Chapter 2
Fuzzy Systems and Scientific Method – Meta-level Reflections and Prospects

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Despite the great success of fuzzy systems in various applications, we still need their further studies from the standpoint of their metatheory, methodology and the philosophy of science. This objective means that in the context of fuzzy systems we should consider more such aspects as the role of scientific outlooks and research paradigms, concept analysis, scientific argumentation, hypothesis assessment, theory formation, scientific explanation and ethics. Below we consider these subject matters at a general level and we also attempt to subsume them under Lotfi Zadeh's recent ideas on approximation.

2.1 Background – Principal Western Traditions in Scientific Method

Our outlooks constitute our assumptions and knowledge on nature, society and the human beings as well as our philosophical conceptions on these issues. A scientific outlook, in turn, presupposes that the foregoing assumptions and knowledge are acquired and justified by using scientific methods. Below we consider some central aspects of fuzzy systems from the standpoint of their metatheory, methodology and the philosophy of science, and we particularly deal with problems of scientific method.

This section sketches historical and ideological background in the Western world for our study. Section 2 considers aspects of concept formation and interpretation, section 3 deals with argumentation, in section 4 we examine scientific explanation and theory formation, section 5 provides guidelines for scientific ethics and section 6 concludes our study.

The definitions on such terms as *science* or *scientific method* would already require wider considerations, but at this stage we only establish that science should acquire novel knowledge in a systematic and rational manner and the scientific method, in turn, guides in a systematic manner our research when we organize and examine our rational and experimental processes and principles [40]. We consider additional features for these below.

We can consider our scientific research process from various standpoints [12, 17, 21, 26, 27, 28, 29, 30]. First, the historical approach, in particular the history of science and methodology, provides a basis for our present research traditions.

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Second, our outlooks stem from our philosophical and religious traditions. Third, we apply certain scientific methods and even adopt certain research paradigms. Fourth, in the science of science we can examine science from the empirical standpoint, for example, the economy, sociology or psychology of science. Finally, the politics of science is an important factor because the funding sources are often controlled by political decision makers. In the light of this categorization, we focus on historical and methodological aspects as well as on the politics of sciences from the ethical standpoint.

When a scientific outlook is adopted, our scientific assumptions and assertions have to be continuously open for criticism and discussion and this also concerns the still continuing debates on the demarcation between the scientific and nonscientific outlooks and methods. Fuzzy systems provide a good example of this because their scientific nature has been criticized in particular by several mathematicians and logicians.

The Western scientific outlooks stem from two mainstreams, the philosophies of the ancient Greece and Christianity. Despite their distinct origins, these traditions integrated in the conduct of inquiry in particular in the Scholastic philosophy, which prevailed in Europe in the Middle Ages. This integration meant in practice that the hypotheses, argumentation, theories and explanations were adopted from the ancient Greeks (in particular from Plato and Aristotle), whereas their contents and justifications had to correspond with the doctrines in the Bible. A typical example of this approach was the Greek Eudoxan planetary model which due to its geocentric nature was also acceptable to the Christian community. On the other hand, valuable research in bivalent logics and mathematics was also performed, and these studies were usually independent of religious commitments.

The link between Christianity and the scientific community weakened already in the late Middle Ages, and by virtue of certain inventions and discoveries made in the natural sciences, these sciences actually abandoned Christianity by the 18th century. Essential persons in this process were Galileo, Francis Bacon and Newton, inter alia. In addition, the philosophy of Enlightenment played an important role in this process. However, in the Western world the influence on Christianity still prevails to some extent in our ethics and even in the creationistic biology [12, 17, 21, 26, 27, 28, 29, 30].

Since the abandonment of Christianity, it has been the guiding principle in the Western scientific outlook that the human reasoning provides the sole basis for all our studies. This principle was adopted in the both epistemological mainstreams, viz. rationalism and empiricism. The former aroused problems in the natural sciences and thus the latter was adopted to be the prevailing approach to knowledge acquisition, hypothesis testing and theory formation in these disciplines. According to empiricism, which mainly has the British origin (Locke, Hume etc.), the scientific research is based on our observations and experiments, whereas rationalism also accepts researcher’s “intuition" or “pure reasoning", even instead of experiments (Kant suggested a compromise theory of these two traditions). Since Newton, in particular, mathematical notation and calculus are also widely used in the natural sciences [21, 26, 27, 28, 29, 30].

The extensive rise of the Western human sciences (the social and behavioral sciences, economics, the Humanities, etc.) began in the 19th century, and two main methodological approaches were adopted. The one advocated the idea on the unity of science by presupposing that the human sciences should also apply the methods of the natural sciences, whereas the other suggested alternative or complementary methods for these sciences. For example, the former approach, which was strongly advocated in the positivistic tradition (e.g., Schlick, Carnap), assumed that the human beings are only complicated machines or automata ("homeostats") and thus they are not distinct from the other inanimate or animate entities, whereas the latter approach emphasized the unique goal-oriented or intentional behavior of the human being. The idea on intentionality stemmed from the Geisteswissenschaften tradition ("human" or "spiritual" sciences, e.g., Dilthey), in particular from phenomenology and hermeneutics. The rise of Marxism in the 20th century was the third main factor in this methodological debate even though in this tradition the concept of human being was close to the positivistic point of view [5, 6, 13, 23, 38].

As regards the present situation in the Western human sciences, we seem to have two main methodological traditions. First, the quantitative research tradition which stems from the positivistic tradition and Marxism and, second, the qualitative research based on the ideas of the Geisteswissenschaften.

Hence, today quantitative methods, empiricism and mathematical calculii prevail in the methodology of the natural sciences. These disciplines also use widely bivalent logic in their argumentations. In the human sciences, in turn, we apply both quantitative and qualitative methods but usually these methods are nevertheless applied separately.

Even though the Western methodology seems to prevail globally today, we must bear in mind that there are also such several outstanding scientific traditions outside the Western culture from which we have espoused a lot of innovations as the Egyptian, Mesopotamian, Indian, Chinese and Arabic traditions. For example, Christianity has strictly speaking several features in common with the non-Western philosophies.

As regards the role of fuzzy systems in the modern scientific method, fuzzy mathematics and logic have been revolutionary approaches in particular in the Western world. Their innovative features are the humanlike processing of imprecise, multi-valued and linguistic entities in concept formation, argumentation, theory formation and model construction. Today fuzzy systems have a well-established position in the various disciplines of the natural sciences, whereas in the human sciences more applications are required, and thus in there fuzzy systems still await their golden age. At a general methodological level fuzzy systems have a possibility to integrate the Western and non-Western methodological traditions to a great extent and their methodology can also act as a mediator between the quantitative and qualitative methods. Some examples are provided below. However, fuzzy systems still encounter certain methodological problems and below we also consider these issues.

2.2 The Challenge of Concept Formation and Interpretation

2.2.1 A Case Study – Sketching the Exegesis of Fuzziness

In the scientific concept formation we consider the meanings of terms and these meanings are specified according to our concept analyses and interpretations. As an outcome, we can also perform definitions. This section considers typical challenges which fuzzy systems can meet in concept formation.

At first we consider the meaning of *fuzzy*. The exegesis of terms comprises various aspects. For example, a term can be homonymous (*premises*), ambiguous (*fuzzy, fuzzy logic*), equivocal (*reasoning*), univocal (*real number*) or synonymous (*epistemology, theory of knowledge*). The meanings of terms can also include denotations, connotations or both of them. In addition, it is usually assumed that in the conduct of inquiry we should only operate with the cognitive meanings in which case we can assess the truth values of our statements, whereas in our everyday life emotive meanings based on our emotions and values are also used. Unfortunately, it is still now and then possible that false or emotive arguments with negative value judgments are also stated in the scientific community, and the emotional judgments against fuzzy systems provide an examples of this.

We also have to bear in mind that the meaning of a term depends upon the context, the usage of the term as a speech act, term's role in the common knowledge, linguistic conventions in society and the period of time when the term is used. For example, the meaning of the term *fuzzy* in the common usage is distinct from that of applied to soft computing, and thus the context, common knowledge and linguistic conventions determine its usage. The employment of this term in the manner of Lotfi Zadeh is also a fairly modern interpretation, and thus it was unknown to us prior to the 1960's. We also constantly introduce such novel meanings of terms to fuzzy systems research which are unfamiliar to the other scholars in the scientific community (soft computing, defuzzification, granulation, precisiation, etc.). We could still reconsider whether this is a good policy if we attempt to promote the idea of fuzziness fluently [8, 9, 10, 11, 22, 30, 43].

