

Japan Fuzzified: The Development of Fuzzy Logic Research in Japan

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Declaration

I hereby declare that this thesis is composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or professional qualification.

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Abstract

This thesis investigates the development of fuzzy logic research in Japan from the late 1960s to the early 1990s. Fuzzy logic, the banner under which several interrelated theories, concepts, and applications are grouped, can be traced to an article, originated in the U.S., in 1965. The theory was claimed to imitate the imprecise way of classification used in human thinking. Although it is widely used now in a number of areas of mathematics, engineering, and even social sciences, it has been attacked extensively and has created much controversy. On the other hand, it is often remarked that an affinity between fuzzy logic and Japanese thought has made Japan a major research site of fuzzy logic. By employing theoretical resources from sociology of science as well as science and technology studies (STS), and drawing on written sources and interviews, this thesis charts the development of fuzzy logic research in Japan.

Overall, the development of fuzzy logic research in Japan is seen as a popularization process, in which three consecutive periods are identified with regards to the ways fuzzy logic reached a growing audience. In the first period, from the late 1960s to the late 1970s, fuzzy logic research was an academic undertaking, with mathematical manipulations the main way of conducting research. The theory of scientific organization is applied to analyze fuzzy logic research in this period, and in particular the *kōza* (departmental chair) system, a feature of the Japanese academic system, is found to play an important role in the proliferation of fuzzy logic. The second period, spanning from the late 1970s to the late 1980s, saw an upsurge of applications of fuzzy logic to control engineering. Technical demonstration was a core activity in this period, and STS work on demonstrations and proofs is utilized to discuss the way in which fuzzy logic drew the attention of a growing audience. Finally, in the third period, spanning from the late 1980s to the early 1990s, fuzzy logic reached the general public by attracting wide coverage in mass media. The role the Japanese transliteration of the word 'fuzzy', 'fajyi', played in the promotion of fuzzy logic in this period is discussed. The influence of the word 'aimai', the indigenous concept that served for a time as the Japanese translation of the word 'fuzzy', and the perceived affinity between fuzzy logic and Japanese thought, is analyzed as well.

Notes on Asian Language Usage

Aside from those in bibliography, all Japanese and Chinese person names are given in traditional order, that is, family names first. The revised Hepburn system of romanization is used for transliterating Japanese terms, except for some commonly used place names such as Tokyo and Osaka, in which macrons that stand for long vowels are omitted.

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Chapter 1

Introduction

Prologue

At an early point of my stay in Japan for the research upon which this thesis is based, I mentioned the subject matter of the thesis, a sociologically informed history of fuzzy logic research in Japan, to a few Japanese people that I knew. I was intrigued by the same response I got from three among them, a prompt one offered right after I told them the research topic. Theirs was a question: ‘Are “fajyi” (the Japanese transliteration of ‘fuzzy’, which stands for fuzzy logic) and “yuragi” the same thing?’ Not yet at that time having an idea of what ‘yuragi’ was, the response nevertheless directed me to the potential common factor that united the responses of these three persons. These three were a university professor in his late forties, a Ph.D. student in his twenties, and a ‘salaryman’ (white-collar worker) in his thirties. Considering the different ages and background of these people, the mass media was the most obvious factor that could unify their response.

Later on, I came to know that ‘yuragi’ is the Japanese translation of ‘fluctuation’, a term used in physics and mathematics (Saji 1994: 620), and yuragi in the above context refers to ‘1/f fluctuations’, a phenomenon that cuts across nature, biology, and artificial devices. Also called ‘pink noise’, 1/f fluctuations characterize those processes whose power spectral density as a function of frequency is inversely proportional to frequency (Wikipedia contributors). 1/f fluctuations are sometimes put alongside ‘fractals’ (Musha 1980), special geometrical curves that occasionally fall inside the scope of chaos theory (Smith 1998: 20). 1/f fluctuations are a characterization of a certain quality that exists in the natural as well as artificial worlds. On the other hand, fuzzy logic is a new way of dealing with mathematical sets and logic, a conceptual innovation. In other words, 1/f fluctuations and fuzzy logic are quite different in scope and aims. But how did they come to be mixed up by the above three persons? The answer is indeed to be found in the mass media. Both of these concepts had extensive mass media coverage in Japan from the 1980s to 1990s, in television, radio, and newspaper commercials for the home appliances that claimed to apply them as design principles. Articles featuring them as main themes also appeared in popular science magazines and in commentary columns in newspapers. Both ‘fajyi’ and ‘yuragi’ acquired meanings that implied flexibility, and the two words, as well as the popularity they received, were used to serve as social

commentaries on contemporary social conditions.

Despite crucial differences, 'fajyi' and 'yuragi' in Japan share some common features. Neither was first proposed nor discovered by Japanese scholars. Nevertheless, in Japan, they acquired meanings that went beyond the scope of the original scientific endeavours. The additional meanings, I surmised at an early stage of this research, were at least in part gained from the Japanese translation of the original terms. It appeared that the meanings of Japanese words chosen for translating 'fuzzy' and 'fluctuation' were brought to bear on the interpretations of the meanings of those scientific terms. From this perspective, it became clear to me that nuances in Japanese language mattered and that my learning to read Japanese literature on the topic was going to be an indispensable part of this research. For about half a year during the earlier part of my stay in Japan, I therefore attended Japanese language school while searching for written material and possible contacts for this research. The language training equipped me with a sufficient command of intermediate level Japanese sufficient to read Japanese material without much difficulty, and to conduct interviews in Japanese where communicating in English was not feasible for that purpose.

This thesis deals with the history of fuzzy logic (or fuzzy set theory) in Japan.¹ Broadly speaking, it is treated as a popularization process, in which fuzzy logic evolved from a strictly academic endeavour to an enterprise that became widely known to the public. In particular, the way by which fuzzy logic travelled from the U.S. (where it originated) to Japan, the change of research practices during the popularization process, and the effect of translation associated with the process will be the foci of this thesis. This chapter begins by introducing social commentaries made with fuzzy logic, followed by a more technical description of fuzzy logic and a short history of its development in Japan. Sections on literature review, data collection, and an outline of this thesis will then follow.

Fuzzy Logic as a Critique of Western Dualism

A fuzzy subset of some universe U is a collection of objects from U (the set part) such that with each object is associated a subjective evaluation, a degree of membership (the fuzzy part), which is always a number, between zero and one, measuring the extent to which an element is in a fuzzy set. The set of numbers between zero and one is an infinite set. We use these numbers to assess a membership at its true worth. This assessment is a belief. We have moved from

¹ The difference between the two terms, fuzzy logic and fuzzy set theory, will be clarified soon.

fact-based criteria to feeling-based criteria for truth. *Truth, like beauty, is now in the eye of the beholder* (Negoita 2002: 1044, my italics).

So says a fuzzy theorist, seeing fuzzy set theory – in which a sharp distinction between members and non-members of a given set is not drawn and, as a consequence, in which a blurring of the boundary between what is true and what is not occurs – as a significant instance of science of the postmodern era. Politically, the collapse of the Berlin Wall in 1989 is said to mark the end of the modern period, the underlying idea of which was ‘the belief in a two-valued logic, where between the true and the false there is nothing, no nuance, as a direct rejection of the claims to relevance of the non-Aristotelian logic, banned as a superstition of the religious premodernism’ (Negoita 2002: 1043). The ‘law of the excluded middle’ – a law in logic which states that either a statement or the negation of it is true, and dictates the inference steps of the Aristotelian two-valued logic – is said to be a ‘modern’ law (ibid: 1046). Affinity between postmodernism and fuzzy theory is thus established by this formulation.

If the subjective undercurrent in Western science, of which ‘theories in quantum physics’ were well-known instances and the fuzzy ‘paradigm’ its recent exemplification (Negoita 2002: 1044, 1047), is regarded as a linear development of history that led the modern stage to the postmodern, then a global cultural geography complicates the picture. A report aimed at comprehending the competitiveness of those Japanese electronics products that utilized fuzzy logic, published by the U.S. Department of Commerce in 1991, states: ‘From a philosophical viewpoint, the fuzzy logic concept is attuned to the fundamental teachings of Zen Buddhism, which perhaps contributed to the Japanese acceptance of this concept’ (quoted in Kosko 1993: 182). This serves as a typical example of a revisionist view that values Japanese science and technology, alternative to the dominant one that regards developments in science and technology as monopolized by the West.

The new view on Japanese science and technology, which emphasizes possible lessons that could be learned from it, stems from a belief in the contributions of the science and technology of Japan to its sustained higher economic growth (as compared to its Western industrialized counterparts), its high productivity, and its export surplus from the mid 1970s (Morris-Suzuki 1999: 227). In parallel with an emphasis on the successful policies adopted by the Japanese government in promoting scientific and technological research, a cultural interpretation that addressed the link between traditional culture and thought of the Japanese, and Japan’s creativity in science and technology, emerged. The above quote by the U.S.

Department of Commerce is such an instance made in the context of the trade conflict between U.S. and Japan in the 1980s.² In fact, the cultural interpretation was preceded by popular works in physics, which see an affinity between quantum physics and traditional East Asian thought, written by authors in the U.S. in the late 1970s – *The Tao of Physics: An Exploration of the Parallels between Modern Physics and Eastern Mysticism* by Fritjof Capra, and *The Dancing Wu-Li Masters: An Overview of the New Physics* by Gary Zukav (Morris-Suzuki 1999: 230).³

The taking-up and use of these works both within and outside of Japan, for drawing a link between the new scientific paradigm and traditional Japanese thought, manifests international and local complications. For a long time, Japan had been viewed as a mere imitator of the West; however, with the emergence of the new paradigm with which traditional Japanese thought accorded neatly, ‘the very source of Japan’s earlier scientific backwardness and derivitiveness [*sic*] could now become sources of scientific creativity’ (Morris-Suzuki 1995: 119).⁴ Moreover, the link became a stake in arguing the developmental phase of Japan in modernity; it was used to promote a ‘postmodern’ way of social organization as a solution to the social malaise of the modern era. This kind of ‘social theorising’, argued by Morris-Suzuki,

...creates what advocates of the new science would doubtless call a ‘positive feedback loop’, reinforcing images of society as an organic, harmonious whole. In step one, the paradigm of the new science is presented as conforming to the traditional Japanese image of universal harmony and interconnectedness; in step two, that paradigm is transferred back from science to society to give ‘traditional’ ideas of a new patina of postmodern scientific validity (ibid: 124).

² Regarding the trade figures, ‘the Japanese merchandise trade surplus with the United States took off in the mid 1970’s, doubling about every two years through the mid 1980’s until it flattened out at \$40-50 billion annually’. For the U.S. in the 1980s, the yearly deficit in merchandise trade balance with Japan accounted for about one-third to half of the deficit in its overall merchandise trade balance (Callon 1995: 164-165).

³ ‘Wu-Li’ is the Chinese translation for ‘physics’, which literally means ‘reason of things’.

⁴ The impact of the issue of scientific creativity on Japanese scholars still lasts. This can be seen, for instance, from recent research on this by historian of science and technology Koizumi Kenichiro and philosopher of science Murata Junichi. Koizumi treats the search for an identity in the technological realm, that had been disheartened due to Japan’s defeat in the WWII, as contributing to its post-war efforts made in innovations in refining consumer products – seen by others as less valued than original ideas (Koizumi 2002). Murata, on the other hand, draws on Japanese philosopher Nishida Kitaro’s concepts and SCOT (social construction of technology) approach in a comparative manner, to address the creativity embedded in the local socio-technical network of Japan that mediated its technological transfer from the West (Murata 2003). Although the problems they address are quite different in scope, both, it seems to me, offer revisionist concept of scientific creativity in (and beyond, in the case of Murata) the Japanese context.

The law of the excluded middle, Negoita argues, underlies much of the social malaise of the modern era such as the two world wars, which 'drives people to destroy one another', and 'furnishes the portrait of the enemy so bright' (Negoita 2002: 1047). 'Binary logic was readily equated with Western dualism', in contrast, 'fuzzy logic was identified with Japan's 'cyclical', 'circuitous' or 'vague' thought patterns"; 'where Western thought perceives truth in black and white, Japanese thought perceives it as a spectrum of black, grey and white' (Morris-Suzuki 1995: 122).

Certainly the attempts to equate binary logic with Western dualism and fuzzy logic with Japanese thought are oversimplified in that they treat culture as static and homogeneous. They also 'are based upon a misreading of the relationship between science and society' in that they treat science as autonomous and free from social and political influences (Morris-Suzuki 1995: 125). The assumption appears to be that there is a one-way relationship from science to society: new development of science can be used to make a picture for how society should be organized in a way that fits science – but not the other way around.

Apart from questioning, with Morris-Suzuki, the oversimplified relationship between science and society on which the discourse of the 'new science paradigm' (among which fuzzy logic was a significant one) was based, this thesis is concerned more with the time before that oversimplified relationship could be argued. How did fuzzy logic become so visible that it was regarded as a major strand in the 'new science paradigm'? The question is even more significant if we consider the history of fuzzy logic before it became a 'paradigm', as noted by two fuzzy theory researchers in the U.S.:

The paradigm shift initiated by the concept of fuzzy set and the idea of mathematics based on fuzzy sets, which is currently ongoing, has similar characteristics to other paradigm shifts recognized in the history of science....The concept of a fuzzy set, which underlies this new paradigm, was initially ignored, ridiculed, or attacked by many, while it was supported only by a few, mostly young and not influential (Klir and Yuan 1995: 30-31).

Uneven Developments

It is hardly surprising that, after the publication of Thomas Kuhn's influential *The Structure of Scientific Revolutions*, proponents of a burgeoning science would try to draw an analogy between the situation they faced and the examples from the

history of science that Kuhn offers in his book. In spite of the intricacy and problem of applicability of the paradigm concept, scholars of different fields all boast of a 'paradigm shift' whenever they have found a new path for doing research. But regardless of whether the concept of paradigm can be applied to the case of fuzzy logic, and the contested interpretations of 'paradigm' itself, many historical and technical accounts on fuzzy logic, the above quote included, resort to the paradigm concept in describing its development. Not surprisingly, images of martyrs in history of science, such as Galileo, are invoked to bring out the lonely yet steadfast figure: in this case, Lotfi A. Zadeh, the recognized founding figure of fuzzy logic (Hirota 1993a: 42). Despite the issue of applicability of the paradigm concept, one of the reasons behind this type of invocation is the resemblance between a point in the development of fuzzy logic and a time before a new paradigm held sway, as shown in some examples in the history of science. In the words of the above quote: 'it was initially ignored, ridiculed, or attacked by many' (McNeill and Freiburger 1993: 46-48).

However, the subsequent paths of fuzzy logic were quite different across the globe. Of particular interest is the road taken in Japan, where numerous technological applications, especially of fuzzy control that included a flagship project on a subway system, were developed in the 1980s, and where the usefulness of fuzzy logic, a theory as such, was claimed to be substantiated. The seemingly ready application of fuzzy logic in Japan seems to support the argument of an existing cultural link between the 'new science paradigm' and traditional Japanese thought: in spite of the fact that fuzzy logic originated in the U.S., the 'paradigm shift' made possible by its further development was precipitated by researchers in Japan, who worked in a cultural milieu receptive to it. However, even if we accept that there is a 'paradigm shift' to the 'new science', the 'paradigm' was no less new to Japanese researchers. As Anca Ralescu, a computer scientist from the University of Cincinnati, U.S., who once worked in Japan for the Laboratory for International Fuzzy Engineering Research Institute (LIFE) observes:

In what to many seemed an overnight phenomenon, fuzzy control reached new heights of popularity in Japan during the mid to late eighties due to its use in the manufacturing of home appliances. However, we know now that it took close to twenty years of work in fuzzy theory to reach the current status of this technology in Japan (Ralescu 1994: xiii).

Prof. Terano Toshirō of the Tokyo Institute of Technology was one of the few

researchers who first promoted fuzzy research in Japan in the early 1970s. In response to the question about the popularity of fuzzy logic in East Asia, he introduced a fable titled 'Konton' (translated as chaos) by the ancient Chinese Taoist philosopher Chuang-tzu as a hint to the answer. The fable goes as follows. Two ancient kings wanted to give something in return for the hospitality they received from a common friend who was also a king. The third one, named Konton, had no sensory organs on the face, which fact was considered a great pity by the two kings. Thus, they began to bore a hole each day on the face of konton for putting in sensory organs, thinking sensory experience a gift. Nevertheless, right on the seventh day when the well-meaning work was eventually finished, konton died. To Terano, the lesson to be learnt from the fable is that 'extreme pursuit of rationality in overestimating human wisdom will result in a loss of the most valuable thing'; we try to solve difficult problems by 'microscopic analysis, but this means killing Konton. Instead, it may be necessary for us to view the whole of things as they are, macroscopically' (Terano 1994: 14-15).

The fable suggests that East Asian researchers have a better chance of having the cherished capability of seeing macroscopically. However, even for those East Asian people who have been influenced by a Taoist tradition, the fable Terano told needs an exegesis made from the teachings of 'Tao' to make its meaning comprehensible, not to mention the way in which 'Konton' was related to fuzzy logic, human wisdom, or macroscopic thinking, as hinted by Terano. Moreover, in his recollections on the activities in the mid 1970s of a fuzzy research group formed in Tokyo by Terano and others, Fukuda Toshio, a well-known roboticist, states that if it were not for the charismatic leadership of Terano, the group might have been broken up (Fukuda 1996). How is it, then, that some twenty years later, Terano – the one who had experienced the obscurity of fuzzy research in the early days – invoked ancient Asian philosophy to account for the ready acceptance of fuzzy logic in Japan?

The above framing of the problematic of the fuzzy logic phenomenon in Japan brings us to several questions which this thesis is going to address. Firstly, how was fuzzy research sustained before it became broadly visible in its later phase? Secondly, how did it find its way to industrial applications? Thirdly, how did East Asian thought become affiliated with fuzzy logic? These questions necessitate a start-over with an introduction of fuzzy logic and its development in Japan.

What is Fuzzy Logic?

Fuzzy logic is the banner under which several interrelated theories, concepts, and applications are grouped.⁵ Although the historical reconstruction narrative identifies ‘vagueness’, the idea proposed and investigated by philosophers Bertrand Russell (1923) and Max Black (1937) as its predecessor, it is generally agreed that an article by Lotfi A. Zadeh in 1965 set the scene for the entangled history of fuzzy logic that ensued. Zadeh was born in 1921 in the former Soviet Azerbaijan, was trained in electrical engineering in Massachusetts Institute of Technology and Columbia University, and became a professor first at Columbia University and then in the late 1950s, in the department of electrical engineering at the University of California Berkeley, where he remains. In the journal article ‘Fuzzy Sets’, Zadeh put forward a new way of thinking about set theory (Zadeh 1965a). (Crisp) set theory was developed by the German mathematician Georg Cantor in the nineteenth century, and assigns a sharp distinction between a member of a set and the one that is not. Correspondingly, the result of characteristic function, which indicates whether an element belongs to a specific set or not, can only be either one or zero. In other words, a statement about whether a member belongs to a set is either true or false. In contrast, Zadeh considers the common way humans use adjectives, and recommends that we amend the characteristic function to allow values that fall in the interval between zero and one. For example, when we consider if a person is tall, we can assign her as belonging to different sets in different proportions (see Fig 1.1): a person of 179cm height can be said to be high in the grade of 0.6 and moderate high in the grade of 0.4 (Tanaka 1997: 11). Thus fuzzy sets allow non-integral ‘membership functions’. Zadeh claims that people reason in fuzzy terms and that the fuzzy set can be seen as a semantic extension of the crisp set.

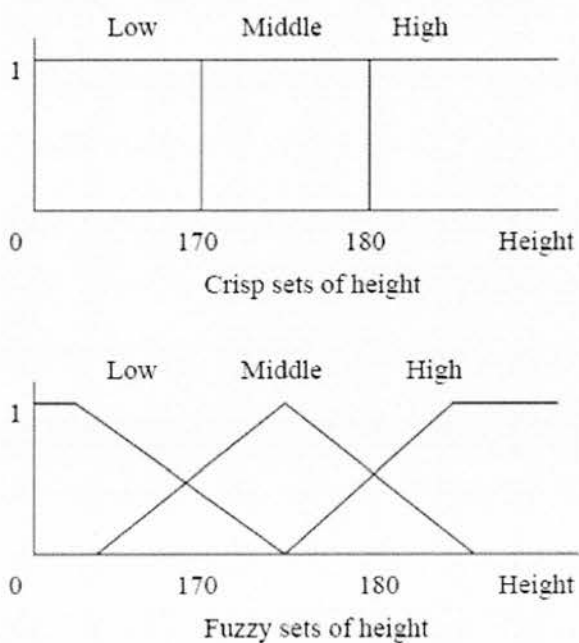


Fig 1.1 Fuzzy sets of height (reproduced from Tanaka (1997: 11))

⁵ In Japan, however, ‘fuzzy theory’, rather than ‘fuzzy logic’, is more often used when referring to the whole research area. In this thesis, although ‘fuzzy theory’ and ‘fuzzy logic’ are used interchangeably unless when the latter term is used specifically to refer to a research area in mathematical logic, the former is used more frequently when the focus is on Japan.

In 1972, Zadeh further suggested fuzzy reasoning, the basic idea underlying what is called fuzzy control thereafter (Zadeh 1972; 1973). Fuzzy reasoning, at heart, uses inference rules called ‘fuzzy IF-THEN rules’. These rules are said to be imitating what people think and do in practical situations. When predicates A, B, C of an inference rule ‘IF x is A, and y is B, THEN z is C’ are fuzzy sets, the rule becomes a ‘fuzzy IF-Then rule’. If we put the above rule into a practical context of setting an air conditioner, for example, it can go as ‘IF room temperature is ‘a little high’, and humidity is ‘quite high’, THEN increase the air conditioner setting to ‘High’’. Since A, B, and C are fuzzy sets, when this fuzzy IF-THEN rule is installed, it still applies in the proximity of the assigned value A and B. In the above example, when the temperature remains a little high, and humidity is high instead of quite high, the conclusion (output) could be ‘increase the air conditioner to ‘moderate high’’. Here the inference rule underlying this control algorithm is called a ‘generalized modus ponens’ (Klir and Yuan 1995: 234). Many such fuzzy IF-Then rules can be combined in different weight for control purposes, and these non-analytical rules thus provide an alternative to the usually used analytical control theory.

The Protagonist's Explanation of the Origin of the Idea

The idea of vagueness, as probed by Bertrand Russell and Max Black, and many-valued (used interchangeably with multi-valued) logics of which the Pole Jan Łukasiewicz was the most famous precursor, are recognized as the forerunners of fuzzy logic in various places, including a journalistic account (McNeill and Freiburger 1993), a promotional text (Kosko 1993), and general university textbooks and tutorial materials. However, ‘fuzzy’ logic, as proposed, by Zadeh does not bear the name ‘vague’ logic, ‘many-valued’ logic, or ‘multi-valued’ logic. Instead, the name came from a publicizing consideration. Zadeh states that, as the word fuzzy is often associated with a negative meaning, it can arouse hostility, which serves as one of the ways to get publicity. Furthermore, the word logic is chosen for a similar reason: although the whole enterprise rests more on an alternative idea on set theory than on logic, the name logic makes more sense to ordinary people than ‘set’, which is more mathematically implicated and thus more distant (McNeill and Freiburger 1993: 49).⁶

⁶ Zadeh’s seminal article in 1965 was titled ‘Fuzzy sets’. The name ‘fuzzy logic’ did not appear until his 1975 article ‘Fuzzy Logic and Approximate Reasoning’ (Zadeh 1975). Besides the campaigning of Zadeh himself, books of promotional implications on fuzzy logic might also have effects on why the idea of fuzziness later became represented by the flagship banner ‘fuzzy logic’. For example, both books by McNeill and Freiburger (1993) and Kosko (1993) have ‘fuzzy logic’ as their title or subtitle.

Apart from the question of whether fuzzy ‘logic’ should be entitled as the banner of Zadeh’s overall project, the ambition of applying his idea to system analysis distinguishes Zadeh from many other logicians. As an electrical engineer by training, he remarks that the idea of fuzziness was proposed as a way of dealing with system analysis:

[I]n the course of writing a book with Professor Charles Desoer on linear system theory, I began to realize that there are many concepts in system theory that do not lend themselves to precise definition. For example, one can give a precise definition of a linear system, a stable system, a time-invariant system, etc. But how can one define what is meant by a decentralized system, a slowly-varying system, a reliable system, etc.?

In trying to formulate such definitions, I began to realize that the problem lay in the Aristotelian framework of classical mathematics – a framework which is intolerant of imprecision and partial truth (Zadeh 1990a: 99).

The assumed merit of utilizing fuzziness in system analysis is well captured in the following quote by two researchers on system science:

Many of us who saw his original papers in 1965 did not realize their significance until many years later. We were even somewhat disappointed in the change of direction that they represented, from hard system science (in which Zadeh had been a major pioneer) to a deliberate acceptance of imprecision in any real system applications. What was not clear at that time is that an ontology that denies the existence of this imprecision itself introduces such major artefacts that it is not just unreal but definitely false and positively misleading. Zadeh saw this as a fatal flaw in classical system science at the same time as the majority of us were looking for new peaks to conquer with the tools that had been so successful in the past. In retrospect one can see that, in many cases, it was the tools that were building the peaks, not conquering them! (Gaines and Kohout 1977: 2)

Imprecision, the antithesis of specificity, is highly valued by fuzzy theorists in modelling systems. The ‘principle of minimum specificity’, as Zadeh calls it, states ‘do not be more specific than necessary’ (Zadeh 1990a: 103). That is, specificity should be pursued according to the intended purpose; it is not valuable in itself. This is because specificity is closely connected to other system characteristics. As a system and fuzzy theorist argues, ‘tolerance (of uncertainty and imprecision) allows

us to use uncertainty and imprecision as commodities that can be traded for reduction of complexity or for increase of credibility of systems models in situations that are otherwise not manageable' (Klir 1990: 92). Zadeh resorts to the analogy of the human brain in explaining the close link between fuzziness and complexity. Just as our vocabulary for colours such as red is only applicable for well-defined tasks, when complexity exceeds the handling capacity of information, the boundaries become fuzzy: thus our vocabularies for colours are fuzzy sets (Zadeh 1990a: 99-100). Therefore, when complexity arises, systems necessarily become fuzzy, and only systems that can manipulate fuzzy concepts handle the ever increasing complexity of our times. Although the analogy can always be called into question and the causal relationship between fuzziness and complexity, as Zadeh argues, is not definitely clear, the superiority of the human ability to process information in various aspects, compared to that of artificial systems, is regarded as legitimizing fuzzy ways of dealing with system problems. Along with neural networks and genetic algorithms, the two data analysis models that draw analogies from either the working of neurons or genetics (Bailer-Jones and Bailer-Jones 2002), fuzzy logic is also seen as one of several approaches that are alternative to the classical symbolic approach of artificial intelligence. In contrast to the 'bottom up' method of neural networks, however, fuzzy logic utilizes the semantic imprecision of natural language and can be seen as a 'top-down' approach.

It seems that Zadeh's perspective on the 'system' idea also alludes to why the top-down, human brain analogy was made. The complexity arising from the analysis of biological system shows an urgent need for a new method for integrating different kinds of systems. A passage that is used occasionally to state the motivation behind fuzzy logic connects it to the work of the biologist and general system theorist, Ludwig von Bertalanffy. It seems that the drive against reductionism led Zadeh to call for an alternative:

Among the scientists dealing with animate systems, it was a biologist – Ludwig von Bertalanffy – who long ago perceived the essential unity of system concepts and techniques in the various fields of science and who in writings and lectures sought to attain recognition for "general system theory" as a distinct scientific discipline. It is pertinent to note, however, that the work of Bertalanffy and his school, being motivated primarily by problems arising in the biological systems, is much more empirical and qualitative in spirit than the work of those system theorists who received their training in exact sciences. In fact, there is a fairly wide gap between what might be regarded as "animate" system theorists and

“inanimate” system theorists at the present time, and it is not at all certain that this gap will be narrowed, much less closed, in the near future. There are some who feel this gap reflects the fundamental inadequacy of the conventional mathematics – the mathematics of precisely defined points, functions, sets, probability measures, etc. – for coping with the analysis of biological systems, and that to deal effectively with such systems, we need a radically different kind of mathematics, the mathematics of fuzzy or cloudy quantities which are not describable in terms of probability distributions. Indeed the need for such mathematics is becoming increasingly apparent even in the realms of inanimate systems (Zadeh 1962: 857).⁷

Development of Fuzzy Logic

Fuzzy logic stimulated extreme responses from the very beginning. On the one hand, the concept encountered fierce criticism. On the other hand, however, fuzzy set theory, together with other concepts introduced by Zadeh, attracted high interest in various disciplines in and beyond the U.S., from philosophy, linguistics, social sciences to mathematics and engineering. Important theoretical developments in the first decade or so included linguistic hedges, as discussed by Zadeh and linguist George Lakoff;⁸ as well as the work by Zadeh and control theorist Richard E. Bellman on fuzzy decision making; fuzzy measures,⁹ fuzzy topology, and fuzzy optimization etc. The decade saw the fuzzification of many traditional mathematical structures such as logics, relations, and functions, and so forth (Yen and Langari 1999: 5). According to a scientometric analysis, up until 1976, twelve years after the year when the idea of fuzziness was proposed in only two publications, there were as many as 763 papers published in total related to fuzzy logic, with a forty percent growth rate in the literature per year (Gaines and Kohout 1977).

