The Prototype Resemblance Theory of Disease

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In a previous paper the concept of disease was fuzzy-logically analyzed and a sketch was given of a prototype resemblance theory of disease (Sadegh-Zadeh (2000). J. Med. Philos., 25:605–38). This theory is outlined in the present paper. It demonstrates what it means to say that the concept of disease is a nonclassical one and, therefore, not amenable to traditional methods of inquiry. The theory undertakes a reconstruction of disease as a category that in contradistinction to traditional views is not based on a set of common features of its members, that is individual diseases, but on a few best examples of the category, called its prototypes, and a similarity relationship such that a human condition is considered a disease if it resembles a prototype. It enables new approaches to resolving many of the stubborn problems associated with the concept of disease.

Keywords: classical concepts, concept of disease, family resemblance, nonclassical concepts, prototype resemblance, the prototype resemblance theory of disease

I. INTRODUCTION

As was argued in a previous paper, the philosophy of disease has reached an impasse and does not progress any more (Sadegh-Zadeh, 2000, 606). This unsatisfactory situation may mainly be attributed to the failure to recognize that there are two types of concepts, classical and nonclassical ones, and that the concept of disease is not a classical one as is traditionally believed, but a nonclassical one and, therefore, requires another approach than is usually taken. In what follows the difference between these two types of concepts is outlined to suggest an adequate method of dealing with the concept of disease.

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To begin with, we will briefly explain why disease should not be considered an opposite of health. We will then carefully distinguish between a class and its members, that is between *disease* as a general category, on the one hand, and *individual diseases* such as measles, myocardial infarction, and pneumonia as its subcategories or members, on the other. These examples demonstrate that the concept of disease does not denote the individual diseases. Its referent is the general category, disease. It will be reconstructed as a nonclassical concept and explicated by *the prototype resemblance theory of disease*. Our theory promises to lead the philosophy of disease out of its impasse and to stimulate innovative inquiry. Throughout the discussion, the term "category" is used as a synonym of the terms "class" and "set." Since usually the latter two terms are employed in formal contexts, for example "the set of prime numbers" in mathematics, we will refer to real-world classes as categories. Examples are the category of birds, the category of diabetics, the category of Gothic cathedrals, and the category of diseases.¹

II. DISEASE IS NOT IDENTICAL WITH NONHEALTH

Usually health and disease are construed as conceptual opposites in that it is said, for example, that health is the absence of disease. We will explain in the sequel why this traditional view is a semantic naivety. Deviating from this traditional view, it has been argued that the opposite of health, that is "unhealth," is not disease, but malady (Clouser, Culver, and Gert, 1997; Sadegh-Zadeh, 1982, 2000; Gert, Culver, and Clouser, 2006). Malady is a broader category than disease. It comprises, besides disease as one of its subcategories, also many others such as injury, wound, lesion, defect, deformity, disorder, disability, and the like. An individual need not necessarily have a disease to lack health. Disciplines such as trauma surgery and reconstructive orthopedics demonstrate that a malady different than disease (e.g., an injury or deformity) will suffice to impair an individual's health and render her in need of medical assistance and care. Based on these considerations, we may metalinguistically state that the antonym of the term "health" is the term "malady" and not the term "disease." Every disease is a malady, but not vice versa.

Although a nondisease term denoting a malady (e.g., "injury") may be explicated plainly, the question of "what is disease?" presents recalcitrant problems both to medicine and its philosophy. As a result, there is as yet no generally accepted concept of disease. Rather, almost every physician and every philosopher of medicine takes her private stance on what disease might be. This overabundance of positions reflects a semantic chaos that prevents any advance in the philosophy of disease. The aim of the present paper is to explain how this unsatisfactory situation could arise and to suggest remedial measures. To this end a few preliminary notes are in order.

III. DISEASE, DISEASES, AND THE INDIVIDUAL PATIENT'S DISEASE STATE

Besides the above-mentioned antonym issue regarding health and disease, there are also additional disruptive semantic factors that ought to be eliminated from the philosophy of disease. They include the following two basic misunderstandings, which will be identified in this section: (1) the confusion of (a) disease as a general category with (b) individual diseases and (2) the confusion of a patient's disease state with a or b.

Disease Versus Diseases

All of us are familiar with clinical terms such as "pulmonary tuberculosis," "myocardial infarction," "gastric ulcer," "diabetes mellitus," "AIDS," and the like. What they denote are called individual diseases, clinical entities, disease entities, or nosological entities, that is *diseases* in the plural. We are told that currently the approximate number of these individual diseases amounts to 50,000. To establish a clear terminology, we will call any such phrase that denotes any of the 50,000 individual diseases (e.g., pulmonary tuberculosis and myocardial infarction) a *nosological predicate* (the Greek term "nosos" means "disease" and "illness"). By using a nosological predicate in a statement like "Alvin has pulmonary tuberculosis" an individual disease is predicated, that is ascribed to a person.

The essence of what has just been said is that there are currently about 50,000 nosological predicates in medical language. There is no doubt that a nosological predicate is clearly definable by a set of necessary and sufficient features (e.g., "someone has pulmonary tuberculosis if and only if she has pneumonia caused by Koch's bacillus"). This definition defines what pulmonary tuberculosis is. It does not define *what disease is*. None of the 50,000 nosological predicates defines the term disease. Disease is the general category that comprises all these 50,000 individual diseases and is thus, as a class, something different from each one of its 50,000 members. An analogy may help to realize the difference. The general category of birds as a class is not identical with particular bird species such as robin, sparrow, crow, ostrich, and so on. We must therefore not confuse a category with its members. Disease is the category. Individual diseases, or diseases for short, are its members.

A nosological predicate denotes an individual disease, while disease as a general category is the denotation of the *concept of disease*. That is, we must distinguish clearly between the concept of disease and nosological predicates such as pulmonary tuberculosis and myocardial infarction (Sadegh-Zadeh, 1977). A nosological predicate is not a concept of disease. It is the proper name of an individual disease. Thus, there are fundamental semantic differences between these two types of notions, that is between what they denote. Due to this difference they require distinct methods of inquiry. In other words, we must distinguish between disease as a general category, on the one hand, and 50,000 individual diseases such as pulmonary tuberculosis and myocardial infarction as its subcategories or members, on the other. The confusion of these two different levels, a typical category mistake, is a main source of misunderstandings and errors in the philosophy of disease. What we will be concerned with in the sequel is the general category *disease* denoted by the concept of disease.

The Patient's Disease State Versus Disease

We must in addition be aware that the disease state of a patient is something different from both an individual disease and the general category. To this end we will introduce a differentiation between token disease and type disease.

A *token disease* is simply the spatiotemporally localized disease state of a patient, that is "the disease of this patient" as a manifestation of an individual disease such as diabetes mellitus or pulmonary tuberculosis in a person. For example, if the patient Alvin has diabetes mellitus, then his disease state, which may be described by a singular statement such as "Alvin has hyper-glycemia and glucosuria and polydipsia" and categorized by the diagnosis "Alvin has diabetes," is a token disease. The class, or the category, of *all* patients whose disease state is described by the same nosological predicate "N," for example "has diabetes" in the present example, represents *the type disease N*, that is diabetes in the present case. Thus, token disease pertains to an individual, whereas type disease is a category. Expressed in Scholastic terminology, token disease is a particular, type disease is a universal.

The distinction above is of paramount importance in debates about whether disease is something value laden or value neutral because more often than not both parties of the debate are victims of a confusion. The question of whether the categorization of something as a disease is a value judgment or not does not concern the token disease, but the type disease. No doctor diagnoses an individual patient as being in a particular disease state, say diabetes, on the basis of a value judgment. By contrast, it is a legitimate question to ask if the decision to categorize a particular cluster of features in the class of human beings, say {blue-eyed, thin-lipped, long-eared}, as a type disease is based on a value judgment or not. The confusion of token disease with type disease, and its negative consequences, may be easily avoided by distinguishing between nosology and diagnostics (Sadegh-Zadeh, 1977).²

Nosology, derived from the Greek term "nosos" meaning "illness" and "disease", is the clinical inquiry into illness and disease in the human population. As a basic clinical science nosology is not a domain-confined specialty such as cardiology or orthopedics, but a transdisciplinary and, regrettably, undisciplined scientific endeavor undertaken in all clinical fields. It is concerned with the *class* of suffering individuals (i.e., with all patients) to gather knowledge on the nature of their suffering and to establish disease categories such as diabetes, pulmonary tuberculosis, AIDS, coronary heart disease, etc. These, then, are usually referred to as disease entities, clinical entities, nosological entities, individual diseases, and the like and are grouped in a *nosological system* as "infectious diseases," "genetic diseases," "autoimmune diseases," and so on. By contrast, diagnostics is concerned with an individual patient or a family to identify the nature of their suffering on the basis of an antecedently available nosological system and vocabulary.

Thus, nosology is concerned with type disease, whereas diagnostics is concerned, among other things, with token disease. What we are doing here is obviously metanosology and not metadiagnostics.

IV. THE RECEIVED THOUGHT STYLE³

We have called the class that contains all diseases the category of diseases or the category *disease*. As mentioned above, currently it contains about 50,000 members. Everyday new ones are added (e.g., alcoholism, computer game addiction, bulimia, dyslexia, etc.) and some other ones are removed (e.g., homosexuality, hysteria, neurasthenia, chlorosis, and drapetomania). The category is thus a dynamic one. How can this *nosological dynamics* be explained and justified? Are there any principles governing it? Without adequate answers to these questions it will not be possible to understand why the category disease includes as its members phenomena such as diabetes, alcoholism, computer game addiction, myocardial infarction, and AIDS and excludes other phenomena such as drapetomania, hysteria, shareholding, tax evasion, dictatorship, militarism, belligerence, and the like.