Below we adopt one traditional approach to philosophical concept analysis, and thus we consider the intensions and extensions of terms. The intension of a term comprises such properties or other concepts which constitute the meaning of this term. The extension, in turn, consists of those things to which the term is referring. For example, the intension of *fuzzy* is its meaning, i.e., the concept of fuzzy, whereas its extension is the set of fuzzy things. Both of these constituents are considered below.

In concept analysis we can start by considering term's simple constituents of intension and then we can add more properties to it gradually, and this technique can even lead to complicated intensions. We also consider the interrelationships between these constituents as well as the similarities and dissimilarities between our intension and the other corresponding intensions. Typical relationships in this context are *x is associated with y, x is part of y, x is the cause of y, x follows y, x contradicts y, x is a intervening condition for y and x is property of y*.

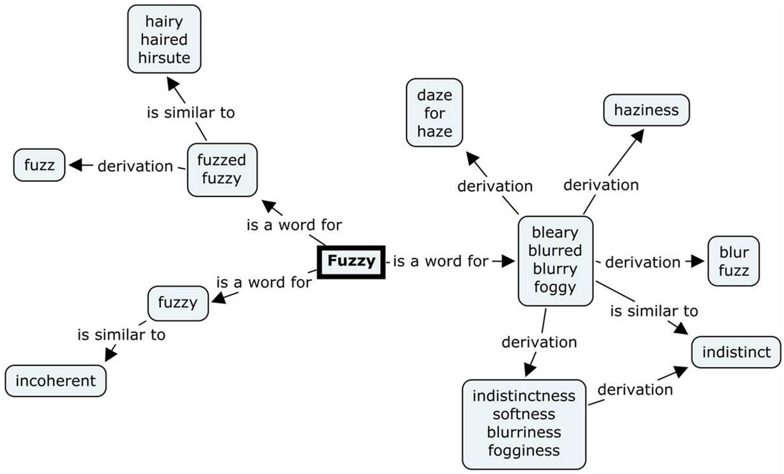

Fig. 2.1. An Example of Concept Analysis of *Fuzzy* According to Visuwords™

Consider now the exegesis of the term *fuzzy*. According to one hypothesis, in the English common usage fuzzy presumably stems from the Low German word fussig (spongy). Today it has various nuances of meaning and the most recent one was specified by Zadeh in 1960's. Figure 2.1 provides one example of examining the intension of *fuzzy* in the common usage when the foregoing technique is used [47]. According to Zadeh, in turn, *fuzzy* and *imprecise* have identical meanings [50, 51, 52, 53, 54, 55, 56]. Zadeh's interpretation leads us to the exegesis of *imprecision* within fuzzy systems.

In the 20th century philosophical literature *imprecision* was often synonymous with *vagueness*, but today we usually assume that vagueness also includes generality and thus we can prefer *imprecision* to *vagueness* within the fuzzy systems. Imprecision, in turn, constitutes ontological, epistemological and various forms of linguistic approaches. The ontological approach considers the existence of the imprecise objects, and in this context the crucial problem is whether there are any imprecise entities or, in particular, whether there exist any fuzzy sets. As we know, such isomorphic mathematical entities as the fuzzy membership functions, which are generalized characteristic functions, are used in the fuzzy models, but are there also the corresponding "true" fuzzy sets in the real world? This problem is still unresolved.

The epistemological imprecision is an outcome of the human being's inability to comprehend, perceive or discern certain precise objects clearly. Hence, in this context the imprecision is not related to the entities in the real world but rather in the human mind and thus we can perceive precise objects as being imprecise (e.g. objects in the fog). This interpretation is related to uncertainty because in both cases we deal with epistemological aspects. Zadeh's theories of perceptions and FL+ are related to this standpoint (cf. below).

Within the fuzzy systems the linguistic semantic approach seems to prevail. Hence, we assume that the linguistic entities can be imprecise by nature, and in particular the extensions of terms have been in focus. If adopt this approach, we can thus establish that a term is imprecise if and only if its extension contains borderline cases. For example, the term *young person* is imprecise, because its extension, i.e., the set of young persons, includes borderline cases, and we are thus unable to determine its precise limits. Fuzzy sets represent well the idea of extensions with the borderline cases, and on some occasions fuzzy sets are even referred to as quantitative meanings, i.e., the quantitative meaning of *young person* is the corresponding fuzzy set (viz. the extension).

The linguistic semantic intensional imprecision means that the corresponding extension of a term *might* contain borderline cases. For example, *young person* is thus imprecise in such world in which everyone is under 10 years (i.e., clearly young), whereas this term would not be imprecise in the extensional sense in that world.

The linguistic syntactic approach to imprecision assumes that the scope of an imprecise term is unclear. For example, strictly speaking, the statement *I shot an elephant in the pajamas* does not clearly reveal us which party was in the pajamas, because the scope of this word is problematic in this context.

The linguistic pragmatic approach considers the degree of unanimity of our statements. For example, how many persons will agree with the statement *A person of 30 is young* ? The more disagreement, the more imprecision in this sense.

Hence, confusions will arise if various interpretations of *imprecision* are used and our exegesis becomes even more complicated if the term *uncertainty* is also involved. First, several scholars outside the fuzzy research community have argued that fuzziness is actually a version of probability. Second, within the fuzzy system community some scholars assume that *fuzziness* (or *imprecision*) is synonymous with *uncertainty*. We have already stated above that the idea of linguistic imprecision has prevailed and this standpoint is related to semantics, whereas uncertainty is an epistemological issue. Hence, in this sense the distinction between these two concepts should be clear but there are also some historical reasons for this misconception.

Today we agree with the fact that probability theory is an appropriate approach to uncertainty but in fact the meaning of *probability* has varied since the ancient Greek philosophy. In the conduct of inquiry we usually aim at avoiding erroneous statements, and *error* can mean at least ignorance (or incompleteness), falsity and uncertainty. In the ancient Greece such words as *pistin*, *pithanos* and *doxa* were used in this context, and these expressions were usually translated into Latin as *opinio*, *probabilis* and *verisimilis*. When translated into English, in turn, we thus obtained such terms as *probability*, *verisimilitude*, *truthlikeness* and *truth appearance*. Consequently there has been at least two historical approaches to the concept of probability, epistemic (uncertainty) and semantic (truth) traditions. Another example can be found in German (and in a few other languages) in which the term for probability (WAHR*scheinlichkeit*) actually refers to truth [29].

If we would like to find a connection between imprecision and uncertainty or probability at the semantic level, Popper's ideas on verisimilitude and fallibilism as well as the theories on truthlikeness provide one resolution because they consider the notion of degree of truth and this notion also plays an essential role in fuzzy logic. Unlike in fuzzy logic, however, these approaches only apply bivalent logic. We must bear in mind that in this context *probability* is not having its modern mainstream meaning [35, 36].

At the epistemic level, in turn, probability is expected to represent the relation between the hypothesis and evidence (e.g. Carnap, Ramsey, de Finetti) and this relation is dependent upon our knowledge and ignorance. Hence, epistemic probability actually deals with the degrees of belief and this notion can also be considered fluently with fuzzy systems [4, 27, 49].

Today we also have physicalistic (or objective) approaches to probability such as frequency and propensity interpretation (e.g., von Mises, Reichenbach). Then we presuppose that probabilities are dependent upon physical properties assigned to the occurrences in the real world. These approaches are closely related to the idea of modality, and modality, in turn, is related to possibility. Hence, via the possibility theory another connection between probability and fuzziness can be found [27].

Summing up the distinction between imprecision (fuzziness) and uncertainty (probability), the statement *John's age is 21*, provided that John is actually 20 years, has a high degree of truth, whereas the probability of this statement is zero in the light of the evidence that John's age is 20. However, we can also integrate fuzziness with probability and this is carried out in the fuzzified probability theories (cf. below) [14, 56].

