating of objects.

Computer aided design of categorical rating scales: Yoshikawa proposed a system of computer aided design of categorical rating scales using last feature [24]. This system selects and arranges rating categories on a rating scale for each answerer who uses the scale based on both his/her meanings of the adverbs and ease in rating with the scale. ***Figure 9*** illustrates the structure of the proposed system. It works as follows: First, the answerer identifies MFs for adverbs of degree obtained by the system, which are candidates of rating categories. Second, the system constructs possible candidates of rating scale by combining the ad-

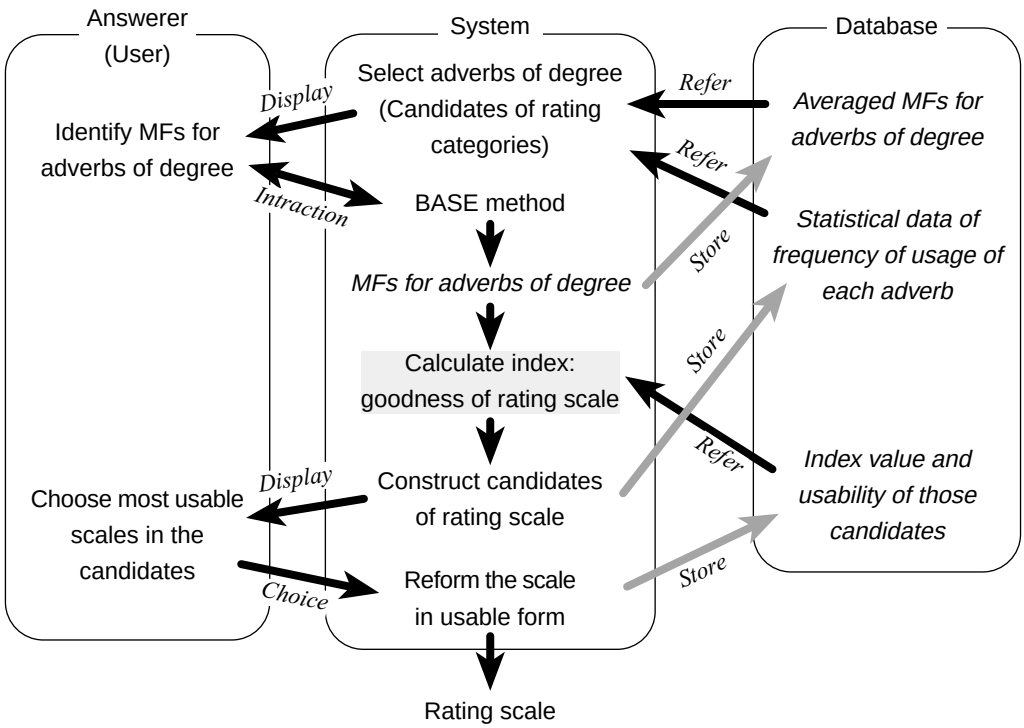

Figure 9: A schema of computer aided design of categorical rating scales

verbs, then calculates "goodness of rating scale" for each one. Third the system selects three or four of better candidates based on their values of the goodness and display the answerer them. Finally, the answerer chooses most usable one in all candidates displayed, then rates the objects using the scale chosen. This system is expected to improve preposterous situation that we forced each answerer to follow only one rating scale into reasonable situation that we can fit his/her rating scale to each answerer.

6. Conclusion

In this paper, I have described and explained subjectivity in HIP, the framework of SIP and relations of it to other fields. Then, I have shown some of their applications as examples of potential applications of SIP. Indeed, SIP has just been born, so nobody knows whether or not it grows into one of new paradigms in engineering as fuzzy sets theory. However, I strongly believe that subjectivity in IP is essential to engineering beyond the twentieth century and the key to success in SIP is to develop useful and unique applications. I hope that the community of SIP expands more and more.

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