FUZZY LOGIC—FORTY YEARS LATER A PERSONAL PERSPECTIVE

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- *Early history—a rocky road*
- *Where are we today?*
- *A glimpse into the future*

Early History--

A Rocky Road

FUZZY LOGIC—KEY POINTS

- *"Fuzzy logic" is not fuzzy logic*
- *Fuzzy logic is a precise logic of approximate reasoning and approximate computation*

The principal distinguishing features of fuzzy logic are:

a) *In fuzzy logic everything is, or is allowed to be graduated, that is, be a matter of degree*

b) *In fuzzy logic everything is allowed to be granulated*

Early History

- *Although I am not a mathematician by training, I always had a deep admiration for mathematics and mathematicians, and believed that most real-world problems have a mathematical solution. But gradually, I began to realize that many real-world problems are much too complex and much to imprecise to lend themselves to analysis based on classical, Aristotelian logic—a logic which is intolerant of imprecision and partial truth.*

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- ***Reflecting this change in my outlook, in a 1962 paper entitled, "From Circuit Theory to System Theory" I said: "We need a radically different kind of mathematics, the mathematics of fuzzy or cloudy quantities which are not described in terms of probability distributions." It is this perception that motivated my conception of the theory of fuzzy sets and fuzzy logic.***

CONTINUED

- ***My interest in machine intelligence and mechanization of human reasoning has a long history, going back to the beginning of my academic career. In a paper published in January 1950 entitled, "Thinking Machines—A New Field in Electrical Engineering," I expressed the view:***

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- ***"Through their association with mathematicians, electrical engineers working on thinking machines have become familiar with such hitherto remote subjects as Boolean algebra, multivalued logic, and so forth. And it seems that the time is not far distant when taking a course in mathematical logic will be just as essential to a graduate student in electrical engineering as taking a course in complex variable is at the present time. Time marches on."***

CONTINUED

- *My first paper on fuzzy sets was published in 1965. For many years thereafter, fuzzy set theory and fuzzy logic were objects of controversy, derision and debate. Among my few early supporters was my best friend, Richard Bellman, the father of dynamic programming. This is what he wrote when I sent him the manuscript of my paper, "Fuzzy Sets."*

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Journal of Mathematical Analysis and Applications

Dear Lotfi:

I think that the paper is extremely interesting and I would like to publish it in JMAA, if agreeable to you. When I return, or while in Paris, I will write a companion paper on optimal decomposition of a set into subsets along the lines of our discussion.

Cordially,

Richard Bellman

Letter from Max Black, Cornell University

June 21, 1967

Dear Professor Zadeh,

You were good enough to send me, some time ago, some of your recent papers on topics connected with "Fuzzy Sets." If I have not written before, the reason has not been lack of interest, but an inescapable press of other duties.

Now that I have had a chance, at last, to study your work, I want to express my admiration and interest. I believe that your ingenious construction promises to provide intellectual tools of great value.

In case you have not come across it, I might draw your attention to an early article of mine, entitled "Vagueness" (Philosophy of Science, Vol. 4, 427-455; reprinted in my book, Language and Philosophy, Cornell University Press, 1949). A more recent article on similar topics is "Reasoning with Loose Concepts" (Dialogue, Vol. 2, June 1963, 1-12).

I would be happy to see offprints of any of your further publications.

Yours sincerely,

Max Black
Director

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- *A country in which fuzzy set theory and fuzzy logic were welcomed with opened arms was Japan. Just a year after the publication of my first paper on fuzzy sets, I received two letters which are excerpted below.*

Electrotechnical Laboratory, June 14, 1966

Dear Prof. Zadeh:

My name is Hidemitsu Ogawa, I am the official engineer of the Ministry of International Trade and Industry, Japanese Government. I am making research in pattern recognition at the Electrotechnical Laboratory.

I read with very interest your paper on "Fuzzy Sets" in Information and Control. I will tell you my impression. I think that the concept of a fuzzy set is very important for problems of pattern recognition and information processing. In these fields, the notion of a fuzzy set provides us with good visibility."