The foregoing discussion on the meaning of fuzziness already shows that there is still a lot of work in the concept analysis within the fuzzy systems. Other examples which require more exegesis in this context are the notions of truth, linguistic modifier, fuzzy quantifier, granulation, precisiation, defuzzification, information, perception and similarity [8, 9, 10, 11, 50, 51, 52, 53, 54, 55, 56]. Concept analysis provides us a basis for definitions and we consider this subject matter in the next section.

2.2.2 Definitions within Fuzzy Systems

Definitions are essential in concept formation and we usually apply them in the linguistic form

$$\ldots =_{df} \ldots$$

in which the expression on the left is the term to be defined (the definiendum) and the expressions on the right (the definiens) give the meaning or the description of the definiendum. For example, we can define

$$\textit{fuzzy} =_{df} \text{imprecise.}$$

Traditional rules for definition presuppose that, first, the definition is not allowed to be circular. This rule means in practice that the definiens is not allowed to include the definiendum (recursive definitions do not obey this rule). Second, the definition should not contain too imprecise or figurative terms. This principle, however, is a matter of degree in practice. Third, the definiens should not contain negative terms if corresponding positive terms can be used instead. In addition, definitions should follow such psychological rules as they should replace complicated terms with simpler ones.

In the conduct of inquiry we define the central terms of our studies and in this task we should take into account the available definitions of these terms, their correspondence with the real world and even the alternative methodological traditions. In addition to only clarify the meaning of a term, a definition can be the objective of the study, a hypothesis, an outcome of the study or it can link theoretical concepts to our observations. For example, if the term *fuzzy logic* is considered, definitions prior to the 1960's are unavailable and today, according to the traditional bivalent logic, fuzzy logic is not "real" logic. The correspondence of the meaning of *fuzzy logic* with the real world can also be problematic because of the novel usage of the term *fuzzy* [19, 22, 28].

Hempel [19] suggested four types of definitions. The first main category, the descriptive definitions, includes definitions that describe the meanings of the terms already in use. In addition, we can meaningfully assign truth values to these definitions. Its first subcategory comprises analytic definitions and then we assign to the definiendum an expression which has identical intension with it. For example, the definition,

$$\textit{fuzzy} =_{df} \text{imprecise}$$

is true if the terms *fuzzy* and *imprecise* have identical intensions, i.e., if the concept of *fuzzy* is identical with the concept of *imprecise*.

In the second subcategory, the non-analytic definitions, the definiendum and definiens should have identical extensions, i.e., they should refer to identical sets. For example, the definition

$$\textit{fuzzy} =_{df} \text{imprecise}$$

is true if the set of fuzzy entities is identical with the set of imprecise entities.

The second main category, the stipulative definitions, assigns names by stipulation to new linguistic or symbolic expressions (nominal definitions) as well as it provides "scientific" meanings to terms that are also in common usage (explications). In this context it is not meaningful to consider the truth values of these definitions. For example, if we use nominal definition and we define

$$\textit{fuzzy} =_{df} \text{imprecise},$$

we actually make a linguistic convention that *fuzzy* means imprecise.

In explication, in turn, the definition

$$\textit{fuzzy} =_{df} \text{imprecise}$$

assigns a scientific or technical meaning for the term *fuzzy*, and this meaning can be distinct from the common usage of this term (Zadeh has applied this to *fuzzy*).

In fact, within fuzzy systems all the foregoing types of definitions have been applied and thus it would be recommendable to mention to the other researchers, what kind of definition is used in the study in order to avoid extra confusions.

Wittgenstein [46] attempted to solve the definition problems of imprecise and complex terms by formulating the principle of family resemblance. According to him, by describing the essence of a thing or object is impossible in the case of imprecise and complex terms, and hence we should use terms which are characteristic but not necessary of the definiendum. For example, in the case of the term *human being*, we are unable to assign any necessary features or meaning components to human beings, but rather this term should consist of such generally accepted meaning components as *rational*, *two-legged*, and *intentional*, and a being is human if most of these components may be assigned to it. Wittgenstein also emphasized the role of exemplification when terms of this type are described. Wittgenstein's idea has been applied to grouping in statistics, and in this context these groups are sometimes confusingly referred to as fuzzy sets. Putnam, in turn, refers to the meaning components of this type as cluster terms [37].

The operational definition, which is a method to determine concept's or variable's structure or to measure its quantity, is also regarded as being one type of definition on some occasions, but strictly speaking we can thus establish several alternative definitions to a given term, viz. one for each measurement. These "definitions" are maintained in particular in the positivistic traditions of science. For example, an operational definition on *fuzzy reasoning* should reveal us how this inference is performed, but since there are several inference methods available, each of them represents one definition. We encounter the similar problem with the *degree of membership* because there are various methods to measure this quantity and each of them establishes an operational definition for this term. Hence, the operational definitions can provide us with the diversity of definitions for each term, and this situation is often unacceptable in the light of the concept formation and in the practice of science [26, 28].

Another problem with the operational definition is that there are many such terms which are difficult to measure directly or numerically as person's attitudes, motives, intentions and values, and thus they have problems with their validity of the measurements. Validity problems can still exist even though we aim to specify measurable counterparts for these terms (operational indicators). At a general level, this problem is a part of the controversy between the quantitative and qualitative research because the latter sets strict limits to plausible numerical measurement (cf. also below) [26, 28].

On the other hand, in measurement fuzzy systems can provide a useful link between quantitative and qualitative modeling if we use fuzzy linguistic concepts and variables when we examine our theories and observations. Then we can obtain more direct and informative data which can also be examined conveniently in a computer environment. Recently Zadeh has again focused on this important subject matter in his theory of perceptions [20, 25, 30, 55, 56].

2.2.3 The Challenge of Interpretation

Interpretation, which is an essential method in the qualitative research, usually refers to delivering messages, explanation, exegesis or translation, and it has been performed in the conduct of inquiry since the ancient Greece (Aristotle, Schleiermacher, Dilthey, Heidegger, Gadamer etc.). Originally interpretation was applied to linguistic expressions and text documents but today we also scientifically interpret such objects or phenomena as pictures, movies, music, dreams and the human behavior in particular within the hermeneutic and Geisteswissenschaften tradition in general [6, 13, 22, 30, 45].

In general, interpretation comprises two main levels, our conceptual system and our object of research. The former includes the meanings provided by us, and the latter focuses on object's original, latent and intrinsic meanings. For example, *fuzziness* can only mean imprecision to us, whereas originally it also has other meanings. An object of latent interpretation would be the assumption that Lotfi Zadeh preferred the term *fuzzy* to *imprecise* in his publications in order to arouse more interest in fuzzy systems. Finally, we can consider such intrinsic aspects of fuzziness as its moral and esthetical values.

In interpretation we aim to understand fully the meaning of our object of research, and in practice we can apply such methods as the hermeneutic circle in this task. The application of this method presupposes that in the beginning we have some foreknowledge (*Vorverständnis* in German) or preconceptions on the object or phenomenon under study. This knowledge is based on our experience, education, traditions, historical facts etc. The foreknowledge is assessed according to our scientific inquiry and it is subject to modification during our study. In our modification we assume that the whole of the object or phenomenon may be understood according to its parts, and vice versa. This interaction is a continuous circular process, and in the manner of a helix, it should lead us to the deep understanding of our problem. Our interpretations should also correspond well with the true nature of the object or phenomenon under interpretation. Finally, by virtue of successful interpretation, we may explain and understand both the relevant revealed and unrevealed features and constituents of the objects or phenomena [22].

For example, if a student is reading his/her first textbook on fuzzy systems, at the very beginning he/she has only cursory knowledge on fuzziness and fuzzy systems. While reading the book, he/she does not necessarily understand all its details immediately, but the more he/she reads, the better general view is attained, and simultaneously, the better the details are understood. Thus, he/she is able to understand the details according to the general view, and vice versa. Finally, a good understanding of fuzzy systems should be attained.

However, there are no detailed methods available for making interpretations but rather some general and approximate guidelines. Another problem is that our interpretations are more or less subjective by nature even though we should aim to minimize subjectivity. Despite these problems the foregoing method is widely applied to the qualitative research (cf. section 3).

