INTRODUCING STUDY FUZZINESS IN COMPLEXITY RESEARCH

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Abstract

Fuzziness, vagueness, uncertainty, imprecisely is something that we always found in our world. Thus, it's impossible to use classical logic in our effort to understanding the real world as complex system. Unlike classical logic which requires a deep understanding of a system, exact equations, and precise numeric values, fuzzy logic incorporates an alternative way of thinking, which allows modeling complex systems using a higher level of abstraction originating from our knowledge and experience. With fuzziology, we can find one kind of study fuzziness of human understanding when dealing with social complexity.

Keywords: fuzzy, fuzziness, fuzzy logic, fuzziology, complexity, complex system, edge of chaos, non-linear dynamic system.

1. Introduction

According to the Oxford dictionary, '*fuzzy*' is an adjective which have meaning: *dim, faint, hazy, foggy, misty, blurred, blurry, indistinct, unclear, vague, shadowy, indefinite, obscure, ill-defined, woolly, distorted*. By all this meaning, we can say something fuzzy if it related with something which we can not explain or understand using usual or common logic in human thinking process.

Logic to most people relates to two state of thinking, the idea that the outcome can only be either true or false, 1 or 0, right or wrong. This form of logic dates back to the ancient Greece and is perfectly adequate to answer simple questions in single dimensions. But in the fact human life are not facing with one dimensional world and much statements in our live is not simple enough to place in position right or wrong, true or false, 0 or 1. Fuzziness, vagueness, uncertainty, imprecisely is usually we found in our world.

Thus, when we want to know and understand our world, it is important to take fuzziness put into our study.

In the conceptual thinking, fuzziness relates to definition of fuzzy sets, as introduced by Lofti Zadeh, a professor at the University of California at Barkley, in 1965. Fuzzy sets introduced as the concept of a class with unsharp boundaries and marked the beginning of a new direction by providing a basis for a qualitative approach to the analysis of complex systems in which linguistic rather than numerical variables are employed to describe system behavior and performance. This approach canters on building better models of human reasoning and decision-making. His unorthodox ideas were initially met with some skepticism but they have since gained wide acceptance.

2. Fuzzy Set and Fuzzy Logic

2.1 Historicity of Fuzzy Set and Fuzzy Logic

The precision of mathematics owes its success in large part to the efforts of Aristotle and the philosophers who preceded him. In their efforts to devise a concise theory of logic, and later mathematics, the so-called "Laws of Thought". One of these, the "Law of the Excluded Middle," states that every proposition must either be True or False. Even when Parmenides proposed the first version of this law (around 400 B.C.) there were strong and immediate

objections: for example, Heraclites proposed that things could be simultaneously: True and not True.

It was Plato who laid the foundation for what would become fuzzy logic, indicating that there was a third region (beyond True and False) where these opposites "tumbled about." Other, more modern philosophers echoed his sentiments, notably Hegel, Marx, and Engels. But it was Lukasiewicz who first proposed a systematic alternative to the bi-valued logic of Aristotle.

In the early 1900's, Lukasiewicz described a three-valued logic, along with the mathematics to accompany it. The third value he proposed can best be translated as the term "possible", and he assigned it a numeric value between True and False. Later, he explored four-valued logics, five-valued logics, and then declared that in principle there was nothing to prevent the derivation of an infinite-valued logic.

Knuth proposed a three-valued logic similar to Lukasiewicz's, from which he speculated that mathematics would become even more elegant than in traditional bi-valued logic. His insight, apparently missed by Lukasiewicz, was to use the integral range [-1, 0 +1] rather than [0, 1, 2]. Nonetheless, this alternative failed to gain acceptance, and has passed into relative obscurity.

It was not until relatively recently that the notion of an infinite-valued logic took hold. In 1965 Lotfi A. Zadeh published his seminal work "Fuzzy Sets" which described the mathematics of fuzzy set theory, and by extension fuzzy logic.