Sincerely,

Hidemitsu Ogawa

Electrotechnical Laboratory

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Nippon Hoso Kyokai, 1966

Dear Sir,

In one of the last volumes of "Information and Control," I have read your interesting papers on "Fuzzy Sets."

We are working about 'Pattern Recognition,' 'Artificial Intelligence' or something like that since just a short time, and therefore I am highly interested in your work.

Yours sincerely,

Yoshinori Uesaka

INTERDISCIPLINARY COLLOQUIUM ON MATHEMATICS IN THE BEHAVIORAL SCIENCES

Discussion of "Fuzzy Sets and Concepts," by L.A. Zadeh on November 18, 1966.

Arthur Geoffrion (WMSI)

I agree with your remark during the Colloquium that the present development of fuzzy sets is probably still overly restrictive for many potential applications. It is applicable when there is a standardized and perfectly accurate method of measuring degree of class membership, but it seems to be considerably less applicable otherwise, as when opinion is involved.

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H.P. Edmundson (Linguistics, UCLA)

Professor Zadeh's view that the concept of fuzzy sets seems to be needed in many disciplines has been supported by comments today from specialists in the fields of psychology, economics, and logic. In this connection I would like to point out that fuzzy sets also arise in linguistics. In particular, in the study of semantics, attempts to formulate satisfactorily the notion of a semantic space using crisp sets has essentially failed.

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As a consequence, the modeling of meaning as a set of senses or the modeling of synonymy in terms of equivalence classes has proved difficult to justify either theoretically or empirically. It seems likely that the concept of fuzzy set will provide a way to account for what has been called a "semantic space" and lead to a suitable metric or pseudometric. Similarly, it also may lead to a satisfactory way to replace the strict dichotomy of sentences as grammatical or ungrammatical, by a more natural concept involving grade of membership.

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- ***Many others were not so kind. Here is a sample. Following the presentation of my first paper on the concept of a linguistic variable, Professor Rudolf Kalman, a brilliant scientist and a good friend of mine, had this to say:***

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"I would like to comment briefly on Professor Zadeh's presentation. His proposals could be severely, ferociously, even brutally criticized from a technical point of view. This would be out of place here. But a blunt question remains: Is Professor Zadeh presenting important ideas or is he indulging in wishful thinking? No doubt Professor Zadeh's enthusiasm for fuzziness has been reinforced by the prevailing climate in the U.S.—one of unprecedented permissiveness. 'Fuzzification' is a kind of scientific permissiveness; it tends to result in socially appealing slogans unaccompanied by the discipline of hard scientific work and patient observation.

In a similar vein, my esteemed colleague Professor William Kahan—a man with a brilliant mind—offered this assessment in 1975.

"Fuzzy theory is wrong, wrong, and pernicious." says William Kahan, a professor of computer sciences and mathematics at Cal whose Evans Hall Office is a few doors from Zadeh's. "I can not think of any problem that could not be solved better by ordinary logic."

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"What Zadeh is saying is the same sort of things 'Technology got us into this mess and now it can't get us out.'" Kahan says. "Well, technology did not get us into this mess. Greed and weakness and ambivalence got us into this mess. What we need is more logical thinking, not less. The danger of fuzzy theory is that it will encourage the sort of imprecise thinking that has brought us so much trouble."

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- ***Two decades later, at an award ceremony of ACM, Professor Kahan, a good friend though a severe critic of fuzzy logic, had this to say:***

Lotfi I hope you enjoy good health long enough to be invited to the White House to receive from the President a medal…

"for successfully distracting the Japanese for so long."

MY RESPONSE

- ***I appreciate the point made by Professor Kahan. I would feel even more complimented had he added to the list the Chinese, the Russians, the Germans, the French, the Italians, the Spanish, the Dutch, the Indians, and the Poles, among others. After all, it takes a very special talent to be able to fool so many people for so long.***

NEAR MISS

Golden Fleece Award, awarded by Senator William Proxmire

- ***Senator Proxmire singled out "Fuzzy Logic" as an example of NSF's waste of taxpayer's money. I came close to winning this award.***

- ***Note: I have never met a critic of fuzzy logic who had an understanding of what it is.***

Garrett Birkhoff, Harvard University, Department of Mathematics

March 14, 1974

Dear Professor Zadeh:

My friend Yosh Shimamoto kindly sent me a xerox copy of your admirable editorial on "Mathematics—A Call for Reorientation", perhaps from the IEEE Newsletter. (If from the SIAM or CBMS Newsletter, I must have missed it!)