A nosologist—someone who does nosology—is a powerful ruler because diseases come primarily from nosology, which thereby drives the medicalization machinery of the health care industry. That means that the categorization of a new phenomenon *X* such as diabetes, alcoholism, or computer game addiction as a disease is a nosological act. In performing such an act, a physician or clinical scientist, as a nosologist, institutes in the population of human beings a dichotomy in that she partitions the population into two categories: the category of those who have the new disease, *X*, and the category of those who do not have it.

From the methodological point of view, the nosologist's act comprises two steps. First, she introduces, usually by poor or no definitions, new nosological predicates such as "diabetes," "alcoholism," and "computer game addiction" into the language of medicine. For example, she suggests that "diabetes mellitus is the state of having the features hyperglycemia, glucosuria, and polydipsia," or more generally, "*X* is the state of having the features A, B, and C." Second, she asserts that "*X* is a disease." For instance, "diabetes is a

disease," she says. Now our basic question is the following one: When asserting that the new class *X*, which she has delimited, is a disease, how does or could the nosologist justify this categorization? Could it be that *X* was not a disease and she has erred?

We have a new class X, (e.g., diabetes) on the one hand, and the antecedently available category *disease* already containing 49,999 members, on the other. What is the rationale behind the new, 50,000th categorization statement which says that "X is a disease"? Why does the nosologist not assert that "X is not a disease" instead? Does she have a reason for preferring affirmation to denial? It is exactly at this juncture that medicine's concept of disease, if it were available, could regulate nosological conduct. One would in that case be in a position to examine whether it is true that the new phenomenon X is, according to that concept of disease, a member of the category *disease*. Alas, there is no such concept. Mystique and mysticism are reigning instead. As a result, every medical textbook implicitly or explicitly obeys a local concept of disease. The present author once recorded 14 different such concepts used in 14 medical textbooks (see Sadegh-Zadeh, 1977, 11).

A discipline can hardly be considered a scientific one if it is allegedly concerned with a particular category without having a concept of that category at its disposal to tell us what the category looks like. Medicine thus turns out an arcane endeavor like astrology because it lacks a concept of disease, although it avers to devote itself to the etiology, diagnosis, and therapy of just that category. Because of this apparent conceptual deficiency in medicine's foundations, the question of "what is disease?" constitutes an ongoing subject of debate. A strange characteristic of this debate is the persistent attempt to *define* the term "disease" by searching for a set of "essential features common-to-all diseases," that is common to phenomena such as, for example, diabetes, pulmonary tuberculosis, AIDS, hepatitis, alcoholism, computer game addiction, etc., *that are already contained* in the category of diseases. Thus, one looks at "all diseases" to abstract from them features of the following type that one considers "common-to-all diseases":

A disease is a type of internal state which is either an impairment of normal functional ability or a limitation on functional ability caused by environmental agents (Boorse, 1997, 9).

Surprisingly, it remains unnoticed that this method to abstract features common-to-all diseases is a petitio principii on the grounds that "the diseases," so called, will come into being qua diseases *after* a concept of disease one is seeking has already been defined, but not before. Before one has introduced a concept of tree, there are no such things as "trees." Thus, a concept of disease has to precede, and not to succeed, the inclusion of some phenomena as its individual instances and the exclusion of other phenomena as its noninstances. Instances and noninstances of what? That means that the question of "what is disease?" (what is a tree? what is

a mountain? what is love?) can only be decided prescriptively, not descriptively. Otherwise put, it must be tackled axiomatically, not empirically (Sadegh-Zadeh, 2000, 611). Obviously it would be conceptual nonsense to believe that the demarcation line between tree and bush could be determined by empirical examination of trees and bushes. The same is true of the boundary between disease and nondisease. The concept of disease in medicine is an analog of the concept of right in the theory and practice of jurisdiction. Nobody will be able to find out "what is right?" by inspecting the real-world human behavior or existing laws and legal literature. This is so because it is a normative concept and, as such, it can only prescriptively be established (Sadegh-Zadeh, 1980, 408).

Both the lack of a concept of disease in medicine and the petitio principii mentioned above are due to the impossibility of introducing a concept of disease by using traditional methods of concept formation. The impossibility is concealed by the erroneous thought style to conceive *every* category as being representable by a concept that indicates "essential features common to all of its instances." This deeply entrenched tradition originates from the ancient Greeks, especially Plato and Aristotle. In Plato's dialog *Meno*, written about 380 BC, Socrates asks Meno to tell him "What is virtue?" After some difficulties Meno confronts in answering the question, Socrates teaches him: "And so of the virtues, however many and different they may be, they have all a common nature which makes them virtues; and on this he who would answer the question, 'What is virtue?' would do well to have his eye fixed. Do you understand?" (see *Meno* 71e–75a, especially 72).

Extensive evidence has been provided against this *classical* thought style by the former Berkeley experimental psychologist Eleanor Rosch and others in the last quarter of the 20th century (see Rosch, 1973, 1975, 1978; Smith and Medin, 1981). We will sketch this evidence below to demonstrate why the classical thought style is methodologically untenable. Due to its shortcomings and by allowing for petitio principii, it encourages everybody to propagate her idiosyncratic concept of disease depending on what she personally considers as the "common nature" of all diseases. Thus, it constitutes the source of a semantic chaos that has rendered the philosophy of health and disease an academic palaver preventing any progress.

V. CLASSICAL CONCEPTS

We will distinguish between classical and nonclassical concepts to show that the concept of disease is a nonclassical one and ought to be dealt with accordingly. We may provisionally state that a concept is a classical one à la Plato and Aristotle above if it denotes a category whose members have a number of identical properties, say a common nature. Otherwise, it is said to be a nonclassical one. We will be more precise below. To begin with, it is advisable not to confuse an object with its name. Here the term "object" is a general phrase denoting individual things, classes, relations, etc. When we define something, it is always the name of an object and never the object itself. An object is not defined, it is demarcated, described, characterized, analyzed, and the like. The term "definition" is a metalinguistic one and, as such, it applies to elements of language only.

We will in the following discussion be concerned with categories as our objects. Their names are known as classificatory or qualitative concepts, terms, or predicates. For example, the term "bird" is the name of the category of birds; the term "fruit" is the name of the category of fruits; likewise, the term "disease" is the name of the category of diseases. Thus, it is terms like "bird", "fruit", and "disease" as elements of language that are defined, but not the categories themselves they denote as their referents in "the world out there." By defining its name, a category with the specific boundaries it gets allocated thereby. Having said that, for the sake of convenience one may in an unambiguous context also prefer the elliptic wording "we will now define the category *X*" to the cumbersome formulation, "we will now define the predicate '*X*' that denotes the category *X*."

Let C be a category. Consider now a sentence of the form "x is a C" stating that the object x belongs to that category, for example "figure 1 is a square" (see fig. 1).



In this example, figure 1 is our object *x*, and square is the category to which it belongs. We use this simple example from ordinary life to avoid medical examples because the analysis of the latter ones is too complex and would render our present communication unnecessarily more difficult.

Suppose now that someone points to figure 1 declaring that "figure 1 is a square." When we ask her "how do you know that?" she will try to justify her claim by explaining that the figure has a set of features (or synonymously: properties, attributes, characteristics, criteria, traits) that define just the "nature" or the

"essence" of a square. For instance, she will say "it is a closed figure, it has four straight sides, its sides are equal in length, and it has equal angles." If our query did not pertain to a square, but to something else, for example "why do you categorize diabetes as a disease?," we would get an analogous answer in that she would reply, à la Christopher Boorse (see his definition of the term disease presented above), "because diabetes impairs the normal functional ability, and the impairment of normal functional ability is the essential feature of disease."

As these examples demonstrate, it is customarily assumed that for a category, there are a number of "essential" features defining it. This assumption implies that in order for something such as figure 1 or diabetes to be a member of a particular category C, *it must possess a set of defining features* to meet the nature or essence of C-hood. This is the classical, essentialist view of categories referred to in the previous section. We call this ancient view of reducing a category and concept to a finite number of defining features the view of *reductive definability* of concepts. Accordingly, a category is said to be a *reducible category* if its name is reductively definable, an *irreducible category*, otherwise.

We may now define what we mean by the term "classical concept." The shorthand "iff" stands for the connective "if and only if" throughout.

Definition 1. A concept is said to be:

- 1. a reducible or *classical* one iff it denotes a reducible category, for example the concept of square in the example above and
- 2. an irreducible or *nonclassical* one iff it denotes an irreducible category, for example our concept of disease (see below).

The doctrine of reductive definability has been too plausible and influential throughout history to leave any room for alternative perspectives. Also the concept of disease has shared the faith of all other concepts and has been subjected to this doctrine to be erroneously considered as reductively definable and denoting a reducible category. So, it is supposed that for an entity to be a member of this category, that is *a* disease, it must possess a set of defining features to meet the nature of diseasehood. It is said, for example by Boorse, that it must bear the feature "impairment of normal functional ability or a limitation on functional ability caused by environmental agents" and the like. We will demonstrate below why this essentialist approach is inadequate and unacceptable. To this end, we must take a few preparatory steps.