Interpretation is also used in quantitative research more or less implicitly. For example, if we use mathematical models, we actually apply mathematical interpretation to the phenomena under study. In statistics, interpretation is used in the context of cluster analysis, factor analysis and hypothesis assessment, inter alia. Since the Pythagoreans, some scholars have even assumed that all the phenomena in the real world can be considered within the mathematical calculus. In this context, however, we must draw a distinction between the mathematical and real world. The former can be exact, deducible, consistent and rational by nature but the latter does not fulfill these conditions and thus their full correspondence is problematic. For example, a sophisticated mathematical model can be inappropriate in practice [22]. Hence, we have to draw a distinction between the Pythagorean style of “mathematism" and mathematics.

Within fuzzy systems linguistic interpretation plays a central role because we assign linguistic labels to fuzzy sets. Hence, the “quantitative meanings" of fuzzy terms are fuzzy sets or relations. In the framework established in section 2.2 this means that, given such term as *young* in the reference set of ages, its intension is its common usage meaning, i.e., the concept of being young, and the extension is the fuzzy set of young persons. Thus, the label of this set is *young*. This means that we label the fuzzy sets according to our interpretations and this procedure is subjective by nature. It also follows that the fuzzy terms have two “meanings" in practice, their intensions and corresponding fuzzy sets.

In addition, since we are unable to label all fuzzy sets in our models, we usually formulate a family of labeled archetype sets, and by using linguistic approximation, we attempt to label other sets according to these archetypes. This linguistic and approximate “discriminant analysis" is another example in which case we make interpretations.

Since the interpretations and artificial languages within fuzzy systems should correspond well with both the natural language and the real world, we should have an appropriate linguistic framework to the fuzzy linguistic variables. Our fuzzy artificial language should comprise a vocabulary and both syntactic and semantic rules. We also need a universe of discourse for fuzzy sets and appropriate linguistic variables. The values of these variables, in turn, are formulated by using primitive terms, linguistic modifiers, connectives, quantifiers, various qualifiers etc. For example, *many Swedes are tall, and very likely they are often fairly happy* could be such an expression [30, 33, 51, 52, 53].

We should also provide a psychological basis for our linguistic framework. For example, the author has applied Osgood’s semantic differential technique in this context [30, 32]. In this case we first select two antonymous primitive terms for each variable, and the rest of the values are usually their modified and compound versions. For example, given the variable *age of persons*, our primitive terms are obviously *young* and *old*. The other values can be *fairly young, neither young nor old* (the middle point) and *fairly old*, if we use five values. If we examine the attitudes or opinions of persons, we can also use Likert’s scales in which case we use such values as *I strongly agree, I agree, I neither agree nor disagree, I disagree and I strongly disagree*. Osgood’s and Likert’s scales are widely used in the human sciences but

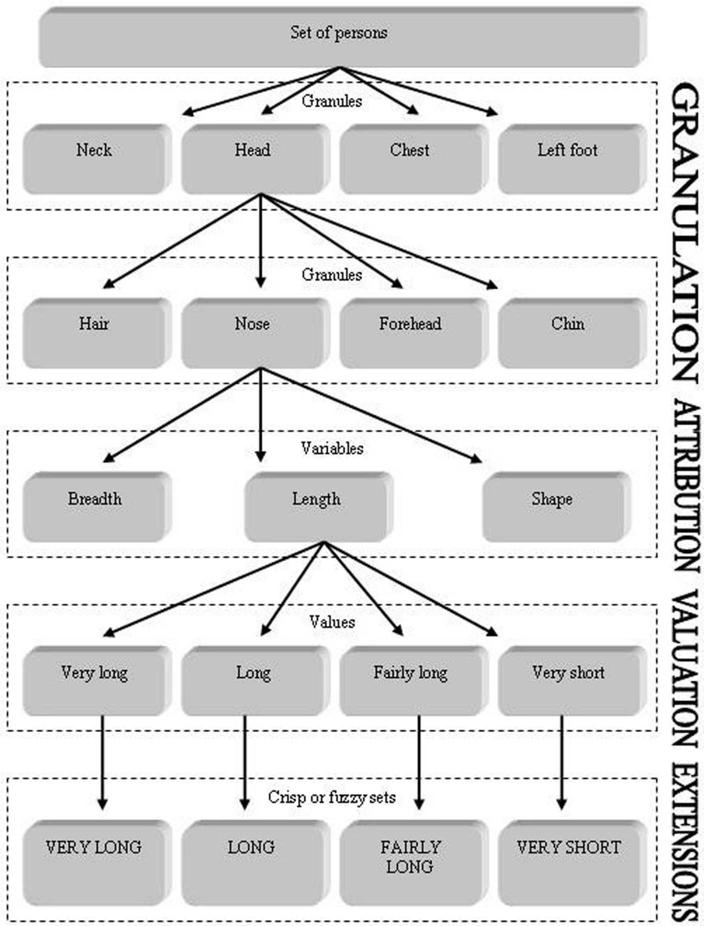

Fig. 2.2. Structure of Zadeh's Information Granulation

they are usually subsumed under the conventional statistical analysis. Fuzzy systems enable us to take into account better their linguistic and approximate nature in a computer environment and thus we can also apply pure qualitative modeling [30].

Zadeh has suggested a comprehensive theory to formulate a fuzzy artificial language [51, 52, 53, 54]. Unfortunately, it seems that many researchers have not fully understood its great value and applicability thus far. Hence, in practice we still operate much with fuzzy sets and mathematical notation in our model construction although we should rather use actual fuzzy linguistic entities and fuzzy logics. Figure 2.2 provides an example of Zadeh's information granulation approach when it is applied to linguistic variables and the foregoing idea of quantitative meaning.

Although we would have an appropriate syntax for our fuzzy language, we still can encounter problems in semantics because several quantitative meanings for fuzzy terms, which stem both from normative and descriptive standpoint, are available.

Examples are the meanings of *very* and *fairly* as well as the “interpretation" of connectives and quantifiers. At least the normative interpretations are still established on more or less subjective grounds.

An important topic in semantics is the problem of truth. In philosophy, a distinction is usually drawn between the definitions and criteria of truth [27, 40]. The former considers the meaning or nature of truth, and hence it concentrates on semantic problems. The latter examines the procedures for recognizing or testing the truth values of sentences, and it thus focuses on epistemology (if we maintain that only sentences can have truth values). For example, according to the widelyused correspondence theory, we can define that the linguistic statement *Lotfi Zadeh lives in Berkeley* is true if and only if he lives in Berkeley. On the other hand, the verification of this statement in practice belongs to the problemacy of recognizing the truth.

In definition, the correspondence theory of truth seems to be the mainstream approach within fuzzy systems, even though this principle is presented only implicitly in the literature [40]. Hence, we regard truth as a relation between a given language and the real world. First, this means that the meanings of linguistic expressions and the connection between a given language and the real world are based on human conventions. Second, the truth of a statement is determined by the real world, and thus its truth is independent of our stipulations [29].

Since truth is not a manifest property of statements, it is possible that a sentence is true although we do not recognize its truth. Hence, we also have to establish the criteria for testing or measuring the truth values of sentences. The applicability of using our truth value assignments in our model or theory construction is a traditional example of such criteria, and this criteria also seems to be widely used within fuzzy systems.

Since we use multivalued logics within fuzzy systems, we will encounter a diversity of interpretations on *truth* [28, 30]. For example, we can state that a compound statement is partially true if only a part of it is true and the rest is not true. A statement is totally true if all of it is true. A statement is a partial truth if it expresses a part of the whole truth, but also excludes some (often relevant) true parts. We may also assess that a statement is more or less close to being true (or false). If metric or mathematical concepts are applied, then the notion *degree of truth* may be used in this context and in fuzzy logic this approach has prevailed. In practice, however, the concept of the degree of truth is still problematic and various alternative methods for assigning or measuring it are used. This subject matter is also related to the problems of proximity, similarity and dissimilarity. Section 4 sketches one resolution to this problem.

Recently, the Internet has aroused new challenges to interpretation in a computer environment. Since we have enormously information available in the Internet, we should have appropriate tools and methods for finding the relevant information for us. Intelligent agents, knowledge discovery, data analysis and semantic web are examples of these. However, the crucial problem in this context is how computer systems could understand sufficiently the contents of the web documents, and thus we encounter again the problem of interpretation. For example, is the document under consideration providing some arguments or explanations, is it true or how could we make an abstract on it? Various interpretation models for computers are available already but we still await the real “killer" product. The more extensive use of qualitative methods with fuzzy systems could provide one resolution to this challenging problem.

