1

In the Beginning Was the Word, and the Word was Fuzzy

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1.1 Fuzziness of Our Lives: A Personal Story

The world is awesome. The world is immense and complex, it is not easy to understand, not easy to change – but we humans have mastered it reasonably well. Because of the unstoppable progress of human knowledge, we live happier and longer lives, we travel faster, we recover faster from illnesses and accidents. During the millennia of our civilization, great geniuses provided breakthrough insights, and numerous scientists and engineers, geniuses and simply talented, translated these insights into practically useful ideas.

In the history of science, we can track many such insights – e.g., the idea of an atom. The history of ideas is fascinating and complex, but in a nutshell, each idea follows the same basic trajectory: First, we have a vague philosophical idea, then it is transformed into a more precise (but still somewhat vague) idea formulated in the language of natural sciences, and finally, the idea becomes described in the absolutely precise language – language of mathematics.

I have always been fascinated by the two extremal point of this process: the original philosophical insight and the final absolutely precise mathematical model. Because of this fascination, I decided to study Math – with the emphasis on its fundamental applications to science and engineering.

What are the main objectives of science and engineering? Our ultimate objective is to improve the world. For that, first, we need to know how the world operates, what will happen if we perform a certain action (or if we do not do anything). Making such predictions is the main objective of natural sciences: physics, biology, etc.

Once we know how the world operates, once we know what are the possible consequences of different actions, of different decisions, we can start deciding which actions, which decisions are the most beneficial. This is the subject of optimization, engineering, decision making, and other related disciplines. To make a meaningful decision, we must know which outcome is more beneficial to us – and which outcome is less beneficial; for complex decision, this is not easy to decide.

Finally, once a general decision is made, once an engineering design is selected, we need to find the details of this design. In other words, we need to translate a general description (e.g., an abstract mathematical description) of the desired decision into an exact sequence of well-defined steps – i.e., into an algorithm.

Surprisingly, everything is fuzzy. Because of my interests, I started attending three research seminars: a seminar on mathematical aspects of physics and space-time geometry led by Revolt Pimenov, a seminar on decision making and game theory led by Nikolai Vorobiov, and a seminar on algorithmic (constructive) aspects on mathematics and corresponding mathematical logic led by Nikolai Shanin – all three leading Russian researchers in their areas. Since these were seminars organized by the Math department, I expected a lot of mathematical models and proofs, and there were a lot of them. But surprisingly, all three researchers emphasized the extreme importance of informal, vague ideas and of imprecise reasoning.

I was not that surprised that when we describe human decision making or human reasoning, we need to take into account human imprecision. However, I was really surprised to learn that theoretical physicists, even the most mathematically skilled ones, use informal reasoning and intuition to decide which terms in the corresponding complex equations are "small" and can therefore be ignored – without explicitly defining what "small" means. Moreover, physical equations are usually so complex that without such simplifying reasoning, it is not feasible to come up with any solutions. A convincing example comes from the history of General Relativity: a famous mathematician David Hilbert came up, in 1916, with the same equations as Einstein with a delay of only two weeks – *but* all Hilbert had was equations, while Einstein also had approximate solutions, solutions based on informal reasoning, solutions that could be (and were in 1919) experimentally checked.

From Hegel to Zadeh. To tell the truth, I should not have been that surprised, because in the former Soviet Union, we all studied philosophy, and one of the main messages – coming from Hegel, a beloved philosopher of Marx and Lenin – was that the traditional two-valued logic was not always adequate for describing human reasoning. First, real properties are not always absolutely true or absolutely false – they are only true to a degree. Second, human reasoning is dynamic, our opinions change with time, real properties change with time, while the traditional logic is static. This was part of what Hegel called dialectics.

And this was something we hated because it was coming from our brutal communist dictators, dictators who did not hesitate to throw a well-known professor in jail just for reading books published in the West and for expressing their opposition to the regime in private talks. One of such arrested professors was Revolt Pimenov. He got off easily: instead of a long term in a prison hard-labor camp (that he endured in the 1950s), he was sentenced to an internal exile to a far North town. I visited him there, and you know what he talked about? Hegel. Pimenov loved Hegel, he believed that Hegel's vague ideas had great potential. He was not deterred by the fact that Communists loved

Hegel: they also loved the music of Tchaikovsky and Beethoven, but they are still great composers – as well as Wagner is a great composer irrespective of the fact that Hitler loved his music.

Coming from Pimenov, a person who was not allowed to leave the town and had to weekly report to the political police, this was convincing. I started reading all this seriously. And then I happened to read some papers by Lotfi Zadeh and realized that this is it, this is – finally – a precise mathematical presentation of the vague ideas about vagueness.