A reducible category, denoted by a concept C, is a class whose members share $n \ge 1$ common features, say F_1, \ldots, F_n , such that the features are individually necessary and jointly sufficient to define the concept C.⁴ In this way, the category is reduced to the common possession of the features F_1, \ldots, F_n , that is, $F_1 \& \cdots \& F_n$. In our present example, we would obtain the following definition of our concept where x is any object:

x is C iff x is F_1 and ... and x is F_n .

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(1)

For instance, the concept of "square" denoting the category of square objects may be defined by the above-mentioned features "closed figure, four straight sides, sides equal in length, equal angles" in the following fashion:

x is a square iff x is a closed figure and x has four straight sides and x's sides are equal in length and x has equal angles.

The feature set $\mathcal{F} = \{F_1, ..., F_n\}$ with $n \ge 1$ used in the present example is $\mathcal{F} = \{$ closed figure, four straight sides, sides equal in length, equal angles} with n = 4. For a feature F_i from among the feature set $\{F_1, ..., F_n\}$ to be individually necessary, each instance of the category must have it. For a set of features $\{F_1, ..., F_n\}$ to be jointly sufficient, each entity having that feature set must be an instance of the category. Thus, the feature set is a defining one for the concept C.

Apparently this reductive view of concepts is based on a postulate that we will refer to as the *common-to-all* postulate. The view is generally held in medicine, in other disciplines, and in everyday life. It says that for any concept signifying a corresponding category, there are a limited number of defining features *common to all* of its instances. For example, in order for something to be a square it must have the features such and such; in order for something to be a bird it must have the features such and such; likewise, in order for something to be a disease it must have the features such and such; likewise, in order for something to be a bird of view, this position requires that any concept C be defined by a biconditional of the form (1) above that has the structure of an explicit definition. The biconditional (1) is equivalent to the conjunction of the following two conditionals:

If x is C, then x is F₁ and ... and x is F_n.
 If x is F₁ and ... and x is F_n, then x is C.

Sentence 2 expresses the joint sufficiency of the features. Sentence 1 states the individual necessity of the features since it is equivalent to the following set of sentences:

If x is C, then x is F_1 If x is C, then x is F_2 : If x is C, then x is F_n

each of which requires the individual presence of a feature $F_{i'}$ (In a conditional of the form "if α , then β " the antecedent α is said to be sufficient for the consequent β . And the consequent β is said to be necessary for the antecedent α since the conditional is equivalent to its contraposition "if not β , then not α .")

Since Plato and Aristotle it has been believed that all categories are of the reducible type characterized above. Accordingly, in nosology and metanosology one tries to define the concept of disease in a fashion like the notion of a square is defined (i.e., as if there existed a number of features F_1, \ldots, F_n common-to-all diseases such that "something is a disease iff it has the features F_1, \ldots, F_n "). Only from such beliefs can feature-enumerating ambitions emerge like the one cited in section IV above: "A disease is a type of internal state which is either an impairment of normal functional ability, i.e. a reduction of one or more functional abilities below typical efficiency, or a limitation on functional ability caused by environmental agents" (Boorse, 1997, 7f.). As a result, no consensus will ever be reached on the concept of disease in this way since different scholars have different tastes and choose and enumerate different sets of such features. This continuing disagreement and debate may come to an end only by recognizing that the category of diseases is an irreducible one as we will demonstrate in the sequel.

VI. NONCLASSICAL CONCEPTS⁵

In contrast to the traditional view sketched in the previous section, nearly all real-world categories are irreducible ones and, according to our terminology introduced above, all concepts denoting such categories are nonclassical concepts. In most cases, the instances of a real-world category do not possess a set of common features as square figures do. Examples are birds, fruits, vegetables, furniture and, as we will see below, diseases. For example, try to propose a defining set of features that are common-to-all members of the category *bird* embracing such diverse subcategories as robin, sparrow, nightingale, crow, bird of paradise, bird of prey, albatross, ostrich, emu, penguin, etc. You will not succeed because these innumerable bird types do not share a birdhood-establishing feature set such as, for instance, {has-feathers, has-a-beak, flies, chirps, lays-eggs, ...} that would uniformly recur in all of them to define the nature of birdhood. Rather, they are characterized by only *partially overlapping* feature sets such as {A, B, C}, {B, C, D}, {C, D, E}, {D, E, F}, {E, F, G}, and other ones in the following fashion:

Robin	ABC
Crow	BCD
eagle	CDE
ostrich	DEF
penguin	EFG

(2)

Although neighboring bird types in this chain have something in common, two distant ones such as robin and penguin evidently have nothing in common. And most interestingly, there is nothing common to all. All of them are birds nonetheless because due to the adjacent members' *resemblance* with respect to two features, the birdhood of only one member in the chain causes the birdhood of the rest. We may now realize how distorted an image of "the world out there" we have got from the classical thought style to look for features common-to-all entities that we subsume, or want to subsume, under a general label such as "bird," "fruit," "vegetable," "furniture," or "disease." And wherever we fail to identify such common features, we are prone to suppose or even to insist that the entities possess them nevertheless because we are obviously unable to imagine that it could be otherwise.

One will also encounter this frustration in searching for a set of defining features that might be common-to-all instances of the category *disease*. The reason for the failure is simply that there are no diseasehood-establishing properties uniformly recurring in all clinical entities to yield a reductively defined, unobjectionable concept of disease. To put it concisely, there is no such thing as the nature of disease.⁶ For instance, human conditions such as myocardial infarction, acute hearing loss, alopecia areata, and abnormal prognathism are considered diseases, but they have nothing in common that would justify their uniform categorization as diseases, for example no electrocardiogram abnormalities, no enzyme increase or decrease, no infection or inflammation, no swelling or pain, no impairment of functional ability, no sleeplessness, and nothing else.⁷

A category such as bird, fruit, vegetable, furniture, and disease is called an irreducible one if, like (2) above, there is no defining set of necessary and sufficient features common to all of its instances. Thus, an irreducible category does not satisfy the common-to-all postulate of reducible categories. This curious finding does not mean or imply that terms denoting irreducible categories such as bird, fruit, vegetable, furniture, and disease are undefinable, rendering the construction and maintenance of scientific languages impossible. On the contrary, it only disproves the universality of the classical doctrine of reductive definability based on the ancient common-to-all postulate. We have therefore to abandon this doctrine and search for another principle of categorization that works. The solution we are searching for lies in the relationship of *similarity* between the instances of a category that welds them together to constitute the category. We will now sketch this idea to explore if we can use it in our metanosology. For details, see (Sadegh-Zadeh, forthcoming).

VII. RESEMBLANCE STRUCTURES

In the early 20th century, there emerged a discussion on the vagueness of statements and concepts (see Peirce, 1902; Russell, 1923; Black, 1937, 1963), which eventually led to the genesis of many-valued logics in the 1920s, on the one hand, and of fuzzy logic in 1965, on the other (see Post, 1921; Lukasiewicz, 1930; Reichenbach, 1944; Kleene, 1952; Zadeh, 1965). Ludwig Wittgenstein did not publicly participate in this discussion, although he was also concerned with the vagueness of concepts and discovered the limitation

and unsuitability of the reductive common-to-all postulate, posthumously published in his *Philosophical Investigations* (Wittgenstein, 1953). In a context analyzing issues related to language, meaning, reference, and vagueness, he introduced the legendary notion of a *language-game* (Ibid. section 7) that paved the way for a new direction in the philosophy of language. To explain this novel term, he referred to *games* and, by reflecting on their category, he destroyed the time-honored common-to-all postulate thus:

Consider for example the proceedings that we call "games." I mean board-games, card-games, ball-games, Olympic games, and so on. What is common to them all?-Don't say: "There must be something common, or they would not be called 'games'"-but look and see whether there is anything common to all.-For if you look at them you will not see something that is common to all, but similarities, relationships, and a whole series of them at that. To repeat: don't think, but look!-Look for example at board-games, with their multifarious relationships. Now pass to cardgames; here you find many correspondences with the first group, but many common features drop out, and others appear. When we pass next to ball-games, much that is common is retained, but much is lost.—Are they all "amusing"? Compare chess with noughts and crosses. Or is there always winning and losing, or competition between players? Think of patience. In ball-games there is winning and losing; but when a child throws his ball at the wall and catches it again, this feature has disappeared. Look at the parts played by skill and luck; and at the difference between skill in chess and skill in tennis. Think now of games like ring-a-ring-a-roses; here is the element of amusement, but how many other characteristic features have disappeared! And we can go through the many, many other groups of games in the same way; can see how similarities crop up and disappear.

And the result of this examination is: we see a complicated network of similarities overlapping and criss-crossing: sometimes overall similarities, sometimes similarities of detail. (Wittgenstein, 1953, section 66.)

I can think of no better expression to characterize these similarities than "family resemblances;" for the various resemblances between members of a family: build, features, color of eyes, gait, temperament, etc. etc. overlap and criss-cross in the same way.—And I shall say: "games" form a family ... (Wittgenstein, 1953, section 67).

The central idea that Wittgenstein has suggested loosely in the context quoted above is the replacement of the common-to-all postulate by *family resemblance*.⁸ A vast amount of thought has been devoted to this proposal in philosophy and social sciences ever since. However, it remains a mere metaphor yet. Notwithstanding the prominence it has gained in the literature in the meantime, we cannot use it in our metanosology to explain why 50,000 heterogeneous human conditions such as myocardial infarction and alopecia areata are deemed to form, like Wittgenstein's "games," a coherent category called the category of diseases. The reason of our hesitation is that Wittgenstein's conception of family resemblance is philosophically defective. The resemblances between members of a family are causally due to the

members' *origin* from the same germ line, that is gene family. So we may state: "That a and b belong to the same family is the cause of their resemblance." However, Wittgenstein reverses this causal order in that he metaphorically explains the belonging of some members to a *family* by resemblances between them: "That a and b resemble is the cause of their belonging to the same family." That is, Wittgenstein's idea around resemblance as a basis of categorization carries something innovative and interesting, though, we must give up its constituent term "family" to prevent misconceptions. By so doing, we may forge a link between his insights and Eleanor Rosch's aforementioned experimental studies on categorization to construct the concept of a *resemblance structure* that we will use as our basic tool.