⁷ Both system and fuzzy theorists Brian R. Gaines and George J. Klir quote this passage as indicating what motivated Zadeh. However, in an interview Zadeh seems to reject any influence Bertalanffy has on him: ‘And the camp [electrical engineers] I was a member of did not think too much of the other camp [Bertalanffy and the biologists]. To us those people were crackpots. They took a sort of mystical view of the thing’ (McNeill and Freiberger 1993: 22). Zadeh also presents a similar tone in a personal retrospection on the formation of system theory: ‘...It was during this period [1950s] that the idea of what is now known as system theory began to crystallize in my mind. There was some earlier work by Ludwig von Bertalanffy[sic] on what he called ‘Theory of General Systems’, but his approach has a different agenda and was philosophical and biological in its orientation’ (Zadeh 1996: 96). Here Zadeh seems to differentiate system in physiological sense and system in dynamic sense. For the three common meanings the word ‘system’ is referred to, which lasted from nineteenth century: physiological system, systems of philosophy, and dynamic systems, see Mindell (2003).

⁸ According to the *Oxford English Dictionary*, hedge here refers to ‘a word or phrase used to avoid over-precise commitment, for example etc., often, or sometimes’.

⁹ Fuzzy measures will be explained in chapter 3.

Applications that would be of interest to industry emerged nearly a decade after Zadeh's seminal paper appeared. Among these the most notable was the application to control engineering, first developed by Ebrahim H. Mamdani and his student Sedrak Assilian at the University of London in 1974. They utilized 'fuzzy IF-THEN rules' to control a steam engine in a laboratory setting. Other early applications include, among others, those in civil engineering and in analyzing traffic conditions (Yen and Langari 1999: 6). However, within the first decade or so, applications were confined to academic circles and were, for the most part, experimental. It was not until the late 1970s that real industrial applications came into being. In 1978, Peter Holmblad and Jens-Jorgen Østergaard of the Danish F.L. Smidth & Company tested a fuzzy controller in a cement kiln. It went into permanent operation in 1980 and was known widely as the first industrial application of fuzzy control (McNeill and Freiberger 1993: 119).¹⁰

The subsequent development of fuzzy logic, after Zadeh's seminal work, took different forms in different parts of the world. As mentioned above, there was intense interest in fuzziness within many fields, immediately after Zadeh proposed his idea. However, due to the antagonism toward and controversy over fuzziness, which will be addressed in Chapter 2, interest in fuzzy logic declined in the early 1980s in the U.S. and Europe (McNeill and Freiberger 1993: 124-126). Although characterization of research interest according to geographical areas will certainly fall short when taking into account the nuances within each area and the international interactions between different areas, in general, the development of fuzzy logic can roughly be portrayed as having distinct geographical features: research in Eastern Europe and in China concentrates on mathematical theory, whereas in Japan it is the most application-oriented.

With the booming in applications of fuzzy logic (see below), and the widespread 'explosion' of neural networks research in the late 1980s (Olazaran 1993: 406-410), neural networks, as a tool for data analysis, were incorporated with fuzzy logic into hybrid systems. Researchers have applied the two techniques in two ways: either neural networks techniques are used for the identification of fuzzy membership functions, and for learning and adaptation in so-called 'neuro-fuzzy' systems, or the notion of fuzziness is utilized, for example, to encode input data in neural networks systems (Bezdek 1992: 31-32; Klimasauskas 1992: 53; Zadeh 1994a: 78).

In the meantime, Zadeh began to promote the idea of 'soft computing', which

¹⁰ In fact fuzzy control was applied to a lime-reburning kiln at a paper mill in Sweden in 1979, which was also done by Holmblad and Østergaard. The engineers regard this as the first industrial application of fuzzy control, but perhaps due to its smaller scale, this case is less known (McNeill and Freiberger 1993: 120).

he identified as consisting of fuzzy logic, neural networks, and ‘probabilistic reasoning, with the latter subsuming belief networks, genetic algorithms, parts of learning theory, and chaotic systems’ (Zadeh 1994a: 78). According to Zadeh, the utilization in design of these unconventional approaches is the major reason why home appliances and various consumer electronics had higher ‘Machine Intelligence Quotient’ after 1990 than before. The word ‘soft’ is characterized in sharp contrast to ‘hard’: the latter denotes precision, certainty and rigour; while the former emphasizes the ability to ‘exploit the tolerance for imprecision and uncertainty, learn from experience, and adapt to changes in the operating conditions’ (Zadeh 1994a: 77-78).¹¹ In addition to numerous applications in mathematics and in engineering, attempts to apply fuzzy logic to the social sciences were also made sporadically.¹²

Development of Fuzzy Logic in Japan

From the 1980s, as interest in fuzzy logic research in the U.S. and Europe dwindled, Japan, with the emergence of numerous applications of fuzzy logic, assumed a leading role. However, in the late 1960s and early 1970s, Zadeh’s paper on fuzzy sets interested only a handful of scholars in Japan. Among them were Terano Toshirō (Tokyo Institute of Technology) and Shibata Heki (University of Tokyo) in Tokyo and Tanaka Kōkichi (Osaka University) and Asai Kiyogi (Osaka Prefecture University) in Osaka. They formed small research groups, the ‘Working Group on Fuzzy System’ in Tokyo in 1972, and ‘Fuzzy Science Research Association’ in Osaka in 1980, respectively.¹³ In the early stage, not much attention was paid to fuzzy research and thus exchanges were mostly confined within academic circles (Hirota 1995). Fuzzy research spread more quickly after the International Fuzzy Systems Association (IFSA) was founded in 1984. In that year, the two above-mentioned groups merged into the IFSA Japan branch.

¹¹ The *raison d’être* for fuzzy logic is criticized by Bayesian statisticians as the ‘behaviourist hypothesis’ stated as the following: ‘Human are intelligent. Intelligent reasoning is imprecise. Therefore, intelligent systems should emulate imprecise human reasoning’ (Laviolett and Seaman 1994: 6). What is implied in this criticism is that Zadeh implicitly links intelligence with imprecision. For the controversies between Bayesian statisticians and fuzzy theorists, see Chapter 2.

¹² See, for example, Ragin (2000), Smithson (1987), and Smithson and Verkuilen (2006).

¹³ The Japanese name for the Working Group on Fuzzy Systems is ‘Aimai sisutemu kenkyūkai’ (Aimai Systems Research Association). Noteworthy is the Japanese translation of the word fuzzy: ‘aimai’. It has corresponding kanji (Chinese characters) and means vague and uncertain. In Japanese and in Chinese as well, it also has a negative connotation of liaison when connecting with certain words. Until late 1980s, both ‘aimai’ and ‘fuzzy’ circulated in Japan. It is suggested that because the Japanese transliteration of the word fuzzy implies mathematical research, which is much narrower in scope, Terano proposed the idea of ‘aimai engineering’ in order to promote engineering applications in 1974 (Hirota 1993a: 46). For issues around Japanese translation of the word fuzzy, see Chapter 5 and 6.

From the late 1970s, academic interest in fuzzy research was supplemented by exploration of its potential as suggested by Mamdani's experimental steam engine. Mamdani was invited as a visiting scholar to the Tokyo Institute of Technology, and presented his research entitled 'Linguistic Plant Controllers Using Fuzzy Logic' to the monthly meeting of the Working Group on Fuzzy Systems in May 1977 (Hirota 1993a: 62; Shibata 1977: ii). With some Japanese companies keen on developing fuzzy technologies, the 1980s saw the coming of age of fuzzy applications. Among the 'success stories' are the Sendai subway system, developed by Hitachi, which utilizes fuzzy control for train operation, and the controller designed by Fuji Electric, Co., in which fuzzy logic is used for controlling chemical injection in water treatment plants. The latter was first implemented in a water treatment plant in Sagami-hara city. Both projects were conceived in the late 1970s, and were realized in 1987 and 1986, respectively. The Sendai subway system is especially identified as a key development in 'the first fuzzy boom' that characterizes the years from 1987 to 1990, when many industrial applications came into view. Some of these applications were shown at the demonstration sessions at the Second IFSA (International Fuzzy Systems Association) Congress held in Tokyo in July 1987 – a week after the Sendai subway system went into operation – and the congress is said to have triggered the first fuzzy boom among academic researchers and industrial engineers (Hirota 1993a: 71; 1995: 47-49). Applications in this period include, among others, elevator control (Hitachi), highway tunnel ventilation control (Toshiba), combustion control for refuse incinerator (Mitsubishi), automobile transmission control (Nissan, Honda, Mitsubishi) etc. According to a survey, industrial applications of fuzzy logic in Japan numbered only twenty in 1986, but accumulated to more than one hundred and twenty in 1989 (Hirota 1993a: 77).

The year 1990 saw the start of 'the second fuzzy boom', characterized by the extensive application of fuzzy logic to home appliances and consumer electronics (Hirota 1993a: 109; 1995: 53). The 'Aisaigō (the model 'beloved wife') Day Fuzzy' washing machine, which was developed and put on the market by Mastushita Electric Co. in February 1990, brought about the second fuzzy boom as many other manufacturers followed by producing similar products. In the same year, the transliteration of the word 'fuzzy', 'fajyi', won the gold award for the new word of the year in Japan. Overall, by 1992, there were already nearly six hundred cases of fuzzy applications in the world with most of these in Japan (Hirota 1993b: 5). It is also suggested that the fuzzy boom in Japan from the late 1980s contributed to a new wave of upsurge in interest in fuzzy technology in Europe (von Altrock 1995: 277).

After the first fuzzy boom, the Japanese government became interested in fuzzy

logic and funded two large research projects. It has thus been argued that the first fuzzy boom was the watershed of the institutional arrangements of fuzzy research in Japan (Hirota 1995: 43). Before 1987, research activities were more scattered and can be characterized as having been advanced by university scholars or by the co-operation between university scholars and industry engineers. In 1989, not only was the Japan Society for Fuzzy Theory and Systems (SOFT) established and its official journal published, but the two above-mentioned projects commenced. The first was undertaken by the Ministry of International Trade and Industry (MITI) and some corporate sponsors. They provided ¥5 billion (\$40 million) to establish the Laboratory for International Fuzzy Engineering Research Institute (LIFE) exclusively for a six-year project for advancing fuzzy theory and its applications. Specifically, half of the funding was from 49 major electronics and automobile companies, and MITI took charge for the other half (McNeill and Freiburger 1993: 245). The second was a smaller five-year project, entitled 'Fuzzy Systems and Their Applications to Human and Natural Systems'. It was sponsored by the Science and Technology Agency (STA) with a funding of ¥1.2 billion (Hirota 1995: 49).¹⁴

The scale of LIFE can be gleaned by juxtaposing it with the budget of the notorious Fifth Generation Computer project, which was funded by MITI with support from the industry. The project lasted for eleven years from 1982 to 1992, and spent ¥54 billion in total (Callon 1995: 8). Although LIFE only spent only about a tenth part of the budget of the Fifth Generation Computer project, the influence of the first fuzzy boom that led to LIFE can still be seen.

The gradual institutionalization of fuzzy logic research can be marked by important events in chronological order as listed below (Fajyi gakkai henshū iin-kai 1999: 126-127; Lin and Chen 1995: 20-21; McNeill and Freiburger 1993):

Year	Event International	Event in Japan
1965	Zadeh proposed the idea of fuzzy set	
1972	Zadeh hinted at control application in 'A Rationale for Fuzzy Control'	Working Group on Fuzzy Systems founded in Tokyo
1974	First U.S.-Japan fuzzy seminar held at Berkeley	

¹⁴ Regarding the assumed role of MITI, STA, and the Ministry of Education (MOE), in science and technology research, Scott Callon describes as the following: 'all three organizations have jurisdiction over the promotion of Japanese science and technology, although theoretically there is a division of labor, with MOE sponsoring basic research, MITI doing commercially relevant research, and STA coordinating overall policy'. In effect, the three are competitive for government budgets and 'making occasional raids into one another's spheres of influence', with STA the most disadvantaged: 'STA is handicapped in the R&D tug-of-war because it is only an agency, not a full ministry, lacking the institutional power that ministerial rank and privilege brings with it' (Callon 1995: 34).

1977	Fuzzy logic was introduced into China	
1978	<i>International Journal of Fuzzy Sets and Systems</i> founded	
1980		Fuzzy Science Research Association founded in Osaka
1981	Chinese Mathematics and Fuzzy Systems Association founded in China <i>Journal of Fuzzy Mathematics</i> founded in China. Renamed to <i>Journal of Fuzzy Systems and Mathematics</i> in 1987.	
1984	International Fuzzy Systems Association (IFSA) and four branches of it: China, Europe, Japan and North America founded	
1985	First IFSA Congress (Majorca island, Spain; held biennially henceforth)	First Fuzzy Systems Symposium (Kyoto; held annually henceforth)
1987	Second IFSA Congress (Tokyo, Japan)	
1988	NASA conference on Artificial Neural Systems and Fuzzy Logic (Houston, U.S.)	International Workshop on Fuzzy System Applications (Iizuka, Fukuoka prefecture)
1989		Japan Society for Fuzzy Theory and Systems (SOFT) and its official journal founded (four issues a year; changed to six issues a year from 1992); Laboratory for International Fuzzy Engineering Research Institute (LIFE) founded
1991	Zadeh proposed 'Soft Computing'	
1992	First Fuzzy Conference held by IEEE (IEEE International Conference on Fuzzy Systems, FUZZ-IEEE)(San Diego, U.S.; held annually henceforth)	
1993	<i>IEEE Transactions on Fuzzy Systems</i> founded (four issues a year)	
1994	First IEEE World Congress on Computational Intelligence (WCCI) held (Orlando, U.S.) WCCI includes FUZZ-IEEE, IJCNN (International Joint	Laboratory for International Fuzzy Engineering Research Institute (LIFE) disbanded

	Conference on Neural Networks), and CEC (International Congress on Evolutionary Computation); held once for four years, changed to biennially since 2006	
2003		The name of the Japan Society for Fuzzy Theory and Systems (SOFT) was changed to the Japan Society for Fuzzy Theory and Intelligent Informatics but the acronym remains

Exploration of the History of Fuzzy Research in Japan

In the early 1990s, roboticist Fukuda Toshio coined 'FAN' as an acronym for fuzzy logic, AI, and neural networks, and symposiums in the name of 'FAN' began to take place annually in Japan (Sugeno et al. 1995: 7). The acronym 'FAN' is used only in Japan. Outside Japan, 'intelligent systems' is the phrase commonly used to refer to what 'FAN' means in Japan. The content of 'FAN' covers to some extent that of 'soft computing' that Zadeh proposed, but the juxtaposition of fuzzy logic, AI, and neural networks deemphasizes differences between fuzzy logic, AI, and neural networks. In fact, there were conflicts between the first two approaches.¹⁵ In contrast, the phrase 'soft' computing, with an insinuation that symbolic AI is to the contrary, does not ignore the differences that the acronym 'FAN' deemphasizes.

The contest for the definition of machine intelligence, as hinted by Zadeh's characterization of soft computing as having higher 'Machine Intelligence Quotient', was far from a minor issue in the history of fuzzy research, both outside and within Japan.¹⁶ In 1983, a year after the Fifth Generation Computer project was carried out, a popular computer magazine published a parodic article featuring the conception of the Sixth Generation Computer project based on 'fuzzics' (a compound word made

¹⁵ There were also controversies between AI and neural networks. As noted by a Japanese researcher in a round-table discussion on the similarities and differences between AI, neural networks, and fuzzy logic, the meaning of AI has greatly changed. In the 1960s, neural networks approach was quite central to AI. However, over the years, the meaning of AI somehow narrowed down to refer only to expert systems (Doshita et al. 1991: 35). With the proliferation of applications of AI, fuzzy logic, and neural networks, they were on several occasions put together for discussion in Japan in the 1990s (e.g. Doshita et al. 1991; Sugeno et al. 1995). In 1994, the Society of Instrument and Control Engineers (SICE, the largest society of control engineers in Japan) edited a handbook on neural networks, fuzzy logic, and AI, a weighty tome of about 1,400 pages (Umano 1995: 66). For the controversy between symbolic AI and neural networks from the late 1950s, see Olazaran (1993).

¹⁶ Compared to 'AI', a more modest phrase 'machine intelligence' has been used instead recently because of the complexity of intelligence has been acknowledged by research in the fields of cognitive science etc., although AI is still widely used (Mukaidono 1992: 74).

up of ‘fuzzy’ and ‘logic’) by the ‘Ministry of Totalling’ (a non-existent organization whose name is pronounced in the same way as is MITI in Japanese) (quoted in Aimai kagaku kenkyū-kai 1983: 7). Although a parodic article, the difference between fuzzy inference and the approach that the then extant artificial intelligence took, as claimed in the article, would nevertheless be shared by fuzzy researchers: ‘Because on many occasions, people think and infer basing on an incomplete knowledge base, the ability of fuzzical[sic] inference is indispensable to the realization of more intelligent computers. The Sixth Generation Computers which make fuzzical[sic] inference possible, can be said to be a step closer to human than is the Fifth Generation’ (ibid: 7).¹⁷

In fact, both Tanaka Kōkichi, one of the founding figures of the Fuzzy Science Research Association in Osaka, and Shimura Masamichi, former associate professor in Tanaka’s laboratory, who moved from Osaka University to Tokyo Institute of Technology in 1976 and became a member of the Working Group on Fuzzy Systems in Tokyo, had done some fuzzy research but later left it for symbolic artificial intelligence.¹⁸ They advised Mizumoto Masaharu (a student with a newly earned Ph.D. in 1971 on fuzzy theory under Tanaka’s supervision) that it would be better to do research on the then emergent artificial intelligence instead of clinging to fuzzy theory. To them, fuzzy theory was ‘useless’.¹⁹ This attitude was prevalent both in Japan and internationally.²⁰

Mamdani’s application of fuzzy inference to control was an antidote, as it were, to this attitude. From the late 1970s, the audience of fuzzy theory in Japan extended to include industrial engineers. A gradual transition then took place, from a more mathematical way of doing fuzzy research for an audience in academic circles, to a more practical way of showing the usefulness of fuzzy logic for an audience of engineers. The transition assumed a different way of proving. In the former, the attempt was usually to manipulate mathematical symbols by following logical inference procedures; in the latter, not only technical criteria were used for evaluation, but the efficacy of fuzzy logic in improving performances had to be confirmed. This issue came to the fore especially when fuzzy control became widespread, as controversies around the efficacy of fuzzy control arose.

Just as one of AI researchers’ strategies for claiming that artificial intelligence is

¹⁷ Years later, Yamakawa Takeshi, a professor who built hardware systems which implemented fuzzy logic as their working logic, did refer to ‘fuzzy computers’ as the Six Generation Computers, as opposed to the Fifth Generation Computers which were seen as the most advanced digital computers. (Yamakawa 1988: 152-154). For Yamakawa’s hardware systems, see Chapter 4.

¹⁸ Mizumoto interview.

¹⁹ Mizumoto interview.

²⁰ Sugeno interview.

comparable to human intelligence was to operationalize intelligence in a way that favoured the achievements in AI (Turing 1950), one of the ways fuzzy researchers promoted fuzzy control, a linguistic model of human reasoning, was to claim that fuzzy control was much closer to what skilled operators do in their work. This was accomplished by technological demonstrations, which consisted of both performing a series of real-time demonstrations, and experiencing real applications such as the Sendai Subway. For instance, both the Second IFSA Congress held in Tokyo in 1987 and the International Workshop on Fuzzy System Applications held in Iizuka in 1988 had demonstration sessions. Eleven devices or programs were shown in the former, and a robot that handled bean curds without breaking them, among others, was shown in the latter. In AI, one way of carrying out the above-mentioned task of putting AI alongside human intelligence was through the so-called 'Turing test'. Technological demonstrations of fuzzy control are comparable to the Turing test in that, for both, some criteria are so defined as to be characterized as more human – criteria that machines in the past could not fulfil.

Demonstrations of fuzzy logic were also underway in some areas of performance which were, for a long time, certainly not thought of as ever achievable by machines; that is, in those most humanly human, such as the area of art. These demonstrations also, sometimes, carried with them an East Asian tinge; for instance, a robot demonstrating flower arranging (Hirota 1993c). This East Asian tinge was complemented by claiming, a link between fuzzy theory and East Asian thought, as Terano Toshirō's invocation of Chung-tzu mentioned before shows.

The link was established partly by way of translation. The original Japanese translation of the word 'fuzzy', made by Terano, was 'aimai'. However, as *aimai* is a culturally charged word, explanations and interpretations of fuzzy theory had become inextricably associated with meanings of *aimai* in the Japanese context. And *aimai*, in turn, turned out to be a word denoting characteristics of those fields in which humans outperformed machines. The word *aimai* gave way to the Japanese transliteration of 'fuzzy', as 'fajyi', when fuzzy logic reached an even wider audience with the second fuzzy boom in home appliances and consumer electronics brought about by several large manufacturers. This change in usage preference from 'aimai' to 'fajyi', as a result of the promotional efforts of these manufacturers, was accompanied by a change in the meaning of the word 'fuzzy' in the Japanese context.

In order to chart the history of fuzzy research in Japan as an enterprise which extended its reach to a growing audience, that is, from an audience consisting of a small circle of academic researchers, to include industrial engineers, and, finally, to the general public, I will view the development of fuzzy research in three not

exclusively demarcated periods. The first period spanned from the late 1960s to the late 1970s when fuzzy research remained largely an academic undertaking and had not been formally institutionalized. Then came the second period, which spanned from the end of the first period to the late 1980s, when the first fuzzy boom emerged. In this period, industrial applications surfaced and the efficacy of fuzzy logic was interpreted by fuzzy researchers' use of a humanized language, on the one hand, and put under scrutiny by other researchers, on the other hand. The third period spanned from the late 1980s to the early 1990s, in which the first fuzzy boom was followed by the second, and fuzzy research in Japan reached an apex with the establishment of the Japan Society for Fuzzy Theory and Systems (SOFT) and the commencement of the two projects funded by the government. During this period, the original translation, 'aimai' had given its way to the transliteration, 'fajyi'.

These three periods will be explored by distinct conceptual perspectives, according to a prominent theme by which each period is characterized. These take on issues of organization of scientific research; problems regarding demonstrations and proofs, especially in AI related fields; and issues concerning translation. The prominent themes of the second and the third periods are linked and can be conceived in broader terms as the problem of interpretation. What follows is the literature review of the first two of these perspectives. The third perspective will be seen as an expansion of the second and will be delineated along with the analysis in Chapters 5 and 6.

Literature Review

Science as Reputational Work Organizations

The theory of scientific organizations was developed, among others, by sociologists Randall Collins, Stephan Fuchs, and, in the most detailed way, Richard Whitley from the late 1970s. This theory tries to combine structure-oriented Mertonian sociology of science with the results of constructivist laboratory studies. Therefore, it is argued, the theory concerns both cognitive and social aspects of the production of the sciences, and is an attempt to develop a comparative framework which was neglected by micro-level laboratory studies (Collins 1988: 291; Fuchs 1992: 8-9; Whitley 2000: 4-6). Since reward allocation is a key issue in the conceptualization of this theory, I will make it the starting point.

The origin of interest in the reward system of scientific communities can be traced back to the work of sociologist of science Robert Merton. Noting the rapid and

cumulative growth of scientific knowledge as opposed to other forms of knowledge, Merton sought to find the institutional setting which contributes to the exercise of control over the behaviour of scientists and the quality of their knowledge production (Barnes and Edge 1982: 13; Mulkay 1977: 98). From a structural-functional perspective, Merton identifies four institutional imperatives to which members of a scientific community conform in order to secure the steady production of scientific knowledge: universalism, communality, disinterestedness, and organized scepticism. Later on Merton added to these the norms of originality and humility. Although the famous original four norms articulated by Merton were refuted as not consistent with observations and can be used by scientists as rhetorical resources (Barnes and Edge 1982: 18), Merton's discussion of scientific norms, and particularly his focus on competition for originality and priority in the scientific community especially, opened up new ground for detailed study of the scientific community.

As Mulkay puts it, 'the analysis of the normative structure of science could not be regarded as complete until it had been shown that rewards were allocated so as to produce general conformity to the norms previously identified' (Mulkay 1977: 99). The call for detailed empirical study became more urgent when Merton himself found there is incongruence between the selfish behaviour of scientists in priority disputes and the norm of communality – the willingness to share knowledge with other members. Issue of reward allocation became the key to understanding the behaviour of scientists, and was explored by Warren Hagstrom (Ben-David 1978: 199-200).

Hagstrom depicts the scientific community as a recognition exchange system for valuable information. Scientists share their results openly without the overt expectation of return from the community, as if in a pre-capitalist gift-giving exchange system (Hagstrom 1965: 13). However, the expected return, not overtly stated, is the recognition of the donor's status as a member of the community. Recognition by other competent members is the most desired reward for scientists. Scholars have argued that Hagstrom's theory is still a Mertonian functional explanation, in that it is still concerned with why scientists obey the norms (Barnes and Edge 1982: 18; Latour and Woolgar 1982: 37). In contrast to Hagstrom's pre-capitalist tone, Latour and Woolgar provide a more capitalist oriented position in arguing that scientists exchange information for their own use, to gain credibility and then exchange it for other rewards.

Analyses by Hagstrom and, to a lesser degree, Latour and Woolgar, contributed to the general view that interactions within scientific communities are mediated by a special form of general currency: recognition. As a general currency, recognition

channels all kinds of individual motives in science and serves as the route to specific rewards desired by various individuals, contributing to reputation, promotion, research grants and so on (Barnes and Edge 1982: 15-17).

The proposition of the recognition concept led to subsequent qualitative and quantitative studies exploring how recognition is distributed, and how the scientific institution is seen as simultaneously a reward, communication and allocation system in which its operation usually leads to stratification and generates a self-reinforcing elite structure. That is, by monopolizing recognition, prestigious groups tend to receive more funds, more talented researchers and thus attain further valuable results (Barnes and Edge 1982: 17; Ben-David 1978: 199; Mulkay 1977: 101-103). In this stratified setting, the elite confines the range of acceptable information, and through the reward system, recognition is distributed to those who address legitimate problems and conform to current cognitive and technical standards, so that intellectual deviance is discouraged (Mulkay 1977: 106).

In this regard, to explore what makes radical innovation possible is an interesting issue because for this to happen, to a certain extent some disruption of the extant elite structure is necessarily involved. This issue has mostly been investigated by the research area called 'specialties studies'. The term 'specialties' was given by Hagstrom, referring to small groups of researchers who share more narrowly-defined concerns and are familiar with each other's work (Hagstrom 1965: 159). In other words, a specialty defines a particular problem and confines the boundary of communication and control. Apart from the term specialties, which emphasizes the problem area in which researchers are interested, there are other terms which stress the informal organizational relationship between small groups of researchers that bear similar meanings to specialties: Derek de Solla Price's 'invisible college', Diana Crane's 'social circle', 'solidarity group', Nicholas Mullins' 'networks' and 'clusters' and so forth (Barnes and Edge 1982: 19; Hess 1997: 73). Drawing on network analysis, specialties studies explore how a particular emergent specialty gets established; in other words, how an innovation within or beyond a discipline becomes institutionalized.

For our purposes, it is useful to see how Hagstrom depicts the development of a deviant specialty, the 'groups whose members feel they are not awarded as much prestige within the discipline', who either 'accept the goal of their discipline but believe their specialty is much more important than others give it credit for' or 'reject the central goal of their larger discipline and the legitimacy of the prestige system in it' (Hagstrom 1965: 187). Deviant specialties lead to organizational conflict, and the most common punishment by the larger discipline is to reject them for university

appointments, and deny them the opportunity of having graduate students and publishing. If some measures of adaptation cannot soothe the conflict, a deviant specialty will eventually lead to the formal differentiation of the discipline (Hagstrom 1965: 187-209).