I want to distribute copies to all my colleagues here, and the copy I have is already about fourth generation xerox. Could you perhaps send me a clean, dark copy?

Incidentally, I also like "fuzzy sets".

Sincerely,

Garrett Birkhoff

A COMMENT ON "FUZZY LOGIC"

San Jose Mercury News Review 3-7-93

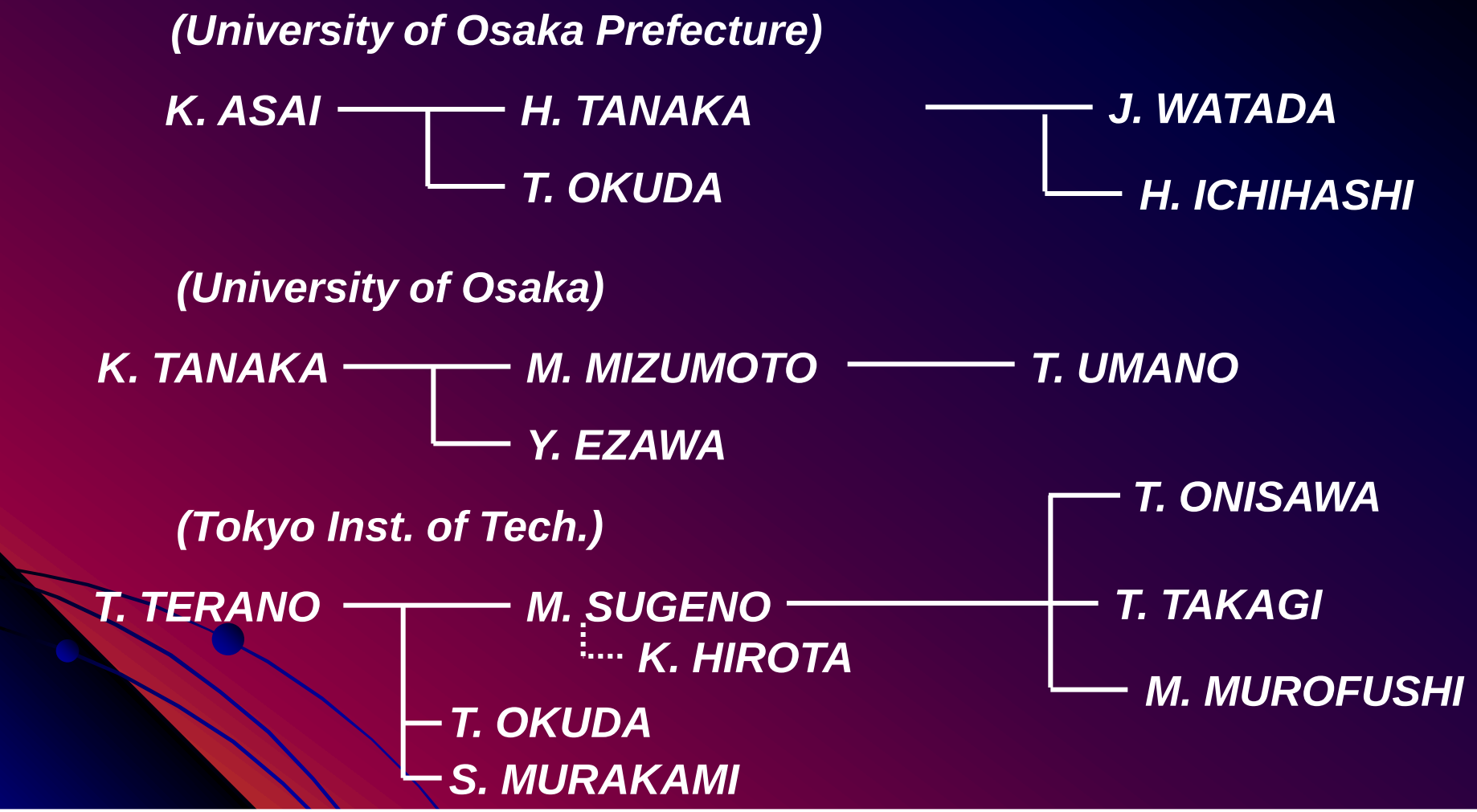
"Fuzzy logic is the prodigal technology of the 90's. Invented by a University of California, Berkeley, professor in 1964, it has found far greater understanding and acceptance in Japan, where it is used in everything from subways to washing machines."