We have mainly considered linguistic problems thus far but they are crucial if we apply fuzzy systems. If our linguistic frameworks have such plausible basis which correspond well with the real world, we can model fluently phenomena of nature, human behavior and human reasoning. A good linguistic basis is also a necessary condition to carry out further developments within fuzzy systems. We still have such great challenges in this context as the modeling of human interpretation, and it seems that the more extensive use of qualitative methods could better meet these challenges.

The following sections consider other relevant selected methodological topics in the light of linguistic framework of fuzzy systems and imprecise concepts.

2.3 Scientific Reasoning and Hypothesis Assessment

2.3.1 Approximate Reasoning – Past, Present and Future

Approximate reasoning is one of those central topics which has aroused lively debates with the traditional bivalent approaches. By reasoning we generally mean such thinking act that proceeds from assumptions to conclusions. Reasoning has originally been performed in the animate world but today machines can also reason to some extent. In traditional argumentation, our assumptions are usually known as the premisses (premises) or hypotheses [56], and in approximate reasoning these premisses and/or the conclusions are imprecise. Fuzzy reasoning, in turn, applies approximate reasoning and fuzzy systems [16, 20, 22, 42].

We can study reasoning from such standpoints as psychology, physiology, biology, logic and methodology. Below we focus on logico-methodological aspects and thus we mainly consider problems of logic and argumentation.

If we perform reasoning, we should first specify our arguments or find the existing arguments in our object of study. Second, it is also important to draw a distinction between arguments, explanations and descriptions. For example, consider the statements

1. Lotfi Zadeh introduced the principles of fuzzy systems because he wrote the first papers on this topic.
2. Lotfi Zadeh introduced fuzzy systems in order to construct better computer models.
3. Lotfi Zadeh introduced fuzzy systems.

They represent argument, explanation and description, respectively, but on some occasions we also use their combinations. Below we consider arguments, whereas explanation is examined in Section 4 [22]. Various types of reasoning are available [27].

First, theoretical reasoning usually applies affirmations and standard forms of reasoning methods (e.g. syllogisms). For example, if the Modus Ponens syllogism is applied, we can reason that

Lotfi Zadeh lives in Berkeley. (premiss)
If Lotfi Zadeh lives in Berkeley, then he lives in the USA. (premiss)
Lotfi Zadeh lives in the USA. (conclusion)

Second, practical reasoning leads to certain acts or modes of behavior. For example,
If fuzzy systems are good at model construction, I will use them.

Third, in heuristics we consider the invention of new ideas and hypotheses as well as the discovery of new objects or phenomena. Zadeh's insight on fuzzy sets provides an example of invention, whereas the planet Uranus is an example of an object that was discovered.

Fourth, we can consider how our ideas, hypotheses or discoveries can be tested, proved, accepted, rejected, confirmed or disconfirmed. The hypothetico-deductive method and hermeneutic circle are well-known approaches to assess the hypotheses.

Reasoning can base on intuitive and informal rules and assessments, but, owing to developments in logic, today symbolic representation and formal arguments are used in particular in the bivalent logics. An essential reason for the controversy between fuzzy systems and traditional logic is that the former does not fulfill the formal conditions established by the latter. In brief, the syntactic structures of fuzzy systems have had justifiability problems from the standpoint of bivalent logic even though a lot of valuable work has been done in fuzzy logic in this field. In a sense, fuzzy systems seem not to fulfill the idea of the “mental beauty" which is the alleged feature of the traditional mathematics and formal bivalent logics. This principle of the formal correctness of reasoning in the manner of bivalent logic has played a central role in the Western scientific outlooks but today we should call into question its plausibility due to the developments and results of the fuzzy systems.

On the other hand, the bivalent logics have encountered semantic problems because our actual reasoning does not correspond with them. The well-known unsuccessful attempts to establish this correspondence are those suggested by the Pythagoreans, Galileo, Leibniz, Hilbert and Carnap, inter alia, and hence today the bivalent traditions generally maintain that their logics are only normative by nature, i.e., instead of describing our actual reasoning, they show us how we should perform our reasoning. It is, however, also problematic whether this normative approach is justified in the modern conduct of inquiry due to the limitations and problems of bivalency. It has even been stated that bivalent logic was sufficiently simple calculus to use in the precomputer age, whereas today we can apply more applicable systems with the computers [3, 16, 24, 44].

We can also study reasoning by considering the nature of our premisses, in which case the fundamental question is whether they are necessarily true or not. In the former case we can apply demonstration and in the latter case dialectics. Examples are Euclid's geometry and Socrates's reasoning method, respectively.

If we, in turn, consider the relationship between the premisses and the conclusion, a distinction between deductive and inductive reasoning is usually drawn [27, 40].

Deductive reasoning contains nothing in the conclusion that is not already contained in the premisses. This idea provides a basis for syntactic validity (or theoremhood), which is a research object of proof theory. Semantic validity means that the conclusion is true whenever all the premisses are true. In traditional bivalent logic tautologies are semantically valid, whereas in the fuzzy logic we can also consider whether truth-preserving reasoning with an alternative degree of truth fulfills semantic validity.

In inductive reasoning, it is assumed that the conclusions go beyond what is contained in their premisses and thus it is regarded as ampliative with respect to our knowledge if the conclusions are true. Unlike deduction, induction is, however, not necessarily truth-preserving, and thus it is possible for the premisses to be true, but the conclusion non-true. In this context the degree of support for the conclusion provides a basis for the concept of inductive strength. Another clear distinction between deduction and induction is that in the former we can add new premisses to our premiss set and the conclusion still logically follows from this set. In practice, various types of inductive reasoning are available.

The fuzzy systems seem to mimic the human reasoning fairly well, and by virtue of the idea of the gradation of truth they are semantically meaningful and they can also resolve such traditional paradoxes of bivalent logic as the Sorites (Falakros) paradox [41]. However, several practical applications are based on ad hoc logical structures or on mere fuzzy set models. In addition, some arguments typical of fuzzy reasoning still stem from more or less intuitive and subjective assumptions, this making it possible that researchers may also be persuaded by invalid arguments or erroneous operations. We also have the unfortunate situation that, despite the general aim of fuzzy systems to use linguistic and human-friendly notation and expressions, a lot of mathematical and logical notations as well as pure mathematical operations are still used in this context.

Recently, Zadeh has established the principles of the extended fuzzy logic, FL+, and in this context we can reason by applying both traditional validity (p-validity) and novel f-validity [50]. In the former case we operate with precise theorems, classical deducibility, syllogisms and formal logic, whereas f-validity is related to informal and approximate reasoning and approximate "f-theorems" (Fig. 2.3). According to Zadeh ([50], p. 2),

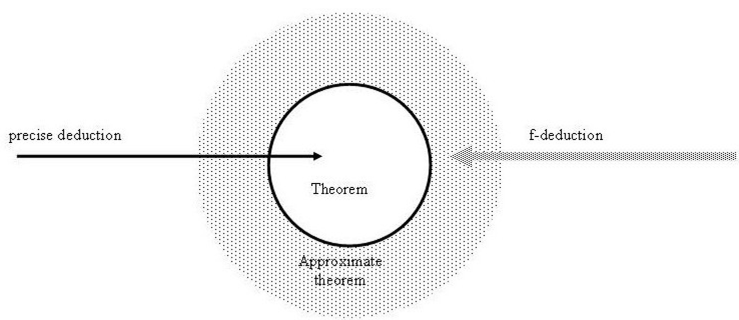

Fig. 2.3. Zadeh's Syntactic F-validity Yields Approximate Theorems

"A simple example of a f-theorem in f-geometry is: f-medians of f-triangle are f-concurrent. This f-theorem can be f-proved by fuzzification of the familiar proof of the crisp version of the theorem."

F-validity and f-theorem are examples of Zadeh's Impossibility Principle. This principle informally states that in an environment of imprecision, uncertainty, incompleteness of information, conflicting goals and partiality of truth, p-validity is not, in general, an achievable objective.

