

# A Fuzzy-Semiotic Framework for Modeling Imprecision in the Assessment of Depression

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**Abstract**—This paper presents a new framework to model an assessment process for a complex and multidimensional syndrome such as depression. Since the measurements of depression are inherently imprecise, we explicitly model the context of the assessment process, and we analyze various aspects of imprecision (syntactic, semantic, and pragmatic). The framework is based on fuzzy logic and semiotics. The fuzzy-logic approach allows for the representation of quantitative imprecision of the measurements and the semiotic approach allows for the representation of the qualitative imprecision of the concepts. We have applied this fuzzy-semiotic framework to two types of clinical measurements: the rating by the experts and the filling out of self-administered questionnaires. The proposed framework provides a conceptual foundation for the construction of a medical decision support tool.

**Keywords**— Assessment of depression, fuzzy logic, imprecision, modelling, medical decision, semiotics.

## 1 Introduction

Depression is a common mental disorder characterized by sad moods, loss of interest or pleasure, feelings of guilt or low self-worth, disturbed sleep or appetite, low energy, and poor concentration. Depression represents a major public health problem, and it has a high prevalence worldwide and high societal costs [1]. The World Health Organization (WHO) reports that “depression is affecting about 121 million people worldwide;” furthermore, WHO ranks depression as one of the most burdensome diseases in terms of disability costs [1, 2]. The assessment and treatment of depression are lengthy and complex, and often the patients wait a long time to gain access to psychiatrists. We believe that specialists as well as general practitioners may be assisted by a decision-support tool, which may reduce the waiting time and facilitate earlier medical assistance. The medical decision support tool is not intended to make therapeutic and diagnostic decisions, and it should never replace proper psychiatric examination or harm the crucial relationship and trust between a doctor and a patient. The effectiveness of such a support system depends profoundly on the underlying models of the measurement process. Thus, we present first a framework based on fuzzy-logic and semiotic approaches to model the complex and multi-dimensional concept of depression and its measurement methods. Second, we then use this framework to model two general types of measurements: (1) rating by an expert using

widely accepted rating scales such as the Hamilton Rating Scale for Depression (HRSD) and (2) self-administered questionnaires filled out by patients such as the Beck Depression Inventory (BDI).

This paper is structured as follows. Section 2 surveys various classifications of depression and methods used to measure the severity of depression. Section 3 presents the definition of imprecision in medical data and defines three characteristics. Section 4 presents a fuzzy-semiotic framework for explicit representation of imprecision in medical data. Section 5 and 6 describe the implementation of the framework for the assessment of depression in the context of treatment evaluation and in the context of screening. Finally, the last section presents conclusions and suggests directions for future research.

## 2 Depression and its measurement process

Depression is a term used to cover a wide range of states, from feeling sad or helpless, through minor depression to major depression (MD). There are many approaches to the definitions, classifications, diagnostic criteria, and measurements of depression. These diverse approaches reflect the fact that depression has a complex etiology and presents itself with a variety of symptoms, which differ in different patients. In this paper, we focus on modeling the measurement process; thus we concentrate on a classification of symptoms, their frequency, and duration. However, the measurement process is determined by the definition of depression (its conceptualization). Thus, we cannot model the measurement process without specifying first the various conceptualization approaches.

### 2.1 Conceptualization of Depression

Several conceptual approaches to depression exist, and many authors view depression as a syndrome rather than a single diagnostic entity. In this paper, we focus on major characteristics: (1) depression can be defined by a set of presenting symptoms, which display specific severity, frequency, and duration, (2) depression can be viewed as a dimensional concept in which symptoms may be grouped or clustered into specific dimensions, and (3) depression may be conceptualized as a state or trait.

The symptomatic approach to depression identifies more than 10 symptoms, which have varied definitions and which

are used in different ways by the diagnostic criteria. The symptoms are generally grouped into three classes: *affective* (crying, sadness, apathy), *cognitive* (thoughts of hopelessness, helplessness, suicide, worthlessness, guilt), and *somatic* (sleep disturbance, changes in energy level, changes in appetite, and elimination). Not all symptoms are present at the same time, and the severity of symptoms differs. Moreover, the symptoms may vary in their “directions.” For example, two subtypes of depression are distinguished: depression with vegetative symptoms (e.g., appetite loss, weight loss, insomnia) and depression with reverse vegetative symptoms (e.g., appetite increase, weight gain, hypersomnia). The second subtype, according to the epidemiological studies, is characteristic of one-fourth to one-third or of all people with major depression, and it is more common among women.