"Now, amid ever sharper concerns over America's technological slippage—counterposed by the Clinton administration's high-tech zeal—fuzzy logic is finally finding some respect. Of all the sciences intended to make machines behave more like humans—including artificial intelligence, virtual reality, and neural networks—fuzzy logic appears to have the inside track in practical applications."

CONTINUATION

- *Important contributions to fuzzy set theory began to appear in Japanese journals in 1968. The early pioneers were Professors Asai, Tanaka and Terano. Here is a sample of early papers.*
  - *Hirai, H., Asai, K., and Katajima, S. (1968), Fuzzy automation and its application to learning control systems, Memo, Fac. Of Eng., Osaka City University.*
  - *Mizumoto, J., Toyoda, J., and Tanaka, K. (1969), Some considerations of fuzzy automata, Jour. Of Comp. And System Sci.*
  - *Kitajima, S., Asai, K. (1970), Learning controls by fuzzy automata, Jour. Of JAACE 14, 551-559.*
  - *Mizumoto, M., Toyoda, J., Tanaka, K. (1970), Fuzzy languages, Trans. IECE.*
  - *Tanaka, K., Toyoda, J., Mizumoto, M., Tsuji, M. (1970), Fuzzy automata theory and its application to automatic controls, Jour. Of JAACE.*
  - *Mizumoto, M., (1971), Fuzzy set theory, 11th Prof. Group Meeting on Control Theory of SICE.*
  - *Sugeno, M., (1971), On fuzzy nondeterministic problems, Annual Conference Record of SICE.*
  - *Terano, T., (1971), Fuzziness and its concept, Proc. Of Symp. On Fuzziness in Systems and Its Processing, Prof. Group of System Engineering of SICE.*

GENEALOGICAL TREE



(Meiji Univ.)
M. Mukaidono

(Univ. of Kumamoto)
T. YAMAKAWA

(Univ. of Kyoto)
S. IWAI, S. KATAI, M. SAKAWA, H. FURUTA

CONTINUATION

- *An important event in the evolution of fuzzy logic and its applications was the 1974 Japan-USA Symposium on Fuzzy Set Theory and Applications, held in Berkeley. Japanese participants in this symposium included:*

K. Asai	*University of Osaka Prefecture*
T. Fukumura	*Nagoya University*
N. Honda	*Tohoku University*
Y. Inagaki	*Nagoya University*
T. Kitagawa	*Kyushu University*
M. Kokawa	*Nagoya University*
M. Mizumoto	*Osaka University*
K. Nakamura	*Nagoya University*
M. Nasu	*Tohoku University*
M. Oda	*University of Osaka Prefecture*
M. Shimura	*Osaka University*
M. Sugeno	*Tokyo Institute of Technology*
H. Tanaka	*University of Osaka*
K. Tanaka	*Osaka University*
T. Terano	*Tokyo Institute of Technology*

CONTINUATION

- *Looking back, one cannot but be impressed by the work that was presented. Here is a representative sample of papers:*
  - *Calculus of Fuzzy Restrictions, L.A. Zadeh*
  - *Conditional Fuzzy Measures and Their Applications, K. Tanaka and M. Mizumoto*
  - *Interpretation and Execution of Fuzzy Programs, C. L. Chang*
  - *On Risk and Decision Making in a Fuzzy Environment, S.L. Chang*
  - *Decision-Making and Its Goal In a Fuzzy Environment, K. Asai, H. Tanaka, and T. Okuda*
  - *Recognition of Fuzzy Languages, N. Honda and M. Nasu*
  - *On Description of Fuzzy Meaning of Context-Free Language, Y. Inagaki and T. Fukumura*
  - *Experimental Approach to Fuzzy Simulation of Memorizing, Forgetting and Inference Process, M. Kokawa, K. Nakamura, and M. Oda*
  - *An Approach to Pattern Recognition and Associative Memory Using Fuzzy Logic, M. Shimura*

Where are we today?