2.2 Basic understanding about Fuzzy Logic

Fuzzy sets can be seen as an *infinite-valued logic*; set, the belongingness to which is measured by membership function whose value are in interval between 1 (full-belongingness) and 0 (*non-belongingness*). In formal, the definition can describe like this:

1. Let X be some set of objects, with elements noted as x. Thus,
   X = {x}.
2. A fuzzy set A in X is characterized by a membership function
   mA(x) which maps each point in X onto the real interval [0.0, 1.0]. As mA(x) approaches 1.0, the "grade of membership" of x in A increases.

Then the fuzzy set concept much used in Fuzzy Logic as a way processing data which next become a powerful methodology to problem solving in control system. Unlike classical logic which requires a deep understanding of a system, exact equations, and precise numeric values, fuzzy logic incorporates an alternative way of thinking, which allows modeling complex systems using a higher level of abstraction originating from our knowledge and experience. Fuzzy Logic allows expressing this knowledge with subjective concepts such as very hot, bright red, and a long time which are mapped into exact numeric ranges. Zadeh reasoned that people do not require precise, numerical information input, and yet they are capable of highly adaptive control.

Practically, the basic principles of fuzzy logic are:

1. In fuzzy logic, exact reasoning is viewed as a limiting case of approximate reasoning.
2. In fuzzy logic everything is a matter of degree.
3. Any logical system can be fuzzified
4. In fuzzy logic, knowledge is interpreted as a collection of elastic or, equivalently , fuzzy constraint on a collection of variables
5. Inference is viewed as a process of propagation of elastic constraints.

Let we take example of Fuzzy logic which operated in membership concept like in the statement 'Budi is fat'. The statement could be translated into set terminology as follow: 'Budi is the member of the set of fat guy' and would be rendered symbolically with fuzzy sets as m(FAT), where m is membership function, operating in this case on the fuzzy set of fat guy, which return value between 0.0 and 1.0 depending on the degree of membership. In figure 1 the objective term 'fat' has been assigned as fuzzy values. At 50 kg and below, the person does not belong to fuzzy class while for above 70, the person certainly belongs to category 'fat'. However, between 50 and 70 the degree of membership for the class 'fat' can be assigned from the curve varying linearly between 0 and 1. The fuzzy concept 'fatness' can be extended into 'thin', 'medium' and 'fat' as shown in Figure 2. This is different from the

probability approach that gives the degree of probability of an occurrence of an event (Budi is being fat in this instance).

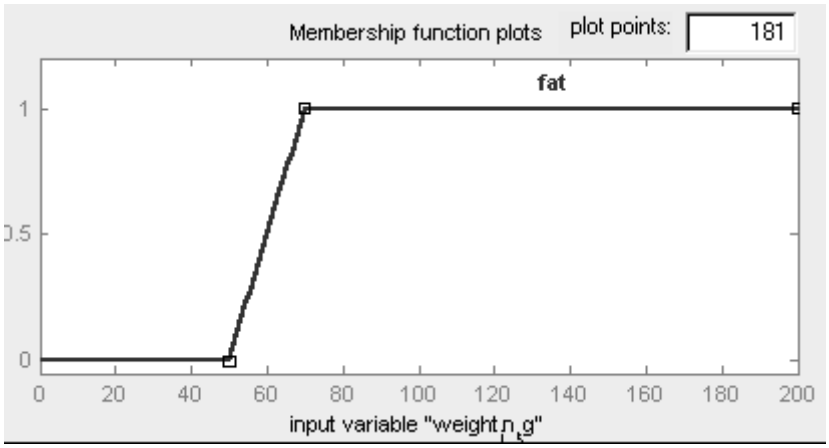

Figure 1. Graph showing membership functions for fuzzy set 'fat'