As a case study of specialty formation, Ben-David and Collins (1966) describe the role of the leader in the emergent discipline of psychology in late nineteenth century Germany. They claim that role-hybridization took place in the process when a researcher moved from a higher (physiology) to a lower (philosophy) prestige discipline; once the leader can accommodate the role conflict resulting from discipline migration, career opportunities compensated for the difference in prestige between the new and old disciplines. They also propose a three-stage model of specialty formation: forerunners, founders, and followers. In contrast, Mullins proposes a four-stage model: paradigm group or normal stage, network, cluster, and specialty or discipline (Edge and Mulkay 1976: 369-371; Mullins 1973). However, in a detailed comparison between their own research on specialty formation and those of other scholars, Edge and Mulkay find that neither model applies for all the case studies. They list fifteen dimensions such as mobility, identity, creation of a new journal etc. of similarities and differences between the results obtained by these scholars (Edge and Mulkay 1976: 382; Hess 1997: 75).

Although, as Geison argues, the detailed and sociological informed study on the specialty formation of radio astronomy by Edge and Mulkay is somewhat compromised by their determination, shared by others in specialties studies, to adopt a conceptually schematic straitjacket (Geison 1981: 21), we can regard Edge and Mulkay's fifteen dimensions as flexible guidelines. Seen in this way, they serve to draw our attention to structural features, and pay heed to the particular organizational characteristics such as degree of functional dependence, hierarchies of authorities, availability of resources, and the role of external knowledge consumer, etc. (Amsterdamska 1985: 332-335). Therefore, research on recognition and specialties, which views scientific community as an institutionalized system of communication, reward, and control, still offers abundant conceptual resources.

In the theory of scientific organizations, variations in organizational characteristics across science are examined along two dimensions: the nature of the tasks, and the nature of coordination (Collins 1988: 292). While Collins uses 'task uncertainty' and 'problems of coordination' to denote the two dimensions, Whitley and Fuchs prefer 'task uncertainty' and 'mutual dependence'. Task uncertainty 'indicates the extent to which scientific production is routinized and predictable' (Fuchs 1992: 82), and 'mutual dependence' refers to 'scientists' dependence upon

particular groups of colleagues to make competent contributions to collective intellectual goals and acquire prestigious reputations which lead to material rewards' (Whitley 2000: 87).

Whitley further divides task uncertainty into 'technical task uncertainty', which indicates '[t]he extent to which work techniques are well understood and produce reliable results in various scientific fields' (Whitley 2000: 121), and 'strategic task uncertainty', which represents 'the degree to which different scientists pursue related or unrelated lines of work, and hence is an uncertainty about whether one's work will be taken by the larger community' (Collins 1988: 292). Mutual dependence is also divided further by Whitley into two subdivisions: 'functional dependence' denotes 'the extent to which researchers have to use the specific results, ideas, and procedures of fellow specialists in order to construct knowledge claims which are regarded as competent and useful contributions'; and 'strategic dependence' which refers to 'the extent to which researchers have to persuade colleagues of the significance and importance of their problem and approach to obtain a high reputation from them' (Whitley 2000: 88). Whitley then produces a typology of sixteen types of scientific organizations by applying the four dimensions, each of which is subdivided into high and low degrees. Seven types remain, after noting that nine of the sixteen types are theoretically improbable, and Whitley gives each of the seven types a special name such as 'fragmented adhocracy' and 'polycentric oligarchy' (ibid: 154-158).

The organizational structure of both engineering and artificial intelligence, the scientific research fields that are the most relevant to fuzzy theory with which this thesis is concerned, is characterized by Whitley it as 'professional adhocracy' (Whitley 2000: 160). It characterizes a research field where technical task uncertainty and degree of strategic dependence are low, and strategic task uncertainty and degree of functional dependence are high:

technical task uncertainty is more reduced, but strategic task uncertainty remains high, the standard skills and technical procedures enable a more typical 'profession' to develop in which reputational organizations control the production and certification of research competence but differ in the extent to which they control work goals and priorities. In 'professional adhocracies' there are a variety of influences on research goals and no single group dominates significance criteria for very long. The bio-medical sciences and artificial intelligence, for example, have a variety of funding sources and employment organizations where research is conducted, and there is no single reputational group to whom all members of the

field are oriented and take into account when developing their research strategies...Knowledge is highly specific and empirically focussed in such fields with a variety of problem formulations and conceptual approaches linked to particular skills. Generality of both problems and materials is unlikely to be very high and a high degree of theoretical integration improbable (Whitley 2000: 160-161).

In addition to the four dimensions that are used to characterize structures of organizations of the sciences, Whitley also points out three important contextual factors that influence task uncertainty and mutual dependence: reputational autonomy, concentration of control over the means of intellectual production, and audience plurality and diversity (Whitley 2000: 105-111). These contextual factors can be used to undertake international as well as historical comparisons of the sciences of interest, as Whitley briefly did in the introduction of the second edition of his book (*ibid*: xxii-xxx).

Whitley's brief mentioning of features of Japan's national research systems is very relevant to our inquiry. Taking the Germanic system as its model, the Japanese academic system features low mobility, high concentration of control by departmental professors, and 'strong hierarchies of university prestige' (Whitley 2000: xxiii-xxv). In Chapter 3, we will analyze the research organization of fuzzy theory in Japan in the early years by taking into account the influence of the Japanese *kōza* (departmental chair) system.

Demonstrations and Proofs

In the late 1970s, as fuzzy research moved from theoretical inquiry to include practical applications, there was a similar shift in attempts to gain credibility for this new area of research. Rather than simply relying on claims for fuzzy logic based on the results of mathematical manipulation, there was an increasing emphasis on technological demonstrations. Two issues on the trustworthiness of the technological demonstrations of fuzzy logic came to the fore. Firstly, on what grounds are technological demonstrations trustworthy? A second related issue is that, even if the trustworthiness of technological demonstrations is confirmed, how can that trustworthiness be ascribed to the effect of fuzzy logic? Regarding the trustworthiness of technological demonstrations, and the issue of interpretation in accounting for technical efficacy, this section will firstly review STS work on demonstration, and then will take artificial intelligence – which, as a research field, is

closely related to fuzzy logic – as an example on the issue of interpretation of technological efficacy.

Demonstration

According to the *Oxford English Dictionary*, one of the meanings of the word ‘demonstration’, most relevant to the practice of mathematics and logic, refers to:

The action or process of demonstrating or making evident by reasoning; the action of proving beyond the possibility of doubt by a process of argument or logical deduction or by practical proof; clear or indubitable proof; also (with *pl.*) an argument or series of propositions proving an asserted conclusion.

In contrast to the process of ‘logical deduction’ usually performed with the aid of only pen and paper in mathematics and logic, technological ‘demonstration’ relies on a different ground. ‘Demo’ is the abbreviation used frequently by engineering communities for technological demonstration. Demos are real-time performances of prototypes or end products carried out in front of an audience. They are intended to show tasks that the artefacts can perform and ways in which the artefacts can be used. The audiences, as witnesses, are expected to believe that the artefacts will in the future deliver the same level of performance as seen in the demos. Demos are also often used to imply that a general characteristic of the technology being applied in the artefacts can be inferred (Rosental 2005: 346). Therefore, demos can be said to rely on an inductive inference, made on the part of the audience from a specific demo, to future operation or general properties of the artefacts being demonstrated.

The underlying reasoning behind demos is one of the ways in which we evaluate the trustworthiness of technology. Donald MacKenzie suggests that there are three main processes through which we know the technical properties of artefacts: authority, induction, and deduction (MacKenzie 1996). In that context, deduction refers to the process in which we infer properties of artefacts ‘from theories or model’; induction, on the other hand, points to the way in which we know them by ‘testing or using them’ (ibid: 250). Just as the major concern for testing is how a similarity relationship between test circumstances and conditions of actual use – a crucial property to be known of the artefacts being tested – is established (MacKenzie 1996; Pinch 1993), the demo serves as a real-time test that tries to persuade the audience into believing that the artefacts or technology being demonstrated will generally behave as in the demonstration. A major difference

between a demo and testing, or using artefacts in general, resides in the contrasting time scales they imply, for demos are carefully prepared beforehand to address the audience for a short period of time.

Regarding testing practices, the case of computerized systems emerges prominently at the interface of the induction-deduction spectrum, for there have been two opposing approaches to ensure their trustworthiness at work, an issue of massive concern in modern life. As MacKenzie details, both formal logic proof and empirical testing, contrasted with each other by their underlying reasoning, have been proposed and utilized to verify computer programs. The former is preferred by its proponents because exhaustive testing is almost always beyond feasibility even for a simple computer program composed of only few lines. In contrast, 'a deductive, mathematical analysis can claim to cover all cases, not merely the finite number that can be subject to empirical testing' (MacKenzie 2004: 70). MacKenzie extends 'cultures of proving', a term drawn from the title of one of Eric Livingston's articles (Livingston 1999), to refer to the different ways in which computer scientists view and practise what counts as proof to them in verifying computer programs. What is emphasized in MacKenzie's use of that term is its plurality: although deductive proof is crucial for disciplines such as mathematics, logic, and computer science, different ideas of the meaning of proof remain within them (MacKenzie 2001: 306, 2004: 74-75).

Demonstrations of fuzzy control provide instances of a conflict between distinct cultures of proving. A controversy surrounding a series of demos of fuzzy logic in Japan arose in the late 1980s and early 1990s. In these demos, a fuzzy controller was used to balance an inverted pendulum. The demos were intended to show the competitiveness of using fuzzy logic as a method for controller design. The efficacy of these demos, however, was challenged by some control theorists who emphasized the priority of theory and deduction in design. A controversy was thus generated, during which time the demos still went on. As will be addressed in Chapter 4, fuzzy logic was to these control theorists a much less mathematical approach to controller design. In contrast, for them, results derived from scientific theories, those of physics, for example, served as valid starting points on which mathematical analyses of the controlled systems could be built.

In the same way that formal logic proof has been used to verify computer programs, the mathematical approach, on which these control theorists insisted, derives solutions from the analysis of mathematical models and, in the words of MacKenzie, 'can claim to cover all cases' (MacKenzie 2004: 70). This ability to cover all cases stems from its deductive inference, which contrasts with inductive

demos. In fact, the control theorists pointed out a case in which those demos would fail if they were conducted under certain conditions. The controversy will be analyzed to show the context in which demos of fuzzy logic were seen as trustworthy. In addition to the real-time demos on an inverted pendulum, two other large civilian applications, especially the Sendai subway, can be said to be also demos of fuzzy logic. In the Second IFSA (International Fuzzy Systems Association) Congress held in Tokyo in 1987, both the controller made by Fuji Electric Co. for a water treatment plant and the controller made by Hitachi for the Sendai subway trains were part of the demonstration sessions. A technical tour arranged for a ride on the Sendai subway for participants was seen as contributing much to the success of that conference (Hirota 1993a: 71; Mukaidono 1988: 74). This brings us to the question of attribution, that is, attribution of the working of those controllers to fuzzy logic.

Interpretation of Efficacy – Take Machine ‘Intelligence’ as an Example

As a theoretical resource that serves to analyze the claim that fuzzy logic successfully models human ways of thinking and doing, this section reviews sociological work on a comparable case. This would be the so-called ‘Turing test’ that decides whether a machine can be said to be intelligent.

In the article ‘Computing machinery and intelligence’ (Turing 1950), Turing proposed an ‘imitation game’ to test the intelligence of a machine. He devised a workable criterion of machine intelligence by translating the general, ill defined question ‘Can machines think?’ into a game that invites an operational answer (Collins 1990: 181). The imitation game originally consisted of a man, a woman and an interrogator, who has to identify the man and the woman correctly through short conversations in the game in which the man pretends to be the woman. In order to remove any gender traits that can be differentiated easily by the interrogator, the man and the woman are located in separate rooms, and conversations are conducted via the help of teleprinter communication. Next, a machine substitutes for the man and plays the game, and the interrogator has to determine which respondent is the machine. As in the original game played by three people, any physical traits that can be identified as the differences between a person and a machine in this new game are masked by the setting of rooms and typewriters. If a machine succeeds in cheating the interrogator in the second imitation game, then it passes the test, and it can be argued that the answer to the original question of ‘Can machines think?’ is also positive. This is the so-called ‘Turing test’. We can see that Turing’s idea of intelligence is reflected by the setting of the imitation game, which in turn is

crystallized in the translation of the original question to the new one, so that all contextual information of a conversation regarded as irrelevant is ruled out. Turing argued: 'the new problem has the advantage of drawing a fairly sharp line between the physical and the intellectual capacities of a man' (Turing 1950: 434).

One of the most vigorous sociological lines of inquiry that has been applied to the issues of machine intelligence is ethnomethodology. Four sociologists and philosophers exemplify this approach to machine intelligence through their examination of the Turing test in their collectively written book. Machine intelligence, they argue, is not an empirical question that can be decided with reference to advances in computer technology, as Turing proposed (Button *et al.* 1995: 13, 134).²¹ Rather, it can be resolved by analysis, by which the optimism that the solution of philosophical questions would rest upon technological development is exposed, and then the link between the two is severed.

They suggest an analogy to show the absurdity of the Turing test. A listener is put outside a room in which the Kronos Quartet and a high quality recording of the quartet's performance take turns in playing. The listener has to decide if there is any difference in the sound between the two. The authors ask that if the two are indistinguishable to the listener, can we say that the CD player that reproduces Kronos' performance has the same musical capabilities as the four artists in the Kronos quartet (Button *et al.* 1995: 135)? The forging of this CD player version of Turing test is to compare different responses we would have toward similar questions. In the music capability test, people will be far more positive that the answer is 'no' than they would be when faced with the Turing test.

Button *et al.* try to show, in two parts, that 'the claim for machine intelligence is as foolish as that for the musically skilled CD player' (Button *et al.* 1995: 136). First they argue that Turing was mistaken in his view of the implementation process of an 'intelligent' program in a computer. Secondly, they scrutinize the rhetoric and eschewal of Turing's reframing of the essential problem. They argue that Turing's idea of a universal machine is but a mechanical execution of instructions given by implemented programs and has nothing to do with mathematics or mathematical skills. Turing did not understand that the mechanization of calculation does not involve any intelligence transfer, so it is quite a wrong thing to argue that a machine

²¹ Turing commented that 'I believe that in about fifty years' time it will be possible to programme computers, with a storage capacity of about 10^9 , to make them play the imitation game so well that an average interrogator will not have more than 70 per cent chance of making the right identification after five minutes of questioning. The original question, 'Can the machine think?' I believe to be too meaningless to deserve discussion. Nevertheless I believe that at the end of the century the use of words and general educated opinion will have altered so much that one will be able to speak of machines thinking without expecting to be contradicted' (Turing 1950: 442).

embodies mathematical skills or intelligence at all. They provide another example to show the peculiarity of Turing's argument:

Since...in the case of human beings, the carrying out of a complex computation *requires* considerable intelligence, do we not also have to say that, in the case of machine, the same operation *requires* considerable intelligence?...one might as well say that since digging ditches requires life when done by human beings, and digging ditches can be done by mechanical digging machines, then ditch-digging machines must be alive (Button *et al.* 1995: 139, original italics).

The above examples bring us to the problem of language usage with regards to how Turing uses the word 'intelligence'. As Button *et al.* argue, in describing how a Turing machine works, Turing did not say a word about what real people do and what is involved in the task of calculation and doing mathematics. In the case of the Turing test, which is intended to test machine intelligence, he also did not provide any hint of how people perceive the testing condition (Button *et al.* 1995: 139-141). In other words, it is the context of the test, which Turing ignored, that is essential to the whole problem. Moreover, we may argue that this deliberate ignorance provides the necessary condition for Turing to perform his rhetoric feat. Turing begged the question of providing an operational definition of what 'intelligence' means by the criterion of passing the test and then proposing that passing the test entails intelligence (Button *et al.* 1995: 142). However, there is a huge discrepancy between intelligence thus perceived and the intelligence to which people usually refer. By ruling out any contextual information people that rely upon to discern what can be identified as intelligence, Turing urged us to admit that the mere simulation of a special field (conversation in the Turing test) of human activity can be said to be intelligent.

As Button *et al.* argue, the Turing test is 'intended to test for intelligence in machines, *but it might equally well be seen as testing the discriminatory powers of the experimental subjects*' (Button *et al.* 1995: 141, my italics). Sociologist Harry Collins, partly inspired by ethnomethodology in his analysis of artificial intelligence (Collins 1990: 98, 191), pushes the issue of the discriminatory powers of experimental subjects even further.

At first glance, the approach Collins takes is not very dissimilar to that of Button *et al.* in that he addresses the mutual definition of intelligence as well as the protocol of the Turing's test (Collins 1990: 184-186). This seems to be akin to what Buttons *et al.* say about the question begging of the Turing test; however, unlike

Button *et al.*, Collins states his sociological approach outright: 'I *want* intelligence to be seen as something having to do with social interaction. That is the basis of my whole argument' (Collins 1990: 245, original italics). Part of Collins's treatment of the Turing test relates to its ethnomethodological characteristics. He says:

The Turing test is so interesting because it is a test of the capacity of a machine to mimic the *interactions* of a human being. It is, then, a test of our abilities to make an artificial human that will fit into a little social organism as opposed to a test of a machine's ability to mimic a brain (Collins 1990: 183, original italics).

'Our abilities to make an artificial human that fits into a little social organism' is arguably demonstrated by the case of the conversation program, ELIZA. In some variants of the Turing test, an interrogator is not informed that there is a test going on. She thus treats the machine as a person and in this situation the Turing test is undoubtedly passed.²² Collins refers to ethnomethodologist Harold Garfinkel's 'counselor experiment' as an exemplar that accounts for this phenomenon: a human being can make sense of information that does not exist (Collins 1990: 98).

However, Collins goes beyond ethnomethodology with his argument on artificial intelligence, by elaborating the contrast between a physical prosthesis such as an artificial heart and a 'social prosthesis' like an intelligent machine. Collins argues that computers cannot be treated as isolated brains. The difference lies in the 'organisms within which they function'. 'The organism into which the intelligent computer is supposed to fit is not a human being but a much larger organism: a social group...just as an artificial heart does not necessarily have to have identical input or output characteristics to a real heart, neither does an artificial human. The embodying organism may be indifferent to variations, or it may compensate for inadequacies' (Collins 1990: 14-15). The concept of social prosthesis therefore aims to emphasize the fact that 'the humans compensate for the deficiencies of artifacts in such a way that the social group continues to function as before' (Collins 1990: 215).

From this perspective, the meaning of the Turing test for Collins lies predominantly on the side of the people rather than the machine. He proposes a

²² The case is vividly showed by Weizenbaum regarding his invention DOCTOR, a therapist ELISA program: 'If ...one were to tell a psychiatrist "I went for a long boat ride" and he responded "Tell me about boats," one would not assume that he knew nothing about boats, but that he had some purpose in so directing the subsequent conversation. It is important to note that this assumption is made by the speaker....The speaker further defends his impression ...by attributing to his conversational partner all sorts of background knowledge, insights and reasoning ability...They manifest themselves inferentially in the *interpretations* he makes of the offered response. (quoted in Suchman 1987: 23-24, original italics)

stringent protocol for the ultimate Turing test in which the attitude of the interrogator, the subject matter to be discussed, and the length of the test etc. are set up in such a way as to make the interrogation so hostile that passing the test is an extremely difficult task. In a sense, the effort here is similar to that of Button *et al.* in its aiming to make the interactive context of the Turing test explicit. However, Collins argues that this is only part of the story. The other part lies in the abilities that humans possess to mimic artefacts. If we choose to discipline ourselves into behaving like machines, then since we are more like machines, machines can behave more intelligently, like us. Take factory floor manufacturing or calculators for example. Since we arrange the tasks of manufacturing and calculation in such a way that they can be done by machines, part of our abilities are ready to be replaced by machines which act 'intelligently' within our society (Collins 1990: 216-221). He thus thinks it makes no difference whether we think about calculators, slide-rules or computers, for they all do arithmetic in the same way, in the sense that we have to compensate for their deficiencies, e.g., to read the answer a calculator gives for the sum $10/3 * 3$ as 10 rather than 9.9999999, the one shown on its screen (Collins 1990: 66; 211). It is because we have regarded their performances as doing arithmetic that we have renounced our right of interpretation of the word 'intelligence'. Therefore, regarding the interpretation of intelligence, it is us, not the machine, that bears the burden of proof. Taken together, for our purpose, the work by Button *et al.* and Collins on the Turing test helps us to pay heed to the contextual information of the positive interpretation of fuzzy technology, and the role people play in the 'social prosthesis', to use Collins's words, in which machines implemented with fuzzy logic work.

Data Collection

Before I conducted the main research on which this thesis is based, a pilot study on the Sendai subway system was carried out in mid April 2004. The aim of the pilot study was to investigate the testing and verifying process of the newly developed fuzzy controller for train driving control in the Sendai subway. Although the original aim proved to be infeasible because I was not granted access to the relevant documents, the interview with the main designer of the controller nevertheless drew my attention to the variability of the interpretations of the Sendai subway system among different accounts. This finding has led me to a focus on the interpretations of fuzzy technology, especially those applications that enjoyed flagship status and/or were put on demonstration. This focus constitutes a major theme with which this thesis is concerned.

As the description regarding fuzzy logic research in Japan provided earlier has implied, a cultural link between fuzzy research and Japanese thought, which was intended to account for Japan's leadership in this research area, appeared rather late – after numerous applications began to emerge. Therefore, in order to problematize the popular cultural link thesis, the issues of how fuzzy research was conducted in the academy, and how it was different from that in other countries before applications materialized became the focal questions. Was there any controversy that ever arose in Japan? If the answer is positive, how did it evolve? If not, what contained it? This leads us to the issue of the organization of academic research.

Since the information relevant to the questions mentioned above can hardly be found in written material, conducting interviews was indispensable for acquiring them. In fact, it became clear to me right after the first few interviews that conducting interviews was also an important way to obtain relevant written material that document past research activities, because interviewees would try to check their memory against those materials during interviews.

Therefore, in addition to documentary sources, interviews constitute the other source of data for this thesis. Although my enquiry into the issue on translation – as was hinted in the very beginning of this chapter – relies largely on documentary sources, interview data play a major role in other parts. Documentary sources here are to be conceived broadly, including articles in international and Japanese professional journals spanning from late 1960s, when fuzzy research was in its inchoate era; reports in house journals on applications of fuzzy logic; published material such as articles in newspapers and magazines, and unpublished ones such as communications circulated between members of research associations, on the promotion and news of fuzzy research in Japan.

Access to the interviewees was mainly gained from two methods: sending formal letters, and 'snowballing'. For the pilot study on the Sendai subway system, for example, contacts were successfully established after reference letters prepared by Prof. Donald MacKenzie, my supervisor, and his former Japanese student, Prof. Hara Takuji, were sent to the interviewees. On the other hand, the snowballing process was made possible firstly by the fuzzy research network between Japan and Taiwan, and was continued by introductions provided by Japanese professors. Furthermore, after I got the membership list of the Working Group on Fuzzy Systems, I tried to contact the members of it by sending them formal letters followed by e-mails of enquiry. Some interviewees kindly replied to my enquiry and connections were thus established. I also obtained access to some interviewees by attending the 21st annual Fuzzy Systems Symposium held in Tokyo in September 2005.

Interviewees include predominantly current and retired university professors who have been doing or who once did fuzzy research, or who specialized in control engineering or systems theory. Other interviewees are industrial engineers who participated in constructing fuzzy control systems, or those who have relevant knowledge of the construction of them.

An issue arising from the process of gaining access to interviewees, related to a methodological issue regarding the use of oral sources, should be discussed here. In the letters that I sent to possible interviewees, I pointed out the possible bearing of their written work on my research. Then, if access was granted, I also raised questions based on their work in the interview. I found this a good strategy to earn the trust of the interviewees as they could find seriousness in me from my reading of their work. Also, they were willing to give interpretations on their past ideas that materialized in their former work. However, although this strategy might have been useful in gaining access to some of the interviewees, why they agreed to be interviewed is of methodological significance. From my experience, introductions provided by Japanese professors did not necessarily secure the reply from targeted interviewees of whom those professors are acquaintances or even colleagues. Why, then, did my formal letters, from someone unknown to the recipients, make some of them forthcoming? In addition to other unknown reasons, a possibility lies in the stakes interviewees have in the history of fuzzy logic. Since the research area has been controversial, the stakes may be higher for the researchers than that in other areas. This brings us to the problem of being 'captured' in STS controversy studies (Scott, Richards, and Martin 1990), that is, the analyst's work becomes the arena for promoting interviewees' idea. Similarly, interviewees might also claim their work to be among the earliest, the best, the most efficient etc. work in certain area.

In practice, as this thesis is concerned with past events and past controversies rather than ongoing ones, the stakes the interviewees have in those past occurrences might not be too high. This would partly account for the reason why I failed to achieve access to some targeted interviewees – for them ongoing research is much more important than past research. On the factual level, on the other hand, I have checked transcripts of the interviews against each other, and also against document sources, to make sure, as much as I possibly can, that the information about the time, place, etc. of past events mentioned in this thesis is correct.

In total 33 in-depth, semi-structured interviews have been carried out. Interviews were conducted in English or/and Japanese, and generally lasted for one to two hours. A list of interviewees, and those who have provided significant information in other forms, is shown in appendix A and B, located at the end of the

main text. Quotes in this thesis from interview transcripts and written material that are originally in Japanese, unless otherwise noted, are all my translations.

Outline of the Thesis

The delineation of the main themes with which this thesis is concerned appears in Chapter 1. Chapter 2 then surveys several important controversies that arose in the U.S. between fuzzy theory and other approaches, and examines how fuzzy theory was conceived by opponents and what was at stake in the controversies. These include, among others, controversies between fuzzy theory researchers and statisticians on the similarities and differences between the concept of fuzziness and probability; between fuzzy theory researchers and artificial intelligence practitioners on the usefulness of fuzzy logic; and between fuzzy theory researchers and control theorists on the priority of modelling in controller design.

Chapter 3 discusses the early development of fuzzy theory in Japan. Fuzzy research was initially confined within academic circles in the U.S. where it originated. Before industrial applications emerged in the early 1980s, the situation in Japan was similar. Since the development of a new specialty within academic circles is inevitably conditioned by characteristics of the higher educational system which provides personnel and resources for research, this chapter begins by reviewing some important features of the Japanese higher educational system, most significant the 'kōza (departmental chair) system'. Overall, this chapter charts the early development by using the analytical framework provided by organizational theory as applied to the production of the sciences.

The academic character of fuzzy research changed enormously after industrial applications materialized. In Chapter 4, I examine the transition of fuzzy research from pure theory to practical applications. Three prominent cases are investigated: a water treatment plant in Sagami-hara city, the subway system in Sendai city, and a technological demonstration using an inverted pendulum, all automatically controlled by fuzzy logic. The cases were seen as successfully showing the usefulness of fuzzy logic. However, the effectiveness of fuzzy control was challenged by different interpretations on the part of control theorists and resulted in controversies. At heart of the controversies was an epistemological issue – the priority of modelling in controller design. I utilize the idea of 'cultures of proving' to compare different ideas of the meaning of a proof held by the two parties involved, as represented respectively by technological demonstration favoured by fuzzy theory researchers and mathematical proof advocated by control theorists. The technical

demonstration/mathematical proof distinction is discussed in relation to the scientification trend of history of control engineering, to which fuzzy logic is seen as a counteract by some Japanese fuzzy researchers.

As fuzzy logic is seen as running counter to the scientification trend, a different idea and genealogy of science was proposed to justify it. In Japan, this was achieved partly by an interpretation of the concept of fuzziness, by arguing that an affinity exists between fuzziness and Japanese thought. After the exploration of the attribution problem in Chapter 4, a semantic reading of the meanings of the word 'fuzzy' in the Japanese context is undertaken in Chapter 5 and 6. In chapter 5, I trace the original translation of the word 'fuzzy' – 'aimai', explaining how Prof. Toshirō Terano, one of the main proponents of fuzzy research, promoted his viewpoints by broadening the scope of fuzzy theory beyond its original version through the translation of fuzzy theory into Japanese. By his using the same word to represent both a new kind of engineering and Zadeh's fuzzy theory, via the presumed equivalence of 'fuzzy' and 'aimai', fuzzy theory became a springboard for his project. This project then became a prototype for talking about fuzzy theory in a specially Japanese way, partly because of what the word 'aimai' implied in its Japanese context. Following a short introduction to the Japanese writing system and the etymology of the word 'aimai', this chapter aims to disclose the role that the word 'aimai' played by analyzing its use in attempts at science popularization by Terano and his student and colleague, Sugeno Michio.