### 2.2 Operationalization of Depression

In our discussion, we refer to two general diagnostic criteria: WHO’s International Classification of Disease (ICD-10 in Great Britain) and the Diagnostic and Statistical Manual of Mental Diseases Fourth Edition (DSM-IV in North America). Both criteria are based on a symptomatic approach and have many similarities and differences [3]. They differ in the set of symptoms; however, both have eight symptoms in common: depressed mood, loss of interest, decrease in energy or increased fatigue, sleep disturbance, appetite disturbance, recurrent thoughts of death, inability to concentrate or indecisiveness, psychomotor agitation or retardation. The ICD-10 and DSM-IV criteria have a significant overlap in diagnosis, yet in some cases the patient may meet the diagnostic criteria in one system but not in the other. For example, the ICD-10 criteria do not take into account bereavement, while DSM-IV excludes a diagnosis of major depression if the symptoms may be linked with the bereavement process. Both diagnostic criteria have been modified several times and remain subjects of ongoing discussions. These modifications clearly indicate the difficulties in defining such a heterogeneous syndrome.

### 2.3 Assessment of Depression

Assessment of depression must be placed in a broader context of clinical decision making. Thus, for example, Nezu et al. [4] define the following questions to guide the selection and interpretation of the appropriate measurement process: (1) What are the goals of assessment? (2) Who is to be assessed? (3) What is the value of a given measure and who is the source of the information? The goals, for example, are screening, diagnosis and classification, clinical hypothesis testing, treatment planning, prediction of behavior, or outcome evaluation. The assessed groups are heterogeneous in terms of age, comorbidity, cultural background, and gender. The measures can be divided along the lines of *idiographic* and *nomothetic* philosophies of measurement. The idiographic approach assumes that each person is unique and thereby requires an individualized method of measurement. Thus, the measuring process requires an assessment by a clinician who follows the general structure of a rating scale, but who can vary the specific questions according to individual needs of the patient. The nomothetic

approach has the goal of generalization, and the measurements strictly follow standardized questionnaires. Moreover, various measures are characterized by varied reliability, validity, and practical utility.

## 3 Imprecision

Imprecision is an intrinsic part of many medical concepts and their measurements. Concepts such as *quality of life*, *state of health*, and *depression* are difficult to define, measure, and quantify. Moreover, a certain level of imprecision is characteristic of all medical data. Imprecision is an inherent part of conceptualization, operationalization, and the measurements themselves. Moreover, imprecision is distinct from incompleteness (absence of value), inaccuracy (value is not close to the “true” value), inconsistency (dissimilar values from several sources), and uncertainty (probability or belief that the value is the “right” value). In our discussion, we focus on three characteristics:

- 1) Imprecision has two aspects: *qualitative* and *quantitative*. The qualitative imprecision is a result of a vagueness of the concept (e.g., quality of life, status of health) and the inability to precisely measure the concept (e.g., inherent imprecision of self-administered depression questionnaires). The quantitative imprecision is a result of a lack of precision in a measurement. We view these aspects of imprecision as pragmatic (vagueness of the concept), semantic (lack of precise measures), and syntactic (lack of precision in a measurement).
- 2) Imprecision is highly *contextual* and *interpretative*, i.e., a statement “I feel sad some of the time” may be sufficiently precise in a specific situation or a more precise statement such as “I feel sad 2-3 times a week for more than 2 hours without any particular reason” may be needed. Thus, imprecision is a quality of a specific value used in reference to a concept in a specific context. Often, imprecise values are sufficient, since the precision may be impossible to attain, impractical, too expensive, or unneeded.
- 3) Imprecision should be viewed in *terms of degrees*. Each concept, its representation, and its interpretation have a certain degree of imprecision or precision. Imprecision in a sense has continuous values. The values can be ordered in increasing or decreasing order of precision. For example, the severity of depressive mood can be described in terms of its frequency and duration with an increasing precision: “occasional sadness” “sadness 2-3 times a day” and “sadness 2-3 times a day more than for 2 hours.”