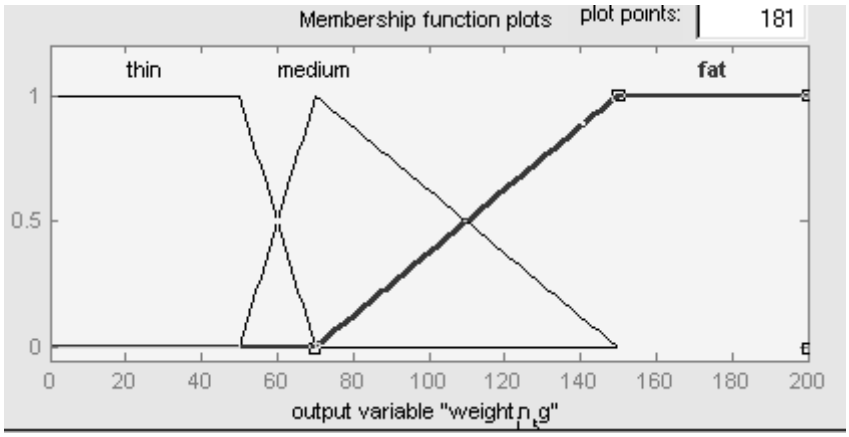

Figure 2. Graph showing membership functions for fuzzy sets 'thin', 'medium' and 'fat'

Real world as a complex system is full of vagueness and imprecise thing. Language as our tools to construct meaning repeatedly can not give single meaning. That is why every effort to assigning rigid values to linguistic variables means that some of the meaning and semantic value is invariably lost. Everything that can not defined precisely and everything that has not clearly boundaries in space and time is considered a bearer of fuzziness. That the reason why fuzzy system (fuzzy sets and fuzzy logic) can help us to describe and to understand our world where we lived in.

3. Complexity and Fuzzy Logic

Complexity approach is decidedly a new way of looking at things, and as such seem to throw out many of those traditional approach used in our scientific work. There is no standard definition of complexity because it depending on base language chosen, the type of difficulty focused on and the type of formulation desired with that language. But there is a consensus that the word complexity is used to refer to study of complex system, which in broad sense we can say that as a system consist of many interacting component. The use of term 'complexity' usually refers to some conditions such as size, variety, difficulty, order and disorder.

In essence a complex system is a functional whole, consisting of interdependent and variable parts, that's why we can not reduce when study it, because we would lose the sight of the properties. Complexity theory however requires that we threat the system as a whole, and thus have a description that includes all aspect. In a complex system it occurred interaction between the elements, which where the interaction take a place in non-linear and dynamic

condition. This interaction is very sensitive to initial condition and as the number of elements and interaction of a system increased, we can observe an 'emergent factor'.
Yet we can also say complex system as self-organizing system, self-producing system and as an un-predictable system. From all of this we can describe that complexity become from mixture between order and disorder state, the state which usually we called as edge of chaos.

Historically, complexity theory has been developed in 5 basic axes which complementary, there are non linear system theory, neural network approach, and computational progress in cellular automata, theory and the practical optimization in genetic algorithm, and distributed system theory and system which self organized. With these, there are so many things expected can be explained by complexity theory, some of them are explaining the emergent structures, measure relative complexity, provide control method for complex systems, generate effective models, etc.

In progress, the advance of computer technology and computation have resulted a kind analysis which accompany 2 analytical forms before (qualitative and quantitative analysis), we say that as computational analysis. This analysis helps very much in complexity approach in his effort to understand a complex system. With this analysis, we can make an artificial system and then we can simulate to see emergence in-deterministic factors.

Nowadays, we can see the expansion of complexity approach has been increasing in his effort to understanding and solving social problems. It happens because we're realize and we can see our social system as complex system which mean is in that social system consist interaction between the elements like interaction between human and interaction between human and his environment.