A reducible category such as the category of even numbers or square figures is a sharply bound collection of objects all of which to the same extent share, due to their (common to all) uniformity, a number of common-to-all features. For example, there is no even number that is more even or less even than another even number. The number 6 is as even as the number 8124. All even numbers are equally even. By contrast, in an irreducible category, there are no common-to-all features because both regarding their number as well as their intensity the features are unequally distributed over the category members to the effect that some members appear more typical than other ones. In the category of birds, for instance, a robin seems to be a more birdlike, typical bird than a penguin. This was convincingly demonstrated by Eleanor Rosch who in experimental studies asked the subjects to rate on a scale from 1 to 7 the typicality of different kinds of birds. Robins were considered the best examples followed by doves, sparrows, and canaries. Owls, parrots, and toucans occupied a medium position. Ducks and peacocks were considered less good examples. Penguins and ostriches ranked lowest. Similar experiments were carried out for the categories furniture, fruit, and clothing (Rosch, 1975).

In the wake of the evidence reported by Eleanor Rosch and others, a *non-classical theory of concepts* is emerging according to which a concept determines a category not by identifying necessary and sufficient features of its members, but by exhibiting the relational structure of the category that is characterized by best examples, called prototypes, such that other category members resemble them to different extents. In the category of birds, for instance, a robin *has feathers, has a beak, lays eggs, chirps, flies,* and so on. Penguins, however, do not possess all these features. They cannot chirp and fly. They only resemble robins to the extent that they *have feathers, have a beak,* and *lay eggs.* This partial similarity to robins renders them less typical examples of birds than robins are, though, they are considered birds none-theless. Thus, defining features of robins such as *has feathers, has a beak, lays eggs, chirps, flies,* and the like are not necessary conditions for an entity to count as a member of the category.

Related examples are the category of fruits with, for instance, an orange being a more typical fruit than a coconut; the category of vegetables with spinach being a more typical vegetable than melon; and furniture with chair and sofa being more typical instances than picture and radio.

This variance of typicality among the instances of an irreducible category lends to the category an internal structure with a central tendency such that some members are more central to the category than other ones at its periphery, giving rise to gradients of category membership. The most central members, let us call them foci or cores, may be viewed as the category's prototypes.

A member's being a *more-typical-instance-than* another member is obviously a *relational feature*, specifically, a comparative one in the form of "*x* is a C *more than* y is," where C is the category, for example "a sparrow is more birdlike than a penguin." It induces some kind of gradedness of membership in the category. This gradedness is best reconstructed as degrees of feature matching, that is similarity between less prototypical members of the category and its prototypes. Such a category we, therefore, call a *prototype resemblance category*, in contrast to Wittgensteinian defective family resemblances. We will introduce this concept in the sequel to interpret the category of diseases as an instance thereof. For details of the theory, see Sadegh-Zadeh (forthcoming).

VIII. THE PROTOTYPE RESEMBLANCE THEORY OF DISEASE

Is it possible to exploit in nosology the conception above to inquire into the category of diseases? How can we ascertain a difference in the typicality of diseases such that, for example, myocardial infarction may bear a greater diseasehood than alopecia areata, while another phenomenon such as homosexuality may turn out a nondisease? Where do diseases come from? Are they value-free, natural phenomena or are they man-made, value-laden artifacts? We will develop a conceptual framework capable of resolving problems of just this type. A preparatory step we now take in this direction is the construction of the concept of a *prototype resemblance category*. It will be instrumental in demonstrating that diseases are best understood as elements of a category of this kind. Specifically, we will reconstruct the class of diseases as an irreducible category that is constituted by some prototypes to which the remaining members of the category, the diseases, are similar to different extents.

Note that the notions of resemblance and similarity will be considered synonyms, though they will play distinct contextual roles in the following text. The term *resemblance* is preferred for use only in the label "resemblance category." In all other contexts the term *similarity* and its derivatives are used.

What we need is a notion of similarity that will enable us to measure or assess the similarity between a member of a category and its prototype. We will construct this notion by means of the concept of a *fuzzy set*. This auxiliary concept constitutes a basic methodological tool of our study. It may, therefore, be sketched first since it is likely that some readers of the present journal are not acquainted with it.⁹

Fuzzy Sets

For different reasons, medical language is one of the most vague scientific languages. Most of its terms defy precisiation because the objects, classes, and relations that they denote have no sharp boundaries and are thus inherently and irremediably vague. The theory of fuzzy sets is an excellent tool to cope with just this kind of vagueness. In what follows, we will employ some of its elementary notions to construct our prototype resemblance theory of disease.¹⁰

Consider as an example a set of people such as {Alvin, Bert, Carla, Dirk}. It is sharply delimited because any of the four objects Alvin, Bert, Carla, and Dirk completely belongs to it, whereas any other object completely does not belong to it, for example Eliza or 9. However, there are also not sharply delimited, blurred sets such as, say "the set of *young* people" or "the set of *large* numbers." How young must an individual be in order to belong to the first set, and how old in order not to belong to it? How large must a number be in order to belong to the second set, and how small in order not to belong to it? There are no unambiguous answers to these questions. For some objects, it is indeed entirely certain that they belong 100% to such a set or 100% not to such a set. For other objects, however, it is not so unambiguous. They are members of the set only to a certain extent, and thus also nonmembers thereof to a certain extent. A set of this sort which at its edge is not sharply delimited and permits a gray level of quasimembership, we designate as unsharp, or according to its inventor, *fuzzy* (Zadeh, 1965).

A fuzzy set is a collection of objects with grades of membership. In contrast to a classical set, it does not have sharp boundaries between members and nonmembers. For example, suppose Alvin and Bert are two brothers. Alvin is *young* to a particular extent, whereas Bert is young to a lesser extent than his brother. Thus, these two individuals are to different degrees members of the same set of young people. The membership degrees of the set smoothly decrease in the direction of nonmembership. The set of young people is thus fuzzy. There is no dividing line between this set and the set of nonyoung people. Like the set of young people, almost all real-word categories are fuzzy sets lacking sharp boundaries. For instance, each of the following terms denotes a fuzzy set: beautiful woman, tree, bush, big orange, much larger than five, healthy, ill, diseased, has a cough, and has icterus. To conceptualize the intuitive idea of fuzziness above, we will first recall the notion of the *characteristic function* of a classical set. Let Ω be a collection of any objects that we may be talking about in a particular context, for example, the population of diabetics. We will refer to Ω as "the universe of discourse." A universe of discourse, Ω , has always a number of subsets. For instance, if the universe of our discourse is the population of diabetics, we may distinguish several subsets therein such as those patients who have type I diabetes and those with a type II diabetes. For any such subset, A, of Ω there is a function, in the mathematical sense, that indicates those members of Ω which are also members of A, and those members of Ω which are not members of A. This function is, therefore, called the indicator function or *characteristic function* of set A. It assigns to a member of Athe value 1 and to a nonmember of A the value 0. Let this characteristic function of set A be symbolized by " f_A ," then it is defined thus: For every member x of Ω ,

 $f_{A}(x) = \begin{cases} 1 & \text{if } x \text{ is a member of A,} \\ 0 & \text{if } x \text{ is not a member of A.} \end{cases}$

For example, let the universe of our discourse, Ω , be the family {Alvin, Bert, Carla, Dirk}, conveniently represented by {a, b, c, d}. Then the subset of male members of this family is MALE = {a, b, d}. So, for members of Ω we have $f_{male}(a) = 1$, $f_{male}(b) = 1$, $f_{male}(c) = 0$, and $f_{male}(d) = 1$. Thus, the function f_{male} characterizes the set MALE completely. It is the characteristic function of this set in the family $\Omega = \{a, b, c, d\}$.

The characteristic function of a set A, f_A , maps the universe of discourse Ω to the binary set {0, 1}, and thus, it takes only the two values 0 and 1. If we generalize this mapping and allow the function to take any value from 0 to 1, then we will become able to represent a *fuzzy set A* by a generalized characteristic function that maps Ω to unit interval, [0, 1]. Such a generalized characteristic function of a set *A* is called the *membership function* of the fuzzy set *A* and is written μ_A with $\mu_A(x)$ being the degree to which individual *x* is a member of the fuzzy set *A*. For example, suppose that in our universe of discourse above, that is the family {a, b, c, d}, the members of the family are, respectively, 18, 30, 37, and 65 years old. When they are considered to be young to the extents 1, 0.7, 0.3, and 0, respectively, then we can identify in the family the fuzzy set of young members with the following membership degrees:

$\mu_{young}(a) = 1$	i.e.	Alvin is young to the extent 1
$\mu_{young}(b) = 0.7$		Bert is young to the extent 0.7
$\mu_{young}(c) = 0.3$		Carla is young to the extent 0.3
$\mu_{\text{young}}(d) = 0$		Dirk is young to the extent 0.