## 4 A fuzzy-semiotic framework

In this section, we present a conceptual framework for modeling imprecision and its qualitative and quantitative aspects. Our framework is based on a complementary combination of the semiotic approach and the fuzzy-logic approach. The semiotic approach provides a model for *qualitative* imprecision, whereas the fuzzy-logic approach

provides explicit representation for *quantitative* imprecision. Our framework addresses also the contextual and interpretative characteristics of imprecision.

4.1 *Semiotic Approach*

We based the framework on Peircean semiotics, which defines “sign” as any entity carrying some information and used in a communication process. Peirce divided semiotics into three categories [5]: syntax (the study of relations between signs), semantics (the study of relations between signs and the referred objects), and pragmatics (the study of relations between the signs and the agents who use the signs to refer to objects in the world). This triadic distinction is represented by Peirce’s semiotic triangle: the *object*, *representamen* (the form which the sign takes), and *interpretant*. Fig. 1 shows the semiotic representation for the assessment of depression. In this model, the “interpretant” refers to the purpose of the assessment (e.g., screening, diagnosis, treatment evaluation), the agents (e.g., patients, clinicians), the perspectives (e.g., health care costs, accessibility, ethics), the biases (e.g., specific subgroups of agents), and the views (e.g., variations in the diagnostic criteria).

Object: Multidimensional Concept of Depression

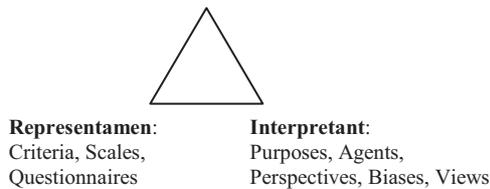


Figure 1: Semiotic triangle.

The assessment involves three aspects: conceptualization (what to measure), operationalization (how to measure), and utilization (how to use the measure). These three aspects constitute a triplet:  $\langle O, M, U \rangle$ , where  $O$  represents a set of objects,  $M$  a set of measures, and  $U$  a set of utilization parameters (interpretants). For example, the representation of depression has a set of objects such as depressive episode, cognitive symptoms, affective symptoms, somatic symptoms, a set of diagnostic criteria and assessment instruments, and a set of clinical guidelines for the assessment process in a particular context.

4.2 *Fuzzy- Logic Approach*

We based the framework on a fuzzy-logic approach (1) to assess the severity of depressive episode as “absent,” “mild,” “moderate,” and “severe” and (2) to assess the severity of particular dimensions of depression. Since the assessment process depends on the clinical context, the accepted definition of depression, and the specific diagnostic criteria, we apply the fuzzy-logic framework to the treatment evaluation and screening.

5 **Modeling the assessment of depression in the context of treatment evaluation**

In this section, we describe the treatment evaluation process, which typically is used in psychiatric clinics to assess clinical

situations and to evaluate the effectiveness of pharmaceutical treatment. We have applied the fuzzy-semiotic framework to model the assessment of depression in the context of treatment evaluation. The evaluation protocol is based on our earlier work on a fuzzy-logic based system to support a depressive episode therapy [6]. In the following subsections, we discuss diagnostic criteria, an assessment instrument, a measure for treatment effectiveness, and an implementation of the fuzzy-semiotic framework.

5.1 *Diagnostic Criteria*

The treatment evaluation requires at least two consultations: pre- and post-treatment. During the first consultation, the clinician evaluates the patients according to diagnostic criteria accepted by the clinic, such as DSM-IV or ICD-10. In this specific application, the clinician uses the Research Diagnostic Criteria (RDC) for ICD-10 to assess the severity of a depressive episode as *mild*, *moderate*, or *severe*, and to classify it as an episode with or without psychotic symptoms and with or without somatic symptoms. During the second consultation, the clinician repeats the assessment, compares the results with the results from the first consultation, and evaluates the clinical situation as a *recovery*, *partial improvement*, *lack of improvement*, and *deterioration*. The RDC for ICD-10 have 16 items, which are rated by the clinician using the Hamilton Rating Scale for Depression (HRSD) and eight additional questions for the items not covered by HRSD.