With looking a social system as complex system, then we urge to see and solve the problem with bottom up approach, that mean we must look the interaction pattern between the agents in the system. It can be a hard thing, when we must facing with fuzziness (vagueness, unclearly, uncertain, obscure) in the processes. It happens because our world is the world which fuzziness surrounded. Be up against it , then complexity must use a logic system which not like classic logic which relates to two state thinking, true or false, right or wrong, 1 or 0. As the complexity of a system increases, human ability to make precise and significant statements about its behavior diminishes until a threshold is reached beyond which precision and significance become mutually exclusive characteristic.

By this reason it seems that fuzzy logic can help us in complexity. It can be, because fuzzy logic as one of non-standard logic, provable can used in the effort to explain the thing that embedded fuzziness and also has yet been applied in engineering field as powerful methodology in control system. Fuzzy systems being inherently nonlinear however can deal with those situations hard to formulate in traditional linear mathematical terms, and this includes complex nonlinear machines and systems with multiple interrelated variables. That's why we can expect fuzzy logic becomes one of tools in complexity.

The applications which may be generated from or adapted to fuzzy logic are wide-ranging, and provide the opportunity for modeling of conditions which are inherently imprecisely defined. For example let we see figure 3. In this figure we can see usage of fuzzy logic in social studies. To understand the real world, people make observation and from this observation getting the data. Then people use the data to make analysis and model. The problem become in this part (see gray area with number 1), because in this part, people

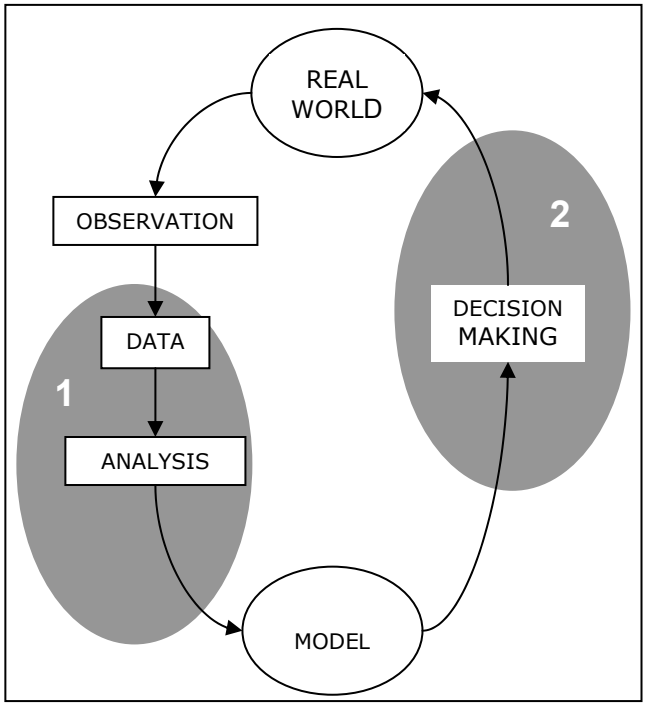

Figure 3. Social studies flowchart

usually make 'defuzzification'- the process eliminated fuzzy – in order to make the work easier, i.e.: we often see people make quantification using common logic (true or false, 0 or 1) by the tools like statistical. When they succeed in making the analysis and the model as the abstraction of the real world, then people try to implement that thing to real world. In this way, the model becomes tools in decision making.

But this model makes new problem when trying to implement. It's hard to make decision using this model which turns up from logic which relates to two states thinking – true or false, 1 or 0 – in order to face with real world. We realize that the real world is full with fuzziness, so it is impossible to make decision without consider the fuzziness of world.

According to this problem, it is important to make refuzzification. It means we make the fuzzy of the world be included again in ours decision. In the figure 3, we can see that process take place in grey area with number 2. We used fuzzy logic in this area as tools to help us in decision making and as decision supporting system.