The function μ_{young} is the membership function of the fuzzy set young in the family {a, b, c, d}. After these intuitive considerations, we may now define what a fuzzy set is. A fuzzy set *A* in, or over, a universe of discourse Ω is a set of $n \ge 1$ pairs of the form $(x, \mu_A(x))$, that is:

$$\mathbf{A} = \{(x_1, \boldsymbol{\mu}_{A}(x_1)), (x_2, \boldsymbol{\mu}_{A}(x_2)), \dots, (x_n, \boldsymbol{\mu}_{A}(x_n))\},\$$

such that x_i in a pair $(x_i, \mu_A(x_i))$ is a member of Ω and $\mu_A(x_i)$ is a real number in the interval [0, 1] denoting x_i 's degree of membership in fuzzy set *A*. For example, the fuzzy set *young* in our example family {a, b, c, d} above is the following set:

YOUNG = $\{(a, 1), (b, 0.7), (c, 0.3), (d, 0)\}$.

In any universe of discourse Ω , there are infinitely many fuzzy sets because the members of the universe can be mapped to unit interval [0, 1] in infinitely different ways. In closing these introductory notes, consider the following two subsets of our example family {a, b, c, d}:

$$MALE = \{a, b, d\}$$

FEMALE = {c}.

These two sets are classical sets with sharp boundaries. On the one hand, the individuals a, b, and d definitely belong to set MALE, whereas c definitely does not belong to it. On the other hand, the individual c definitely belongs to set FEMALE, whereas the other three individuals are definitely excluded. For exactly these reasons, both sets are also fuzzy sets in {a, b, c, d} of the following structure:

These examples demonstrate that every classical set is also a fuzzy set, specifically, a limiting fuzzy set with membership degrees from the twovalued set {0, 1} only. The concept of fuzzy set with values from [0, 1] is thus the more general one and includes the classical case. For more details on fuzzy set theory, see Dubois and Prade (1980); Klir and Yuan (1995); Ruspini, Bonissone, and Pedrycz (1998).

Human Conditions

The concept of fuzzy set briefly introduced above will be used as a tool to reconstruct both the notion of disease and the notion of similarity that we need in comparing individual diseases with one another. In the present section we will prepare the conceptual basis of the former task.

Our aim is to clarify the term "disease" and to develop a precise concept. We have, therefore, to forget the disease paradigm that we currently entertain and to suppose we are ignorant of anything about it. As a first axiom, we decide that the potential domain of application of the term "disease" should not consist of objects such as bookshelves, cars, planets, or ants, but of complex *human conditions* such as heart attack, stroke, breast cancer, love, believing, happiness, tax evasion, and many other possible and impossible things insofar as they are human conditions. Thus, the general term we will use before we have a concept of disease is the phrase "human condition." We will construct this concept in the sequel to delimit the category of human conditions. Later on the term disease will be ostensively interpreted over this general universe of our discourse to constitute a subcategory thereof.

A human condition such as heart attack, love, or happiness is *a set* of $n \ge 1$ states in which a human being may be at a particular instant of time. A simple example is provided by the following set of statements about Alvin: {Alvin is young, Alvin has blond hair, Alvin is a Catholic, Alvin is happy, Alvin has headache, Alvin has fever, Alvin coughs, ... etc. ...}. To simplify the handling of such data that may soon become unwieldy, we represent a human condition not as a set of statements, but as a *set of features* that those statements ascribe to an individual. Our last example now presents itself as the following set of features:

{young, blond hair, Catholic, happy, headache, fever, cough, ... etc. ...}

that the patient Alvin has. This example demonstrates that human conditions are not, and should not, be confined to biological or biomedical states of the organism. They may be conceived as entities that also refer to subjective, religious, moral, transcendental, and social worlds of a *person* such as, for example, intelligence, love, pain, distress, feelings of loneliness, beliefs, desires, behavioral disorders, etc. By assigning names to human conditions, it becomes possible to identify them by using their names such as, for example:

heart attack = {chest pain, elevated CPK concentration, tachycardia, ... etc. ...}, measles = {rash, Koplik's spots, cough, fever, ... etc. ...}, gastric ulcer = {epigastric pain, anorexia, vomiting, ... etc. ...}, alopecia areata = {hair loss on the scalp, ... etc. ...}, being in love = {happy, sleepless nights, longing for the lover, ... etc. ...}.

For instance, the term "heart attack" above denotes a human condition that consists of the features chest pain, elevated concentration in blood of creatinphosphokinase enzyme, tachycardia, etc. In our pursuit of a concept of disease, it would be useful to be able to compare such human conditions with one another and to examine the similarity and dissimilarity between them. This requires a powerful concept of similarity. We will introduce such a concept below. To this end, we will conceive human conditions as partial manifestations of an antecedently available, that is standardized and agreed-upon, global *feature space* \mathcal{F} such as, for example:

 \mathcal{F} = {chest pain, elevated CPK concentration, tachycardia, vomiting, anorexia, epigastric pain, rash, Koplik's spots, cough, fever, increased white blood count, bodily lesion, distress, discomfort, incapacity, dependency, premature death, dyspepsia, coma, bradycardia, elevated LDH, delusion, fear ... etc. ...}.

For simplicity's sake let us symbolize this global feature space, \mathcal{F} , in the following fashion:

 $\mathcal{F} = \{F_1, F_2, F_3, \dots, F_n\},\$

where each F_i is a feature such as chest pain, elevated CPK, tachycardia, and the like. We can now represent a human condition H such as heart attack, measles, gastric ulcer, and so on as a fuzzy set over the feature space \mathcal{F} in the following way. A feature F_i from feature set \mathcal{F} that is present in H is written (F_i , 1), whereas a feature F_j that is not present in H is written (F_j , 0), for example:

heart attack = { $(F_1, 1), (F_2, 1), (F_3, 1), ..., (F_p, 0), (F_p, 0), (F_k, 0), ... \text{ etc. ...}$, measles = { $(F_1, 0), (F_2, 0), (F_3, 0), ..., (F_p, 1), (F_p, 1), (F_k, 1), ... \text{ etc. ...}$,

more specifically:

heart attack = {(chest pain, 1), (elevated CPK, 1), ..., (rash, 0), (Koplik's spots, 0), ..., etc. ...}, measles = {(chest pain, 0), (elevated CPK, 0), ..., (rash, 1), (Koplik's spots, 1), ..., etc. ...}.

In these fuzzy sets, a value such as 1 and 0 is the degree of membership of the respective feature F_i and indicates its presence or absence in the respective human condition. In a real-world human condition, however, a feature may not be definitely present or absent, but present to a particular extent different than 1 and 0. For example, someone may have:

{mild chest pain, highly elevated CPK, severe tachycardia, ...},

whereas someone else has:

{severe chest pain, slightly elevated CPK, moderate tachycardia, ...},

and still another person has:

{very severe chest pain, slightly elevated CPK, mild tachycardia, ...}.

We may therefore generalize the above-mentioned fuzziness of a human condition H thus:

$$H = \{(F_1, \mu_H(F_1)), (F_2, \mu_H(F_2)), \dots, (F_n, \mu_H(F_n))\},$$
(3)

where an F_i is a feature such as chest pain, elevated CPK, etc., and $\mu_H(F_i)$ is a real number in the unit interval [0, 1] indicating the degree of its membership in the human condition H. The heart attack of a particular patient may be described, for example, by the fuzzy set {(chest pain, 0.6), (elevated CPK, 0.9), (tachycardia, 1), (vomiting, 0), ... etc. ...}.

A human condition of the type (3) is a fuzzified human condition or a *fuzzy human condition* for short. It says that feature F_1 is present to the extent $\mu_H(F_1)$, feature F_2 is present to the extent $\mu_H(F_2)$ and \cdots and feature F_n is present to the extent $\mu_H(F_2)$. Note that these numbers do not represent measurement results such as measured intensity, concentration, frequency, height, temperature, or other quantities. They are fuzzy set membership degrees representing the extent to which a respective feature such as chest pain is a member of the set. The important question as to the origin of such feature weights may be answered right now to prevent misunderstandings.

A fuzzy set membership degree in general and in fuzzy human conditions in particular may be provided by a personal assessment as it is usual in psychology and quality of life and quality of health care research, by a measurement on the scale [0, 1], or by the transformation of a measurement result to unit interval [0, 1] if the measurement scale is a different one. It is worth noting that the unit interval [0, 1] used as the range of membership degrees in fuzzy sets is not an odd contraption. The interval [0, 1] provides a universally applicable numerical reference space since all kinds of assessment and measurement scales can easily be transformed to this space. For a detailed and precise reconstruction of fuzzy human conditions, see Sadegh-Zadeh (forthcoming).

Similarity

Based on the concept sketched in the previous section, we will construe individual diseases as particular fuzzy human conditions to show that they constitute an irreducible category and will compare them with one another to analyze similarities and dissimilarities between them. To this end, a concept of similarity is briefly introduced in the present section. For details and formal properties of the concept, see Sadegh-Zadeh (forthcoming).

Similarity will be conceived as a relation between two fuzzy sets, *A* and *B*, of the syntax "fuzzy set *A* is similar to fuzzy set *B* to the extent r" symbolized by simil(A, B) = r. The concept we will introduce will enable us to measure, for example, how similar the following two fuzzy sets are:

{(chest pain, 0.6), (elevated CPK, 0.9)}, {(chest pain, 0.7), (elevated CPK, 0.4)}.

An inverse semantic relationship ties the terms "different" and "similar." It says that the less different two objects, the more similar they are and vice versa. This implies that the less different two fuzzy sets, the more similar they are. In complete accord with this precept, we will construct our fuzzy set similarity relation as the inverse of fuzzy set difference. So let us first introduce a notion of *fuzzy set difference* as our basic term.