5.2 *Assessment Instrument*

The Hamilton Rating Scale for Depression (HRDS) is an assessment instrument, which has been the most frequently used clinical rating scale since its inception in 1960 [7]. The HRDS is completed by a clinician, and it used to indicate the severity of depression in patients already diagnosed with a depressive disorder. The HRDS has 21 items; 17 items are usually used for scoring. The items are measured on a three-point scale (0, 1, 2) or a five-point scale (0, 1, 2, 3, 4). The items are based on symptoms. The items on the three-point scale are quantified as 0 = “symptom absent,” 1 = “slight or doubtful,” and 2 = “clearly present.” The items on the five-point scale are quantified in terms of increasing intensity: 0 = “symptom absent,” 1 = “doubtful or trivial,” 2 = “mild,” 3 = “moderate,” and 4 = “severe.” For example, the symptom *depressed mood* is quantified as 0 = “absent,” 1 = “feeling of sadness, gloomy attitude, pessimism about future,” 2 = “occasional weeping,” 3 = “frequent weeping,” 4 = “extreme symptoms.” Typically, the scores from 17 HRDS’s items are added together, and the final score ranges from 0 to 52 points. Originally, Hamilton did not specify cutoff points; however, generally the scores lower than 7 indicate an absence of depression, scores 7 to 17 indicate mild depression, scores 18 to 24 indicate moderate depression, and scores of 25 and above indicate severe depression. Generally, the HRDS has high reliability and validity. On the other hand, the literature on the HRSD includes many papers criticizing the scale on a number of grounds. One of the important issues for our explicit model of imprecision is a critical assumption about the type of a measurement. The problem is related to the quantification of the concept: is the

HRDS an ordinal measurement scale or is it an interval measurement scale? Thus, although from a theoretical perspective, the HRDS is an ordinal scale, from the practical perspective, the HRDS is perceived as an interval measurement, which means that one unit on the scale represents the same magnitude of change across the entire scale. For example, the symptom *depressed mood* rated from 0 to 4 should have equal distances between the four points. The distance of two units between “absence of depressed moods” (rated as 0) and “occasional weeping” (rated as 2) should be the same as the distance between “occasional weeping” (rated as 2) and “extreme symptoms, when the patient reports only sad feelings in verbal and non-verbal communication” (rated as 4).

We have observed that (1) the HRDS represents an ordinal scale, and the assumption of the equity of distances between units introduces a large measurement imprecision, and (2) the range of values on three-point scale and five-point scale is not sufficient for scaling small changes in symptoms during the treatment. To address these two problems, we have introduced an 11-point rating scale – a range of values from a discrete set: {0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1}. The value 0 means “normal state” (not precisely defined), and the value 1 means extreme pathology (also not specified), the medium values are based on the HRDS range of scores 0–4 (1 = 0.2, 2 = 0.4, 3 = 0.6, and 4 = 0.8). Each item has the same rating range. The 16 items on the RDC for ICD-10 and an example of values for patient  $p_1$  are presented in Fig. 2.