4. Fuzziology as one kind study of fuzziness in Complexity

Fuzziology is one kind study about fuzziness, and according to fuzzy as an adjective, which mean it is about concept in our mind or our brain, fuzziology study fuzziness of human understanding. When studying fuzziness of human understanding, fuzziology focuses on the ways of transcending both duality and non-duality inherent in thinking.
With duality the mind constantly asserts:

A is true and therefore not A is not true, or
A is not true and therefore not A is true.

Non-dualism accepts that

both A and not A are true up to some degree (the case of fuzzy logic), or
neither A nor not A are true.

Both duality and non-duality keeps the mind entrapped in logical speculations, leading either towards confrontation (in the case of dualistic thinking) or towards compliance (in the case of non-dualistic thinking).

Any insightful act of understanding vitally needs the energy of polarities expressed in dualistic thinking as well as serenity accompanying their reconciliation in the framework of non-dualistic thinking. The way to use simultaneously advantages of dualistic and non-dualistic thinking is through expanding our consciousness so that we could flexibly switch from one to another mode of thinking, without being attached to anyone of them.

4.1 Conceptual Basic of Fuzziology

Even the focus in fuzziology is fuzziness in human live, fuzziology is not another mathematical study of fuzziness, and social fuzziology is not another field of application of fuzzy logic. Fuzziology sees that every part in human life had fuzziness therefore it affects any field of human activity.

Fuzziology are the study about fuzziness in human live. We always were facing with fuzziness in our lives; in our experience as a process to find truth, knowledge and wisdom. These processes repeatedly become paradox, like Meno's Paradox in classic story from ancient Greece. Plato describes Meno's paradox of learning in the following way:

- If we don't know what X is, how we can recognize it?
- If we can't recognize X, how can we learn what X is?

Socrates reformulated Meno's paradox into general paradox in human inquiry:

- We know what X is. (then we are not motivated to inquire into what X is)
- We don't know what X is. (then we are motivated to inquire, but are frustrated by the paradox, since we can't recognize instances of X, or what X is in general, to find out what X is)

Socrates approach to this paradox of human inquiry includes three steps includes: (1) generating hypotheses; (2) testing the hypotheses against examples and human experience; (3) philosophic examination of the hypotheses. While examining what people consider as known, Socrates draws out implications and asks questions that may lead them to

contradiction (incoherence), circularity (presupposing what is at issue), infinite regress or other violations of epistemic norms.

The method of inquiry used by Socrates made him aware of the following famous paradox:

The less we know, the more certain and precise we are in our explanations; the more we know, the more we realize the limitations of being certain and precise.

This paradox describes all things happened in dramatic process to inquiry and to prove something in our live. This real world full with vagueness, imprecise thing and the acknowledgment of the fuzziness in our knowledge serves a stimulus for the lifelong inquiry and search for truth and wisdom; and it is this search that makes human life meaningful. Meno's paradox and the paradox of Socrates are at the conceptual basis of Fuzziology.

4.2 Basic postulate of the fuzziology

Fuzziness studied by fuzziology is not 'over there', not in an outer world separated from us, but in the inner world of our own experience, in the 'swarm' of our thoughts and ideas, emotions and feelings, beliefs and dreams. We see and understand as much from the outer world - the world in which we live - as we have already developed inside us while learning how to enrich our experience, hone our awareness, expand our consciousness and strengthen our capacity to sense, think, create and know.

Basic postulate of fuzziology is: Our understanding and knowing grow from within us and cannot be implanted or imposed from without. Human understanding and knowing are self-organizing processes; and any self-organizing process in nature work from inside out. Our perceptions of reality, our experience of the events of life, our thinking and feeling, understanding and knowing are deeply rooted in the life of society and its development; we are simultaneously creators and products of society. The processes of our understanding and knowing are social in their origin and nature. So is the fuzziness embedded in them. Therefore we refer to fuzziology as social fuzziology.