As we know, the fuzzified Modus Ponens, for example, corresponds with Zadeh's FL+ approach. In its usual form, i.e.,

statement 1,
if *statement 2*, then *statement 3*,
thus, *statement 4*,

the approximately identical statement 1 and the antecedent of statement 2 will yield statement 4 as the conclusion and this is approximately identical with the consequent of statement 3. By using this type of argument we can draw approximate conclusions which are close to their true counterparts, and thus f-validity is applied. In practice various fuzzy implications are used in this context and their correspondence with our intuition can be problematic. In addition, true or precise multi-valued implications are usually applied [8, 9, 10].

Naturally we can also apply non-true or approximate implications to the foregoing argument in which case we obtain even more approximate conclusions. Then, unlike in the case of bivalent or true fuzzy implication, the identity between statement 1 and the antecedent of statement 2 do not yield conclusion which is identical with the consequent of statement 3. Since we often apply the extension principle in this context when we calculate the conclusion, this approach means that we do not use bivalent relations as their inducing mappings but rather fuzzy relations. At a general level, the role of non-true and approximate implications should be studied more in this context because then we can better consider and model the approximate interrelationships between the phenomena.

Fuzzy systems applied to approximate reasoning can resolve problems which are superb to bivalent logics. They can overcome the Sorites paradox and model conveniently such challenging phenomena of the real world which are problematic to traditional approaches. The developments within the FL+ systems, in turn, seem to open new prospects at a more general methodological level. The FL+ system also seems to have connections to fallibilism, scientific realism, verisimilitude and the theory of truthlikeness. These aspects as well as some applications of approximate argumentation are discussed in the following sections.

2.3.2 Approximation and Reasoning with Hypotheses

When we assess the truth or justifiability of our hypotheses, we usually apply implicitly or explicitly the Modus Tollendo Ponens syllogism, i.e., *statement 1* or *statement 2*,

it is not the case that statement 1,

thus, *statement 2*.

Hence, in our hypothesis assessment we first establish all possible relevant assumptions or resolutions concerning our object of research. Then, we eliminate those assumptions from our “disjunction of assumptions" which contradict the evidence. For example, from the disjunction *Lotfi Zadeh lives either in Berkeley or New York* and the evidence *Lotfi Zadeh does not live in New York*, we can conclude that he lives in Berkeley.

Various types of hypotheses are available. For example, the working hypotheses are such alternative concepts, theories, models or methods which we consider in the beginning of our studies. The causal hypotheses assume causal connections between entities. In interpretation our foreknowledge is our initial hypothesis. Causal and interpretative hypotheses are used in the quantitative and qualitative research, respectively.

The disjunctive method can be subsumed under the more general principle that we can always find the true hypotheses by eliminating the false ones. However, the well-known raven paradox of falsificationism challenges this idea by reasoning that in practice we are unable to verify the statement that all the ravens are black because it is impossible to find all of them but, on the other hand, only one counterexample can falsify it. Thus we should prefer the falsification approach in hypothesis assessment. If we instead of this “dogmatic" falsification approach assume more liberally that both the acceptance and the rejection of a hypothesis are relevant procedures in the conduct of inquiry, we maintain fallibilism [27, 35, 36].

Mill [26, 27] has also applied the foregoing elimination method of hypotheses to his well-known reasoning method of difference. Consider that we have the two testing conditions, c_1 and c_2, which are similar except for one factor, f, and this factor occurs in c_1 but it does not occur in c_2. Now, according to Mill, if a certain phenomenon only occurs in c_1, we may reason that factor f is the cause of this phenomenon.

In the modern quantitative research we use causal hypotheses and in this context falsification and Mill’s principle are applied to the widely-used hypothetico-deductive method (Galileo, Descartes, Boyle, Peirce etc.).

From the logical standpoint, it stems from the classical bivalent Modus Tollens syllogism in which case we can reason that

if *statement 1*, then *statement 2* (true implication),

statement 2 is false (i.e., its negation is true),

statement 1 is false (conclusion).

It follows that if *statement 2* is true, *statement 1* may be true or false, and, in a sense, the syllogism is thus useless for us.

In the hypothetico-deductive method we apply the Modus Tollens by assuming that *statement 1* is our hypothesis and *statement 2* is usually its observable or testable logical consequence. The justifiability of *statement 2* is thus based on our experiments and observations, and if these are inconsistent with this statement, we reject our hypothesis. If, in turn, our experiments and observations correspond with *statement 2*, the Modus Tollens will not provide us with any resolution. Hence, in the latter case we have to replace deduction with induction and then one method is to assume that our hypothesis is only "confirmed". Sufficient confirmations, in turn, will lead to the acceptance of the hypothesis [5, 18, 19, 21, 22, 23, 25, 26, 27, 35, 36, 38].

In practice, the hypothetico-deductive method thus uses the hypotheses, which stem from the researcher's context of discovery and inventions, deduces tests and experiments from these hypotheses and finally either rejects or confirms the hypotheses according to the empirical evidence. Rejection is based on deduction, whereas confirmation is performed according to inductive reasoning.

If we use probability statements, the assessment on the relationship between the hypothesis and the evidence is more challenging than in the deterministic case. Examples of these are the statistical tests in the human sciences in which case we consider the acceptance of the null and alternative hypotheses at the given levels of significance [14, 15].

We have to bear in mind that we are unable to use the hypothetico-deductive method when we attempt to develop new ideas or hypothesis but these belong to the field of heuristics. This restriction also concerns hypotheses assessments in the ideal or imaginary conditions.

Within fuzzy systems we can also apply fuzzified probability theory, and the most recent version of this is suggested by Zadeh in his theory of second-order probability [50]. In this theory both the events and the probability functions can be approximate and thus we can use such statements as *the probability that John is very young is fairly low*. His theory provides one approach to the foregoing idea on degree of confirmation in epistemic probability. Zadeh's theory on probability can also be subsumed under his FL+ and thus we could apply it to approximate statistical reasoning, inter alia. Another method in the FL+ would be to generalize the traditional second-order theory by considering such statements as *the probability that the probability of John being very young is fairly low is very high*. These subject matters would extend a new frontier within both the fuzzy systems and the probability theory.

If we, in turn, apply a fuzzified version of the Modus Tollens to hypothesis assessment, we can also use linguistic and approximate constituents. The essential advantage of the model of this type over the conventional version is that the truth values of the premisses may also be gradually between true and false. It follows that we may acquire more information from the hypotheses than in the conventional case. In practice we can now assume that a false consequent yields a false hypothesis and otherwise the degree of confirmation increases as the truth value of the consequent approaches truth. In other words, the more convincing evidence for the hypothesis, the higher the degree of confirmation (and the lower the degree of disconfirmation). For example, the more various experiments support our hypotheses, the more this hypothesis is gradually confirmed or accepted.

Naturally, as in the case of the Modus Ponens, the implication in the fuzzified Modus Tollens can also be non-true. For example, if this implication is only fairly true, we can establish that even the false consequences of the hypotheses do not necessarily lead to mere false hypotheses. Equally the truth values of the consequents close to true may already lead to maximal degrees of confirmation. In general, we may assume that with the non-true implications our conclusions include more "dispersion" or imprecision than in the conventional case, and loose reasoning links of this type are typical in the human sciences in which we usually operate with noisy data and the complicated interrelationships between the variables.

The actual hypothetico-deductive method performs tests and experiments with the hypotheses, but we may also apply it to the interpretative method if we assume that, in addition to these, we may consider the correspondence between our foreknowledge or interpretation hypothesis and the real world on rationalistic grounds. Hence, in this sense, we can also apply the hypothetico-deductive method to the qualitative research. The qualitative hypotheses are usually linguistic and approximate in nature, and they may more often deal with unique and non-recurrent events or phenomena than in the quantitative case. Instead of traditional statistical tests or other experiments we usually employ our observations, intuition, linguistic reasoning and interpretation when we assess the confirmation of our hypotheses. It is even possible that we conduct studies without any hypotheses or we may begin our studies without them and establish the hypotheses later according to our data and materials (e.g. the grounded theory approach) [6, 22].