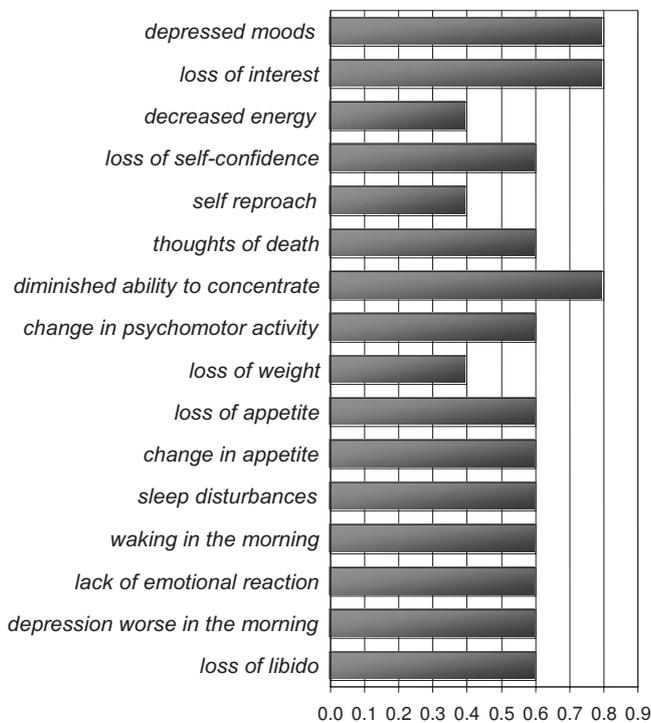


Figure 2: Assessment of depressive episode for patient  $p_1$  using the RDC for ICD-10.

### 5.3 Measure of the Treatment Effectiveness

The treatment evaluation is based on the comparison between the pre-treatment and post-treatment assessment outcomes. In the assessment process, a clinician (a rater) evaluates the intensity of depression for each of the 16 items, and then calculates the relative intensity of depression in percent. The *Relative Depression Intensity*, *RDI*, is calculated for a specific patient,  $p_1$ , rated by a specific rater,  $r_1$ , at given point in time,  $t_1$ , using (1). The RDC criteria for ICD-10 are represented as  $C_1, \dots, C_{16}$  ( $n = 16$ ). The maximum value for each  $C_i$  is 1.

$$RDI(p_1, r_1, t_1) = \frac{\sum_{i=1}^n C_i(p_1, r_1, t_1)}{\sum_{i=1}^n C_i^{\max}} 100\% \quad (1)$$

The RDI values range from 0% to 100% and are interpreted using linguistic descriptors as follows: “absent” corresponds to interval  $<0, 10$ ), “mild” corresponds to  $<10, 40$ ), “moderate” corresponds to  $<40, 70$ ), and “severe” corresponds to  $<70, 100$ .

The efficiency of therapy is measured using the *Therapy Effectiveness Index*, *TEI*. The TEI is based on the RDI assessed during the initial consultation at time  $t_1$ , and the RDI assessed during a later consultation at time  $t_2$ , where  $t_1 < t_2$ , using (2).

$$TEI = \frac{RDI(p_1, r_1, t_1) - RDI(p_1, r_1, t_2)}{RDI(p_1, r_1, t_1)} 100\% \quad (2)$$

The values of the TEI relate to four clinical situations: “no improvement,”  $TEI = 0$ ; “recovery,”  $TEI = 1$ ; “partial improvement,”  $0 < TEI < 1$ ; and “deterioration,”  $TEI < 0$ .

### 5.4 Fuzzy-Semiotic Model for the Treatment Evaluation

From the semiotic perspective, the assessment process involves a representation and an interpretation of the assessment outcomes. The outcomes of the assessment are interpreted with reference to specific patients, raters (clinicians), and specific timing. Thus, we conceptually model the assessment process as a tuple shown in (3).

$$\text{Assessment} = \langle P, R, \{(O, V)\}_{i=1}^n, T \rangle \quad (3)$$

Where  $P$  represents a finite set of references to the patients,  $R$  represents a finite set of references to the raters,  $O$  represents a finite set of outcomes,  $V$  represents a finite set of values for the outcomes, and  $T$  represents a finite set of time points. The outcomes,  $O$ , consist of the criteria,  $C$ , and the measurements,  $M$ . The measurements can be *quantitative* and *qualitative*.

The quantitative measurements are absolute scores (calculated as the sum of all items from a diagnostic scale) and relative scores or indexes (calculated as a ratio between the patient’s score and the possible maximum score value). For example, the relative intensity of depression, the RDI (shown earlier in Fig. 2) is 60 %.

The qualitative measurements are linguistic descriptions such as “symptoms do not meet criteria for any depressive episode,” “mild,” “moderate,” and “severe.” Additionally, the linguistic descriptions may include a phrase concerning somatic and psychotic symptoms. Thus, a qualitative

outcome may be specified, for example as “severe with exclusion of psychotic symptoms.”