4.3 Principles and Theorems of Fuzziology

These are the principles used most in fuzziology:

- Principle of Incompatibility (Zadeh, 1973): As the complexity of a system increases, human ability to make precise and relevant (meaningful) statements about its behaviour diminishes until a threshold is reached beyond which the precision and the relevance become mutually exclusive characteristics. It is then that fuzzy statements are the only bearers of meaning.
  This principle was used by Zadeh for extending the applicability of his fuzzy sets theory and fuzzy logic to the analysis of complex systems.
- Principle of Connectivity-in-Dynamics: No thing and no being can exist in itself or for itself but only in a dynamic relationship with other things and beings.
  This principle relates to the integrity of existence vitally supported by universal dynamics, whose creative, sustaining or destructive powers are constantly demonstrated at different scales of the manifested world. Is it through these dynamics that everything that exists? From an elementary particle to a gigantic galaxy becomes connected in an all-embracing web of relationships?.
- Principle of the Fractality (Mandelbrot, 1982): The geometry of nature is fractal and reveals itself as self-similar structures at different scales of manifestation.
  This principle is at the basis of Mandelbrot's theory of fractals and demonstrates the way self-organization works while unfolding the complex dynamics of nature. Self-similarity is a kind of fuzzy repetition; each scale has common features with every other, and yet there are noticeable differences. Fractals are inherent in the holistic unfolding of individual, social and existential dynamics: the macrocosm is a fuzzy projection of the microcosm, the external world of individuals is a fuzzy projection of the inner world of their experience, each level of development of consciousness has similarity both with the previous (less developed) and the next (more advanced) levels and yet has its own distinguishable characteristics, its own strength and weakness.

By using the principles above, we can get two theorems become the basic principles used in fuzziology.

Both theorems are:

1. First impossibility theorem
   It is impossible to eliminate fuzziness from any explanation that tends to make sense of
   - the wholeness of the existential dynamics
   - the infinity of their manifested activities.
   - the immensity of their potentiality to create .

   This theorem can prove with following principle of incompatibility and principle of connectivity.
2. Second impossibility theorem
   It is impossible to deal with fuzziness related to a higher level of consciousness from the point of view of a lower level of consciousness.
   The proof of this theorem follows from the Principle of Fractality when applied to the unfolding of existential dynamics.

4.4 Fuzziology and Fuzzy Logic

Even fuzziology and fuzzy logic talk about the same topic, fuzziness, but there are different between fuzziology and fuzzy logic. In the table below we can see the differences between FL and possible forms of fuzziology.

Fuzzy Logic	Fuzziology
Studies classes in which there are no sharp boundaries from membership to non-membership and their applications mainly in the engineering practice.	Studies fuzziness inherent in human experience and knowing, its sources, nature and dynamics, and the ways people deal with it.
Explores a specific type of imprecision associated with the definition of a fuzzy set.	Explores fuzziness as a universal characteristic of human experience and knowing.
Converts human perception into precise symbols for further computer-based processing.	Deals with human perceptions as they are - impregnated with an irreducible fuzziness.
Serves the purposes of control - control over technological processes and machines, engineering systems and robots, natural environment, people, economy and society as a whole.	Serves to sharpen human awareness about the fuzziness of what is considered known, and by exploring its sources, nature and dynamics helps to transcend the limitations it puts on human understanding.
"Accept or reject up to a degree among a given set of possibilities!"	"Don't reject, but don't stay with it either; go beyond the known!"
Uses fuzzy sets, probabilistic reasoning and soft computing.	Uses insights from the ancient wisdom and nonlinear science.

4.5 Fuzziology and Complexity

When developing its approach to study fuzziness, fuzziology acknowledges its dynamic character and makes an emphasis on the following four points:

1. Fuzziness has its sources and supporters, causes and effects, activators that increase it and make it denser and thicker, inhibitors that decrease it and make it rarer and thinner, exposures that make it easily recognizable and obscurer that make it hidden and hard to be disclosed.
2. Fuzziness has its own dynamics - forces and energies that make it move, change, evolve and transform, and its own carriers that are either immaterial like thoughts, ideas, feelings, emotions, longings, beliefs, dreams, aspirations, energy fields and spaces, or embodied in concrete human actions, in specific non-animated and animated forms, in discernible experiential events, in various kinds of signs and omens, phenomena and processes, human-created products and machines.