FUZZY BOOM

- ***Starting in mid 70's, fuzzy logic began to grow in visibility and importance, especially in Japan, the Soviet Union and Eastern European countries, China, France, Germany and Italy.***
- ***A fuzzy boom in Japan began in the late 80's. Its history is well known and does not require elaboration. The following factual information about where fuzzy logic stands today speaks for itself. Japanese scientists, engineers and mathematicians who have contributed so fundamentally to the advancement of fuzzy logic and its applications can take pride in their achievements.***

Factual Information About the Impact of Fuzzy Logic--Metrics

PATENTS

- ***Number of fuzzy-logic-related patents applied for in Japan: 17,740***
- ***Number of fuzzy-logic-related patents issued in Japan: 4,801***
- ***Number of fuzzy-logic-related patents issued in the US: around 1,700***

PUBLICATIONS

Count of papers containing the word "fuzzy" in title, as cited in INSPEC and MATH.SCI.NET databases. Compiled by Camille Wanat, Head, Engineering Library, UC Berkeley, October 21, 2005.

Number of papers in INSPEC and MathSciNet which have "fuzzy" in title:

INSPEC - "fuzzy" in title	MathSciNet - "fuzzy" in title
1970-1979: 569	1970-1979: 443
1980-1989: 2,404	1980-1989: 2,465
1990-1999: 23,211	1990-1999: 5,485
2000-present: 17,785	2000-present: 4,869
Total: 43,969	Total: 13,262

JOURNALS ("fuzzy" or "soft computing" in title)

1. *Fuzzy Sets and Systems*
2. *IEEE Transactions on Fuzzy Systems*
3. *Fuzzy Optimization and Decision Making*
4. *Journal of Intelligent & Fuzzy Systems*
5. *Fuzzy Economic Review*
6. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*
7. *Journal of Japan Society for Fuzzy Theory and Systems*
8. *International Journal of Fuzzy Systems*
9. *Soft Computing*
10. *International Journal of Approximate Reasoning--Soft Computing in Recognition and Search*
11. *Intelligent Automation and Soft Computing*
12. *Journal of Multiple-Valued Logic and Soft Computing*
13. *Mathware and Soft Computing*
14. *Biomedical Soft Computing and Human Sciences*
15. *Applied Soft Computing*

Miscellaneous

- ***Patents on Cruise Control and Collision Avoidance Using Fuzzy Logic, Neural Nets, & Probabilistic Methods (D. Filev)***

	Cruise Control / Collision Avoidance		
Owned \ Method	**Fuzzy Logic**	**Neural Nets**	**Probabilistic**
Automotive Companies	**36 / 16**	**21 / 8**	**2 / 2**
Automotive Vendors	**63 / 43**	**43 / 50**	**12 / 19**
Other / Unassigned	**90 / 93**	**80 / 163**	**21 / 72**
Total	**189 / 152**	**144 / 221**	**35 / 93**

Citations (L.A. Zadeh)