The difference between two fuzzy sets, *A* and *B*, will be defined as a relation of the form "fuzzy set *A* differs from fuzzy set *B* to the extent r" symbolized by diff(*A*, *B*) = r. The value r is a real number in the unit interval [0, 1]. To define the basic notion diff(*A*, *B*), we need the following two auxiliary notions that will be introduced in turn: "the greater one of two numbers a and b," and "the absolute value of a real number."

Of two numbers a and b, the greater one is called max(a, b) and the lesser one is called min(a, b). These two functions, max and min, that we will use below as auxiliary notions are defined as follows:

 $max(a, b) = a, \text{ if } a \ge b$ = b, otherwise $min(a, b) = a, \text{ if } b \ge a$ = b, otherwise.

For example, max(5, 3) = 5 and min(5, 3) = 3. Sometimes we need the *absolute value* of a real number *r*, denoted by |r|. The absolute value |r| of a real number *r* is its size without regard to its sign. Thus, it is defined as follows:

If r is a real number, then
$$|r| = \begin{cases} r, & \text{if } r \ge 0, \\ -r & \text{if } r < 0. \end{cases}$$

Consider the real number r = 5 as an example. We have |5| = 5. And if r = -5, then we have |-5| = -(-5) = 5, too. Thus, |5| = |-5| = 5. Let Ω be a universe of discourse and let *A* and *B* be two fuzzy sets in Ω such that:

$$A = \{(x_1, a_1), \dots, (x_n, a_n)\},\$$

$$B = \{(x_1, b_1), \dots, (x_n, b_n)\},\$$
(4)

where an a_i is the degree of membership of x_i in set A, and a b_i is the degree of membership of the same object x_i in set B. The difference between these two fuzzy sets is defined as follows (the formal presentation of the definition is overly simplified. For details, see Sadegh-Zadeh, forthcoming):

Definition 2. If A and B are two fuzzy sets of the form (4) above, then diff(A, B) = $|a_1 - b_1| + ... + |a_n - b_n| / \max(a_1, b_1) + ... + \max(a_n, b_n)$.

For example, if our fuzzy sets are:

 $X = \{(x, 0.6), (y, 0.9)\},\$ $Y = \{(x, 0.7), (y, 0.4)\},\$ then we have: diff(X, Y) = (|0.6. - 0.7| + |0.9 - 0.4|) / (0.7 + 0.9) = 0.6 / 1.6= 0.375. This calculation shows that set *X* differs from set *Y* to the extent 0.375. After these preparatory remarks, we now introduce fuzzy *similarity* as the additive inverse of fuzzy set difference in the following way:

Definition 3. simil(A, B) = 1 - diff(A, B).

For instance, our two example fuzzy sets *X* and *Y* above with the difference 0.375 between them are *similar* to the extent 1 - 0.375 = 0.625. A very convenient method of computing similarities we will use below is provided by the following interesting Similarity Theorem that follows from Definition 3. For details, see (Lin, 1997; Sadegh-Zadeh, forthcoming):

Similarity Theorem. simil(*A*, *B*) = min(a_1 , b_1) +...+ min(a_n , b_n)/max(a_1 , b_1) +...+ max(a_n , b_n).

Regarding our two example fuzzy sets *X* and *Y* above, we have according to this theorem:

simil(X, Y) = 0.6 + 0.4 / 0.7 + 0.9 = 0.625.

Similarity as defined above is a relationship between fuzzy sets. According to Definition 3, its extent is a real number in the unit interval [0, 1]. The concept introduced is applicable to fuzzy human conditions and, consequently, to diseases that we will now reconstruct as a subcategory of the category of fuzzy human conditions.

The Category of Diseases

It has already been noted above that the current nosological system of medicine allegedly comprises about 50,000 individual diseases. Examples are myocardial infarction, gastric ulcer, breast cancer, alopecia areata, alcoholism, schizophrenia, etc. A fundamental problem of metanosology not perceived in medicine is the question *wby* these human conditions are categorized as diseases and other ones are excluded, for example menstruation, pregnancy, tax evasion, smoking, torture, terrorism, and so on. (We do not mean that the latter examples are or have to be categorized as diseases. We only ask why they are *not* categorized as diseases.)

What is called a disease in medicine is representable as a fuzzy human condition of the form H = { $(F_1, \mu_H(F_1)), (F_2, \mu_H(F_2)), ..., (F_n, \mu_H(F_n))$ }. Each F_i therein is a feature from the feature space $\mathcal{F} = \{F_1, F_2, F_3, ..., F_n\}$ mentioned in "Human Conditions" above. It may be a symptom, complaint, problem, sign, or finding; $\mu_H(F_i)$ is the degree of its membership in H. Formal examples are:

 $\begin{array}{l} \text{myocardial infarction} = \{(F_1, 1), (F_2, 0.7), (F_3, 0.9), \dots, (F_p, 0), (F_p, 0), \\ (F_k, 0), \dots \text{ etc. } \dots \}, \\ \text{gastric ulcer} = \{(F_1, 0), (F_2, 0), (F_3, 0), \dots, (F_p, 0.8), (F_p, 0.7), (F_k, 1), \dots \text{ etc.} \\ \dots \}, \end{array}$

alopecia areata = { $(F_1, 0), (F_2, 0), (F_3, 0), ..., (F_p, 0), (F_p, 0), (F_k, 0.2), ...$ etc. ...}

For instance, myocardial infarction may be something like the following fuzzy set:

{(chest pain, 1), (elevated CPK, 0.7), (tachycardia, 0.9), (vomiting, 0.2), \dots etc. \dots }.¹¹

These examples demonstrate that the so-called diseases, reconstructed as fuzzy human conditions, are too different from one another to share commonto-all features that could provide *necessary and sufficient conditions* of their diseasehood. For this reason, the nosological class that comprises such fuzzy human conditions as diseases cannot be based on, and represented by, a classical, reductively definable concept of disease. Despite the long history of medicine, it has not yet been possible to suggest such a concept, and scholars are still debating about it in vain. Due to the lack of common-to-all features of diseasehood, the question arises how the irreducible category of diseases is constituted to house completely different individual diseases as its members nonetheless.

On the one hand, there is no doubt that a number of so-called diseases are myths and conceptual illusions, for example drapetomania and hysteria. On the other hand, there are human conditions such as heart attack, breast cancer, epilepsy, and many others that have been known throughout the history of medicine and are encountered in all human societies today. What is usually meant by "diseases" are *such real-world phenomena and similar ones* even though the belief in their existence depends on perspectives, for example conceptual and epistemic systems that one holds. Although all these human conditions are different from one another and lack any common-to-all features, they are placed, within the large category of human conditions, in the same subcategory labeled diseases. Our question above asks how this categorization may be understood and justified. The answer to this question we suggest is *the prototype resemblance theory of disease* that now follows.

We assume that there are a few human conditions such as heart attack, breast cancer, stroke, epilepsy, pneumonia, measles, smallpox, schizophrenia, and the like, which have existed for a long time, probably since the dawn of mankind. For reasons that we will discuss in the next section, each of these few human conditions is *christened* a disease by the society and is handled as a prototype disease. This act of naming is an ostensive definition of the term "disease". Any human condition that bears sufficient similarity to such a prototype disease is also considered a disease. Thus, the category of diseases in a society is grounded on two factors: (1) existence of one or more human conditions each of which is *named* a disease and viewed as a prototype disease and (2) sufficient similarity of some other human conditions to a prototype disease. This idea may be cast in the following concept of disease.

Definition 4. Let $\{D_1, ..., D_n\}$ be a small set of $n \ge 1$ fuzzy human conditions such as {heart attack, breast cancer, stroke, epilepsy, pneumonia, measles, smallpox, ..., schizophrenia} each of which in a particular human society is named a disease. Then in this society:

- 1. Any element of the set $\{D_1, ..., D_n\}$ is a disease, referred to as a prototype or core disease.
- 2. A fuzzy human condition *X* is a disease if there is a disease D_i in $\{D_1, ..., D_n\}$ and an $\varepsilon > 0$ chosen by the society such that simil(*X*, D_i) $\ge \varepsilon$.

Note that this concept of disease is a nonclassical one because it does not reduce diseasehood to a set of common-to-all features. It only requires that there be at least one prototype human condition named disease by the society and that a human condition be similar to such a prototype disease to a particular extent in order to count as a disease, too. Suppose, for instance, that in a particular society the following simplified fuzzy human condition is a prototype disease:

heart attack = { $(F_1, 1), (F_2, 0.7), (F_3, 0.9)$ }.

The minimum degree of similarity to this prototype disease that a human condition is required to bear in order to be categorized as a disease may be $\varepsilon = 0.5$. The degree of similarity between the following human condition:

gastric ulcer = { $(F_1, 0.8), (F_2, 0.7), (F_3, 0.2)$ }

and heart attack above is 0.653. This is easily computed after the Similarity Theorem mentioned in the last section thus:

simil(gastric ulcer, heart attack) = 0.8 + 0.7 + 0.2/1 + 0.7 + 0.9 = 1.7/2.6 = 0.653.

Since 0.653 > 0.5, the human condition *gastric ulcer* above is considered a disease. By contrast, the following human condition:

pregnancy = { $(F_1, 0.1), (F_2, 0.2), (F_3, 0.4)$ }

cannot be considered a disease because it is similar to the prototype disease heart attack above only to the extent 0.153.