3. Fuzziness is able to self-organize into dynamic patterns with boundaries that can become rigid and hard-to-surpass or soft and easy-to-permeate, to form attractors or repellers in the experiential or mental space of the individuals, to structure into layers (levels) of fuzziness going deeper into one's thoughts and feelings, or into whirlpools (vortices) of mental, emotional or spiritual energy producing creative forces - powerful individual urges and drives - that enable fuzziness to transcend the boundaries of its dynamic patterns, to move from one level to another, from one attractor to another, from an individual to another.
4. Fuzziness can never be fully eliminated from the human perception of reality and experience of life - from our thinking and feeling, from our understanding and knowing.

But at the same time fuzziology does not directly explore complexity as a 'non linear behavior of the system at the edge of chaos'; the study of this kind behavior is the focus of complexity science. So fuzziology is not merely apart of the research in complexity, and nor is complexity reducible to fuzziology. From the Zadeh principle's of incompatibility which say that human ability is diminishes to make precise statements about its behavior as the complexity of a system increases, until a threshold is reached beyond which precision and significance become mutually exclusive characteristic, make the consequence to locates fuzziness in human capacity to make or find meaning in statement, not in objects themselves. This situates the centre of fuzziology outside the complex systems and the complex world these statements are about. Fuzziology is not a substantive science making truth claims about the world. It is a kind of meta science concerned with human capacity to make sense of the world.

The threshold mentioned in Zadeh's incompatibility principle can be connected with the idea of the edge of chaos, the zone where highly productive between order and chaos. It was where new more complex forms of order were born, order out of chaos. Zadeh's major contribution to this thinking was to realize that as this boundary or threshold is approached, the old rules of thinking become inapplicable and break down. From this, we make three observations, i.e.:

1. The concept edge of chaos appeared fuzzy to our mind, and needed to be so. It is poetic rather than scientific, though it was created as a result of computer experimentation with cellular automata. It connects with sensuous physical experience at the same time as it makes links between physics and biology.
2. The concept is therefore simultaneously a major concept in complexity and also a significant example of the creative and productive use of fuzzy thinking to put into the laboratory of social fuzziology.
3. Thus, fuzziology and the theory of complexity and chaos are not adjacent but related fields of thought, and are more like complementary traditions that flow into the same broad stream of thought. Complexity and chaos theory has so far been exciting and productive as an invisible and unacknowledged branch of fuzziology, renovating the resources of scientific thinking, rather than directly contributing to the stock of scientific knowledge.

Fuzziology needs the ideas of people who work in the field of complexity and chaos because these ideas are such wonderful examples of holistic thinking at work in the sciences. Complexity and chaos need fuzziology as a framework for them to recognize what it is and what it needs to do so that it can do it more and better, and be understood and valued for what it is.

5. Concluding Remark

Fuzzy systems, including fuzzy logic and fuzzy set theory, provide a rich and meaningful addition to standard logic. We have seen one of the developments study about fuzziness in complexity approach through fuzziology. This is very interesting, but of course there is still chance and challenge to use fuzzy logic in complexity in another form, because the fuzzy set theory attempts to follow more closely the fuzziness that is inherent in most natural language and in decision-making processes.

We expect the progress of new forms usage of fuzzy logic, example in attempting to quantify complexity theory. In the analysis of nonlinear system we need a way of quantifying many interacting variables and fuzzy logic provides this, generating a result that maps all possible interaction of the inputs. This technique has importance in the potential to threat multiple conflicting variables in decision making. Many systems may be modeled, simulated,

and even replicated with the help of fuzzy systems, not the least of which is human reasoning itself.

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