1955-1964: 156
1965-1974: 945
1985-1994: 3,651
1995-present: 7,358

Total: 14,352

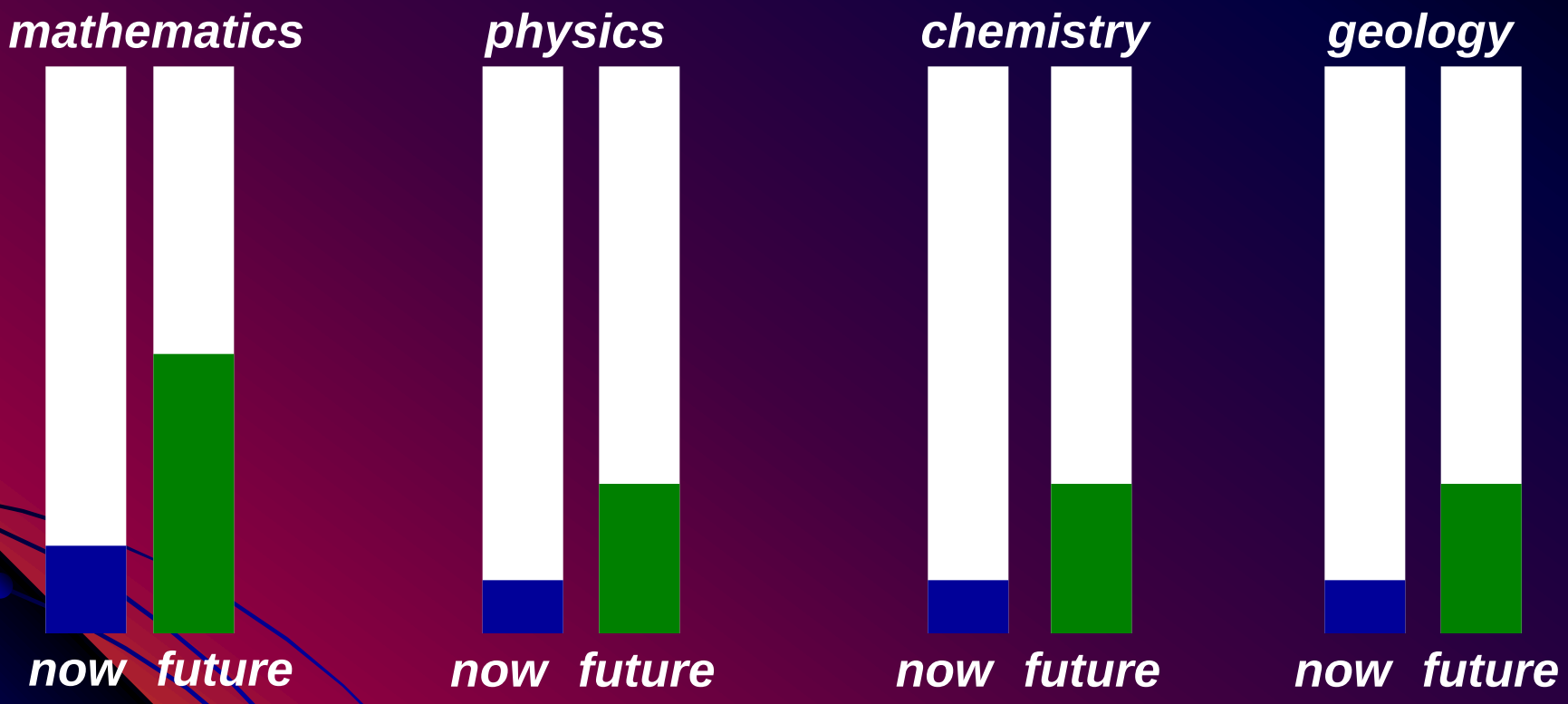
A Glimpse Into The Future

A Glimpse Into The Future

BACKDROP

- *In the 70's, 80's and 90's the principal application area of fuzzy logic has been fuzzy control in the context of both industrial systems and consumer products. Today, as we move further into the age of machine intelligence and mechanized decision-making, what we observe is an emergence of a wide variety of application areas involving recognition and mechanized decision-making. Examples are automated diagnostic systems, decision support systems, information reals systems, quality control systems and knowledge management systems.*

SPECTRUM OF IMPACT/APPLICATIONS OF FUZZY LOGIC



- *In mathematics, the impact is focused on graduation of set membership. No granulation is considered.*