Due to the definite similarity degree ε required in Definition 4 above, the category of diseases emerging from this concept has sharp boundaries and is thus a classical set with all-or-none property. That is, a human condition either is a disease or it is none. However, this concept does not seem to reflect real-world health care where the diseasehood of a human condition is considered to be something gradual, for example very severe, severe, moderate, mild, or very mild. A human condition is not medically treated because it is a

disease, but because it is a disease to a particular extent that is no longer tolerable (see Sadegh-Zadeh, 2000, 629). This characteristic of nosology and clinical practice is taken into account by the following construct that yields a fuzzy category of diseases such that a human condition may be considered a disease to a particular extent. For example, it may turn out that according to such a concept, "myocardial infarction is a disease to the extent 1," whereas "alcoholism is a disease to the extent 0.5" and "alopecia areata is a disease to the extent 0.1." The next overly simplified definition may demonstrate this alternative.

Definition 5. Let $\{D_1, ..., D_n\}$ be a small set of $n \ge 1$ fuzzy human conditions such as {heart attack, breast cancer, stroke, epilepsy, pneumonia, measles, smallpox, ..., schizophrenia} each of which in a particular human society is named a disease. Then in this society:

- 1. Any member of $\{D_1, ..., D_n\}$ is a disease to the extent 1, referred to as a prototype or core disease.
- 2. A human condition X is a disease to the extent ε if there is a prototype disease D_i in $\{D_1, ..., D_n\}$ such that simil $(X, D_i) = \varepsilon$, and there is no D_j in $\{D_1, ..., D_n\}$ such that simil $(X, D_j) > \varepsilon$. That is, if ε is the maximum degree of its similarity with prototype diseases.

The category of diseases emerging from this concept does not have sharp boundaries. A human condition may be a disease to an extent between 0 and 1. For example, let the following human condition be, for simplicity's sake, the only prototype disease:

heart attack = { $(F_1, 1), (F_2, 0.7), (F_3, 0.9)$ }.

Thus, the human condition:

hemorrhoids = { $(F_1, 0.7), (F_2, 0.2), (F_3, 0.4)$ }

turns out to be a disease to the extent 0.5 because simil(hemorrhoids, heart attack) = 0.5. By contrast, the human condition:

homosexuality = { $(F_1, 0), (F_2, 0), (F_3, 0)$ }

is a disease to extent 0 because simil(homosexuality, heart attack) = 0. Depending on the number *n* of the prototypes $\{D_1, ..., D_n\}$ in a prototype resemblance category, we may distinguish between *monofocal* and *multifocal* categories. A category is monofocal if n = 1. It is multifocal if n > 1. Our last example category with heart attack as its only prototype was a monofocal one. However, the category of diseases in real-world medicine is, like the categories of birds, fruits, and vegetables, multifocal. It embraces many distinct prototype diseases giving rise to a number of subcategories such as heart diseases, infectious diseases, neoplasms, genetic diseases, mental diseases, and so on. Since the category is an irreducible one, an individual disease such

as depression that may sufficiently resemble a prototype disease, for example schizophrenia, need not have anything in common with any other, remote disease such as heart attack, glomerulonephritis, or cholelithiasis.

The Empirical Claim of the Theory

The approach we have taken in the last section is not the only possible one to demonstrate that the category of diseases is an irreducible one and is therefore best represented by a nonclassical concept of disease. A philosophically lucid and powerful method to form the whole theory consists in analyzing the issue by constructing set-theoretical predicates. Such an approach is beyond the scope of the present article. We will, therefore, briefly introduce only a simple set-theoretical predicate to frame our theory and to apply it to our problem in the sequel. For details, see Sadegh-Zadeh (forthcoming).

Corresponding to Definition 5 above, we will sketch a concept of *fuzzy prototype resemblance frame* on the basis of which a concept of *fuzzy proto- type resemblance category* will be introduced. The category of diseases will then be interpreted as an instance of this latter concept, that is as a fuzzy prototype resemblance category.

Definition 6. ξ is a *fuzzy prototype resemblance frame* iff there are Ω , A_1 , ..., A_n , B, s, and f such that:

- 1. $\xi = \langle \Omega, \{A_1, ..., A_n\}, B, f, s \rangle$.
- 2. Ω is a nonempty set referred to as the universe of discourse.
- 3. $\{A_1, \ldots, A_n\}$ is a subset of Ω with $n \ge 1$.
- 4. *B* is a fuzzy set in Ω .
- 5. *f* is a similarity function that maps pairs of Ω to [0, 1] as in Definition 3 above.
- 6. *s* is a human society.
- 7. Each member of $\{A_1, ..., A_n\}$ is a member of *B* to the extent 1 if it is considered a prototype in *B* by the society *s*.
- 8. A member *X* of Ω is a member of *B* to the extent ε iff ε is the maximum degree of its similarity with a prototype in *B*, and $\varepsilon \neq 0$; that is iff there is a prototype A_i in *B* such that $f(X, A_i) = \varepsilon$, and there is no prototype A_j in *B* such that $f(X, A_i) > \varepsilon$.

To give a simbple example, suppose that we have:

 $\Omega \equiv$ the class of animals,

 $\{A_1, \dots, A_n\} \equiv \{\text{robin, sparrow, blackbird, crow}\}$ with n = 4,

 $B \equiv$ the class of birds, a fuzzy set in Ω ,

 $f \equiv$ simil, that is the similarity function introduced in Definition 3 in "Similarity",

 $s \equiv$ the society of West Europeans

such that {robin, sparrow, blackbird, crow} are considered prototype birds by West Europeans. So, each of these four animal species is, according to axiom 7 of the definition above, to the extent 1 a member of the class of birds. In addition, according to axiom 8, any other species X in Ω , that is any other animal species, is to the extent $\varepsilon \neq 0$ a bird iff simil(X, A_i) = ε is the maximum degree of its similarity to the four above-mentioned prototypes in the class. Thus, the following structure satisfies all axioms of Definition 6 and is therefore a fuzzy prototype resemblance frame: (animals, {robin, sparrow, blackbird, crow}, birds, simil, West Europeans).

Definition 7. *B* is a *fuzzy prototype resemblance category* iff there are Ω , A_1, \ldots, A_n, f , and *s* such that $\langle \Omega, \{A_1, \ldots, A_n\}, B, f, s \rangle$ is a fuzzy prototype resemblance frame.

For instance, in our above example, the class of birds is a fuzzy prototype resemblance *category* because there are:

animals, {robin, sparrow, blackbird, crow}, simil, and West Europeans

such that the 5-tuple:

(animals, {robin, sparrow, blackbird, crow}, birds, simil, West Europeans)

is a fuzzy prototype resemblance frame. Note that according to the concept presented in Definition 7, a class is a fuzzy prototype resemblance category if it satisfies what is required by the preceding Definition 6. Specifically, membership in a fuzzy prototype resemblance category is a matter of degree. The degree of category membership of an object equals 1 if the object is a prototype; otherwise, it equals the maximum degree of the object's similarity to a prototype. Thus, degrees of membership in the category smoothly decrease in the direction of nonmembership such that the category has no sharp boundaries between members and nonmembers. Most importantly, the category-generating, focal members of the category, that is its prototypes, are chosen by a human society to the effect that the society is in fact the inventor of the category. For example, it may be that what Australians view as the category of birds, vegetables, fruits, furniture, or cloths is not identical with what the Siberians do because the focal members of an Australian category differ from those of the Siberian category. An Australian category may partially overlap a Siberian one, though, they need not match completely. Thus, the question of whether a category "exists in the real world" becomes meaningless. We are now in a position to propose what has been aimed at by the present paper:

Hypothesis 1. The category of diseases in Western medicine, denoted \mathcal{D} , is a fuzzy prototype resemblance category (as defined in Definition 7).

To support this proposition, we will first assemble the conceptual preconditions required:

- 1. Let our universe of discourse be the class of all fuzzy human conditions, denoted \mathcal{H} , that we have conceptualized in "Human Conditions" above.
- Let {D₁, ..., D_n} be a subset of H, for example, fuzzy human conditions such as heart attack, breast cancer, stroke, epilepsy, pneumonia, measles, smallpox, and schizophrenia that we have reconstructed in "The Category of Diseases". We suppose that a couple of human conditions like these examples are considered *prototype diseases* in Western societies. This supposition will be discussed in "Where Do Prototype Diseases Come From" below.
- 3. Let \mathcal{D} be a family of fuzzy sets in \mathcal{H} .
- 4. The society *s* that we will consider may be West Europeans.
- 5. Let the similarity function *simil*, introduced in Definition 3 in "Similarity", act as an instance of the similarity function *f* required in Definition 6.
- 6. Note that there are different degrees of similarity between fuzzy human conditions contained in \mathcal{H} and the prototype diseases $\{D_1, \dots, D_n\}$.
- 7. According to Definition 6, set \mathcal{D} emerges from 1 to 2 and 4 to 6. It is the category *disease* in West European medicine.

These premises in conjunction with Definitions 6–7 imply the following statement:

Hypothesis 2. \mathcal{H} , $\{D_1, ..., D_n\}$, \mathcal{H} , simil, West Europeans \rangle is a fuzzy prototype resemblance frame.

The following corollary is a consequence of Definition 7 (after the rule: " α iff β " implies "if β then α "):

Corollary 1. For every \mathcal{H} : If there are \mathcal{H} , $\{D_1, ..., D_n\}$, simil, and West Europeans such that $\langle \mathcal{H}, \{D_1, ..., D_n\}, \mathcal{D}$, simil, West Europeans \rangle is a fuzzy prototype resemblance frame, then \mathcal{D} is a fuzzy prototype resemblance category.