Chapter 6 examines the way in which the original translation 'aimai' was replaced by the transliteration of the word 'fuzzy' – 'fajyi' – through the promotional efforts of manufacturers that produced home appliances and consumer electronics using fuzzy control from the late 1980s. I utilize the concept of the 'cassette effect' put forward by Japanese translation theorist Akira Yanabu to examine the way in which the word 'fajyi' created new meanings for fuzzy theory. The 'cassette effect' points to the appeal of the semantic emptiness of a newly coined word that attracts users to create meanings for it. I will show in this chapter that the word 'fajyi' was made known to the general public by promotional advertisements, and it acquired new meanings through a narrative that emphasized both a Japanese cultural characteristic and a blurring of the human/machine distinction.

In the last chapter, Chapter 7, I will summarize the main points of this thesis. Also, I will point out the significance of the findings in this study by juxtaposing them against major works in STS-related work on artificial intelligence.

Chapter 2

Historical Overview: Controversies in the Development of Fuzzy Logic

Fuzzy sets theory, with its permission of non-integral membership in a given set, and fuzzy logic, with its permission of truth values other than zero and one, have mathematical implications for fields such as set theory and mathematical logic, in which crisp set theory and bivalent logic have been predominant. Moreover, Zadeh's connection with systems theory (fuzzy theory was proposed with a claimed goal of solving problems in systems theory) meant that the readership of fuzzy theory, unlike other non-traditional logics, extended beyond circles of mathematicians and philosophers – more so after Zadeh's idea was applied to various fields in engineering.

Although the idea of fuzziness spread widely, it also incurred considerable criticism right from the start. It has been suggested that criticism led to the waning of fuzzy research in North America and Europe in the early 1980s (McNeill and Freiburger 1993: 124-126). Several factors have been identified as the reason why the idea of fuzziness aroused such antagonism. Among these are issues such as the negative connotation of the name chosen by Zadeh for his theory, the questionable usefulness of fuzzy theory (a common critique put forward by those who do not believe there is any value in applying the idea of fuzziness usually takes the form of the question 'what is that that cannot be achieved by other means?'), and, as claimed by its proponents, the idea that fuzziness has challenged the routine method of modelling in general science and engineering practice. The sheer novelty of the idea of fuzziness is usually invoked as one of the reason that underlies the antagonism towards it, and often serves as a foil for identifying and criticizing the entrenched western tradition – bewitched by an insistence on precision – of thinking about systems. Significantly, in the years when data processing was still a scarce resource, antagonism was easily translated into denial of funding for fuzzy research. In the late 1960s in the U.S., for instance, it was suggested to Congress that fuzzy logic served as an example of wasting government funds (Yen and Langari 1999: 5). In this chapter, criticisms of fuzzy theory made by logicians, artificial intelligence researchers, statisticians, and control theorists, among others, will be surveyed. At the heart of the criticisms lie two issues: the specificity of the uncertainty that fuzzy theory addresses, and disputes over the attribution of credit for the success of applications.

Fuzzy Logic as a Logic System

Fuzzy logic was claimed to be a way to deal with problems of 'vagueness' in natural language, among which the 'sorites' paradox is a famous case in philosophy of logic. The 'sorites' paradox is often demonstrated by using the example of a heap or a bald man. Removing a grain of sand from a heap does not make it less of a heap. However, if the act of removal is continued, each time with a grain, then the above statement will lead to an absurd conclusion that a heap with no single grain in it is still a heap. Similarly, a man with one more hair on his head than a bald man is still bald. However, if we think that the statement is true, and statements that 'a man with two more hairs on his head than a bald man is still bald', and 'a man with three more hairs on his head than a bald man is still bald', are also true, then finally we will come to a conclusion that a fairly hairy man is still bald – thus a paradox. Since truth values of fuzzy logic are non-bivalent, it has been used to reject the reasoning process of the 'sorites' paradox (Sainsbury 1988: 40-43; Gaines 1977: 48-50). Fuzzy logic does it in the following way. If we agree that a heap of, say, one hundred thousand grains of sand is a heap, then, the truth value of the statement that that heap is a heap is one. Then, under the scheme of truth value assignment in fuzzy logic, we can make the statement that a heap with one less grain of sand than the above-mentioned heap can have a truth value slightly less than one. By adopting fuzzy logic rather than two-valued logic, we will not end up with the conclusion that the statement 'a heap with no grain at all is still a heap' is true, since the truth value of the statement, obtained after a series of subtractions made to the truth values of former statements, can be as small as zero. Therefore fuzzy logic saves us from the 'sorites' paradox.

However, some philosophers, whose research focuses on the problems of 'vagueness', take issue with this proposal. One of their major complaints results from the phenomenon of 'higher-order vagueness' when fuzzy logic is applied (Read 1995: 190-191; Williamson 1994: 127-128). They argue that a problem still exists even if we assign numerical, non-bivalent truth values to statements. For instance, the statement "It is wet" is true to a degree greater than 0.729, as argued by philosopher Timothy Williamson,

...is extremely vague. In many contexts it is neither true nor clearly false. Attempts to decide it can founder in just the way characteristic of attempts to decide ordinary vague statements, such as 'It is wet' in borderline cases. The mathematical terms in

[it] may be precise, but the notion of the degree of truth of a sentence is not a mathematical one. It represents an empirically determined mapping from sentences in contexts to real numbers. Even if statistical surveys of native speaker judgements were relevant to deciding [it], the results would be vague. It would often be unclear whom to include in the survey, and how to classify the responses. The problem is that the vagueness of [it] goes unacknowledged (Williamson 1994: 128)

The problem, however, is pertinent not only to fuzzy logic but applies to other multi-valued logics as well. There was a similar attempt, as Williamson describes, to 'develop a theory of sets membership of which is a matter of degree' made by Abraham Kaplan and Herman Schott who 'measured degree of membership of empirical cases by real numbers between 0 and 1, and defined corresponding notions of intersection, union, complementation and subset' in 1951 (Williamson 1994: 120).²³ But unlike Kaplan and Schotts' attempt, which 'fell on stony ground' (ibid: 120), fuzzy logic received much more attention in the study of vagueness. It can be argued that the recently recurring philosophical interest in the problem of vagueness has put fuzzy logic under attack as being a representative of multi-valued logics.

For example, the philosopher of logic Susan Haack has since the late 1970s criticized fuzzy logic on linguistic and methodological grounds. The linguistic criticism points to the problem of the fuzzification of truth values, and can be seen as in a similar vein as Williamson's criticism mentioned above. Haack argues that, by assigning numerical values other than zero or one to the truth values of statements, fuzzy logic still imposes artificial precision: 'fuzzy logic only postpones, and does not eliminate, the need to introduce arbitrary boundaries' (Haack 1996: 239). Moreover, she argues that, without a formal method for fuzzy logic to assign truth values, the imposition of arbitrary truth values by informal intuition ends up with insurmountable complexity. Haack's critique of fuzzy logic is part of her project of arguing that 'deviant logics', as she calls non-classical logic systems, are unnecessary; instead some revisions should be made to classical logic to form extended logics (Haack 1996).

Fuzzy Logic versus Artificial Intelligence

²³ The article by Kaplan and Schott is titled 'A Calculus for Empirical Classes' which appears in the journal *Methodos*, volume three. As Williamson describes, Kaplan and Schotts' attempt was made 'with applications to empirical science in mind'; although with less elaboration their attempt bears similarity with Zadeh's work (Williamson 1994: 120).

Criticisms of fuzzy logic regarding its status as a logic system have not been confined to logicians' circles. Adversaries also came from within the fields of computer science and artificial intelligence where conventional logic has prevailed. In 1993, U.C. San Diego computer scientist Charles Elkan presented a paper entitled 'The Paradoxical Success of Fuzzy Logic' at the annual conference of American Association of Artificial intelligence (AAAI), the major AI conference in North America. The paper even received an award as one of the four best articles at the conference and subsequently threw fuzzy researchers into tumult.²⁴

In that paper, Elkan identified two paradoxes concerning fuzzy logic. First, although fuzzy logic has been successful in real world applications, its foundations 'remain under attack'. The second paradox is that most successful applications are '... controllers, while most theoretical accounts on fuzziness deal with knowledge representation and reasoning' – thus a gap exists between theoretical development and applications (Elkan 1994: 3). In order to show that fuzzy logic is inherently flawed, Elkan constructed a proof of a 'theorem'. The proof of the theorem is carried out according to a definition that he thought legitimate in a fuzzy logic system. Given that the theorem is derived as a logical consequence from the definition, it should be coherent with the definition. The consequent of the theorem, however, assumes a collapse of fuzzy logic to conventional two-valued logic, and results in a contradiction (Elkan 1994).²⁵ The paper aroused several counter-attacks and even protests by figures in fuzzy research. Protests included a letter addressed to organizers of the AAAI 1993, and a co-written forum article in *AI Magazine* 1994. Also, detailed refutation articles were published in the August 1994 issue of *IEEE Expert*, along with Elkan's revised version of the original paper and reply. The major point of the counter-attacks on the part of fuzzy researchers was that, in Elkan's proof, he mistakenly introduced into the definition a requirement that is not called for in fuzzy logic, and he wrongly applied the 'law of excluded middle' which is only valid in a conventional two-valued logic system.²⁶ The tones of these exchanges were hostile and personal attacks on Elkan abounded. Fuzzy researchers also expressed the fear that Elkan's paper would have the same effect as the 'Lighthill

²⁴ The controversy is analyzed in great detail by Rosental (2003; 2008).

²⁵ The definition was given by using fuzzy logic operators conjunction (\wedge), disjunction (\vee), and negation (\neg) as the following: (1) $t(A \wedge B) = \min \{t(A), t(B)\}$; (2) $t(A \vee B) = \max \{t(A), t(B)\}$; (3) $t(\neg A) = 1 - t(A)$, and (4) $t(A) = t(B)$ if A and B are logically equivalent, where A and B are two arbitrary assertions. From the definition above Elkan proposed a theorem: if $\neg(A \wedge \neg B)$ and $B \vee (\neg A \wedge \neg B)$ are logically equivalent, then for any two assertions A and B, either $t(B) = t(A)$ or $t(B) = 1 - t(A)$ (Elkan 1994: 3). In other words, the result of the theorem shows that the only possible truth values are zero and one, which is characteristic of binary logic.

²⁶ See Chapter 3 of Rosental (2008) for the complexity of this point.

report' (Berenji et al. 1994), a pessimistic judgment on the outlook of AI published by Sir James Lighthill in 1973, which impeded the development of AI for a decade in the U.K.. As Elkan identified himself as within the symbolic AI approach, Elkan's move could possibly be put in the context of the opposition between classical AI and 'soft computing', a banner under which fuzzy logic, along with other non-traditional techniques such as neural network and genetic algorithms, are categorized.

Fuzzy Logic versus Probability Theory

Similar to the criticism made by logicians, criticism of the idea of fuzziness made by Bayesian statisticians emerged in the late 1970s. Although not as dramatic as Elkan's conference paper, Bayesian statisticians' criticism appeared as position papers along with responses in forums in professional journals. Most famous among the papers are those by Dennis V. Lindley, Peter Cheeseman, and Michael Laviolett and John W. Seaman, which appeared in *International Statistical Review* in 1982, *Computational Intelligence* in 1988, and *IEEE Transactions on Fuzzy Systems* in 1994 respectively.

Competition for the right to speak for the concept of 'uncertainty' lies at the heart of the debates between fuzzy theorists and Bayesian statisticians. In 1978, Zadeh developed 'possibility theory' based on fuzzy sets, with the term he himself coined (Zadeh 1978). Possibility is argued to represent uncertainty that is not statistical in nature. Zadeh explained the difference between possibility and probability by a simple example. The interpretation of the statement 'Hans ate X eggs for breakfast, with X taking values in $U = \{1, 2, 3, 4, \dots\}$ ' by possibility theory is 'the degree of ease with which Hans can eat u eggs' which constitutes 'the possibility distribution associated with X' (Zadeh 1978: 8). In contrast, probability interpretation denotes the likelihood for X to take values 1, 2, 3, 4,.... An imperfect oval provides another example. Promoter of fuzzy research Bart Kosko argues that an oval is a fuzzy ellipse and there is 'nothing random', i.e. nothing relevant to statistics about the matter (Laviolett and Seaman 1994: 5). The possibility theory has helped fuzzy theorists to infiltrate the territory of the concept of uncertainty, which used to be in statisticians' hands.

The most common response from Bayesian statisticians to the idea of fuzziness is that it is not impossible to make a probabilistic interpretation of fuzzy sets (Cheeseman 1986; Laviolett and Seaman 1994). In so doing, the concept of fuzziness can be subsumed in probability. More generally they are sceptical about the utility of the whole fuzzy enterprise. Their position is usually represented by two statements: 1.

‘Probability is the only satisfactory measure of uncertainty’; 2. ‘Anything that can be done with fuzzy logic can be better done with probability’, therefore ‘fuzzy logic is unnecessary’ (Yen and Langari 1999: 178; McNeill and Freiberger 1993: 184). The unnecessary application of fuzzy logic is even seen as an unusual event in history. Two statisticians quoted a remark from a non-statistician colleague: ‘Usually, a new theory must find problems to which it uniquely applies in order to survive. Fuzzy sets have, over more than 25 years, been the exception of that rule’ (Laviolett and Seaman 1994: 14). And the ‘Kalman filter’, a control technique widely used in guidance and control and argued to be far more complicated than any fuzzy control technique that has been utilized, was also invoked by statisticians as emblematic of the superiority of probabilistic methods (McNeill and Freiberger 1993: 183). In order to demonstrate that different kinds of uncertainty do exist as a response to statisticians’ arguments, a common strategy that fuzzy theorists adopted was to juxtapose fuzzy theory and other theories which relied on conceptions of uncertainty that could not be fully addressed by probability.

What is noteworthy regarding the debates between Bayesian statisticians and fuzzy theorists is the context in which these debates took place, which is related to the status of the Bayesian position within the statistics community. It is suggested that the revival of Bayesian (subjective) probability in the 1970s and 1980s was due partly to the availability of cheap computing resources after the objective (frequency) interpretation of probability had held sway for over a century (McNeill and Freiberger 1993: 181).²⁷ In their response to the arguments of fuzzy theorists, Bayesian statisticians argued that fuzzy theorists only addressed objective probability on which they forged their criticism on probability. In other words, in pointing out that there was also a subjective school of probability, Bayesian statisticians claimed that one more model existed, which emphasized subjects’ experience, than fuzzy theorists thought. The following quotes clearly show that Bayesian statisticians saw the popularization of fuzzy approach as linked to the under-promotion of the Bayesian method:

Probably the most important reason (that the fuzzy approach has been so popular) is the prevailing idea that probabilities are necessarily frequencies – a view that drastically restricts the domain of applicability of probability. It is in areas where there are no obvious frequency interpretations, such as the interpretations of

²⁷ In this regard, it is perhaps not a mere coincidence that two important Bayesian statisticians L. J. Savage and I. J. Good were once assistants respectively to John von Neumann and A.M. Turing, the two prominent figures who helped to lay the foundation of modern computing. As Hacking has it, ‘It is as if the modern Bayesian idea is a by-product of the age of computers’ (Hacking 2001: 185).

linguistic terms, that the fuzzy approach is most firmly entrenched (Cheeseman 1986: 101).

Nearly all statisticians and statistical practitioners have been trained primarily in the classical school, which emphasizes the frequency interpretation of probability. The lack of emphasis on subjective probability in the training of most statisticians has naturally led to a corresponding lack of emphasis on this subject in service courses taught for engineers and other nonstatisticians. The resulting ignorance has left a vacuum which fuzzy set theory has rushed in to fill (Laviolett and Seaman 1994: 6).

If Bayesian probability did revive in the 1970s and 1980s, as stated above, it is no surprise that there was a conflict over the new 'subjective' pasture. In the 1990s, some fuzzy theorists admitted that, while fuzzy theory and probability theory can be distinguished in their applicability to various kinds of tasks, they are nonetheless complementary rather than mutually exclusive. The choice between one or the other technique could be made according to their respective cost-effectiveness in specific application contexts (Yen and Langari 1999: 178).

Fuzzy Control versus Conventional Control

From the late 1980s, with the emergence of 'successful' applications for control purposes, a spotlight has been put on fuzzy logic by those who supported different approaches. The controversy that computer scientist Charles Elkan aroused, as mentioned earlier, was one of the many that arose as a result of a growing interest in figuring out the reasons that contributed to the success of fuzzy logic in control. In 1998, several control theorists held a head-on debate with Zadeh and fuzzy researchers on the pros and cons of fuzzy control compared to conventional control. It was featured as one of the plenary sessions of the IEEE Conference on Decision and Control that year.

The main opponent of Zadeh in the debate was Michael Athans, a former professor of Massachusetts Institute of Technology. Other participants in the debate were Karl Åström and Gene Franklin on the conventional control side, and Reza Langari and Demitre Filev on the fuzzy control side. As the debate was held some twenty years after fuzzy logic was first applied for control purposes, it can be inferred from the strategies adopted by the participants what were the respective niches into which fuzzy control and conventional control were placed over the years.

According to the report of the debate, 'the participants' intent was obvious: to choose the playing field that would favour their side of the debate':

Athans's tack was clearly to keep the debate narrowed to one of conventional versus fuzzy control for problems in which either is applicable. Zadeh, on the other hand, was clearly interested in broadening the debate to include... areas that tend to require rule-based control (Abramovitch and Bushnell 1999: 88).

The main argument of Athans was that most control problems 'could be solved with much better results from a conventional perspective', and that rule-based fuzzy control 'were only appropriate for toy class problems' (Abramovitch and Bushnell 1999: 89). Athans and other control theorists also complained about the unsystematic method of design – they 'did not see a normative, descriptive process in existence for fuzzy control design' (ibid: 89). Without the normative and descriptive process regarded by these control theorists as indispensable, 'it was hard to say much about the performance or stability of the system', since 'no inherent explicit model is used to derive the rules' for rule-based fuzzy control (ibid: 89).

Zadeh, on the other hand, stated that fuzzy control 'starts with human solution', and 'accepts the fact that a solution may not always work for every situation, but is happy with a solution that works many, many times' (Abramovitch and Bushnell 1999: 89). Zadeh also resorted to those outside the debate session for support by asking rhetorical questions:

Zadeh then spoke about all the applications that were being completed using fuzzy logic and gave a count, based on an Internet search, of the growing number of papers that are based on fuzzy control. He posed the following questions to the audience: 'Do you really think that all these people are stupid? Do you think they do not know what they are talking about?' He then answered, 'No, I think not' (Abramovitch and Bushnell 1999: 89).

Control theorist Kimura Hidenori was among the audience at the debate session. He recalled vividly the atmosphere of the debate (not surprisingly, from a viewpoint common among control theorists):

Athans brought a large number of people together to listen to him. And Zadeh came with a very gay, green jacket; he always wears this sort of colourful clothes.

Almost all of what he said was not taken seriously by the audience.²⁸

That fuzzy control did not use an explicit model, as Athans complained, had been one of the major arguments against fuzzy control. This will be analyzed in more detail through a concrete example in chapter 4.

From a Prominent Mathematician

In an article on ‘The Health of Mathematics’, mathematician Saunders Mac Lane evaluated how well mathematics was being done at the time of writing by reviewing the trends in publication (Mac Lane 1983). He noted, on the one hand, that in some specialties ‘too little is published’, since practitioners relied on personal communications rather than on published material. On the other hand, however, in some fields, specialization has resulted in the opposite problem: ‘too much is published’ (ibid: 53-54). For him, the case of fuzzy sets served as an example of the latter problem:

The opposite trouble of excessive publication may arise because of publish-perish pressures but also comes about because ideas – even very attractive ones – have been grossly overdeveloped. There are hordes of examples...

The case of fuzzy sets is even more striking. The original idea was an attractive one – instead of saying that an element x is or is not in the set A , let us measure the likelihood that x is in A . Someone then recalled (*pace* Lawvere) that all mathematics can be based on set theory; it followed at once that all mathematics could be rewritten so as to be based on fuzzy sets. Moreover, it could be based on fuzzy sets in more than one way, so this turned out to be a fine blueprint for the publication of lots and lots of newly based mathematics. This has duly been done, complete with extravagant claims for applications (e.g., “fuzzy” decision theory). Most of those intended do not seem to have materialized. New ideas are nice, but promotional gimmicks are not (ibid: 54).²⁹

Within the Fuzzy Research Circle

All this criticism from various fronts did not build a consensus view as regards

²⁸ Kimura interview.

²⁹ Prof. Murofushi Toshiaki informed me of this reference.

the idea of fuzziness among fuzzy researchers; rather, from within the fuzzy research community, there were also comments which claimed that the development of fuzzy research had been overly shaped by defensiveness to outside criticisms. For instance, Milan Zeleny, a scholar of management systems, complained in the journal *Human Systems Management*, that the development of fuzzy research had lost sight of the initial motivation. The ‘principle of incompatibility’, that is, the unavoidable trade-off between complexity and precision that motivated Zadeh’s project, according to Zeleny, was disregarded – a fact he called the ‘irrelevancy of fuzzy set theories’. This resulted in the ‘fetish of precision, rigor, and mathematical formalism’. As he made it clear:

The principle of incompatibility applies to all descriptive methodologies and fuzzy sets theories simply cannot be excluded. We observe that as the axiomatic precision of fuzzy sets increases, basic axioms continue to go unchallenged, being accepted as dogmas, and active proponents of fuzzy sets insist that fuzzy sets should deal with imprecision in precise terms, the ‘fetish of precision, rigor, and mathematical formalism’ reaches new heights. Thus, according to the remarkable principle of incompatibility, the theory loses its significance and relevancy (Zeleny 1984: 302).

Name Matters

Common to many criticisms, whether they were from researchers specializing in philosophical logic, artificial intelligence, or control theory, was a concern regarding whether ‘fuzzy logic’ served well as an umbrella term for various applications of Zadeh’s idea on fuzziness. Control theorist Michael Athans complained that ‘[fuzzy control] does not use fuzzy logic’s method of capturing uncertainty’, and he ‘often found it hard to find the connection between fuzzy control and the principles of fuzzy logic as developed by Lotfi Zadeh’ (Abramovitch and Bushnell 1999: 89). This questioning of a lack of connection also constituted one of the ‘paradoxes’ that Charles Elkan pointed out regarding the success of fuzzy logic. As noted earlier, Elkan contended that most successful applications are ‘... controllers, while most theoretical accounts on fuzziness deal with knowledge representation and reasoning’ (Elkan 1994: 3). As a response to the argument made by Zadeh and others fuzzy researchers against criticism that fuzzy logic ‘works’, philosopher of logic Susan Haack contends:

...the fact that [fuzzy controllers] work does nothing to establish the philosophical bona fides of the fuzzy logic articulated by Zadeh...

If fuzzy logic is construed, as Zadeh and co. suggest it should be, as a nonclassical theory of truth-preserving inferences, fuzzy technology does not rely on it, and so the successes of that technology cannot be claimed to its credit. If, on the other hand, fuzzy logic is construed as an attempt to represent the mental processes through which people go when making adjustments to kiln thermostats, air-conditioners, etc., there is a connection with fuzzy technology. But, of course, so construed, fuzzy logic is not, after all, an attempt to represent truth-preserving inferences, and is not, after all, a theory in the same domain as classical logic; in fact, so construed, it is obviously not properly describable as a 'logic' at all (Haack 1996: 230-231).

Therefore, the banner 'fuzzy logic' that Zadeh chose to represent the whole enterprise is not without cost. It has led to the argument that fuzzy logic, understood as a logic system, has nothing to do with the successfulness of fuzzy control, which has been made, as we have seen, many times (Abramovitch and Bushnell 1999; Elkan 1994; Haack 1996). Much has been said for clarification on this. For instance, in reply to Elkan's criticism, Zadeh stated that 'fuzzy logic in the narrow sense plays a very minor role in fuzzy control, just as classical logic plays a very minor role in classical control theory' (Zadeh 1994b: 43). It may well be that, for Zadeh and other fuzzy theorists, responsibility lies on the critics' part to properly differentiate 'fuzzy logic' in the narrow sense of the term from that in the broad sense of the term. However, it is sometimes difficult to tell what sense of the word 'logic' fuzzy theorists refer to when they are talking about the successfulness of fuzzy applications. Fuzzy theorists can argue that the fault is not theirs, but it can be shown that their own usages lead to confusion, which has its root in the fact that Zadeh, in the midst of the development of fuzzy research, chose an overarching label – fuzzy logic – for an ensemble of various concepts.

Invention over Science

If Milan Zeleny's complaint pointed to the trend that fuzzy research had become more and more precise (a trend contrary to the initial motivation), Zadeh, however, had been trying to uphold the initial motivation. This was usually done, when he introduced fuzzy logic to audiences, by referring to early criticisms that devalued fuzzy logic as imprecise and unscientific. Quoting comments made in the

early 1970s on fuzzy logic by computer scientist William Kahan, and in particular, control theorist Rudolf Kalman, was a common practice in Zadeh's lectures. These comments devalued fuzzy logic as unscientific. Take Kalman's comment, which Zadeh mentioned in his lecture in Japan in 1989 and in his statement in the debate with Michael Athans on fuzzy control in 1998, for example:

We do *talk* about fuzzy things but they are not scientific concept [*sic*]. Instead, let us view the development of science as something like the following. You look at a vast mass of facts – fuzzy or not – and you would like to make some sense out of it. This is usually done through rising to a higher conceptual level, by working harder than the average person. Some people in the past have discovered certain things, formulated their findings in a *non-fuzzy way*, and therefore we have progressed in science. (Kalman 1972, quoted in Zadeh 1990b: 3, original italics).

The methodological view held by Kalman assigned fuzzy logic a place down the hierarchy of scientific research. As a response, this hierarchy was often reshuffled by fuzzy researchers. This can be seen from the counter-arguments to Elkan's attack on the credit assignment problem of fuzzy logic. The problem was appropriated by fuzzy researchers to draw boundaries, using philosophy and the concept of science as resources. This strategy is well noted by sociologists of science. For instance, Gieryn (1983) and Collins and Pinch (1979) provide examples of how the concept of science and philosophy are utilized, whether rhetorically or technically for boundary drawing. However, unlike the example offered by Collins and Pinch (1979), philosophy and the concept of science are not always appropriated in positive meanings; they can be used negatively. As Gieryn notes, in boundary work 'science' is not fixed but contextually variable; its meaning and content depends upon the goals of the specific party (Gieryn 1983: 792).

For instance, in his response to Elkan's criticism, Mamdani – who first applied fuzzy if-then rules for steam engine control in 1974 in the UK (McNeill and Freiburger 1993: 107-116) – categorized three different areas of AI research: the descriptive, the prescriptive and the applicative. In his characterization, researchers in the descriptive area try to figure out human cognitive processes and those in the prescriptive group deal with different reasoning systems and various kinds of logic. Both groups are concerned with whether the models they use are correct or not. Mamdani claims that the models proposed by these two areas of researchers are difficult to prove using controlled experiments. The third 'applicative' group of research, on the other hand, is concerned with the building of industrially successful

artefacts. These artefacts 'are successful in their own right, and do not owe their success to the underlying theory or a mathematical model' (Mamdani 1994: 27). Mamdani argues:

Applications address the scientific needs of a specific domain, and cannot replace experiments conducted to test a theory... There is a common misconception that models are created and then applied, and that success then legitimizes a model. This view is superficial, because an application's requirements seldom match the underlying axioms of the model exactly (Mamdani 1994: 27).

In order to point out Elkan's misunderstanding of the relationship between theory and application, Mamdani goes on to address a more tangible analogy:

...the wide spread success of logic circuits cannot be used to legitimize Boole's logic any more than the industrial success of fuzzy logic control legitimizes the philosophical correctness of fuzzy logic (Mamdani 1994: 27).

What Mamdani says is reminiscent of the debate around the relationship between science and technology: can scientific theory be validated by successful practical application? Do general theoretical formulations of science regularly generate successful practical applications? (Mulkay 1979: 63) Mamdani's argument suggests that philosophy for him is not something to be drawn upon; rather, it should be avoided in AI research. He claims that:

Prescriptive models can only be argued over at a philosophical level – an ability few AI researchers possess. Philosophical disputations about prescriptive models...have nevertheless, helped to enlightened many difficult points. In the end, however, such disputations can never completely settle the matter (Mamdani 1994: 28).