The fuzzy systems thus seem usable to qualitative hypothesis assessment as well if we apply such foregoing methods as the FL+ or fuzzified Modus Tollens. However, these systems still apply traditional methods when the hypotheses are assessed. By applying our novel approximation theories, we can acquire more informative results and assess our hypothesis in a more versatile manner. In particular in the human sciences these methodological innovations are relevant because several of their computer models are still fairly primitive in particular in the qualitative research.

In addition to concept analysis, argumentations and descriptions, explanations are relevant in the conduct of inquiry, and in the following section we consider this subject matter.

2.4 Approximation and Scientific Explanation on Human Behavior

Scientific explanations make our objects of research intelligible for us. An explanation constitutes of two parts, the phenomenon or problem to be explained (explanandum) and our explanation for it (explanans). With the explanations we attempt provide answers to such questions as *why?*, *what for?* and *what is the purpose for?*

Within fuzzy systems we usually apply such causal or probabilistic explanations which are used in the natural sciences and these do not take into account the intentions or motives of beings because their origin is in the inanimated world. For example, if we would like to know fully the reasons which led Lotfi Zadeh to formulate the theory of fuzzy systems, we should also understand his aims, motives and the other underlying causes and these aspects go beyond the natural sciences. We also encounter this problem in such quantitative branches in the human sciences as behaviorism. Hence, we should also apply additional explanations when we model the modes of human behavior [18, 19, 39].

According to the well-known slogan in the Geisteswissenschaften, we explain (erklären) nature but we understand (verstehen) history which means that in general the entities of the natural sciences neither establish any goals nor have any motives, whereas in history, and more generally in the human sciences, goal-oriented or motive-based behavior of agents is typical.

In the natural sciences Hempel's subsumption theory is widely used in which case we formulate the explanans according to the given initial conditions and appropriate general laws by using either deduction or induction. When the human beings are involved, it is nevertheless difficult to find any general laws nor even clear cause-effect relationships in person's behavior. This is mainly due to their noisy data and the complicated interrelationships between the variables (e.g., elaboration problems).

In the qualitative research and the Geisteswissenschaften tradition we do not primarily attempt to find the causes for the phenomena but we principally aim to make appropriate interpretations to these phenomena. As was mentioned above already, we first attempt to understand the phenomenon under study and at this stage we usually apply our foreknowledge. This process leads us to our initial interpretation. Second, we apply such methods as the hermeneutic circle in order to enhance or finetune our interpretation. Finally, we should yield an intelligible interpretation which also explains well the phenomenon [48].

For example, consider the following: Lotfi Zadeh realized in the 1960's that the available computer models were inappropriate to several applications particularly when imprecise model entities were involved. As a creative person, who constantly aims to design better theories and models, he attempted to resolve this problem and his new position in the liberal university in Berkeley provided a good working environment for this. Hence, he introduced fuzzy systems in order to construct better models. We have thus provided one possible qualitative explanation on the formulation of fuzzy systems.

The goal-oriented behavior of the human beings is taken into account in the teleological explanations, and Aristotle applied one already referred to as the practical syllogism. Our goal-oriented behavior can be conscious (intentional) or subconscious by nature. For example, Lotfi Zadeh's inventions concerning fuzzy systems based evidently on conscious goals to provide better resolutions to computer modeling, whereas presumably due to the subconscious fear that the fuzzy systems will replace the traditional mathematical modeling, some scholars have aimed to avert the dissemination of these systems. As a borderline case we can also study goal-directed behavior which is common to beings and objects in both the animated and inanimated world. In this case the functions of these objects can give us the impression that these objects have deeper goals or end states but in fact these acts or functions are neither conscious nor subconscious by nature. Examples of these are the body temperature control of living beings and an auto pilot system in an aircraft. Thus, the goal-directed behavior belongs to the category of quasi-teleological or functional explanations.

Other models for explanation are also available such as the genetic and statistical explanations. Since the latter applies probability theory and statistics, we can also use fuzzified probability in this context. For example, we can provide a probabilistic explanation that the wide acceptance of the fuzzy systems in the Asian countries is likely due to their multivalent philosophical and religious traditions.

On the time axis the distinction between causal and teleological explanations means that, given the explanandum, the former attempts to find its causes from the past or present, whereas the latter focuses on the present or future events. For example, if we state that the fuzzy systems were invented because Lotfi Zadeh's new environment in Berkeley was sufficiently liberal for this work, we apply causal explanation. If, in turn, we state that the reason for this invention was that we could use better models in the future, a teleological explanation is used. Naturally, we can often use these explanations simultaneously:

PAST →	PRESENT	← FUTURE
Liberal environment	Invention of fuzzy systems	Better models
(causal explanans)	(explanandum)	(teleological explanans)

Although we already have several good fuzzy models operating in goal-directed systems, we still lack such systems which take into account the goal-oriented behavior of the human beings. The fuzzy goal-oriented systems would nevertheless be very useful in particular in the behavioral and social sciences, economics, game theory, decision making, decision support systems and even in robotics. Possible complementary methods in this context could be adaptive systems, cognitive maps, evolutionary computing, cellular automata, theory of networks and swarm theory, inter alia [1, 2, 7, 31].

Another interesting object of research within fuzzy systems would be approximate explanation. Niiniluoto suggests within his theory of truthlikeness that if we are unable to apply conventional explanations, we could use approximate explanations instead [29]. In an approximate explanation the explanans is in the neighborhood of the correct explanation, i.e., its truth value is not true but between true and false. Niiniluoto, however, applies bivalent logic in this context and thus his approach does not sufficiently correspond with the actual ideas of approximation and truthlikeness. With fuzzy logic, in turn, we can assign various degrees of truth to our approximate explanans as well as we can apply the approximate deduction of the FL+. In practice we thus assess the degree of similarity between our explanans and its true counterpart, and the higher the degree of similarity, the higher the degree of truth for our explanans is obtained.

For example, the statement that the engineers favor today fuzzy systems in computer modeling because they have proven to be good in practice since the 1990's, is a non-true explanation because the plausibility of these systems was recognized already in the 1970's and 1980's. Hence, we have one such possible approach to approximate explanation which can be subsumed under the FL+.

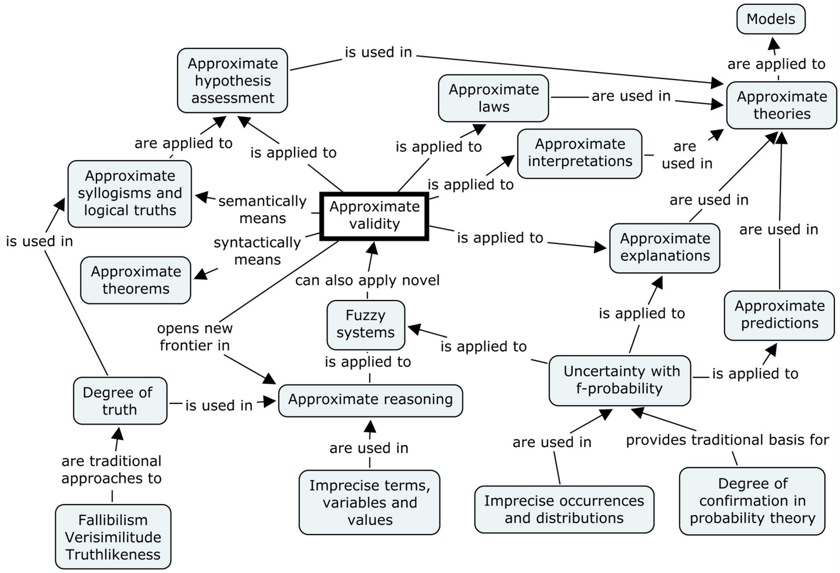

Fig. 2.4. The Possible Role of the FL+ in the Conduct of Inquiry

Since the scientific theories constitute descriptions, explanations, predictions and interpretations which base on our observations, experiments, formal argumentation and pure reasoning, we can also consider approximate theories. We can thus assume that if our theory is close to its true counterpart theory, we have formed an approximate theory, and we can even consider its degree of truth when fuzzy systems are used. In addition to Niiniluoto's theory of truthlikeness, Popper has considered this subject matter in his theory of verisimilitude from the bivalent standpoint [35, 36]. Popper presupposes that we aim to form true theories (cognitivism) but in practice our theories can be non-true. If we perform successful research, our theories will approach their true counterparts and thus they are always corrigible by nature. The similar idea is applied in Peirce's fallibilism, and in general, scientific realism has maintained this outlook (Peirce, Lenin, Popper, Hempel) [27].