Hypothesis 1 follows from Hypothesis 2 and Corollary 1.

Where Do Prototype Diseases Come From?

From our considerations above, it follows that the vast majority of the 50,000 individual diseases in current Western medicine are derived diseases in that their diseasehood is grounded on their similarity to some prototype diseases. Thus, the fundamental question of medicine (i.e., what is disease?) reduces to "what is a prototype disease?" or "where does a prototype disease come from?" We have already dealt with this question in the precursor of the present paper and will give here only a brief summary (Sadegh-Zadeh, 2000, 632f).

According to our approach, the category of diseases is relative to human societies because its prototype elements, as its generators, are instituted by human societies. Examples are human conditions such as epilepsy, stroke, breast cancer, and angina pectoris. They have been known for a long time, have already been well described in the Hippocratic Corpus, and have been determining the growth of the category ever since. A human condition of this type has been christened "disease" by human beings in the past to mean that the life of the afflicted person is threatened and she is suffering and in need of help, treatment, care, advice, and any other useful assistance that may relieve her pain and prevent death, incapacitation, and continuing discomfort. To put it concisely, the afflicted person's state is *named* "disease" by the society to denote something that it finds undesirable and whose amelioration through medical care it finds desirable. From the semantic point of view, this christening act is an ostensive definition of the term "disease" by members of a particular society in that they point to a human condition declaring "this we call disease" like the christening act "this ship we call USS Dwight D. Eisenhower." Viewed from an action-theoretic perspective, the term may be interpreted as a *social-deontic* construct in the following sense.

Viewed from the perspective of animals themselves, there are no diseases in the animal world. For whatever reasons, an impaired animal does not enjoy compassion, treatment, and care by other animals and falls prey to predators or suffers and eventually dies. The opposite is the case only in human societies because in human societies impairment and suffering of an individual provoke nursing actions by others. They are *action provoking*.

The adjective "deontic" derives from the Greek term "deon" for "that which is binding," that is *duty*. Deontic norms in a community are moral or legal rules regulating what is permitted, required, or forbidden in that community, for example, "thou shalt not kill" and "thou shalt render assistance to those who need it." A deontic construct in such a society is a state of affairs brought about by members of the society if there are deontic norms in this society according to which the actions they perform or omit to bring about that state of affairs are required or forbidden. For example, being literate is a deontic construct in Germany because going to school is legally required in Germany. It is these legal norms that make the people learn and become literate.

A *prototype disease* in a society is a deontic construct of this society because it emerges, qua *something-to-be-treated* and thus christened disease, and not qua an entity or phenomenon, from deontic norms of the society. As a particular human condition such as, for example, heart attack, epilepsy, stroke, or breast cancer, it provokes actions of members of the society to rescue the afflicted, to help her, and to ameliorate her condition. Such a human condition is designated a disease simply to have a name for this type of action-provoking states of affairs. Its primary characteristic is its being action provoking. It is action provoking not because it is a disease in the interpreted sense of this term, but because the members of the community where it occurs share basic values and attitudes such as sanctity of life, love, benevolence, compassion, sympathy, and charity according to which rescue, relief, help, remedy, and care are deontically required in *such circumstances*. By their nursing, remedial, and preventive actions and attitudes, they bring about the collective act of treating something as a disease which without this act would not be a disease, comparable to impairments in the animal world. It is questionable if human monads who would not live in polyads, that is human communities, would ever consider themselves as having any disease. That means, by analogy to the Wittgensteinian impossibility of private language, that there are no private diseases. Diseases qua diseases are, as deontic constructs of a society, essentially social artifacts. For details of this theory, see Sadegh-Zadeh (forthcoming).

IX. CONCLUSION

The concept of disease is a subject of continuing discussion in the philosophy of medicine. The opinions about what disease may be, however, are still very divergent. As we have diagnosed elsewhere, the discussion has ended up in a blind alley and has become sterile (Sadegh-Zadeh, 2000). We have attributed the failure to the common misconception of disease as a category that is characterized by necessary and sufficient features.

To clarify the misconception, we have in the present paper distinguished between reducible and irreducible categories. The former ones are denoted by classical concepts and the latter ones by nonclassical concepts. Whereas a reducible category is reductively definable by a set of necessary and sufficient features, irreducible categories are not reductively definable. We have shown that diseases form an irreducible category to the effect that a nonclassical concept of disease is required, and have suggested such a concept. The result is the prototype resemblance theory of disease. According to this theory, human conditions that constitute the category of diseases in medicine do not have sufficient and necessary features of diseasehood. The category is organized around a number of prototypes as its foci such that other human conditions that resemble them to particular extents are also included in the category to be called diseases. It is thus a multifocal resemblance category comprising, around different foci, subcategories such as infectious diseases, heart diseases, genetic diseases, and so on. In constructing our theory, fuzzy logic has served as a tool. It offers a host of facilities to develop a novel methodology in the philosophy of disease. We have abstained from using these facilities, however. For more details, see Sadegh-Zadeh (1999, 2000, forthcoming).

NOTES

This article is dedicated to Professor Lotfi A. Zadeh on the occasion of his 87th birthday.

^{1.} In the present context, we use the term category in its natural language sense that is to be distinguished from the formal concept of category that is the subject of the mathematical *category theory*.

^{2.} In the present text, the following terms are considered synonyms: feature, property, attribute, characteristic, criterion, and trait.

3. The term "thought style" that has contributed to Thomas Kuhn's notion of a paradigm is the well-known construct by Ludwik Fleck introduced in his social epistemology in 1935 (see Fleck, 1979).

4. The symbol " \geq " reads "greater than or equal to." A symbol of the form " F_i " such that the subscript "t" is its number is a placeholder for any feature.

5. The idea of nonclassical concepts outlined in this section is based on the theory of categorization that has originated with the former Berkeley psychologist Eleanor Rosch (1973, 1975, 1978). About the issues I am discussing here, I have learned a lot from (Reed, 1972; Rosch, 1973, 1975, 1978; Smith and Medin, 1981; Lakoff, 1987; Andersen, 2000). All constructions, conceptualizations, and errors are my own responsibility, however.

6. Note that we are talking about disease as a general category. We are not talking about "the nature" of individual clinical entities. An individual clinical entity may of course have defining features to enable the formation of a nosological predicate in classical fashion. For example, the predicate "pulmonary tuberculosis may be introduced by an explicit definition of the following form: "A person has pulmonary tuberculosis" if and only if she has pneumonia caused by Koch's bacillus." The definiens of this definition fixes the features "pneumonia" and "caused by Koch's bacillus" as sufficient and necessary conditions of pulmonary tuberculosis. That is, recall the distinction between *nosological predicates* and the *concept of disease* discussed in "Disease Versus Diseases."

7. The term "alopecia areata" means hair loss on the scalp or elsewhere on the body such that hairs fall out in small, round patches about the size of a quarter.

8. It is said that Wittgenstein might have adopted the idea of family resemblance from Friedrich Nietzsche. Nietzsche in his *Beyond Good and Evil* (first published in 1886) is speculating about the "family resemblance of all Indian, Greek, and German Philosophizing," which he attributes to the "affinity" of their languages (Nietzsche, 1954, section 20).

9. The following three terms are in fact synonyms: set, class, and category. They are used in different contexts, however. The term "set" has formally precise criteria and is used only in formal, mathematical and logical contexts. The term "class" is more informal and less precise. The term "category" is the most general and informal one. It is used preferably for real-world classes such as birds, vegetables, shoes, animals, etc. Examples are "the set of even numbers," "middle class US citizens," "the category of birds." In our considerations, we will need the most precise one of these terms, that is "set" (see also footnote 1). A set is a collection of any objects referred to as its elements or members. We distinguish between classical sets and fuzzy sets. A *classical* set has clear-cut boundaries, for example the set of even numbers or "the set of one's siblings." Due to this characteristic, an object is definitely a member of the set or it is definitely not a member of the set. A third option does not exist. That is, there is no object at an intermediate point between definite membership and definite nonmembership. If some objects, for example the objects a, b, and c, form a set, we write {a, b, c} to represent that set and read "the set of objects a, b, c." An alternative method to represent a set is the following one: A set whose members are characterized by a particular attribute A is written " $\{x | x \text{ is } A\}$ " and read "the set of all x such that x is A." For example, the set of diabetics is $\{x \mid x \text{ is a diabetic}\}$. For convenience, sets are represented by Roman capitals. Their members are represented by lower case letters. A set A is said to be a subset of a set B if all of its members are also members of B. For example, the set of diabetics is a subset of the set of all human beings who have a disease.

10. The term "fuzzy set" is the basic concept of *Fuzzy Theory*, popularly known as "fuzzy logic." This theory is a rapidly developing, multidisciplinary science of vagueness and uncertainty, and as such, best suited for dealing with vague entities like diseases. It was inaugurated by the computer scientist Lotfi A. Zadeh at the University of Berkeley in 1965 (see Zadeh, 1965; Yager et al., 1987; Klir and Yuan, 1996). It is more and more becoming the leading methodology in all scientific disciplines and technology, including medicine. See, for example, Mordeson, Malik, and Cheng, 2000; Szczepaniak, Lisboa, and Kacprzyk, 2000; Steimann, 2001; Barro and Marin, 2002.

11. For detailed examples of fuzzy representation of individual diseases, see Mordeson, Malik, and Cheng, 2000; Szczepaniak, Lisboa, and Kacprzyk, 2000; Steimann, 2001; Barro and Marin, 2002 and the journal *Artificial Intelligence in Medicine*.

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