Mamdani then argues that, since many AI researchers are trained in mathematics, they tend to 'legitimize' prescriptive models 'on the grounds of mathematical symmetries or some intrinsic sophistication'. He accuses Elkan of being anti-inventions:

...some beauty of the form often plays a significant role in assessing the worth of a model (and the intellectual enterprise of a researcher) rather than the content or

industrial usefulness...Elkan...subscribes to an anti-inventions culture. Accentuating form without attention to the content is like praising beauty and ignoring the brain. To use the colloquial term, the scientific mythology within AI has created a 'bimbo science' (Mamdani 1994: 28).

In Mamdani's presentation, science becomes 'mythology', and mathematical beauty becomes dogmatic and conservative. This kind of reversing of the traditional hierarchy of science was a response to criticisms, since 'the tag "fuzzy" is seen as debasing to the sombre image of science' (Mamdani 1994: 28). The newly built hierarchy of 'invention' over 'science' is emblematic of the strategies of fuzzy researchers in claiming their legitimacy within AI research. Compared to the strategies used by cybernetic practitioners (Bowker 1993), although both claim a new hierarchy of science, some fuzzy researchers like Mamdani claim not only a reordering of the position of fuzzy logic in the scientific hierarchy, but also a refutation of the ranking standards of science. The practical, entrepreneur spirit is also present in an account of another researcher of fuzzy logic:

Zadeh realizes that it was much more important to have a good model of the semantics of human concepts and perform reasonable operations than to have a bad model and perform verifiably correct operations...he offered a model based on the established notions that can be easily grasped by engineers and researches alike as a step toward formalizing human reasoning... As long as the laws of human reasoning are not well understood, a good model of human reasoning should be expected to preserve some paradoxes; experimentation with the model may deepen the understanding and help resolve them (Freska 1994: 21).

The confidence of fuzzy researchers lies in part in the popularity of fuzzy logic applications:

Some of the shortcomings that Elkan attributes to applied fuzzy logic are due to the gap that exists between theory and application, despite the revolution in the industrial use of fuzzy logic. We believe, however, that it is too soon to scrutinize this gap (Vadiee and Jamshidi 1994: 38).

This kind of presentism also underpins the rhetorical question asked by the founding figure, Zadeh:

What are the reasons for the rapid growth in the number, variety, and visibility of fuzzy logic applications? (Zadeh 1994b: 43)

From the beginning of its history, fuzzy logic has been dismissed by various scholars as unscientific, according to a common measure of what the word scientific should connote: precise, consistent, and logical, which are antithetical to the connotation of the word 'fuzzy' (McNeill and Freiburger 1993: 46-49). The debate between proponents and opponents of fuzzy research shows how its practitioners responded to critics. In particular, the very definition of science was altered by the standards of fuzzy logic. As Zadeh notes in the end of his reply to Elkan, science will eventually accommodate fuzzy logic as one of its members:

Indeed, it would not be surprising if, in retrospect, the skeptics will find it hard to understand why they failed to realize that fuzzy logic is a phase in a natural evolution of science – an evolution brought about by the need to find an accommodation with the pervasive imprecision of the real world (Zadeh 1994b: 45).

In other words, science should be measured according to the very existence of the popular approach fuzzy logic.

Concluding Remarks

One of the strategies of the boundary work that fuzzy researchers took in defending fuzzy research, which can be characterized as, as we have seen, the 'invention over science' narrative, was to a large extent built upon extensive application of fuzzy theory to industrial and consumer products carried out in Japan. On the other hand, most of the criticisms from outside the fuzzy research community reviewed in this chapter were made by researchers in the U.S. Differences in the ease of acceptance of fuzzy research in the two countries have attracted observers' attention. In addition to some attempts at a cultural explanation that too easily associates fuzzy logic with East Asian thought, as we have seen in chapter 1, another approach points to the differences of the funding policies in the two countries as a contributing factor. D. Schwartz, a fuzzy logic researcher at Florida State University discerns a differential feature of the Japanese academic system, as compared to that of the U.S.:

Japanese university professors are all paid on a twelve month basis, so that they have no need for summer salaries, and are typically provided at least the minimal funding necessary to do their research. Hence there is not as much incentive as in the US for faculty to compete for research funds, which means there is less cause to discredit ideas other than one's own (Schwartz 1991).

This, however, should not be taken as saying that there have been few critics in Japan. There have been, and a key issue of interest is how the system could contain controversies and keep research going. In the next chapter, I will trace the early history of fuzzy research in Japan through the working of a distinct feature of the Japanese academic system, the *kōza* (departmental chair) system.

Chapter 3

Fuzzy Theory in Japan in the Early Years

Fuzzy theory research was initially confined only within academic circles in the U.S. where it was originally from, and this was also the case when it was introduced to Japan, until industrial applications emerged. However, the Japanese counterpart of the U.S. academic system bears little resemblance to the latter, although the Japanese system has been influenced by the U.S. through the occupation of Japan by the Allied Powers following WWII. Since the development of a new specialty within academic circles is inevitably conditioned by characteristics of the higher educational system that provides personnel and research resources, this chapter begins by reviewing some important features of the Japanese higher educational system, most significantly the 'kōza system', as noted e.g. by Sigurdson (1995) and explored in detail by Coleman (1999). Overall, this chapter charts the early development of fuzzy research in Japan, and explores the role of the kōza system in shaping the structure of its organization.

Characteristics of the Japanese Academic System³⁰

Although the Japanese academic system was reformed by the dictates of the General Headquarters of the Supreme Commander for the Allied Powers (hereafter GHQ) and has become one that is more comparable to the U.S. system after WWII, distinct features of the German system on which it was originally modelled remain. These are taken to be unique characteristics that serve to differentiate the Japanese system from its Anglo-Saxon counterparts (Sienko 1997: 117-118; Whitley 2000: xxiii-xxiv).

The most notable feature is the so-called kōza (departmental chair, or 'course' or 'lectures' literally) system (Coleman 1999: 19). The kōza system is a special institutional arrangement within departments at national universities.³¹ In a department, there are usually several kōza, each of which is staffed with only one

³⁰ For a more general description of Japanese universities and academic research, see Sigurdson (1995: 59-95).

³¹ In Japan, national universities are in general more prestigious than private ones and public yet not national ones. Among all national universities, the former seven imperial universities (two in former colonies excluded): Tokyo (established in 1877), Kyoto (1897), Tōhoku (1907), Kyūshū (1910), Hokkaidō (1918), Osaka (1931), and Nagoya (1939) are deemed to be the most elitist universities. Some private universities like Waseda University and Keio University, however, also hold top ranks in status, but private universities that enjoy such a level of prestige remain few.

professor (kyōju), one associate professor (jokyōju), and two research associates (joshu, literally means assistant) subordinate to the professor and the associate professor respectively. In medical schools there are more staff members under the kōza professor, but the arrangement is basically the same (Coleman 1999: 20). Funding is distributed fairly evenly to each kōza (Sigurdson 1995: 72).³² The general expectation is that, within a kōza, the associate professor will be promoted to the professor and one of the research associates to associate professor, but it is not always the case – the professor has the right to choose from the candidates. The arrangement allows only one of the research associates to be promoted to the associate professor when the kōza professor leaves, retires, or dies (Coleman 1999: 22-23). Taken together, this means maintaining good relationships with the kōza professor is a critical issue for the career prospects of those who are lower in rank.

Research associates may or may not have a Ph.D. degree when they start working under kōza professors. However, those research associates without a Ph.D. degree can earn themselves one – the requisite qualification for professorship – even if they are not enrolled as postgraduate students while working as research associates. This is another important feature of the Japanese academic system: the ‘thesis Ph.D.’ – the Ph.D. degree awarded on Ph.D. thesis alone without any required graduate coursework (Coleman 1999: 68). Its roots can be traced to a stipulation of the Academic Degree Ordinance of 1887, which states that a doctorate degree can be conferred to those who show equivalent level of scholastic competence to those who earn their doctorate degree by entering the graduate school (referred to as the course doctorate). The first doctorate ever awarded in Japan in 1888 was a thesis Ph.D. After WWII, the Civilian and Education Section of the GHQ tried to abolish the thesis Ph.D. system but the system remained in place owing to the insistence of the Japanese side. The Academic Degree Regulations issued by the Ministry of Education in 1953 state that ‘the doctorate degree can be awarded to candidates who have submitted a doctorate dissertation which has been examined and accepted by a graduate school and who have been recognized as having the equivalent or greater academic competence’ (Nishigata and Hirano 1989: 8-12). As a degree, there is no

³² Unlike research grants that are on an application basis, kōza professors in national universities automatically receive annual funds for research expenditure. Called ‘kōhi’ (literally university expenses), this money is distributed to kōza professors according to the disciplines they are in. Recently the figures of the annual funds for each kōza approximate to ¥ 2 million (1 Japanese Yen equals to about 0.05 British Pound), 1.5 million, 1.2 million, 0.4 million, and 0.3 million for those in clinical medicine, basic medicine, physical sciences, social sciences, and humanities respectively. As far as kōhi is concerned, public (metropolitan, municipal, and prefectural) universities have similar funding schemes to national ones. Information for this footnote is from personal communications with Etō Hajime.

difference between a course doctorate and a thesis Ph.D., as far as serving as the prerequisite for professorship is concerned. The percentage of the thesis Ph.D.s to all doctoral degrees earned remained high until recently. For instance, slightly under half of all science doctorates and over half of all engineering doctorates granted in Japan were thesis Ph.D.s as of 1997 (Sienko 1997:117-119). Researchers in private companies who lack a Ph.D. degree are the ones who follow the thesis Ph.D. route the most often. The system has served as an incentive scheme for researchers in companies, but has also been criticized for the less transparent application process than that of the course doctorate. Although faculty members of national universities were not allowed to engage in joint research with private companies until 1983 (Koizumi 1993: 313), the thesis Ph.D. has existed so long that it might have facilitated under-the-table exchanges between the university faculty and private companies (Iguchi 2002: 116-117).

Before we proceed to the early research on fuzzy theory in Japan, a note of Zadeh's view on system theory helps to set the context in which fuzzy theory was recognized and accepted in Japan. This was not least because the idea of a fuzzy set, the earliest in the whole fuzzy enterprise, was born of system theory as Zadeh himself claims.

Zadeh's View on System Theory³³

Two months before his famous article 'Fuzzy Sets' was published in June 1965, Zadeh presented a paper in a symposium on system theory held by the Polytechnic Institute of Brooklyn in New York. The title of the presented article 'A New View of System Theory' was later changed to 'Fuzzy Sets and Systems' when its content was abbreviated for the proceedings (Seising 2005: 96; Zadeh 1965b: 29). Both titles hint of Zadeh's involvement in system theory, and an ambition to apply fuzzy sets to systems. In fact, as noted by Seising, as early as 1954, Zadeh had already tried to introduce 'some of the basic notions of system theory' in an article titled 'system theory' at a time when 'it has not yet been officially recognized as a scientific discipline' (Seising 2005; Zadeh 1954:16). Perhaps not coincidentally, in that same year biologist Ludwig von Bertalanffy (1901-1972) founded the Society for General System Theory (later changed to the Society for General Systems Research, hereafter SGSR) as an affiliate of the American Association for the Advancement of Science with economist Kenneth Boulding, mathematical biologist and game theorist Anatol Rapoport, and physiologist Ralph Gerard (Bertalanffy 1969: 14-15; Hammond

³³ In the literature, both 'system theory' and 'systems theory' are used.

2003).³⁴ From the early 1960s onward, Zadeh co-authored and co-edited books on system theory, and called himself a 'system theorist' (Zadeh 1969a: 199; Zadeh and Desoer 1963; Zadeh and Polak 1969).

General system theory (hereafter GST), as conceived by Bertalanffy, has as its origin Aristotle's dictum that 'the whole is more than the sum of its parts'. Addressing particularly the relationships between components of a system and noting that an analogy exists between different kinds of systems, one of the aims of the SGSR is to 'investigate the isomorphy of concepts, laws, and models in various fields, and to help in useful transfers from one field to another' (Bertalanffy 1972: 28). For Bertalanffy, GST 'is a logico-mathematical field whose task is the formulation and derivation of those general principles that are applicable to "systems" in general' (ibid: 26). Although he acknowledged research in cybernetics that followed Norbert Wiener's work as an independent and parallel development to GST, Bertalanffy has pointed out the differences between GST and cybernetics, as represented by the work of Wiener and his followers, being in the former, the point of departure and primary model are 'basic science' and 'dynamic system of interactions', while in the latter they are 'technology' and 'feedback circuits' (ibid: 28). Bertalanffy emphatically rejects the claim that views system theory as 'springing out of the last war effort' as cybernetics is often seen, and identifies cybernetics as 'a part of a general theory of systems; cybernetic systems are a special case, however important, of systems showing self-regulation' (Bertalanffy 1969: 17; 1972: 28).

In various places, Zadeh tries to differentiate himself from the more 'philosophical' approach of Bertalanffy (McNeill and Freiburger 1993: 22; Zadeh 1996: 96). Zadeh's view of system theory can be gleaned from some of his work on this topic. Five paragraphs of Zadeh's 1954 article 'System Theory' were largely reproduced in a 1962 article 'From Circuit Theory to System Theory' (Zadeh 1954: 16; 1962: 856). Zadeh states in both articles that '[t]he distinguishing characteristics of system theory is its generality and abstractness, its concern with the mathematical properties of systems and not their physical form', and system theory is 'a scientific discipline devoted to the study of general properties of systems, regardless of their physical nature. It is to its abstractness that system theory owes its wide applicability....' (Zadeh 1954: 16; 1962: 856-857) In the 1962 article, Zadeh identifies Wiener as laying the foundations for cybernetics, and contrary to what Bertalanffy suggests, he continues, 'of which system theory is a part dealing

³⁴ In her book on the history of general systems theory, Debora Hammond adds psychologist James Grier Miller to the list of the founding figures of the SGSR because, she claims, that '[Miller] worked closely with Gerard and Rapoport and contributed substantially to the formation and evolution of the SGSR' (Hammond 2003: xiii)

specifically with systems and their properties' (Zadeh 1962: 857). Zadeh also suggests four 'well established fields which may be regarded as branches of system theory: circuit theory (linear and nonlinear), control theory, signal theory, and theory of finite-state machines and automata', and rules out systems engineering and operations research because they are 'concerned specifically with the operation and management of large-scale man-machine systems, whereas system theory deals on an abstract level with general properties of systems, regardless of their physical form or the domain of application' (Zadeh 1962: 858).

A passage from the article 'From Circuit Theory to System Theory', which is often used by researchers to state the motivation behind fuzzy set theory (Gaines 1979: 6-8; Klir 1990: 89; Seising 2004: 1003), as we have already seen in chapter 1, is worth quoting again at length:

Among the scientists dealing with animate systems, it was a biologist – Ludwig von Bertalanffy – who long ago perceived the essential unity of system concepts and techniques in the various fields of science and who in writings and lectures sought to attain recognition for “general system theory” as a distinct scientific discipline. It is pertinent to note, however, that the work of Bertalanffy and his school, being motivated primarily by problems arising in the biological systems, is much more empirical and qualitative in spirit than the work of those system theorists who received their training in exact sciences. In fact, there is a fairly wide gap between what might be regarded as “animate” system theorists and “inanimate” system theorists at the present time, and it is not at all certain that this gap will be narrowed, much less closed, in the near future. **There are some who feel this gap reflects the fundamental inadequacy of the conventional mathematics – the mathematics of precisely defined points, functions, sets, probability measures, etc. – for coping with the analysis of biological systems, and that to deal effectively with such systems, we need a radically different kind of mathematics, the mathematics of fuzzy or cloudy quantities which are not describable in terms of probability distributions. Indeed, the need for such mathematics is becoming increasingly apparent even in the realms of inanimate systems, for in most practical cases the *a priori* data as well as the criteria by which the performance of a man-made machine system is judged are far from being precisely specified or having accurately known probability distributions** (Zadeh 1962: 857, emphasis mine).

As well as differences, there are similarities between Bertalanffy's GST and

Zadeh's version of system theory. On the one hand, they seem to share a concern of the pertinence of a constructed model to the reality it is intended to represent. As Bertalanffy notes, while the merits of mathematical models – 'unambiguity, possibility of strict deduction, verifiability by observed data' – are widely known, '[t]his does not mean that models formulated in ordinary language are to be despised or refused' (Bertalanffy 1969: 24). He goes on to argue,

A verbal model is better than no model at all, or a model which, because it can be formulated mathematically, is forcibly imposed upon and falsifies reality. Theories of enormous influence such as psychoanalysis were unmathematical or, like the theory of selection, their impact far exceeded mathematical constructions which came only later and cover only partial aspects and a small fraction of empirical data (ibid: 24; original italics).

In this regard, Bertalanffy's view of mathematics is echoed in Zadeh's complaint about the failure of 'conventional mathematics' to deal with systems, mentioned in the above long quote from Zadeh's article 'From Circuit Theory to System Theory'. In particular, Zadeh explicitly claims that fuzzy sets could be a way to deal with the complexity of biological, 'animate' systems – the starting point and focus of Bertalanffy's GST (Zadeh 1969a: 199-200). The following quote, in which Zadeh expresses discontent with existing mathematical approach to biological systems resonates well with Bertalanffy's concern over the relevance of models:

The great complexity of biological systems may well prove to be an insuperable block to the achievement of a significant measure of success in the application of conventional mathematical techniques to the analysis of such systems. By "conventional mathematical techniques" in this statement, we mean mathematical approaches for which we expect that precise answers to well-chosen precise questions concerning a biological system should have a high degree of relevance to its observed behaviour (Zadeh 1969a: 200).

On the other hand, as we have seen, Zadeh differentiates himself from the more 'philosophical', more 'empirical and qualitative' approach of Bertalanffy, and all four established branches of system theory as suggested by him – circuit theory, control theory, signal theory, and theory of finite-state machines and automata – are highly mathematical (Zadeh 1962: 857-858; 1996: 96). This view of system theory is reflected well in his writings on system theory, which are filled throughout with set

theoretical notations and differential equations (Zadeh 1969b; Zadeh and Desoer 1963). These contrast sharply with Bertalanffy's book on GST, which is concerned with the unity of science, and is philosophical, even anthropological and historical in tone – mathematical equations only appear sporadically (Bertalanffy 1969). On an evaluation of set theory, which he identified as one of several trends in systems theory in the late 1960s, Bertalanffy said:

The general formal properties of systems, closed and open systems, etc., can be axiomatized in terms of set theory. In mathematical elegance this approach compares favourably with the cruder and more special formulations of "classical" system theory. The connections of axiomatized systems theory (or its present beginnings) with actual systems problems are somewhat tenuous (Bertalanffy 1969: 21).³⁵

From this perspective, it can be argued that, if the fuzzy set was the basis of 'a radically kind of mathematics' that Zadeh envisioned, insofar as it was conceived in the strain of the system theory the practitioners of which 'received their training in exact science' (Zadeh 1962: 857), the development of the fuzzy set as applied to system theory would follow in the way on which Bertalanffy commented in the above quote. In that case, Zeleny's critique that later development of fuzzy theory led to the 'fetish of precision, rigor, and mathematical formalism' (Zeleny 1984: 302), as mentioned in chapter 2, would not be too surprising.

Fuzzy Theory Research in Japan from the Late 1960s

In a table (see Table 3.1 below) consisting of genealogical trees of fuzzy theory researchers in Japan, provided by Japanese researchers to Zadeh in 1990, three main groups of researchers, or two major groups in Osaka and Tokyo, in terms of regional basis, are listed (Zadeh 1990c: 73). Although the table is not a complete one, as Zadeh himself notes (*ibid*: 74), the table, along with Table 3.2, which lists early works by Japanese researchers, nevertheless provides us with a rough sketch of how Japanese researchers in 1990 saw the configuration of the research network and to whom recognition should be given.

³⁵ What Bertalanffy classifies as 'classical' system theory is that which only 'applies classical mathematics, i.e., calculus' (Bertalanffy 1969: 19).

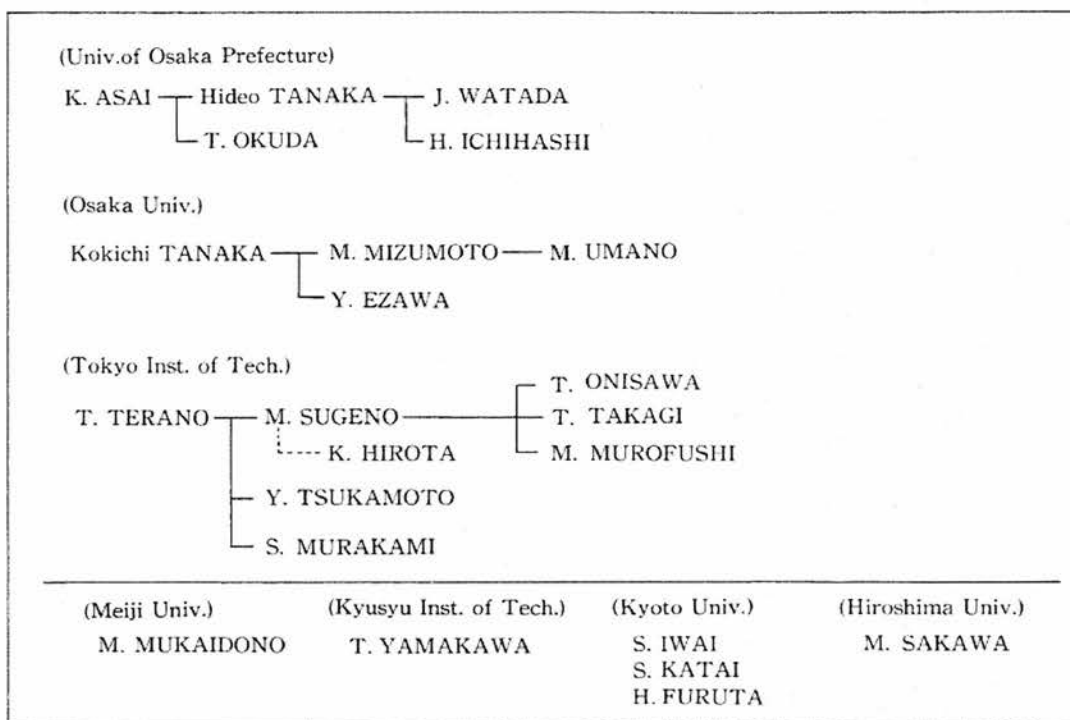


Table 3.1 Japanese Fuzzy Theory Researchers (Zadeh 1990c: 73). Solid lines in the genealogical trees represent direct supervision, and the dotted line represents de facto, but not official, supervision.

Hirai, H., Asai, K., and Katajima, S. (1968), Fuzzy automaton and its application to learning control systems, Memo, Fac. of Eng., Osaka City University, 10, 67-73.

Mizumoto, M., Toyoda, J., and Tanaka, K. (1969), Some considerations on fuzzy automata, *Jour. of Comp. and System Sci.*, 3, 409-422.

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*, 53, c, 333-340.

Tanaka, K., Toyoda, J., Mizumoto, M., Tsuji, H. (1970), Fuzzy automata theory and its application to automatic controls, *Jour. of JAACE*, 14, 541-550.

Asai, K., and Kitajima, S. (1971), Learning control of multi-modal systems by fuzzy automata, *Pattern Recognition and Model Learning*, Plenum Press, New York.

Mizumoto, M., (1971), Fuzzy sets theory, 11 th Prof. Group Meeting on Control Theory of SICE.

Sugeno, M., (1971), On fuzzy nondeterministic problems, *Annual Conference Record of SICE*.

Tamura, S., Higuchi, S., and Tanaka, K. (1971), Pattern classification based on fuzzy relations, *IEEE Trans. on Systems, Man and Cyber.* SMC-1, 61-66; also in *Trans. IECE*, 12, 937-944.

Terano, T., (1971), Fuzziness and its concept, Proc. of Symp. on Fuzziness in Systems and Its Processing, Prof. Group of System Engineering of SICE.

Mizumoto, M., "Fuzzy Automata and Fuzzy Grammars," Dr. Thesis, Osaka University, 1971.

Table 3.2 Early Works on Fuzzy Theory by Japanese Researchers (Zadeh 1990c:

The Tokyo Group

The Tokyo group, of which Terano Toshirō was a central figure, was the earliest in setting up routine seminars devoted to fuzzy theory. Note that, however, this in no way implies that Terano was the first Japanese professor who did research on fuzzy theory. In 1968, Terano, then a professor at the Tokyo Institute of Technology (hereafter TIT), first heard of fuzzy sets when he ‘called on the famous Italian neural network researcher Prof. Cianello[sic] on his way back after attending a conference in Europe’ (Sugeno 2005: 5).³⁶ With a background in mechanical engineering, Terano (1922-2005) had worked in the Railroad Research Institute and the Ship Research Institute of the former Ministry of Transport, before becoming professor of the system dynamics *kōza* at TIT in 1962. Morita Yajirō and Tsukamoto Yahachirō were then associate professor and research associate, respectively, of that *kōza* (Tōkyō *kōgyō daigaku* 1985: 376). Terano was known for his work on the dynamic model of the ‘once-through boiler’ (*kanryū boirā*), which earned him awards from the Japan Society of Mechanical Engineers and also from the former Ministry of Transport (*ibid*: 5).

How system theory was conceived at the TIT affected the way by which fuzzy set theory was accepted. Earlier experiences in the Railroad Research Institute and the Ship Research Institute made Terano well aware of issues in large scale systems, and his interest in those issues continued after he moved to TIT. As he said, ‘we have been problematizing large scale systems, and the research of fuzzy theory was launched because we take it as a new methodological macro approach to tackle large scale systems’ (Terano 1989: 983). To him, railroad accidents are exactly one of the problems of large scale system. On 9th Nov. 1963, a railway accident took place near Yokohama when two commuter trains ran into a derailed freight train, killing 162 people (Kubota 2000: 114-115). The 1963 catastrophic accident made many, Terano included, who had experience in railroad engineering take into consideration the social aspects of large scale engineering systems.³⁷ This concern made him see fuzzy set theory in terms of its applicability to engineering systems, especially to facilitate a better collaboration between humans and machines, by describing human behaviour in systems in fuzzy terms.³⁸ Terano translated the word fuzzy into ‘*aimai*’

³⁶ Prof. Cianello here refers to the Italian cybernetician Eduardo R. Caianiello (1921-1993).

³⁷ Email to the author from Etō Hajime, 28 July, 2005.

³⁸ Sugeno interview.

in Japanese, and, instead of introducing only fuzzy set theory, in 1974 he proposed ‘aimai engineering’, in which fuzzy set theory is one of the approaches to handle the human sensations and feelings in systems composed of both people and machines. According to Terano, subjective aspects of human beings were being ignored by then existing engineering approaches, and should be emphasized in order to facilitate the accommodation of engineered artefacts in society (Terano 1974: 38-41).

Before ‘aimai engineering’ was proposed, Terano organized an ‘aimai symposium’ in 1971, on behalf of the systems section of the Society of Instrument and Control Engineers (Terano 1989: 983). In February 1972, with Shibata Heki, professor of the Institute of Industrial Science at the University of Tokyo, Terano invited researchers from different engineering backgrounds from various institutions, some of them from his former affiliations, to form ‘the Working Group on Fuzzy Systems’ (aimai sisutemu kenkyū-kai) and to hold regular seminars. The seminar series took place every one to two months at TIT and the University of Tokyo alternatively, and from 1975, presentations were collected in the yearly *Summary of Papers on General Fuzzy Problems* – seven volumes in total until 1981. According to the names listed in these seminar reports, membership fluctuated between 40 and 61, and their affiliations between 20 to 34 institutions. However, some of the members were only nominally listed because of their relationships to other participants,³⁹ and those frequenting the seminar series numbered closer to about 20 to 30.⁴⁰ Among the participants, Terano’s colleagues and students consisted of about fifteen people who made up the largest group followed by the group led by Shibata, which consisted of about half of the number of Terano’s group. A glance at the first volume of the seminar reports hints at the broad scope of the engineering orientation of the working group: paper titles include, for instance, ‘Informatics in Eco-Technology’, ‘A Dynamic Model of Collective Human Flow from Big Fires’, ‘Measurement, Information and Human Subjectivity Described by an Order Relationship’, and ‘A Subjective Evaluation on Attractivity of Sightseeing’ (Terano 1975: vii-viii).

At TIT, system theory was not only followed by individual researchers but also was an institutional approach. In 1975, TIT launched the Department of Systems Science at the postgraduate level with three *kōza*: system theory, system management and system control (Tōkyō kōgyō daigaku 1985: 683). The establishment was due to efforts of Terano, Prof. Matsuda Takehiko of management science, and primarily Prof. Ichikawa Atsunobu, whose background was in electrochemistry with an emphasis on automatic control, and who was also a participant of the working group

³⁹ Takahara interview.