I published this connection in one of my reviews in Zentralblatt für Mathematik – a mathematical review journal. I described this connection as a report in my philosophy class – and not only I got an A+, I – a student of Jewish origin – was invited to a post-graduate program in philosophy of math, an invitation which at that time (of the official Soviet persecution of Jews) was almost unheard of. (This invitation did not work out, by the way :-)

From theory to practice. Fuzzy logic became one of my areas of interest. At first, I was mostly interested in mathematical, theoretical aspects of fuzzy techniques. But it so happened that in 1980, after defending my PhD (in space-time geometry), I started working at the Institute of Electrical Measurement Instruments, where we were not only developing theoretical foundations but also helping to solve practical problems related to measurements and measuring systems. When talking to scientists and engineers, we realized that in their practice, in addition to measurement results, they use their intuition, their imprecise knowledge that they cannot express in exact mathematical terms – only in terms of natural language words like “small” or “very small". Some researchers proposed to use fuzzy techniques to handle this knowledge. My boss Gennady Solopchenko asked me, as a professional mathematician, to help Leon Reznik, his doctoral student, to look into these papers and to see how fuzzy techniques can be applied to our problems. I was hooked. Mathematics was interesting and still simple enough to be useful, and practical consequences of taking this imprecise knowledge into account were impressive. Leon incorporated fuzzy techniques into an automated system for testing combustion and jet engines – a system that became a crowning point of his dissertation.

From slavery to freedom. Soon after that, I emigrated to the US. Now I was able to attend conferences; previously, as most Soviet scientists, I could not attend conferences outside USSR without KGB permission – and this permission was almost never given. Now I was able to submit papers to international journals – previously, I could not do it without KGB permission which was almost never given; I was once summoned to the KGB and threatened with jail for smuggling my math paper abroad.

I saw all the great people doing research in fuzzy, I saw Lotfi himself – and I was amazed to realized that not only he was a great researcher, he was also a tireless promoter of fuzzy techniques, a tireless helper to young people – in short, a true leader.

Fuzzy is one of my main research interests – the other is a related area of interval computations. I am happy. I am happy that my results and applications – as well as results and applications of others – help solve practical problems. Not everything is perfect in this world – to put it mildly – but I look optimistically into the future. Human ingenuity, human goodwill have overcome many crises, and I am sure that eventually, the future will be good.

What will be the role of fuzzy in this future?

1.2 Future of Fuzzy

Fuzzy is – and will be – ubiquitous. In the past, there was a lot of publicity about the use of fuzzy techniques in the cars, camcorders, trains, elevators. You do not see that many article about fuzzy in the popular press anymore. Does that mean that there are fewer applications of fuzzy? Not at all. For example, in his plenary talk at the 2011 NAFIPS conference, Dimitar Filev mentioned that many control systems in the cars use fuzzy control. Fuzzy techniques have become so natural and commonplace that the newspapers no longer consider it worth mentioning. After all, calculus is also used a lot in engineering practice – but there are not too many articles in the newspapers about the use of calculus (or the use of algebra, about the routine use of computers) – because this is now mainstream. Similarly, fuzzy has largely become mainstream.

This is exactly what Zadeh intended – to create a new tool that is often helpful, this is what fuzzy has largely become, and this is what it will be in the future.

Future of fuzzy: research directions. The successes of fuzzy techniques do not mean that all the problems have been solved. Far from it. There are many technical problems. And there is also an important fundamental problems that still needs to be researched further.

Indeed, as we have mentioned earlier, according to Hegel, there are two main reasons why the traditional logic is not fully adequate to describe human reasoning: first, it is crisp, while the actual reasoning is often fuzzy; second, it is static in the sense that truth values do not change, while human reasoning is dynamic. There are a few articles about dynamic fuzzy logic [2, 3, 4, 5] but this direction is still not very well developed, and this is where a lot of progress still has to be made.

New application areas. As of now, most successful applications of fuzzy are to engineering. However, as I mentioned, my interest in fuzzy started because I realized the importance of imprecise reasoning in physics. As of now, there are few applications of fuzzy to fundamental physics; see, e.g., [1]. This is the area where I expect most progress in the future, and I think that it will help physics a lot.

Instead of conclusion: future is fuzzy, and fuzzy is future. With all this progress, fuzzy techniques – as part of a general scientific toolbox – will undoubtedly continue to excel.

Acknowledgment

This work was supported in part by the National Science Foundation grants HRD-0734825 and DUE-0926721, by Grant 1 T36 GM078000-01 from the National Institutes of Health. My most sincere thanks to Rudolf Seising, Enric Trillas, Settimo Termini, and Claudio Moraga for their invitation, to all fuzzy researchers for being such a great community, and, of course, to Lotfi Zadeh, who started this area, who inspired us all – and who continues to generate great ideas.

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