Once again, fuzzy systems could open new vistas in theory formation, if we apply Zadeh's FL+ and the degree of truth to approximate theories. It also seems that several of our theories today are still non-true by nature. Fig. 2.4 depicts the possible role of the FL+ in the conduct of inquiry in general.

Summing up, such particular features of human beings as their goal-oriented behavior are often ignored when fuzzy systems are used in the human-scientific applications. This is due to the fact that quantitative methods are mainly used in this context, but we should also apply both traditional and fuzzified qualitative methods to a great extent. In addition, we should consider the application of such novel theories as the FL+ to approximate explanations and theories in general.

2.5 Aspects of Scientific Ethics

Ethical aspects have a growing importance in the scientific community and thus within fuzzy systems we should take them better into account in the future. In ethics we consider the approval or disapproval, rightness or wrongness, goodness or badness and virtue or vice of our judgments. We also study the desirability or wisdom of our actions, dispositions, ends, objects or states of affairs [40].

The empirical traditions in ethics focus on the studies on our moral behavior and explanations on our moral judgments. This approach is, in addition to such philosophers as Hume and some positivists, usually adopted in the social and behavioral sciences (e.g. Westermarck). The other, more “philosophical" traditions, mainly consider those moral principles or recommendations which guide our behavior or the ways of life. In both cases we can consider the judgments of our ethical values (axiology) and the judgments of our ethical obligations (deontology). The philosophical mainstream traditions in ethics have concentrated on the recommendation approach and deontology [40].

In the scientific ethics we examine those ethical principles, rules, norms, values and virtues which scientists should accept and follow in the conduct of inquiry. All researchers can encounter ethical problems in their studies and thus they should be familiar with the prevailing scientific ethics. However, to date there are no such universal rules available but we can only provide some guidelines, and some of these ideas already stem from Aristotle’s philosophy. Within the fuzzy systems research, in particular, we still lack such comprehensive ethical rules as the ethical code for the IEEE. Below we sketch a framework for establishing these rules for fuzzy systems.

First, as a professional person, we can presuppose that a researcher should be a good expert. This criterion means that he/she should have a good knowledge on the results and sufficient skills on applying the methods in his/her field. He/she should also be sufficiently creative to provide novel scientific knowledge. As an instructor and mentor, a researcher should disseminate his/her expertise to the students and to society [34].

In order to attain these goals, a researcher is usually expected to be truly enthusiastic in performing his/her studies in an honest, exhaustive and a critical manner. It is also widely presupposed that a researcher should not work for his/her personal or methodological school’s profit but rather for the benefit of nature and humanity. The social aspects, in turn, presuppose that the membership in the scientific community is possible for everyone, for example, for both men and women or rich and poor. If we consider the researcher’s profession at an even more general level, a question arises whether this profession is having some privileges concerning the ethical rules, i.e., due to the particular nature of this profession, are the researchers also working beyond the prevailing ethical principles [34]?

Second, a researcher should evaluate whether his/her research objects are ethically acceptable. Today we generally presuppose that our studies are public and they are not allowed to be injurious to nature or humanity, and thus military research and some areas in medicine and biology, for example, are problematic. It is also usual today that these research policies vary between the nations. On the other hand, it is characteristic of human nature to be always curious and thus to be interested in all the phenomena in the real world. Hence, in order to resolve this contradiction it is sometimes suggested that we are allowed to study anything but we should be selective in publishing our results. Another resolution has been a moratorium which, for example, has been applied to cloning. In practice, however, it is often problematic to estimate the possible risks or damages caused by our studies but in any case we must always attempt to consider thoroughly these consequences.

Third, we should consider our research methods. Today human experiments are strictly controlled by international laws, and according to them, our research should cause neither physical nor mental injuries to the persons under study. We must also guarantee the protection of privacy for these persons. A borderline case in this context is such injurious experiment in which the researcher only uses his/her own body.

The animal experiments, in turn, should evidently follow the rules similar to the human experiments, but in this context the corresponding laws are more flexible. However, it is generally presupposed that these animals should be treated well and we should also avoid to cause them unnecessary pain. In practice, for example, the medical animal experiments are more widely accepted than those carried out in the cosmetics industry. In addition, today we do not accept that the “intelligent" animals are used in these experiments.

Fourth, the autonomy of the scientific community is also problematic. It seems that the researchers usually wish to perform their studies independently, but in practice the political decision makers, business world and the funding sources aim to control this work. Hence we should find an appropriate equilibrium between these possibly contradicting aims.

Finally, today nature protection plays an important role in our globe and thus we can presuppose that our research should not cause any environmental hazards. It is even recommendable that we could promote the idea of sustainable development in our environment, technology, economy, education, world peace and health care.

Fuzzy systems usually require a high-tech environment with computers. Hence, in this respect, they can arouse some ethical problems. First, most of their research work is performed in the highly developed countries or only in the highly developed areas in the development countries. The poor areas in the world are thus outsiders in this work. In addition, the great majority of the researchers are still males. We could greatly expand our scientific community, increase our creativity potential and promote equality if these obstacles could be removed.

Second, many fuzzy applications are designed for military or business purposes. It follows that in these cases the data, methods and results are not necessarily public for the scientific community. It is also evident that these studies do not necessarily aim to the welfare of our nature or humanity.

Third, in the light of such crisis scenarios of futurologists which deal with the possible problems in our environment, economy, energy consumption and health, we could contribute more our efforts to resolve these problems because fuzzy systems seem to have a great potential in these areas. For example, appropriate fuzzy applications can reduce energy consumption, enhance medical and social care or provide user-friendly technology to such areas in our globe which still are at low educational stage. Since free and equal education for both boys and girls seems to be the silver bullet for attaining a high standard of living today, fuzzy systems research should empower this policy by producing good learning tools and aids for e-learning and instruction in general. Fortunately, many of the available studies serve already these purposes partially or implicitly.

Hence, today ethical aspects should always be taken into account within fuzzy systems research. These principles should correspond with such subject matters as the international laws and declarations concerning nature protection, human rights, equality, peace and sustainable development. A good starting point for this policy would be that we establish a global ethical code for the researchers who study fuzzy systems.

2.6 Conclusions

We have considered fuzzy systems from the standpoint of their metatheory, methodology and the philosophy of science. In particular, we have examined concept formation, argumentation, explanation, theory formation and ethics. In concept formation we should take more into account the actual nature of linguistic variables as well as psychological factors, because fuzzy systems apply such artificial languages which should correspond well the natural languages. Hence appropriate vocabulary and both syntactic and semantic rules are expected. Methods for good interpretations of data and documents are also required because the available, mainly quantitative approaches, seem to be insufficient.

In argumentation we should develop more the idea of approximation in the manner of the FL+. In the semantic examination we should consider fuzzified syllogisms, fuzzy validity and the degree of acceptance (or rejection) in hypothesis assessment. Syntactical examinations, in turn, should consist of approximate deducibility and theoremhood. We could also consider the distinction between induction and deduction when this fuzzy argumentation is used.

In the scientific explanation we should provide a methodological basis for approximate teleological and probabilistic explanations because they are essential in particular in the human sciences. We should also consider the possibilities for using approximate explanations generally in an intelligible manner.

Today ethical aspects are very important in the conduct of inquiry. Thus we should establish ethical code for those researchers who work with fuzzy systems. Another important subject matter, which is related to ethics, is sustainable development.

At a more general level, we should consider how the foregoing ideas can be applied to both traditional and approximate theories. We should also examine more the role of fuzzy systems in the human sciences, in particular in the qualitative research, because in these fields we should be able to operate with noisy numerical or non-numerical data sets, unique or non-recurrent events, non-numerical methods, linguistic and approximate reasoning, complicated networks of variables and only probable conclusions.

If we apply fuzzy systems in the foregoing manner, we can extend the frontiers of science and we can also apply better quantitative and qualitative methods in combination. It is even possible that we can thus bring the Western and Eastern outlooks closer to each other.

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