⁴⁰ Hirota interview.

on fuzzy systems.⁴¹ These three founding professors served as the *kōza* professors of the newly established department: Terano for the system theory *kōza*, Matsuda for the system management *kōza*, and Ichikawa for the system control *kōza*. Ichikawa's exposure to systems theory was from a year working as a postdoctoral research fellow at the systems research centre in the former Case Institute of Technology (hereafter CIT, which later became Case Western Reserve University) from 1960 to 1961 (Ichikawa 1990: 9-10). This centre, one of the earliest institutions devoted to systems theory, also hosted another important Japanese researcher on system theory, Takahara Yasuhiko.

Takahara (born 1935) is a graduate in applied physics of the University of Tokyo. From the late 1950s, he worked as an engineer for the development of instruments for measurement at Hokushin Electric Corp., a company specialized in automation. His interest in system theory was stimulated by the launch of the Russian satellite Sputnik, and by books on introductions to computer science and system theory written by Takahashi Hitetoshi (1915-1985), a former professor in physics at the University of Tokyo. Takahara went to CIT for doctoral study in systems theory from 1963 to 1967 on a Fulbright scholarship.⁴² From his time at CIT onwards, under the supervision of systems theorist Mihajlo D. Mesarović, who later became a core member of the Club of Rome, Takahara pursued a 'mathematical general systems theory', a formalized theory of systems, with his Ph.D. thesis emphasizing on theory of hierarchical systems (Takahara 2005: 4-6). After working as an assistant professor at CIT, an engineer of Hokushin Electric Corp. again, and a visiting professor at CIT, in 1971 he was invited by Prof. Matsuda Takehiko to serve as an associate professor of Matsuda's *kōza* of system management at TIT (*ibid*: 4; 9).⁴³

Takahara's coming to TIT incidentally affected the route of a research associate in Terano's *kōza*. Sugeno Michio (born 1940), a graduate in physics from the University of Tokyo, had worked in Mitsubishi Atomic Power industries, Inc. for three years before going to TIT in 1965. Sugeno's work at TIT originated through the introduction of Tsukamoto Yahachirō, who was one of his undergraduate friends and was then Terano's research associate. Sugeno served as a research associate to the associate professor Morita Yajirō, under Terano's *kōza*, and was then searching for a

⁴¹ Takahara interview.

⁴² Takahara interview.

⁴³ Takahara interview. It is hardly a general case in Japan that a person trained abroad and without any former relationship with the *kōza* professor could be promoted to professorship within that *kōza*. That Takahara has co-authored a book with Mesarović at a time when systems science rose in TIT could be part of the explanation.

possible Ph.D. thesis topic, with the theory of hierarchical systems one of the choices. However, Takahara's Ph.D. thesis had led Sugeno to redirect his attention to computer chess game playing. After discussing this with Prof. Terano and Morita, Sugeno considered that the idea of fuzziness could be useful for his project, but to serve his purpose it would need to be more developed than what could be implied from Zadeh's article 'Fuzzy Sets'. Instead of using probability measures to tackle algorithms of chess playing, Sugeno decided to use 'fuzzy measures' to evaluate moves in chess playing.⁴⁴ In 1975 Sugeno earned his Ph.D. – a thesis Ph.D. – on 'fuzzy integral' and was later promoted to the associate professor of the system theory *kōza* (of which Terano was the professor) in the Department of Systems Science in 1977. Takahara took Terano's post and became the professor of the system theory *kōza* in 1979. Later, Matsuda Takehiko, the *kōza* professor of system management became the president of TIT, and Takahara moved back to serve as the *kōza* professor of system management. Takahara's former post in the *kōza* of system theory was then taken up by Sugeno in 1983 (*Tōkyō kōgyō daigaku* 1985: 683).⁴⁵

While Takahara worked with Terano and Sugeno for some time, Takahara holds a rather different view on fuzzy theory – although he was a 'nominal' member of the Working Group on Fuzzy Systems. Owing to a deep concern with mathematical formalism, Takahara recalls that 'I couldn't appreciate fuzzy set theory at that time'; for him, the problem of fuzzy theory is that 'how can you define the membership function?'⁴⁶ His view in this regard was similar to that of Ichikawa Atsunobu – who was also a member of the Working Group on Fuzzy Systems. As he notes, '[Ichikawa] made a comment saying that fuzzy theory is not a "fuzzy" theory, because in order to

⁴⁴ Here 'measure' is a mathematical notion specified in a research field called measure theory. Measure is an extension of mathematical notions of length, area, and volume developed in ancient Greek mathematics. For example, the Greeks used inscribed and circumscribed polygons to make an approximation of the area of a circle (Sattinger 2004: 3). Roughly speaking, areas of a circumscribed polygon and an inscribed polygon can be seen as the upper and lower measures of the area of a circle. In measure theory, the notion of measures is extended and applied to sets, and different definitions of measures correspond to distinct kinds of 'integrals', which can be understood as ways to estimate areas in the sense of the example given above. Regarding fuzzy measures, it was proposed as a parallel concept to probability measure. In Sugeno's words, '[c]oncerning randomness, we have so-called probability measures. Therefore it seems to be indispensable that we build a concept of "measure" in order to discuss fuzziness at the same level as that of randomness'; '[fuzzy measures] are defined as subjective scales for fuzziness. Fuzzy integrals are the functionals with monotonicity defined by using fuzzy measures. Those correspond to probability expectations' (Sugeno 1975: 55). In fact, R. E. Smith's PhD thesis on measure theory on fuzzy sets, completed in 1970 at the University of Saskatchewan, Canada, preceded Sugeno's work on fuzzy measures (Gaines and Kohout 1977: 16).

⁴⁵ Sugeno interview; Takahara interview. Prof. Terano retired from TIT (a national university) and became a professor in Hōsei University (a private university) in 1982. Until recently, in Japan, professors in public universities are forced to retire at the age of 60. Professors retired from public universities often move to private universities to continue their professorship. For private universities, the age of 70 is the retirement age for professors.

⁴⁶ Takahara interview.

implement fuzzy theory, they have to write down everything in strict terms, e.g. you have to define membership functions and everything. So in the sense fuzzy set theory is not really “fuzzy” theory’.⁴⁷ Although Takahara was known for his negative attitude towards fuzzy theory by the fuzzy research circle at TIT, the small number of faculty members in the department of systems science meant that he served as the Ph.D. thesis examiner for three students who wrote their theses relating to fuzzy research – all three listed in table 3.1 under direct supervision of Sugeno.⁴⁸

Terano’s promotion of aimai engineering was supplemented by Sugeno’s theoretical approach. As noted by some of my interviewees who knew him well, Terano was a very practical, pragmatic system engineer who was interested more in good results rather than theory.⁴⁹ As reflected in the title of the earliest book promoting aimai engineering, ‘the book is titled ‘aimai engineering’ but not ‘aimai science’ because rather than investigate the nature of ‘aimai-ness,’ its applications are of more concern’ (Terano 1981:15). In contrast, Sugeno has been interested in developing theories, as indicated by his rather productive and frequently cited works on fuzzy measures, fuzzy integrals, and later modelling of fuzzy control and fuzzy systems.⁵⁰ After getting a Ph.D. degree, Sugeno stayed for two years in London and Toulouse where he met researchers who were already, or were to become, significant figures in fuzzy research in UK, France and Spain: E. H. Mamdani, Didier Dubois, Henri Prade, and Enric Trillas. After going back to Japan, he stayed at TIT until moving to the Institute of Physical and Chemical Research (Riken) in the year 2000.⁵¹ While at TIT, Sugeno has supervised more than one hundred master’s and Ph.D. students, many of whom chose fuzzy theory as their topics. Some of his students have also made significant theoretical contributions and stayed at TIT after gaining their Ph.D.⁵² The concentration of Terano, Sugeno and their students on fuzzy research has earned TIT a reputation for work in this field.

The leader of the second largest university-based participant group in the Working Group on Fuzzy Systems was less earnest in promoting fuzzy research. Shibata Heki (born 1931) is of similar background in mechanical engineering as Terano. His Ph.D. thesis concerned the problems of vibrations of the pantograph

⁴⁷ Takahara interview.

⁴⁸ Takahara interview.

⁴⁹ Takahara interview; Tanaka interview.

⁵⁰ For example, a paper by Sugeno and Takagi Tomohiro, one of Sugeno’s students who earned his Ph.D. in TIT on the fuzzy modelling of systems (Takagi and Sugeno 1985) has been cited for more than 1,500 times. Data from ISI web of knowledge, accessed on 2nd Jan, 2007.

⁵¹ Sugeno interview. For the history of Riken, see Coleman (1990).

⁵² Ralescu and Ralescu interview. Terano, Takahara and Sugeno all remained at TIT until reaching the age of retirement.

(devices that carry electricity to trains from overhead wires) and its dynamics. Shibata and Terano came to know each other through a common interest in safety related issues in automatically controlled systems.⁵³ Although admitting that fuzzy sets theory could be a useful tool in the making of decisions in systems and thus has its role in engineering, Shibata did not pay much attention to its development despite making a few comments (Shibata 1976). Rather than specifically in fuzzy theory, his interest was predominantly in safety issues ranging from those in traffic systems to the earthquake-resistance of large systems such as nuclear power plants and chemical plants. Without a focus on fuzzy research comparable to that of Terano's group, few of the participants of the Working Group on Fuzzy Systems from the University of Tokyo continued with research on fuzzy theory. Shibata's orientation towards fuzzy theory has thus had an effect on the current state of affairs of fuzzy research in the University of Tokyo: few, if indeed any, researchers are pursuing research along this line. Considering the mobility in the Japanese academic system, this comes at little surprise: in post war Japan, inter-university mobility is quite low, 'except for some Ph.D.s from elite universities moving to less prestigious ones for their first jobs' (Whitley 2000: xxiv). For such a prestigious university as the University of Tokyo, according to a statistics as of 1989, 87 per cent of the faculty graduated from the same university (ibid: xxiv).

Thus, the prestigious status that the University of Tokyo had been holding was a factor in the non-development of fuzzy theory in it. This applies also to the case at Kyoto University, because these universities are more 'traditional' – which means that professors in science and engineering there tend to pursue relatively mathematically demanding topics.⁵⁴ From the viewpoints of the postgraduate students in science and engineering who were interested in advanced mathematics in the two universities in the 1970s, fuzzy set theory was then less developed, and 'some parts of it looked funny rather than fuzzy'.⁵⁵ Let us now turn to a group of researchers near Kyoto.

The Osaka Group

Unlike the Tokyo group, which started with an interest in applying fuzzy theory

⁵³ Shibata interview.

⁵⁴ Shin interview.

⁵⁵ Interview data. As a rough reference to the prestigious status of Kyoto University, 'almost all the Japanese Nobel Prize winners in the field of science have come from Kyoto University' (Sigurdson 1995:88). Also, among the three Japanese scholars who won the Fields Medal in mathematics from 1954 onwards, two of them were trained at least until master's level at Kyoto University.

to engineering systems, researchers in the Osaka group, were initially more specifically concerned with the application of fuzzy set to the theory of automata. For the purpose of introducing the Osaka group, I shall begin with a brief account of the theory of automata, to show how fuzzy set was brought into the scene.

Zadeh's first article on fuzzy set theory, 'Fuzzy Sets', was submitted to the journal *Information and Control* at the end of November, 1964 and was published in June, 1965. Although, as it is noted, the article underwent a short peer review process because Zadeh himself was one of the editorial board of *Information and Control* (Seising 2004: 1589; 2005: 96), the journal was far from representing a vested interest of an academic clique, even from the viewpoint of that time.⁵⁶ Members of the editorial board of the journal included psychologist George A. Miller who had collaborated with the renowned linguist Noam Chomsky, mathematician John von Neumann's co-worker on game theory Oskar Morgenstern, information theorist Claude Shannon, cybernetician Norbert Wiener, and Zadeh, among others from its very beginning in 1957.⁵⁷ From the late 1950s onwards, the theory of finite automata and formal languages became one of the main themes in the journal.⁵⁸

According to authors in the field, automata theory was biologically inspired. It arose in the mid 1930s from mathematician Alan Turing's modelling of a human calculator who executed certain finite rule-governed instructions, the 'Turing machine' with infinite memory. In 1943, neuropsychiatrist Warren McCulloch and logician Walter Pitts used mathematical logic to model the function of neurons and proved that the neuron net they constructed is essentially a formal automaton (Arbib 1975: 279; Burks 1975: 298). In short, 'the automaton can carry out all operations that can be specified in a finite number of words' (Heims 1991: 20). With the emergence of digital computers, in the late 1940s, von Neumann combined the work of Turing and McCulloch and Pitts to form his 'theory of automata' which aimed to be 'a coherent body of concepts and principles concerning the structure and organization of both natural and artificial systems, the role of language and information in such systems, and the programming and control of such systems' (Burks 1966: 18). Aware of 'the close connection between mathematical logic and

⁵⁶ According to Kimura Hidenori, a Japanese control theorist who did his Ph.D. study in the latter half of 1960s in the interview, '[*Information and Control*] was a good journal, at least at that time, many important papers appeared in that journal....[although papers on] information were more than control'.

⁵⁷ For works by Miller, Shannon, and Wiener that bore the imprint of war time efforts, see Edwards (1996).

⁵⁸ The journal lasts for 30 years from 1957 to 1986, and was continued as *Information and Computation*. A change of name took place because, as its editor said in 1987, that 'less than a handful of articles on Control Theory have made their way into print during the past 5 years; this field is now represented by numerous other specialized journals. Our new name accurately reflects the journal's contents and the expertise of its editorial boards' (Meyer 1987: iii).

automata' as envisaged by mathematician Kurt Gödel's work, von Neumann stated that 'logic will be at the heart of the mathematics of automata theory' (*ibid*: 25). However, von Neumann's theory was not completed due to his early death, and the study of theory of finite automata (which was thought to be a more accurate description of actual computers than was the Turing machine), less ambitious in vision as compared to von Neumann's general theory 'emerged from the convergence of lines of research in mathematical logic, neurophysiology, and electrical engineering' from the 1950s onwards (Mahoney 2004: 227-228).

The link between the theory of automata and formal languages is less surprising if viewed from the viewpoint that logic has been serving as a tool to formalize natural language for a long time (Burks 1975: 298). Chomsky and George A. Miller published 'Finite State Languages' in the journal *Information and Control* in 1958, and in 1959 Chomsky's article 'On Certain Formal Properties of Grammars' in the same journal 'introduced the now central "Chomsky hierarchy" of finite-state, context-free, context-sensitive, and recursively enumerable (Turing) languages' which were shown by later researchers to correspond to models of digital computers with different levels of complexity: finite automata, pushdown automata, linear bounded automata and Turing machine respectively (Mahoney 2004: 230). One of the early researchers on finite automata, Michael O. Rabin, also had an article generalizing finite-state automata to probabilistic automata in the same journal in 1963 (Rabin 1963).⁵⁹ In 1964, Chomsky himself became a member of the editorial board of that journal.

It was in this context that the first international journal article on fuzzy theory by Japanese scholars appeared (Mizumoto 2002: 1). Then at Tōhoku University, Nasu Masakazu and Honda Namio in April 1968 published 'Fuzzy Events Realized by Finite Probabilistic Automata' in the journal *Information and Control*. The article combined fuzzy sets, as introduced by Zadeh, and the probabilistic automaton, as developed by Rabin (Nasu and Honda 1968).⁶⁰ Later, they also tried to develop

⁵⁹ More technically, finite automata 'are mathematical models for systems capable of a finite numbers of states which admit at discrete time intervals certain *inputs* (incoming signals) and emit certain *outputs*. If the system is in state s and the input is σ then the system will move into a new state s' which depends only on s and σ and will have an output which depends only (is a function of) on s' . Thus the system will transform a sequence of inputs into a sequence of outputs and the relevant aspect of the system is this transformation. Sequential circuits, and even whole digital computers, provided the computer operates using only internal memory or just a fixed amount of tape, are systems which behave like finite automata' (Rabin 1963: 231). For the relation between the theory of automata and formal languages in the context of the theory of computation, see Mahoney (2004).

⁶⁰ The idea behind the probabilistic automata, '[the] natural generalization of finite automata', is to consider the stochastic – seemingly paradoxical – behaviour of deterministic finite automata, for 'even the sequential circuits which are intended to be deterministic exhibit stochastic behavior because of random malfunction of components'. This concern for the reliability of electric components was first

machine models that could recognize fuzzy languages, and to classify these machines by levels of complexity as was done in theories of formal languages and of automata (Honda and Nasu 1975: 279).

Before the article by Nasu and Honda on applying fuzzy set theory to probabilistic automata was published, William G. Wee, a postgraduate student at Purdue University had proposed the idea of a fuzzy automaton and applied it to pattern recognition in his Ph.D. thesis in 1967. With regards to the fuzzy automaton, it was argued that 'fuzzy automaton includes the deterministic and the nondeterministic machines as special cases...fuzzy automata and probabilistic or stochastic machines have entirely different behaviors' (Santos and Wee 1968: 5). Receiving Wee's Ph.D. thesis from his supervisor, computer scientist Tanaka Kōkichi (1919-1983), Mizumoto Masaharu (born 1942) was informed of fuzzy theory for the first time. Then enrolled as a first year Ph.D. student in Tanaka's newly established *kōza* of information science at Osaka University in 1968, Mizumoto decided to pursue a doctoral topic on fuzzy automata and fuzzy grammars in the high tide of automata theory and Chomsky's formal language theory (Mizumoto 2002: 1). Mizumoto earned his Ph.D. in 1971. Tanaka, together with Mizumoto, Mizumoto's fellow student Ezawa Yoshinori and student Umano Motohide, formed a fuzzy theory research group devoted to information science-related aspects at Osaka University, as shown in Table 3.1.

Another group in Osaka was led by Asai Kiyogi. Born in 1923, Asai's student life was interrupted by the outbreak of the war, although military service had prepared him for further studies with hands-on experiences of electrical and communication engineering. After undergraduate and Ph.D. studies in communication engineering with a control engineering emphasis at Osaka University, he became a member of faculty of electrical engineering at Osaka City University in 1962. Through an introduction to Zadeh by his former supervisor Kumagai Sanrō, from March 1967 to March 1968, Asai was a visiting professor in the department of computer science and electrical engineering at U.C. Berkeley, of which Zadeh was the head. Adopting the advice of Fu King-Sun (1930-1985), Asai began his study on fuzzy automata. Born in China and having finished his undergraduate education in Taiwan, Fu was a specialist in pattern recognition teaching at Purdue University. He was also a visiting professor in Zadeh's department when Asai was there. In March 1968, Asai went to Princeton for a conference on information sciences and systems. There he presented a paper on the identification and control of fuzzy systems, which

shown by von Neumann (Rabin 1963: 230-232), which was also expressed in his idea of cellular automata of which living organisms were seen as models (Mahoney 2004: 227-228).

is claimed to be the first paper ever presented by a Japanese scholar on fuzzy theory.⁶¹

After coming back from the U.S. to Japan, Asai took a position at Osaka Prefecture University as the professor of the newly established *kōza* in systems engineering – perhaps the oldest one of its kind in Japan – within the department of industrial engineering, and set out his research on the application of fuzzy theory. Although through different routes – Mizumoto was informed by his supervisor Tanaka of fuzzy theory, and Asai had a direct contact with Zadeh for an extended period of time – they became aware of fuzzy theory via their supervisors' international networks, in which Zadeh was a node owing to his fame as a system theorist. And both of their exposures to research on fuzzy automata were mediated by researchers in Purdue University – both Wee and Fu worked there, and Wee was a student of Fu.

Practising new theories requires passing the trial of the *kōza* system. While working as an associate professor at Osaka City University, the professor of Asai's *kōza*, Hirai Heihachirō, was a specialist in electrical materials – a field distant from Asai's research on control engineering. As Asai remarks, 'after all, it is easier to have a research topic similar to that of the *kōza* professor'.⁶² While the set-up of a new laboratory at Osaka City University for Asai was expected upon his return from the U.S., it was not realized due to budget problems. He thus moved to Osaka Prefecture University for a post in the systems engineering *kōza*. Asai also brought with him a student, Tanaka Hideo from Osaka City University, who intended to study fuzzy theory.⁶³ With Tanaka Hideo's students, Watada Junzō and Ichihashi Hidetomo, who earned their Ph.D. degrees in the early 1980s, Asai formed another fuzzy research group in the Osaka area. This group later put their emphasis of research on the application of fuzzy theory to some subfields in industrial engineering, such as operations research and decision making.⁶⁴

What happened to Mizumoto was more dramatic, as he was a junior researcher in the early 1970s. Although Tanaka Kōkichi introduced fuzzy theory to Mizumoto, and was involved in Japanese fuzzy research circle for some time, most of Tanaka's attention was later drawn to the then burgeoning field of symbolic artificial intelligence.⁶⁵ This can be shown by his efforts in the early 1980s in supervising the

⁶¹ Asai interview.

⁶² Asai interview.

⁶³ Asai interview.

⁶⁴ Ichihashi interview.

⁶⁵ Considering Mizumoto's research at that time was on theory of automata, Tanaka's preference for symbolic artificial intelligence had a precedent of much historical significance. Discontent with research on automata, mathematician John McCarthy promoted the 'symbolic modelling approach' to

translation into Japanese of three of the four volumes of the *Handbook of the Artificial Intelligence* edited by Edward A. Feigenbaum and others – with Fuchi Kazuhiro, leader of the ICOT (Institute for New Generation Computer Technology) that was in charge of the Fifth Generation Computer project.⁶⁶ Thus, after only a short period of interest, Tanaka's attitude towards fuzzy theory was rather indifferent. Thinking that it was difficult to find applications for fuzzy theory, a state of affairs quite different from that of symbolic artificial intelligence in the 1970s, Tanaka had suggested that Mizumoto not pursue research on fuzzy theory.⁶⁷ Not only Tanaka, but Shimura Masamichi, the associate professor in Tanaka's *kōza* who specialized in pattern recognition, had advised Mizumoto not to continue fuzzy research any further because it was of no practical use. As Mizumoto admits, 'that was a time when anything that could be fuzzified served to be the topic of a paper' (Mizumoto 2002: 1). Although Shimura had published a few papers on the application of fuzzy theory to pattern recognition, he 'perhaps held that fuzzy theory is not helpful after writing some papers'.⁶⁸ Shimura later moved to TIT and continued to be a detractor of fuzzy theory there.⁶⁹ After seven years of assistantship in Tanaka's *kōza* without a promotion, Mizumoto eventually moved to Osaka Electro-Communication University, a private university, where he could continue his research freely (Mizumoto and Mukaidono 2004: 103-104).⁷⁰

In Osaka, the 'Fuzzy Science Research Association (Aimai Kagaku Kenkyū-kai)' which held a regular seminar series, was eventually set up in 1980, eight years after the Working Group on Fuzzy Systems was formed in Tokyo – despite the fact that researchers in Osaka had begun exploring fuzzy theory before their colleagues in Tokyo had. The delay was because, firstly, the change in research interests of Tanaka Kōkichi, a person of high status in information science in Osaka – although Tanaka served as the president of the association until his death in 1983. Secondly, there were fewer researchers in Osaka than in Tokyo, something that was true of almost every field especially these newer ones.⁷¹ The term 'science' was chosen as part of the name of the association because, according to the founding

computation in the late 1950s in the U.S., and the term artificial intelligence is probably McCarthy's coinage (Fleck 1982: 176; MacKenzie 2001: 48).

⁶⁶ Tanaka's role in supervising the translation of the *Handbook of the Artificial Intelligence* came to an end due to his death in 1983; the translation of the fourth volume of the *Handbook of the Artificial Intelligence*, the original English version of which appeared in 1989, was supervised solely by Fuchi Kazuhiro.

⁶⁷ Mizumoto interview.

⁶⁸ Mizumoto interview.

⁶⁹ Hirota interview.

⁷⁰ Mizumoto interview.

⁷¹ Asai interview, Mizumoto interview.

members, science was thought of as more broad a concept that included technology, systems science, social science, and human science and so on. Compared to engineering, science would not be thought of only in practical terms.⁷² As of the year 1983-84, there were about ninety members registered in the association (Aimai kagaku kenkyū-kai nyūsu 1984a: 4). In 1984, with the establishment of the International Fuzzy Systems Association (IFSA), the 'Working Group on Fuzzy Systems' in Tokyo and the 'Fuzzy Science Research Association' in Osaka were merged into the Japan Chapter of IFSA (Terano 1989: 42).

Other Groups

Kyoto University, one of the two most prestigious universities in Japan, was connected to fuzzy research in the early 1970s through research on multi-valued logic, to which fuzzy logic can be seen as belonging.⁷³ This connection was facilitated by the workshops held by the Sūri-kaiseki-kenkyūsho (Research Institute for Mathematical Sciences, RIMS), which was founded in Kyoto University in 1963 for promoting pure as well as applied mathematical research. The institute has until now published over 1,500 kōkyūroku, proceedings of workshops held by the institute.

Four among the over 1,500 volumes are proceedings of the workshops on 'Many-valued logic and its Applications', which were held in 1970, 1971, 1982, and 1989. The workshops in 1971 and 1972 in particular were significant for enabling contact to be made between the fuzzy research group at Osaka University and a researcher from Meiji University, Tokyo, who later made his way into the field.

The interest of Mukaidono Masao (born 1942) in fuzzy logic stemmed from his research on three-valued logic. He studied how three-valued (1, 0, and unknown) logic could be applied to fail-safe logic circuits in train traffic signal systems in the late 1960s (Mukaidono 1988: 58). The design goal of a fail-safe logic circuit is to avoid a disaster arising even if a circuit malfunctions; that is, to remain safe even if it fails. Around that time, Mukaidono and his supervisor represented one of the main research groups studying multi-valued logic, along with the groups from Kyoto University and Osaka University, among others. Thinking that three-valued logic, multi-valued logic, and fuzzy logic have similar structures mathematically, Mukaidono began his research on the mathematical properties of fuzzy logic. He

⁷² Asai interview, Mizumoto interview.

⁷³ Multi-valued, multiple-valued, and many-valued are in general used interchangeable when referring to multi-valued logic.

acquainted himself with researchers on fuzzy theory from Osaka University through the workshops on 'Many-valued logic and its Applications'. Mukaidono also met Sugeno Michio at a symposium and was informed of regular seminars held by the Working Group on Fuzzy Systems in Tokyo, and became a participant of that group.⁷⁴

For researchers working at Kyoto University, an interest in fuzzy theory was stimulated in the late 1970s and early 1980s, in various disciplines. For instance, members of a precision engineering laboratory, led by Iwai Sōsuke, had been interested in applying fuzzy theory to information retrieval, and Furuta Hitoshi was interested in its application to reliability issues in civil engineering. Moreover, several Ph.D. students in applied physics and mathematics learned about fuzzy theory in the late 1970s, and became engaged in its application to various problem areas after they were employed after graduation: for instance, Miyamoto Sadaaki in Tsukuba University, Sakawa Masatoshi in Hiroshima University, and others elsewhere.⁷⁵ The many-valued logic workshops in the early 1970s held by RIMS did not arouse an interest in fuzzy logic for many-valued logic researchers in Kyoto University; those faculty members who became interested in applying fuzzy theory in Kyoto University from the late 1970s, did so at a time when fuzzy theory came to be seen as a tool for applications rather than a major research theme – they nevertheless remained few.⁷⁶

Unifying Mechanisms

There were, and still are, mechanisms that have served to unite Japanese researchers in certain fields, by providing joint funding opportunities. What will be addressed here are two such mechanisms that pertain to fuzzy theory research in Japan. One is national, and the other, which is international, reflects an aspect of the post-war arrangement of Japanese scientific research as dictated by the U.S. government.

The international one is U.S.-Japan cooperation on scientific research, which evolved as a surveillance purpose on the part of the U.S. side immediately after the war (Kelly 1965: 461). The cooperation of a mutual kind grew out of the U.S.-Japan Committee on Scientific Cooperation set-up, to facilitate scientific cooperation after Japanese Prime Minister Ikeda Hayato (in post 1960-1964) visited the U.S. in 1961.⁷⁷

⁷⁴ Mukaidono interview.

⁷⁵ Miyamoto interview; Sawaragi interview.

⁷⁶ Sawaragi interview.