Using our framework, an assessment of patient,  $p_1$ , by a clinician,  $r_1$ , at time,  $t_1$ , with outcomes  $o_1$  and  $o_2$  is represented as  $(p_1, r_1, (o_1, 60) (o_2, \text{“moderate”}), t_1)$ .

We present the fuzzy-logic aspect of the framework based on the standardized rating guidelines for the administration of the HRDS, GRID-HAMD-17 [8]. The GRID-HAMD-17 overcomes several shortfalls in the original HRDS, particularly, the high level of imprecision in measures of frequency and intensity. The GRID-HAMD-17 provides specific instructions for the evaluation of the *frequency* and *intensity* for the 12 items and *intensity* only for 5 items (frequency is not applicable for these items). The frequency is represented by four linguistic terms: “absent or clinically insignificant,” “occasional,” “much of the time,” and “almost all of the time.” The GRID-HAMD-17 guidelines specify the mapping between the linguistic terms and the frequency of symptoms measured in days/week. The mapping is defined as follows: “absent” = not occurring, “occasional” = less than 3 day/week, “much of the time” = 3–5 days/week, “almost all the time” = 6–7 days/week. The same definition of frequency is used for all applicable items. The intensity is represented by five linguistic terms: “absent,” “mild,” “moderate,” “severe,” and “very severe.” The terms have specific qualitative mappings for each item.

We present the fuzzy-logic approach, using an example of the first item on the GRID-HAMD-17, “depressed moods.” We have constructed two linguistic variables: *Frequency* and *Intensity of Depressed Moods*. The variable *Frequency* has four terms: *absent*, *occasional*, *much of the time*, *almost all the time*. The membership functions, MFs, for the symptom frequency are shown in Fig. 3. They have been created based on the frequency measured by days per week.

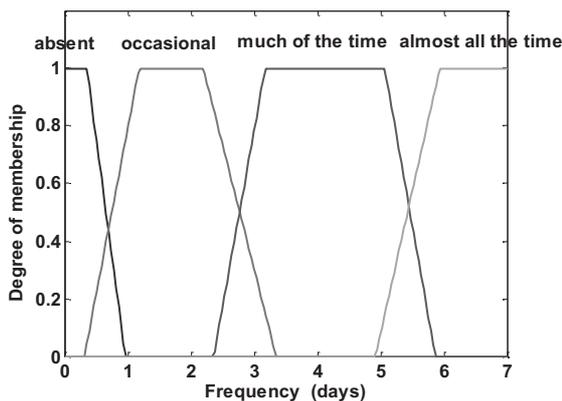


Figure 3: MFs for the frequency of a symptom.

The MFs for the intensity of a depressed mood are shown in Fig. 4. The MFs are based on a continuous scale from 0 to 1, which corresponds to the clinician’s rates on a discrete scale from 0 to 1 with an increment of 0.1. The intensity of the symptom is rated by the clinician based on the GRID-HAMD-17 specification. For example, the depressed mood with a “severe” intensity is described as “intense sadness; hopelessness about most aspects of life, feeling of complete helplessness or worthlessness.”

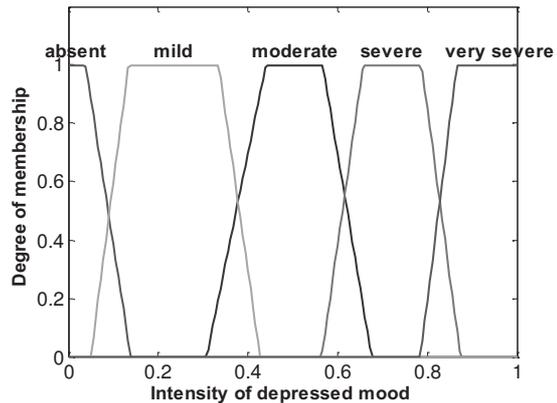


Figure 4: MFs for the depressed mood intensity.