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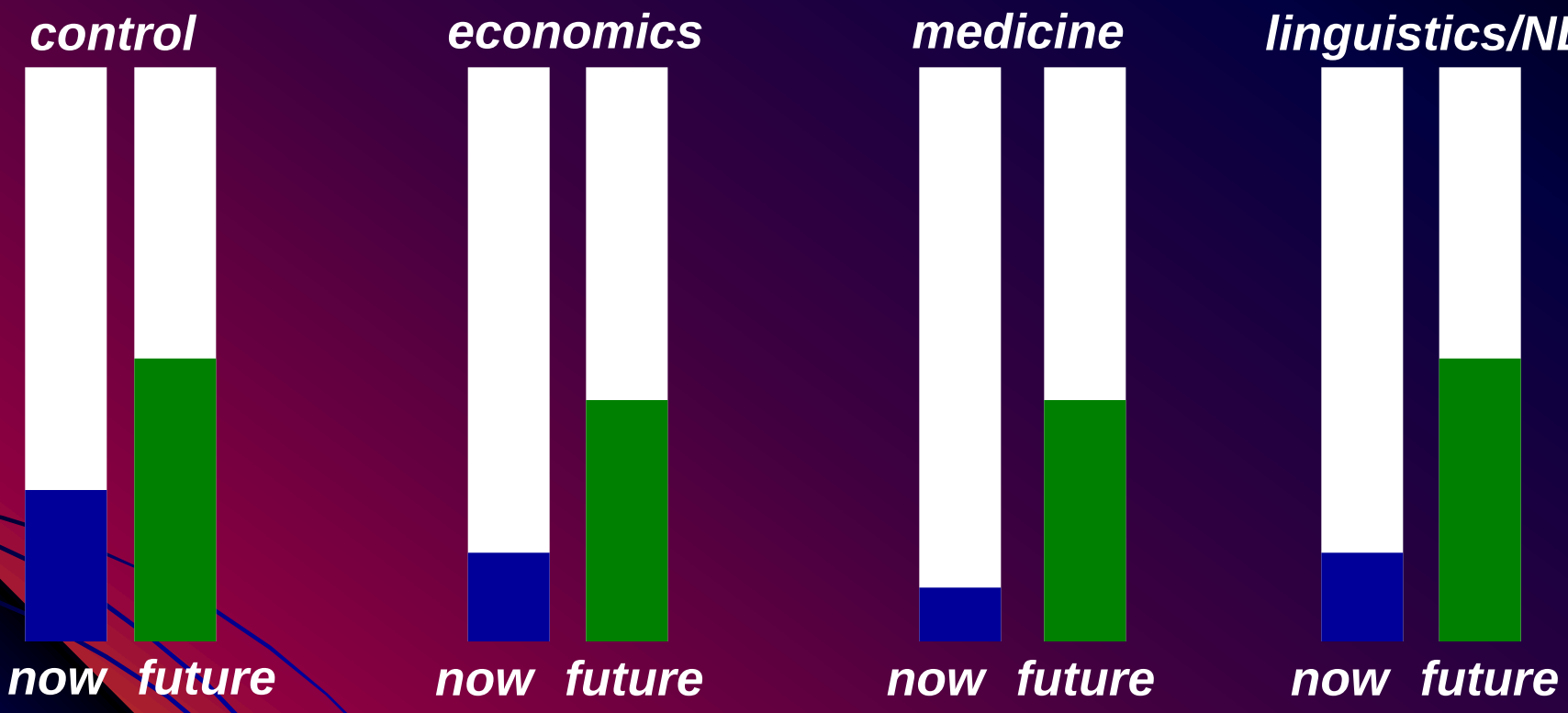
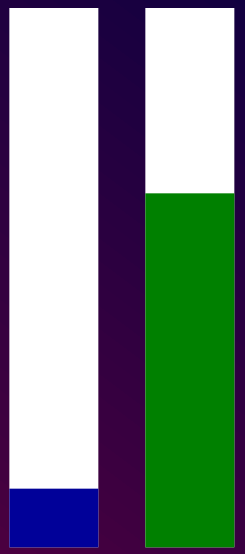

control
economics
medicine
linguistics/NLP
now
future
now
future
now
future
now
future

MY EXPECTATION



- In coming years, the most important application area of fuzzy logic will be the Internet and, in particular, search and question-answering. Reason:
- Much of human knowledge, and especially world knowledge, is described in natural language
- In my view, the most important contribution of fuzzy logic is its capability to serve as a basis for computation with information described in natural language. No other system offers this capability.