⁷⁷ Although, as the agreement of this scientific cooperation was signed during the Cold War years,

Originally, the program consisted of joint research projects, scientific meetings, and a visiting senior scientists program. Funding for individual projects was provided by various agencies, but the National Science Foundation and the Japan Society for the Promotion of Science were the major providers for the U.S. and Japan sides, respectively (Kelly 1965).

Although no joint research project was initiated for fuzzy theory research under the U.S.-Japan Cooperative Science Programs, researchers from the two countries benefited from the seminar series it supported. In August 1970, Fu King-Sun organized a seminar on learning processes in control systems in Nagoya which 'was sponsored by the US-Japan Cooperative Science Program, jointly supported by the National Science Foundation and the Japan Society for the Promotion of Science' (Fu 1971: v). Tanaka Kōkichi, Shimura Masamichi, and Asai Kiyoji were participants from the Japanese side, among others, although only Asai's paper addressed fuzzy theory. All three attended another seminar sponsored by the U.S.-Japan Cooperative Science Program on 'Fuzzy Sets and Their Applications' held at the University of California, Berkeley in July 1974 for four days, with Fu, Shimura, Tanaka, and Zadeh as co-editors of its proceedings (Zadeh, Fu, Tanaka, and Shimura 1975: ix). There were thirteen participants on the Japanese side (observers included), and twenty on the U.S. side (Tanaka 1975:86). In addition to the editors, the Japanese side included, among others, Terano Toshirō, and Inagaki Yasuyoshi, a rather productive information scientist, then at Nagoya University, who presented work on fuzzy automaton and language in that seminar, as did Honda Namio.⁷⁸ Perhaps because of the funding criteria, only those who already held a professorship then could attend, although Mizumoto and Sugeno contributed much to the co-authored papers with Tanaka and Terano, respectively, and were listed as contributors in the proceedings.⁷⁹

On the other hand, the unifying mechanism at the national level was the 'grants-in-aid for scientific research' provided by the former Ministry of Education (Monbushō).⁸⁰ Fuzzy theory researchers in Japan had applied for joint research (sōgōkenkyū) projects in which individual researchers shared funds for their own sub-projects, and their applications were successfully approved three times. These

there were reservations about the military implications of such cooperation expressed by Japanese scientists (Nakayama 2006: 159).

⁷⁸ List of publications in Japanese written by specific researchers can be searched at <http://ci.nii.ac.jp/>.

⁷⁹ Mizumoto interview; Sugeno interview.

⁸⁰ With the Central Government Reform, the former Ministry of Education was combined with the former Science and Technology Agency (STA) to form the Ministry of Education, Sports, Culture, and Science and Technology (MEXT) in 2001.

projects were: ‘Fundamental Research on Fuzzy System Theory and Artificial Intelligence’ in 1976; ‘Research on the Processing and Application of Fuzzy Information’ from 1982 to 1983; and ‘Research on the Evaluation and Modelling of Real Systems that Contain Fuzziness’ with 34 participants in total, Terano and Asai included, from 1985 to 1987.⁸¹ The head investigators of these projects were Tanaka Kōkichi (Osaka University), Asai Kiyoji (Osaka City University), and Morita Yajirō, former associate professor of Terano’s kōza (TIT) respectively (Asai 1994: 3; IFSA Nihon shibu nyūsu 1986: 2).⁸² Through the holding of seminars and symposiums, and the setting-up of various research groups supported by these funds, these joint projects served to facilitate the cooperation and circulation of ideas between Japanese fuzzy researchers. The first two of these were especially important since they predated either an international or a nation-wide Japanese association on fuzzy theory research.

Characteristics of Early Fuzzy Theory Research

As the idea of fuzziness was proposed as a conceptual innovation to deal with uncertainties in systems, it was a newly developed interpretation of uncertainty, a concept that had been dealt with using the tools of probability over hundreds of years in science and engineering.⁸³ As we have seen, fuzzy sets were used to carve out an intellectual space that had been largely occupied by probability, as research by Sugeno on fuzzy measures, and Mizumoto and Asai on fuzzy automata show. Just as probability has been widely used in science and technology, the application of fuzzy theory cut across various research areas and disciplines, although in its incipency in Japan the focus was mainly on systems and information sciences. Japanese efforts on the development of fuzzy logic as a logic system have remained peripheral from the early years.⁸⁴

Below are the features of this new specialty of fuzzy research in the incipient years in Japan:

- (1) Material or resource requirements were low since in the early stage it was rather a conceptual innovation than a technological innovation. As ‘paper and pen’

⁸¹ The application of the third project, filed for the first time for the fiscal year 1984, was rejected. The resubmission was approved for the fiscal year 1985 (Aimai kagaku kenkyū-kai nyūsu 1984b: 4; IFSA Nihon shibu nyūsu 1986: 2).

⁸² Asai interview; information of the projects funded by grants-in-aid for scientific research can be obtained at <http://seika.nii.ac.jp>.

⁸³ For different interpretations of probability that have emerged in its history, see Gillies (2000).

⁸⁴ Etō Hajime, email to the author, 28 July 2005.

research,⁸⁵ resources for building networks among researchers were much more crucial than were acquiring computers or machines that carry out simulation results, characteristic of later research on fuzzy control.

- (2) The mathematical skills required for early fuzzy research were common among system scientists and engineers. More often than not, the idea of fuzziness was applied to researchers' former areas, and properties of such applications investigated. These kinds of investigations substantiated Mizumoto's formerly mentioned comment on the state of affairs at that time: 'when anything that could be fuzzified served to be the topic of a paper'.⁸⁶ Research papers were often presented in a formalized way of inference: definitions followed by theorems and lemmas, common among the practice of systems theory at that time.
- (3) Although research carried out in the above mentioned form, characteristic of earlier work by, for instance, Asai, Mizumoto, and Sugeno, it was accompanied by Terano's promotional articles that presented aimai engineering, of which fuzzy theory is a part, to addresses a wider audience. The early research was highly technical and was addressed to groups of researchers who had professional journals as their major means of communication.
- (4) The reputation of those relatively young fuzzy researchers among other researchers was built upon publications of papers in journals pertaining to their and their supervisors' earlier respective areas, ranging from information sciences, communications, to system sciences, cybernetics, and control engineering. Targeted international journals, for instance, include *Information Sciences*, *Journal of Computer and System Sciences*, *Kybernetes*, *International Journal of General Systems*, *IEEE Transactions on Systems, Man, and Cybernetics*, and *Information and Control*. Japanese journals included official journals of some of the largest societies in electronics and in control – The Institute of Electronics and Communication Engineers, The Society of Instrument and Control Engineers, and The Japanese Association of Automatic Control Engineers.⁸⁷

The effects of the kōza system in the early development of fuzzy theory in Japan

⁸⁵ Etō Hajime, personal communication.

⁸⁶ Mizumoto interview.

⁸⁷ The Institute of Electronics and Communication Engineers (IECE) began in 1917 and its name was changed to 'The Institute of Electronics, Information, and Communication Engineer' (IEICE) in 1987. IEICE has about 33,000 members as of March 2007 (<http://www.ieice.org/eng/about/about.html>). The Society of Instrument and Control Engineers (SICE) was founded in 1961 and consists of about 6,900 members as of May 2008 (<http://www.sice.or.jp/index-e.html>). The Japanese Association of Automatic Control Engineers (JAACE) was established in 1957. Its name was changed to 'The Institute of Systems, Control, and Information' (ISCIE) in 1988. It has about 3,000 members.

can be discerned by comparing the cases in Tokyo and Osaka. Both TIT and Osaka University are elite, though not as prestigious as the University of Tokyo and Kyoto University. Terano Toshirō of TIT and Tanaka Kōkichi of Osaka University held posts of *kōza* professor in system dynamics (later system theory), and information science, respectively (Asai Kiyogi became a *kōza* professor considerably later than Terano did, and worked in Osaka Prefecture University, a less prestigious university). In the early years of fuzzy research, they tried to target audiences and mobilize network resources of their former respective fields.

Although the general practice of putting names of *kōza* professors on the publications of all *kōza* members has been criticized (e.g. Coleman 1999: 21), it can be beneficial for a new specialty seeking to gain recognition because the practice helps to build reputation of those lower in rank through the use of the *kōza* professors' reputation. All of Mizumoto's early publications on fuzzy theory listed Tanaka Kōkichi as a co-author except one that was published in a non-refereed journal, although Tanaka's contribution to those publications could have been tenuous.⁸⁸ While the practice can be detrimental to young researchers' acquisition of their own credit, for a new specialty, it serves as a protective mechanism, especially when the specialty is new and not widely known.

In addition, the evenly distributed funding across *kōza* professors may make it difficult to achieve co-operation for a larger scale science, but its individualistic nature secures, at least at the department level, the freedom of *kōza* professors to do their own research (Sigurdson 1995: 72). As can be seen from the case of TIT, although there were some indifferent or even antagonistic views on fuzzy research in closely related *kōza*, research into it could still be pursued freely without much concern within the department, due to the individuality of *kōza* and evenness of funding across *kōza*.

However, within each *kōza*, subordinates were severely constrained by the authority of the *kōza* professor, and for the research in a new specialty to continue, a powerful *kōza* seems to be necessary. Reputations built on publications did not, however, translate into academic posts in prestigious universities, as shown by the case of Mizumoto, a rather prolific author. While at TIT there was a *kōza* professor, Terano, who had promoted fuzzy research ever since he became aware of it, in Osaka, on the other hand, both Mizumoto and Asai had to move out because their interests were not compatible with those of their *kōza* professors. The *kōza* system, therefore, served as a contributing factor to the proliferation of fuzzy research across Japan in a paradoxical way: with limited posts in a *kōza*, it led to a diaspora of researchers from

⁸⁸ Mizumoto interview.

more prestigious universities to lesser ones.

Therefore, early fuzzy logic research more or less fits the way Whitley characterizes the research fields of AI and engineering. In these fields, technical task uncertainty is low since 'there will be a well-established set of research techniques which can be acquired through formal training programmes and whose use is relatively straightforward and success is easy to determine' (Whitley 2000: 121). Strategic task uncertainty, however, is high, since there is no agreement over 'intellectual priorities, the significance of research topics and preferred ways of tackling them, and the relevance of task outcomes for collective intellectual goals' (ibid: 123). With regards to the degree of mutual dependence, on the other hand, for these research fields, the degree of functional dependence is high since 'scientists have to integrate their research much more with that of particular specialist colleagues' (ibid: 92). However, the degree of strategic dependence is low because 'scientists in these fields do not have to integrate their specialist goals and compete over their access to rewards. So theoretical co-ordination of the various sub-fields is not very strong and the relative prestige of reputations in different specialisms is not the focus of intense conflicts. Reputations tend to be sought primarily in these sub-fields and problem areas rather than in the discipline as a whole...' (ibid: 92).

However, although the *kōza* system serves in general to lower strategic dependence because it provides evenly distributed funding for researchers to pursue their respective research interests, for fuzzy theory research strategic dependence was not so low. This was because the *kōza* system did not necessarily serve as a channel to reputational rewards as fuzzy research had not established itself as a self-contained sub-field where reputation could be sought. This can be seen from the different views with regard to fuzzy research as opposed to systems science in TIT, and from the way that developments at Osaka University were shaped by its focus on symbolic AI. In other words, fuzzy researchers still had to 'persuade colleagues of the significance and importance of their problem and approach to obtain a high reputation from them' (Whitley 2000: 88)

Until the late 1970s, despite the promotional effort by Terano, papers on fuzzy theory by Japanese researchers remained esoterically technical, understandable largely only to those who were versed in probability and 'state-space' techniques in neighbouring specialties. When the applications of fuzzy theory to control emerged, strategic dependence was decreased to a greater extent since fuzzy researchers sought to find a new audience different from those colleagues in systems science and symbolic AI who shared with them the skills of manipulating mathematical and logical symbols. The language used for drawing the attention of this new audience,

practical engineers, was not only friendlier but was also accompanied by technical demonstration. The formalized deduction approach commonly seen in papers on fuzzy theory began to give way to technical demonstrations performed by computers – a theme to which we now turn.

Chapter 4

Fuzzy Logic Goes Public: The Substantiation of the Human Model

The late 1970s saw the turning point for fuzzy theory both in Japan and abroad. Ebrahim Mamdani and his student Sedrek Assilian, at Queen Mary College, University of London, made the first attempt to use fuzzy reasoning to control experimental engines in 1973. This was followed by some experimental trials (Mamdani 1977), and then a few industrial applications followed later in the decade. Of the early industrial applications, the most famous was the control of a cement kiln by F. L. Smidth Co. in Denmark in 1980 (McNeill and Freiberger 1993). In Japan, applications along this line followed soon after. As already noted, Mamdani was invited to TIT as a visiting scholar in 1977. The two earliest projects, both civilian in nature, were conceived at about the same time as the cement kiln project was finalized. It took several years for both to be realized, and the results were frequently cited as 'successful' applications of fuzzy reasoning to automation. One of these two later became the most famous exemplar of the 'usefulness' of fuzzy theory.

The two projects were the water treatment system developed by Fuji Electric Co., and the automatic train driving control system built by Hitachi for the Sendai subway. Both brought to the forefront the issue of human skills which fuzzy reasoning was claiming to imitate. In the former case, it was the skill of operators to put the proper amount of chemicals into the pool where waste water is purified; in the latter case, it was the train driver's skill at regulating the speed of the train.

Meanwhile, when these two systems were put into operation in the latter half of the 1980s, a much smaller scale experiment that utilized fuzzy reasoning to control an inverted pendulum was demonstrated publicly. Unlike the two civil projects, which were real-world applications, the demonstration of the inverted pendulum was used to promote newly developed hardware. As the inverted pendulum was widely used for teaching and testing controller design, and was easily available in an average control engineering laboratory, the demonstration thus helped to find fuzzy theory a much wider audience among practising engineers.

The Sendai subway and the inverted pendulum demonstration received extensive coverage in the mass media, and were turned into the emblems of the successfulness of fuzzy control (McNeill and Freiberger 1993: 157). At the same time, however, particularly regarding the demonstration of the inverted pendulum, the efficacy of fuzzy control was called into question by some control theorists, and resulted in a controversy well known to the Japanese fuzzy research community.

However, Japanese fuzzy researchers did not respond directly. The controversy brought to the fore the issue of modelling in controller design. For the control theorists, mathematical modelling assumes priority. On the other hand, the working of systems controlled by fuzzy logic became the grounds on which fuzzy logic was claimed to be successfully representing a skilled operator's experience and intuition. With the interpretations of the efficacy of fuzzy control now the focus of this chapter, I will analyze the claims concerning fuzzy control by detailing the developments – and counterarguments to the latter two cases – of the Fuji water treatment system, the Sendai subway system, and the inverted pendulum demonstration.

Fuji's Fuzzy Controller for Water Purification Process

The application of fuzzy control to the water treatment process in FUJIFACOM, a subsidiary company of Fuji Electric Co., was initiated by Itō Osamu. With a master's degree in physics from Nagoya University in 1974, Itō became an engineer specializing in control systems for water treatment and their simulation, after entering Fuji Electric Co. He was assigned the project to develop an automatic control system for water treatment plants which, in the late 1970s when the project was conceived, were solely controlled by human operators. The aim of automation was to replace the human operators so that a more even quality of water treatment could be achieved, because “in the twenty-four-hours-a-days” operation of chemical injection, the quality of manual control varied from person to person, depending on how conscientious individual operator was in their duties’.⁸⁹

Itō found that removal of turbidity by injecting flocculants was the most difficult part for automation. The injection rate of flocculants has to be adjusted according to the quality of the raw water, which is constantly changing. Since the reaction between flocculants and particles that are intended to be removed is so complicated that a mathematical model of the reaction is difficult to obtain, information provided by sensors of the change in water quality is insufficient for determining a responding change of flocculant injection rate. In previous systems, the injection rate was decided by skilled operators based on their experience (Yagishita, Itō, and Sugeno 1984: 597). Having found that various methods, from classical to modern control techniques, had proved unsuccessful in automation of the manual control of flocculant injection, Itō took notice of Sugeno Michio's papers on fuzzy control in 1980. In 1981, he began to pursue further study under the

⁸⁹ Itō interview.

supervision of Sugeno Michio and Terano Toshirō at TIT.⁹⁰

In order to automate flocculant injection, Itō set out to construct fuzzy control rules for the job. This was a two steps process. Firstly, knowledge of skilled operators in performing the work was elicited by asking how they responded to different conditions of turbidity, water temperature, and so on. The most important information was considered that which the operators attended to the most. This information was then chosen as input variables. Secondly, when conditions such as turbidity and water temperature change, the way in which operators respond was used to decide membership functions of input variables (Itō 1989: 945). The resulting rules are in the form of 'fuzzy IF-THEN rules', for instance: 'if the turbidity increases at a medium rate, then set the correction amount of flocculant injection at positive small; if the turbidity is at a medium level and the water temperature is not low, then set the correction amount at minus medium' (Yagishita et al. 1984: 600). Noteworthy is that the automatic controller that Itō designed did not act totally according to the control rules extracted from operators' knowledge. Rather, the automatic controller depended, first of all, upon a statistical model based on the data obtained from the past manual operations, which gave the relationship between injection rate and water quality. The 'correction amount' mentioned above, in the 'fuzzy IF-THEN rule', is defined in relation to the model. In other words, the operation of the controller was not model-free; the statistical model was used as the base line. Fuzzy control rules came into effect when the statistical model could not catch the delicate change of water quality during the particle sedimentation process (Yagishita et al. 1984: 599).

The field test of the prototype controller was carried out in the Toyoiwa water treatment plant in the city of Akita. The test and adjustment that ensued continued for three months, from October to December in 1983. After the test, fuzzy control rules (fuzzy implication rules as Itō called them) were adjusted against operation results by skilled operators. In the end, ten fuzzy control rules were finalized. The performance of the resulting fuzzy controller, as claimed by Itō, was comparable to what skilled operators were able to do. It thus satisfied the original goal of automating the chemical injection, and it is said that the ease of operation of the automatic controller ensured that there would be no performance variation between a veteran and a novice operator (Yagishita et al. 1984: 603-604).

However, the Toyoiwa water treatment plant, the test site, did not purchase the fuzzy controller.⁹¹ The actual operation of Fuji Electric's fuzzy controller was

⁹⁰ Itō interview.

⁹¹ As was the case for the automation of subway train control in the city of Sapporo, which will be

realized in a water treatment plant at Sagamihara city, Kanagawa prefecture, in 1986. As a result of some fine-tuning work, fourteen fuzzy control rules, instead of ten, were utilized for flocculants injection (Itō 1995: 104). After that, some ten water treatment plants, several of them in the Kanagawa prefecture adjacent to the Tokyo metropolis, implemented the automatic system made by Fuji Electric Co.⁹² Fuji Electric Co. later developed FRUITAX, the first general purpose fuzzy controller in Japan, by applying the experience obtained from building the fuzzy controller for water treatment plants, and put it on the market in 1985 (Itoh 1993: 141).

The Sendai Subway

As with the case of water treatment plants that utilize the fuzzy controller developed by Fuji Electric Co., the application of fuzzy control to the Sendai subway train was made possible by the promotion effort of Sugeno Michio in the late 1970s. His presentation of fuzzy control at a conference held by the Society of Instrument and Control Engineers (SICE) in 1979 attracted the attention of an engineer, Yasunobu Seiji, from the Systems Development Laboratory of Hitachi Ltd. Yasunobu had a master's degree from Kobe University in 1975, having studied control engineering with a specialization in distributed system control. After graduation, he was employed by Hitachi and was assigned to work on transportation systems, a field in which he himself was interested.

Yasunobu began his career in Hitachi at a time when subway systems were undergoing an early phase of full automation. In Japan, the second half of the 1970s saw the trend of the implementation of automatic train operation (ATO) systems on subways. According to Yasunobu, the automation of subway trains is more urgent than that of overground trains because there is no outside scenery, in addition to traffic signals, for subway train drivers to signpost the position of the trains, and it is more likely for them to get bored and sleepy in such a monotonous environment.⁹³ The first use of an ATO system in a subway in Japan was in the city of Sapporo, Hokkaido in 1976. That ATO system was developed by Hitachi, and Yasunobu

addressed later, that Toyoiwa water treatment did not purchase the fuzzy controller, according to Hirota, was because it would threaten the work of the human operators: 'issues of discharge of workers etc., and technology, are in different dimensions' (Hirota 1993a: 67)

⁹² Itō interview.

⁹³ Before ATO much subway has had ATC (Automatic Train Control) device on board. While ATC only applies automatic control to the braking system to avoid trains from colliding with each other, ATO controls the speeding of trains also and thus realizes a full automatic control – A driver (if there is one) of a train with ATO onboard only has to put a button for the train to move automatically (Umehara 2001: 190).

learned much about it through being assigned the job of tuning it to achieve better performance. One of the indexes of better performance was more energy savings – the importance of which derived from the fact that, at that time, Japan, as well as other parts of the world, was still under the impact of the first oil crisis. With the development of microprocessors in the 1970s, Yasunobu also substituted all of the old hardware of the ATO system in the subway of Sapporo with microprocessors, and made some other minor changes to it.⁹⁴

In 1979, Sugeno's presentation on fuzzy control gave Yasunobu an idea to the answer of how he could do new research on ATO systems. Working at Hitachi's research laboratory brought pressure on the young researcher to publish, and he found that substituting a fuzzy controller for the conventional PID (proportional-integral-derivative) controller in the extant ATO systems was a good idea for that purpose. The idea was approved by the manager Ihara Hirokazu and chief engineer Miyamoto Shōji of the department where Yasunobu worked:

They agreed and supported me. Leaving fuzzy research aside, I was a specialist in traditional control, I gave presentations in conferences, and my work was considered to meet the level of research. Since I was at a research institute, I could not help but to publish something. No matter it is on fuzzy or on ATO, I have to publish if I want to make it, or, it doesn't matter whether I want to make it, I have to publish. At that time fuzzy research was my personal interest.⁹⁵

The only injunction coming from Yasunobu's two immediate superiors, a concern that stemmed from a commercial rationale, was that patents on the new configuration would have to be secured before the publication of any paper on it.⁹⁶

How was fuzzy logic used to drive the train? As psychological analysis of the skill of train drivers shows, goal-directedness is one important feature of that skill (Branton 1978). The enactment of drivers' skill resides to a large extent in the ability to predict how present action affects the achievement of goals that have been set up in the first place. Train drivers have to continuously modify their actions in a predictive manner so that the consequences of their action finally coincide with the once-future goals. For train drivers, 'the future determines the present' (Branton 1978: 186). Yasunobu tried to utilize fuzzy control rules to imitate the predictive ability that is present in train driving. In order to do this, he sought out experiential rules of

⁹⁴ Yasunobu interview.

⁹⁵ Yasunobu interview.

⁹⁶ Yasunobu interview.

thumb that are applied by train operators when they drive. Drivers' plans of action were divided into two main categories, according to their functions, couched in machine-like terms: constant speed control (CSC) which 'starts the train and keeps the train speed below the specified one', and train automatic stop control (TASC) which 'regulates a train speed in order to stop the train at a target position of a station' (Yasunobu and Miyamoto 1985: 8). Considering what train drivers actually do when driving the train, the two functions can be realized by abiding by several rules. For the function of stop control for instance, as Yasunobu and his colleagues note, a driver observes the following rules after passing the point which indicates that action should be taken for a stop at the next station: (1) in consideration of riding comfort, if it can be predicted that the train will be able to stop at the assigned point, then keep the brake notch from changing; (2) for riding comfort and a reduction in running time, apply brake slightly; (3) for stop accuracy, if it can be predicted that the train will not stop accurately, then apply a suitable brake notch (Yasunobu, Miyamoto, and Ihara 1983: 24).

Yasunobu used such 'rules' based on human operators' knowledge of train driving to construct twenty four fuzzy control rules (Matsumoto 1993: 265), and called the method 'predictive fuzzy control'. Simulation using this method showed that the train stopped more accurately. Moreover, due to less changes of brake notch, compared to traditional ATO systems, the fuzzy ATO system saves five to fourteen percent energy according to different simulation and operational results (Yasunobu and Miyamoto 1985).⁹⁷

With the simulation results, Hitachi proposed to the Transportation Bureau of Sendai city the application of fuzzy ATO to its newly planned subway system in 1983. According to Yasunobu, with the caveat offered by the people in charge of the project in Hitachi themselves that, if the performance of fuzzy ATO should fall below expectations then they would go back to the old ATO system which had been proved in Sapporo city, the Bureau finally agreed with the proposal to apply a new technology which was not widely known in Japan at that time.⁹⁸

For the rules of predictive fuzzy control, several goals were taken as important in evaluating the performance of the fuzzy ATO system. These 'performance indexes' include safety (defined as keeping the speed of the train below the speed limit), riding comfort (a frequent change of the notch is seen as detrimental to riding comfort),⁹⁹ traceability (the ability to keep the speed of the train satisfactorily close

⁹⁷ Tashiro interview.

⁹⁸ Yasunobu interview.

⁹⁹ This definition of riding comfort was later criticized. See below.

to the target speed), energy consumption, running time, and stop accuracy. Among these six performance indexes, according to Yasunobu and colleagues, riding comfort, stop accuracy, and energy consumption are difficult to achieve in a traditional ATO system (Yasunobu et al. 1984: 605-608; Yasunobu and Miyamoto 1985: 7-9). Among these three indexes, stop accuracy is the most important criteria, so important as to serve as the criteria of the acceptance test administered by the Ministry of Transport (Unyushō).¹⁰⁰ Why was stop accuracy so important? As a densely populated country, Japan has developed practices for the efficient use of space on its rail station platforms. In addition to signs for people with disabilities, there are usually signs on the platforms which show the position of train doors so that passengers can queue into lines in the right positions.¹⁰¹ These signs in effect serve to demarcate the space of the platforms in an efficient way so that the crowd-flow stepping down from the trains can be moved out of the trains quickly, and passengers queuing on the platforms can quickly be moved onto the trains. They work better if trains stop precisely at the assigned positions. It makes a difference for crowd-flow control if a train stops some fifty centimetres away from the assigned position at the station, especially in such a large, densely populated city as Tokyo – although Sendai is at best a medium-sized city in Japan.¹⁰²

The construction work of the Sendai subway began in 1981. In 1985, two years before its operation, a series of tests of a prototype train was conducted on a five hundred meter test rail. After the realization of the fuzzy ATO system in Sendai subway, Hitachi also secured contracts for fuzzy ATO systems for subways in the cities of Tokyo, Nagoya, Kyoto, Osaka, Kobe, and Fukuoka. Another company, Mitsubishi, also sold its fuzzy ATO system for a subway line in Tokyo.¹⁰³

The fuzzy ATO system of the Sendai subway trains received extensive coverage in articles in newspapers, magazines, trade journals, and books, even before the subway was put into operation on 15 July, 1987. Almost without exception, riding comfort was emphasized and was attributed to a close similarity that the fuzzy ATO system bears to a human driver in handling the speed and brake notches. For example, a book on the subway of Japan states that ‘by using the new technology fuzzy control, the ATO system drives as smoothly as a human driver, and brings excellent riding comfort as a result of smooth acceleration and deceleration’ (Wakuda 1987: 189). In

¹⁰⁰ The Ministry of Transport had merged into the Ministry of Land, Infrastructure and Transport, (Kokudokōtsūshō) in 2001.

¹⁰¹ Yasunobu interview.

¹⁰² The Sendai subway was put into operation in 1987. The population of the Sendai city was about 700,000 in 1985 and 920,000 in 1990 (<http://www.city.sendai.jp/kikaku/seisaku/toukei/toukeijihou/03.html>).

¹⁰³ Tashiro interview.

addition to riding comfort, two characteristics that were deemed to result from the contribution of fuzzy logic also received mention in publications – faster running time and, as we have seen, less energy consumption.

However, whether the fuzzy ATO system could simultaneously improve riding comfort, and decrease running time as well as energy consumption, was questioned by an engineer in the U.S. Working for National Semiconductor at the time when he published articles questioning the efficacy of fuzzy logic, Robert Pease might be seen as an obstinate detractor of fuzzy logic. A series of his articles appeared in the magazine *Electronic Design* from 1993. His criticism of the fuzzy ATO system focuses on the problematic interrelationship between riding comfort, running time, and energy consumption, as claimed by the Hitachi engineers. Basically, Pease argues that, in general, for systems that control vehicles, faster running time means more energy consumption and less riding comfort; if riding comfort is the primary goal, then either the vehicle under control has to be run at a slower speed, or it must waste more energy if a faster running time is also a goal – because, in order to shorten running time, the vehicle has to be run at a higher speed. Therefore, Pease infers that the relationship between fewer change of notches and greater riding comfort – the definition assumed by the Hitachi engineers so as to evaluate riding comfort (a rather subjective feeling) in terms of calculable numbers – is wrong. ‘Unfortunately, the passengers weren’t consulted! Coming into the station with the brakes on hard and leaving them on until the train stops is NOT what riders consider comfortable, even though technically the number of changes of brake setting (brake notch) was small’, so he said (Pease 1994, original emphasis).