## 6 Modeling the assessment of depression in the context of screening

In this section, we describe the screening process using the Beck Depression Inventory (BDI). The BDI was originally developed by Beck in 1961 [9], and since then, it has been used to measure the intensity of depression in psychiatric patients, to screen for depression in family practice, and to screen for depression in research studies. BDI has 21 items evaluating 21 symptoms of depression. Each item is rated on a four-point intensity scale (0 to 3). The currently used BDI version refers to the last 7 days and is typically self-administered [10]. The scores are added together and given a total score between 0 and 63. The common guidelines for the interpretation of scores specify that scores less than 10 indicate “absent” depression, 10 to 18 indicate “mild to moderate”, 19 to 29 indicate “moderate to severe,” and scores of 30 and above indicate “severe” depression.

Using our framework, an assessment of patient,  $p_1$ , by self-reporting,  $r_1 = p_1$  at time,  $t_1$ , with outcomes  $o_1$  and  $o_2$  is represented as  $(p_1, r_1, (o_1, 35) (o_2, \text{“severe”}), t_1)$ . Using the fuzzy-logic approach, we have constructed a linguistic variable *Severity of Depression* with four terms: absent, mild, moderate, and severe. The MFs for the severity of depression are shown in Fig. 5.

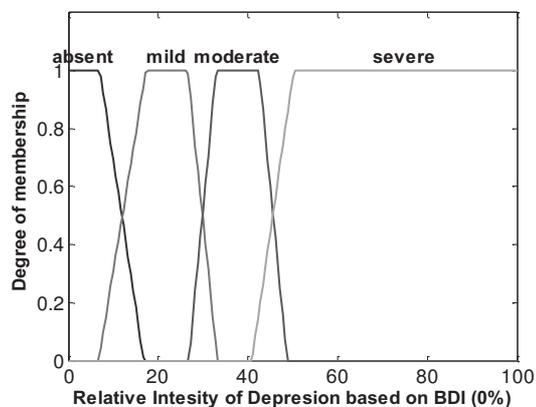


Figure 5: MFs for the severity of depression based on BDI.

We have observed that the assessment of depression is highly contextual and depends on (1) the conceptual basis of the measures, (2) the use of specific guidelines or approaches to the measuring instruments, and (3) the interpretation of the

outcomes. To demonstrate the inherent imprecision of interpretation, we have compared the guidelines for the RDC for ICD-10 (described in Section 5), HAMD-17, and BDI. We have converted the HAMD-17 scale and BDI to indexes, by dividing the HAMD-17 score by its maximum score of 52, and dividing the BDI score by its maximum score of 63. Table 1 shows the mappings between qualitative descriptors and corresponding ranges of scores for the RDC-based evaluation, HAMD-17, and BDI. We have assumed that the scales are interval measurements, and they measure intensity of similar conceptual constructs of depression. Interestingly, we have noticed that the patient  $p_1$ , scoring 60% = “moderate” on RDI, will be classified as “severe” on HAMD-17 and BDI.

Table 1: Depression severity for three assessment measures.

Severity	RDC ICD-10( %)	Indexed HAMD-17 %	Indexed BDI (%)
Absent	< 10	< 14	< 16
Mild	10 -39.9	14 – 33.9	16 – 29.9
Moderate	40 -69.9	34 – 46.9	30 – 46.9
Severe	> 69.99	> 46.9	> 46.9

## 7 Conclusions

In this paper, we have examined three essential characteristics of imprecision: (1) qualitative and quantitative aspects, (2) contextual and interpretative nature, and (3) graduality of imprecision. We have demonstrated that imprecision is an intrinsic part of the assessment of such a complex syndrome as depression. Furthermore, we have presented a fuzzy-semiotic framework for the explicit representation of qualitative, quantitative, contextual, and interpretative aspects of imprecision. We have used a semiotic approach to represent the concept of depression, its symptomatic representations, and the clinical utilization of the measures. Furthermore, we have applied a fuzzy-logic approach to explicitly represent the imprecision of various measures.

We are planning to expand and further formalize the proposed framework and to build a comprehensive data model for the medical concept of “depression” and its assessment in treatment evaluation and screening. We will apply this model in a clinical decision support system for the diagnosis and treatment of depression, as well as in a support system for the treatment of sleep disorders.

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