This criticism, however, seems to result from a lack of information. The English article that Pease refers to does not give any information on what riding comfort actually means, despite a mention of the relationship between fewer change of notches and greater riding comfort (Yasunobu and Miyamoto 1985). Common sensically, for people in general, it is not unreasonable to assume that riding comfort is decided by the way in which a train driver manages speed and brake notches; avoiding abrupt change of notches yields good riding comfort. This is exactly how Pease thought of riding comfort. However, in a Japanese article written by the Hitachi engineers, riding comfort is clearly defined in terms of the vibration in the vertical direction, and the relationship between riding comfort and the vibration in the longitudinal direction (i.e., the direction to which the train proceeds) is claimed to be unclear (and thus is not taken into consideration) (Yasunobu et al. 1984: 608). Although in stating this the Hitachi engineers referred to a book published in 1960 – more than twenty year before their article appeared – they seemed to conform to a

technical custom in the railway industry: in considering riding comfort, longitudinal vibration is often disregarded (Kubota 2003: 249).

In their Japanese article, the Hitachi engineers stated that a frequent change of notches results in 'high frequency shock' that deteriorates riding comfort (Yasunobu et al. 1984: 608). The difference between Pease's idea of riding comfort which is predicated on the effect of the force of inertia on passengers, and Hitachi engineers' more 'technical' definition of riding comfort that focuses on vibrations in the vertical direction can be seen. The point is made more clearly by a comparison between fuzzy ATO and traditional ATO. According to the explanation of Tashiro Ryoji, a chartered engineer who participated in the acceptance tests of the Sendai subway system on behalf of the Transportation Bureau of Sendai city, traditional ATO systems achieve stop accuracy (by a constant change of notches) at the expense of riding comfort. Moreover, they respond poorly to disturbances arising from the train running through places such as slopes and curves in the train route, and this results in poor riding comfort (Anonymous 1988: 4). Ironically, greater riding comfort, one of the most prominent claimed advantages of fuzzy ATO over traditional ATO systems, was not a critical item in the acceptance test. In fact, Yasunobu admits that compared to stop accuracy, riding comfort is only a secondary goal for regulatory bodies: 'riding comfort serves as a symbol of good control in terms of testing results, a sales point, but it is not a criterion; it is not that we can't do without it'.¹⁰⁴ Although the fuzzy ATO was later known in the railway industry largely for its extraordinary level of stop accuracy (Zhang and Su 2002: 137), the way that fuzzy ATO controls the train 'softly' in a similar manner to a human driver to achieve greater riding comfort (Anonymous 1988: 2), was greatly emphasized around the time when the Sendai subway went into operation.

For any automated system to be successfully introduced, people whose work will be replaced by it have to be dealt with first. The ATO system for the Sapporo subway, a predecessor of the fuzzy ATO system in terms of the Hitachi product line, had undergone testing and even implementation phases, but was eventually abolished due to the resistance of the labour union. In the Sapporo subway, there was a driver and a conductor for every train. The transportation bureau once tried to replace the conductor with the newly developed ATO system – which, if successful would have resulted in the so-called 'one-man system' – but failed. However, the Sendai transportation bureau successfully materialized the 'one-man system', i.e., a driver and no conductor for a train, because, unlike in the case of Sapporo city in which the automation project began after the operation of its subway, the Sendai subway

¹⁰⁴ Yasunobu interview.

system was designed as having no conductor in the first place. Even though there is no conductor, a driver is still present in the Sendai subway system because of a regulation rule which maintains that a driver has to be present in every subway train for safety purposes.¹⁰⁵

Therefore, the issue of ‘riding comfort’ of the Sendai subway system is made even more complicated by this regulation. Even if a subway train can be fully automated and controlled remotely, a driver is always present. Furthermore, in order to keep the driving skill of drivers from deteriorating, drivers on the Sendai subway have to drive manually once in every five runs.¹⁰⁶ Except for those who ride so frequently as to tell the difference between an automatically and a manually controlled run, only when one observes the motion of a driver can they be certain whether the train is run by the fuzzy ATO system or by the driver.

Another negative comment on the Sendai subway came from within Japan. This time, the concern was not with the efficacy of the fuzzy ATO system per se, but how the design method should be named. Ikeda Masao, a control theorist, argued in an article in 1990 that Yasunobu’s method should not be called ‘fuzzy control’. Ikeda knew Yasunobu in person because in the early 1970s, Ikeda was for a time working as a research associate in a laboratory next to where Yasunobu was working as a graduate student at Kobei University. Ikeda disagreed with Yasunobu’s claim that the latter’s method could be called predictive ‘fuzzy control’. Instead, he argued that in order for the train to stop at the assigned spot, a predictive model to which weights of various performances indexes can be simulated so that a suitable control command can be chosen, has to be utilized. In other words, Ikeda saw it as a multi-purpose decision problem, and claimed that the method that underlay the fuzzy ATO system was in fact a combination of model-based predictive control, and decision making using fuzzy sets. What Ikeda emphasized is that the utilization of a model is necessary for controlling the subway train. In the case of the Sendai subway, he admitted that fuzzy decision making (the term he preferred compared to Yasunobu’s predictive ‘fuzzy control’) works well, but that this should not be attributed to fuzzy control; rather, it is the accuracy of prediction of the model used that plays the most important role (Ikeda 1990: 70-71). In fact, the use of a partial model for predictive evaluation of fuzzy control commands has been stated by Miyamoto Shōji, the chief engineer in Yasunobu’s department, in an article on fuzzy control (Miyamoto 1986: 460). Whereas it may look trivial in arguing how a method should be rightly named, at the heart of Ikeda’s questioning of the efficacy of fuzzy ATO system is the proper

¹⁰⁵ Tashiro interview.

¹⁰⁶ Tashiro interview.

attribution of the indispensability of a mathematical model.

From Private to Public Demonstration

The fuzzy controller by Fuji Electric for water treatment plants and the fuzzy ATO system by Hitachi for the Sendai subway have similar developmental patterns. Both have utilized skilled operators' working knowledge to construct fuzzy control rules; these control rules were first tested by simulation, and followed by field tests. Both have used partial models to assist fuzzy control rules. However, although both are civil projects, their levels of accessibility differ quite sharply. Whereas it is easy for one to take a ride on the Sendai subway, it is difficult to get into the Sagami-hara water treatment plant. Although as we have seen, it is still difficult to judge the efficacy of the fuzzy ATO system of the Sendai subway even if one takes a ride on it, at least it is more tangible. However, without a comparable level of skill to the operators in the water treatment plant in Sagami-hara city and drivers of the Sendai subway, a general, interested reader can only judge the cases by resorting to the simulation data shown in the journal articles reporting the two cases. Moreover, Robert Pease's complaint seems to make the case look even worse. In order to compare with other subway systems the 'smoothness' of the Sendai subway by considering beyond mere simulation data, Pease asked the Hitachi engineers whether there are other papers published after the operation of the Sendai subway with more data on it. However, he received a negative answer; all he had was an English paper by Yasunobu and Miyamoto published in 1985 (Pease 1994).¹⁰⁷ To check the claims made in the papers, an interested reader can only resort to the limited information (at least from Robert Pease's point of view) that are provided in a small number of papers.

With the Sendai subway, although publicly accessible, it is still difficult to evaluate with regard to claims of the merits of fuzzy logic, even if riding on it. These two cases can be seen not as public, but 'private' demonstrations of fuzzy control. The oxymoron is employed to point to the fact that, if they are to demonstrate the efficacy of fuzzy control, they are only half-way to the goal: those who are interested in the issue either do not have access to the Sagami-hara water treatment plant, or

¹⁰⁷ Yasunobu and Miyamoto (1985) is basically a slightly modified version of their former paper. According to my interview with Yasunobu regarding the issue of paper publication, he states that fuzzy ATO system as a research topic has come to an end after he, Miyamoto and Ihara published a paper on it in 1983 (Yasunobu, Miyamoto, and Ihara 1983). After then Yasunobu began to undertake other research such as application of fuzzy control to other systems.

have difficulty in evaluating the latter of them.¹⁰⁸ This is one of the quandaries of demonstration; it is more so when results were only partially communicated by written reports, as Robert Pease's complaint shows.

Right after the Sendai subway was put into operation, a demonstration of a fuzzy controller that can be said to be more truly 'public' came into view. It was far more accessible to the audience, with its constructed control rules more understandable and far less dependent on skilled operators. The small scale demonstration also gave the audience a chance to challenge it immediately, or to replicate it later in their own laboratories. The demonstration attracted the attention of not only practical engineers but also some control theorists, and prompted the latter to put forward a counter-argument against fuzzy control. Like Ikeda's argument about the fuzzy ATO system, the counter-argument similarly states the priority of the use of models in controller design, but this time more emphatically.

A Controversy over the Inverted Pendulum Demonstration

In a position paper that appeared in a special issue of *Fuzzy Sets and Systems*, the flagship journal for fuzzy theory, to celebrate the fortieth anniversary of Lotfi Zadeh's paper 'Fuzzy Sets', the following comments are found:

Although fuzzy control was initially introduced as a model-free control design method based on the knowledge of a human operator, current research is almost exclusively devoted to model-based fuzzy control methods that can guarantee stability and robustness of the closed-loop system....

The present situation in the area of fuzzy systems and control is characterized by a certain mismatch between the main motivation of readability (using understandable rules, computing with words) and the use of mathematically involved and rather non-transparent techniques to ensure robust performance, in direct analogy with mainstream (nonlinear) control (Sala et al. 2005: 433-434)

While the mismatch results from a gradual shift of the focus of scholarly efforts, made by international fuzzy theory research communities over more than three decades since fuzzy control was first carried out in the early 1970s, this shift is epitomized by the 'demo' on an inverted pendulum and the controversy over it that ensued in Japan.

¹⁰⁸ For a discussion on the distinction between experiments and demonstrations, see Collins (1988).

As well as about fifty sessions, which included more than two hundred typical conference presentations (Yamakawa and Hirota 1989: 137), the second congress of the International Fuzzy Systems Association (IFSA) held in Tokyo from 20 to 25 July, 1987 saw much attention given to 'special demonstration' sessions. In these sessions, eleven real fuzzy systems were presented, including, for instance, experimental laboratory artefacts, such as a model car controlled by oral commands and a ping-pong game playing robotic arm, and controllers for industrial or domestic use made by well-known manufacturers Fujitsu, Hitachi, and Matsushita (Mukaïdono 1988: 65-71). Among these, however, a device that would not normally have aroused too much notice unexpectedly performed amazing feats at the request of some demanding viewers. The device was later not only shown repeatedly in standardized or even expanded ways, but also became a focal point of the controversy between fuzzy logic researchers and control theorists.

The device is an inverted pendulum linked to a 'high-speed fuzzy controller hardware system', as the designer Yamakawa Takeshi, then assistant professor in the department of electrical engineering and computer science at Kumamoto University, Kyushu, called it (Yamakawa 1989: 161).

In control engineering, an inverted pendulum is a light metal pole attached to a cart by a hinge, which can only fall either to the left or right. The cart is put on a one dimensional rail. The pole is kept upright by moving the cart according to the output of the controller, which monitors as inputs the angular position and angular velocity of the pole and the linear position and velocity of the cart. By experience, it is easily known that, when the pole is falling to the left, the cart should be moved to the left in order to keep the pole from falling further. Yamakawa equipped the controller with this kind of experiential knowledge, but only the angle and angular velocity were monitored as inputs. His application of experiential knowledge was as follows: if we define θ to be the angle between the pole and the vertical line, y the position of the cart, and θ' , y' the angular velocity of the pole and the velocity of the cart respectively; then if θ is positive and small, and θ' is positive and small, which means the pole is about to fall down in the positive direction, then let y' be positive and small to counteract that motion; if θ is positive and small, and θ' is negative and small, which means the pole is about to go back to the upright position, then let y' be about zero, i.e., do nothing to it. Yamakawa used a total of seven such 'fuzzy inference rules' as control rules. Each fuzzy inference rule has a corresponding circuit board ('rule board' as Yamakawa called it) for its operation (Yamakawa 1989: 164). The block diagram of the demonstration device is shown below:

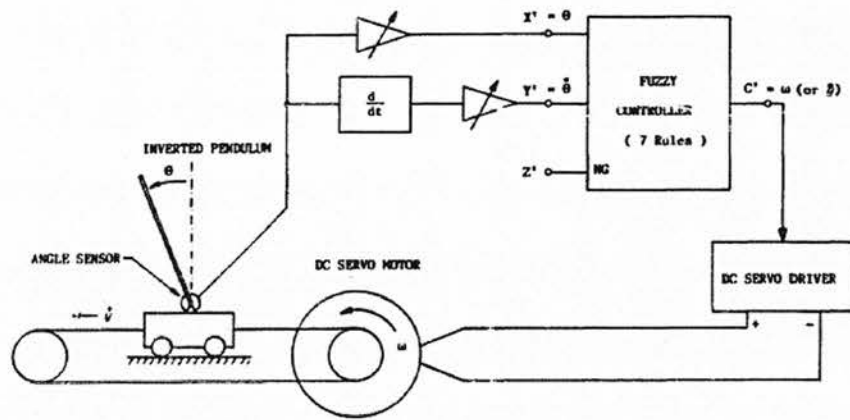


Fig. 4.1 Block diagram of Yamakawa's controller (Yamakawa 1989: 178).

In the real demonstration, the controller was not only said to stabilize the inverted pendulum, but more than that; by the request of some in the audience, the aluminium pole Yamakawa used was substituted by a flower (the mass of which is less evenly distributed compared to a metal pole), and it was still kept upright (Yamakawa 1988: 141-142; 1989: 179). The other unintended demonstration was to remove a 'rule board' of the system, also by the request of a conference participant, in order to see how the pole would fall down. It was reported that, contrary to the participant's and also Yamakawa's expectations, the pole did not fall down even under such a severe condition (Yamakawa 1988: 143-144).

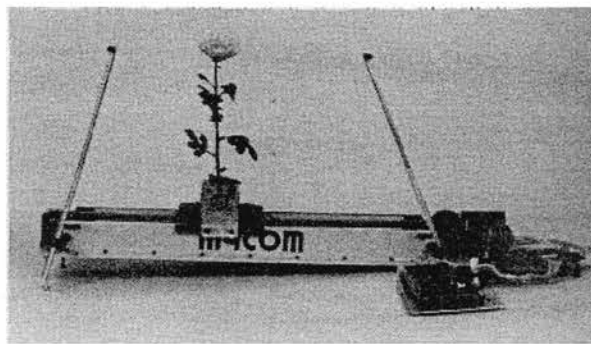


Fig. 4.2 A demonstration similar to Yamakawa's shown by a controller manufacturer in 1988 (Arikawa 1989: 50)

These demonstrations were claimed to show the superiority of fuzzy logic control: the hardware makes possible one million fuzzy inferences per second and thus, the response time is about a hundred times shorter than that of a conventional

controller. They demonstrated robustness (as the case of the flower shows) and ease of controller design (Schwartz & Klir 1992: 32-34), and it was claimed that fuzzy logic control can be applied, for instance, to attitude control of space booster rockets and satellites, automatic aircraft landing system, aircraft and ship cabin stabilization, pattern recognition, biped locomotion, stabilization of nuclear fuel rods etc. (Yamakawa 1988: 148-149). Some of these characteristics attracted engineers' attention (McNeill and Freiburger 1993: 166-167). However, there were some sceptical control theorists who questioned, not the claimed technical advantages *per se*, but what 'the pole is kept upright' means. For them, seeing is not necessarily believing.

Why was the inverted pendulum chosen as a device for the demonstrations?¹⁰⁹ According to control theorist Kimura Hidenori, in Japan, the use of the inverted pendulum in control engineering can be traced to a two-wheel cart, powered by an electric motor, made by professor of applied physics Isobe Takashi and students at Tokyo University in the early 1960s. Isobe attached two springs to the base of the cart. When touching the ground, they served as switches for the electric motor and made the armature of the motor stop before rotating in the other direction. The springs thus made the cart move to and fro (Isobe 1963). Interestingly enough, Isobe's version was also used for public demonstration: his was demonstrated in a yearly university festival at the campus (Kimura 2002a: 65).

In the inverted pendulum, the inverted position is the inherently unstable equilibrium point (Mori et al. 1976). With unstable characteristics but relatively manageable dynamics, inverted pendulums have been widely used for teaching controller design, and as models for biped walking robots and the launching of rockets.¹¹⁰ In colleges and universities, it is one of the basic devices in engineering laboratories, known by students in control engineering as both a model problem in textbooks and a recurrent theme in journal articles. More complicated versions include a double inverted pendulum, in which one pole is put atop another, and even a triple inverted pendulum. Various forms of combination and wide applicability have made it a fascinating problem to mavericks as well as veterans in control engineering. It is of little wonder that in Japan, where research in humanoid robots has been so common, this device is widely known.

¹⁰⁹ Certain forms of inverted pendulum have been used as seismometer since the early 1840s (Dewey and Byerly 1969). More relevant to the issue presented here, Russian physicist Piotr Leonidovich Kapitza did some theoretical and experimental work on the stability of the inverted pendulum in the early 1950s (Shoenberg 1985: 359-360).

¹¹⁰ Shin interview.

Beginning in 1989, when the demonstrations were still being performed, two university professors, Araki Mitsuhiro and Ikeda Masao, published a series of Japanese articles in journals and conference proceedings, analysing the inverted pendulum balanced by Yamakawa's fuzzy controller, as well as fuzzy control in general. Both were control theorists, then in their mid forties, and had been active in international academic communities. Their starting point concerned the same issue: whether or not the inverted pendulum actually achieved stability in the demonstrations.

The issue of stability has a fairly long history in control engineering. It can even be traced to the works of Christiaan Huygens (1629-1695) and Robert Hooke (1635-1703) in the second half of the seventeenth century (Fuller 1976). In the history of control engineering, as commonly perceived, analyses of stability were mainly linked to the Watt governors that were widely used to regulate the speed of water wheels and steam engines in Europe from the eighteenth century onwards, which had a well-known defect of 'hunting' (speed fluctuation). It was in the nineteenth century, when governors were utilized by scientists for their specific purposes, that the dynamics of systems and the issue of stability were explored. For example, George Biddel Airy (1801-1892) used the governor to regulate telescopes for astronomical observations, and James Clerk Maxwell (1831-1879) employed it for measuring the ohm. Through inquiring into the reaction of the governor to disturbances, they touched upon the issue of instability: Maxwell defined it as when the governor's 'output (the controlled speed) will either increase continuously or enter into an oscillation of growing amplitude' (Mayr 1971: 428). Airy had already shown, according to Fuller, that 'the instability of the system could be accounted for by consideration of the differential equations of the system' (Fuller 1976: 115), and Maxwell, by linearizing the equations at issue, demonstrated that the unstable situation 'is mathematically equivalent to the condition that all possible [real] roots, and all possible parts of the impossible [imaginary] roots, of a certain equation shall be negative' (Mayr 1971: 428). However, Maxwell did not give a proof of how the condition was obtained; it was E. J. Routh (1831-1907), Maxwell's fellow student at Cambridge University who did the follow-up work and solved the 1877 Adam Prize problem 'The Criterion of Dynamic Stability'. Similar inquiry in continental Europe was performed by Adolph Hurwitz (1859-1919), with a result that was shown to be equivalent to Routh's work (Mayr 1971: 443-444).

Later on, in the 1920s and 1930s, issues of stability took the form of feedback

amplifiers in electric circuits. They were analyzed by engineers at Bell Labs, U.S., for long-distance transmission of telephone signals. In contrast to the definition of stability in mechanical systems, Harry Nyquist (1889-1976) defined stability in terms of whether disturbances in a circuit vanished after a limited time period, and developed criterion for stability which could be visualized in a two-dimensional diagram. Hendrik W. Bode (1905-1982) also created a graphical technique in a more refined way to discuss stability (Mindell 2002: 126). It was during World War II that engineers realized feedback control systems were essentially the same, no matter whether the systems at issue were mechanical or electrical in form (Mindell 2002: 227-230). Nyquist's method is said to denote the completion of stability analysis on linear control systems (Itō 1984: 34). On the other hand, stability analysis of nonlinear systems began from the work of Russian mathematician Aleksandr M. Lyapunov (1857-1918) in the 1890s, and several engineering techniques including graphical methods were developed (Itō 1984).

The importance of stability analysis in current control engineering can be seen in the way that the history of control engineering is typically told. Take a widely-used college textbook, for example; among the twenty-one figures it lists in the chronological history of feedback control, the inventors of certain devices excluded,¹¹¹ seven out of fifteen are listed largely because of their direct contribution to the stability analysis of control systems (Franklin et al. 2002).¹¹² In tutorials for control engineering, we find section titles like these: 'check stability first' and 'after stability, performance is everything' (Bernstein 1997: 96-97). The priority and the importance can easily be seen.

But critical as it might be for contemporary control engineering, a systematic treatment of stability by practising engineers was made possible only after 'a coherent subject of control systems' had taken shape in the 1930s and automatic control as a discipline had emerged during and after World War II (Bennett 1979: 3). In the nineteenth century, theoretical work was limited to small circles of scientists and engineers, and design of feedback systems had been empirical for a hundred and fifty years before 1940 (Bennett 1979: 3).

This development can be seen as the 'scientification' of control engineering, one among many engineering practices that underwent similar processes. Engineering, as

¹¹¹ There are six such inventors: Drebbel (incubator, 1624), Watt (flyball governor, 1728), Sperry (gyroscope and autopilot, 1910), Black (feedback electronic amplifier, 1927), Bush (differential analyzer, 1927), and Hoff (microprocessor, 1969).

¹¹² The seven figures and their innovations are: Maxwell, flyball stability analysis in 1868; Routh, stability in 1877; Lyapunov, nonlinear stability in 1890; Nyquist, Nyquist stability criterion in 1932; Bode, frequency response methods in 1938; Nichols, Nichols chart in 1947; and Evans, Root locus in 1948.

a systematic exploitation of resources for practical, technological ends, has evolved in various forms across different countries since the nineteenth century – a fact reflected in the contrasting emphasis on either the theoretical or practical side in engineering education (Kranakis 1989; McCormick 2000: Chap. 1). However, since World War II, engineering has undergone scientification and become more theoretically-oriented even in the U.S., a country that had a practical tradition before then (Seely 1993: 367).¹¹³

It is concern with the issue of stability that led to the scientification of control engineering. As might be the case elsewhere, scientification can be identified by the employment of mathematical reasoning (Schaffer 2004: 87-98) – mathematical modelling in this case. Expressed usually in a group of differential equations, a mathematical model represents the system under consideration by parameters that are of interest. A model offers a characterization of the relationships between parameters – thus behaviours of the system at issue, under certain intended conditions, can be described. Moreover, the design process often involves an analysis of the model, to search for conditions under which certain criteria of stability can be obtained, which means that certain relationships between parameters should be maintained. Mathematical analysis of a model thus offers a more or less definite guide to design. Mathematical techniques involved in such a method of design contrast sharply to the former trial-and-error, experienced-based tradition of controller design. With artificial systems becoming more and more complex in the modern environment, the mathematical techniques involved have become more abstruse.

In fact, the development of graphical techniques in the 1920s and 1930s can be seen to have allowed engineers ‘to move them away from having to deal with the mathematics directly’. By transforming mathematical descriptions of systems (in differential equations) to a concrete ‘non-mathematical engineering language’ with graphical techniques, practising engineers can achieve a grasp of the behaviour of systems under consideration with simpler manipulations (Bissell 2004; Bissell and Dillon 2000: 10).

These manipulations, as indispensable procedures of controller design to meet certain specifications, are facilitated by the models engineers use. In general, there are two kinds of modelling in control engineering. One is physical modelling, which

¹¹³ Scientification has resulted in the formation of ‘engineering sciences’ as historians of technology call them. Although there has been dispute about whether a drastic transformation really took place in engineering (Mayr 1976), a historical trend of scientification in engineering seems to be undeniable. For discussions on the pertinence of ‘engineering science’, see Channell (1988), Fore (1988), and Layton (1988).

aims to ‘derive a mathematical model expressed in terms of physical variables such as mass, friction, voltage, current etc.’ by using ‘the assumptions and implications of some scientific or other laws’ (Bissell and Dillon 2000: 5). Balance of forces and the law of conservation of energy are two examples of what might be utilized in this model building process. The equations Maxwell derived to describe the motion of a governor fell in this category. Modelling of the other kind is ‘system identification’, which is done by input-output testing. Although this modelling approach ‘is much less widely known outside engineering circles’ (Bissell and Dillon 2000: 5), the term used for the concerned system, characterized by how it is treated – as a ‘black box’ – is a well known metaphor in science and technology studies. These two modelling approaches are usually combined as iterative procedures in the designing processes. Not only are models simplified in different stages of design for ease of handling, but various mathematical and graphical techniques have been developed to facilitate engineers’ knowledge of system behaviour. Simplification does not imply there is no place for mathematics, however. On the contrary, it reflects the difficulties of dealing with a real system so that mathematics as used by mathematicians has to be transformed to a practical language of modelling, pertinent to engineering concerns. As Chris Bissell and Chris Dillon argue:

Models are starting points for conversations among practitioners about the systems they are claimed to represent. Models have to be mediated and negotiated within a community of practice to make any sense. As part of their development, engineers learn how to talk about their models; they learn what stories to tell about them and to recognize what sorts of conversations are legitimate (Bissell and Dillon 2000: 6).

Stability, then, is a crucial element of this common language of modelling.

Sceptics’ Accounts

The above described common language was shared by the two university professors, Araki and Ikeda, in their questioning of Yamakawa’s demonstrations. Their interest for an inquiry into the demonstrations was stimulated, according to Ikeda, because a company interested in fuzzy control, with which Araki had a working relationship, failed to reproduce Yamakawa’s result.¹¹⁴ Both of their analyses of Yamakawa’s device started by firstly listing the equations of motion of

¹¹⁴ Email to author from Ikeda, 25 Jul 2006.

the inverted pendulum expressed in a group of two differential equations, which have been widely known in textbooks (Ikeda 1989: 237):

$$\begin{aligned}(M + m)\ddot{x} + m\ell\ddot{\theta}\cos\theta &= au - v\dot{x} + m\ell\dot{\theta}^2\sin\theta \\ (J + m\ell^2)\ddot{\theta} + m\ell\ddot{x}\cos\theta &= mg\ell\sin\theta - \mu\dot{\theta}\end{aligned}$$

Where M : mass of the cart

m : mass of the pole

ℓ : distance between hinge and centre of mass of the pole

v : coefficient of viscous friction between cart and rail

g : acceleration of gravity

x : position of the cart

θ : angle between the pole to the vertical line

J : moment of inertia of the pole

μ : coefficient of viscous friction between hinge and cart

a : ratio of force that the cart gets from motor to output voltage

u : output voltage

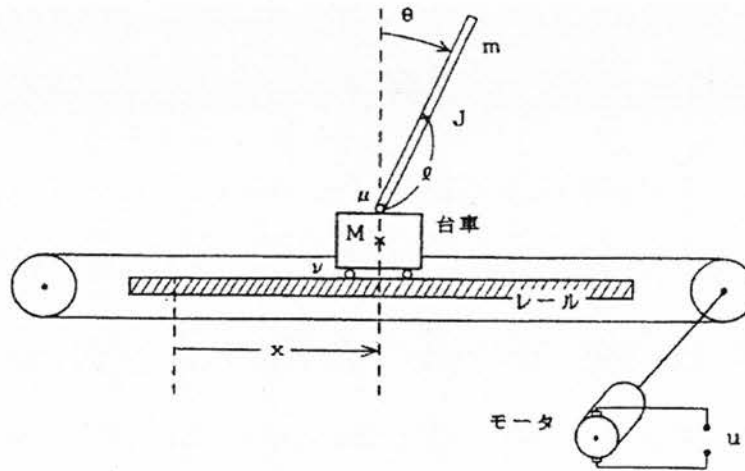


Fig. 4.3 Ikeda's graphical expression of the system (Ikeda 1989: 237)

Then at Kobe University, Ikeda showed, by mathematical analysis, that the cart being static is a necessary condition of the pendulum being stabilized; and therefore it is not possible to stabilize the pendulum only by monitoring angle and angular velocity of the pole, as Yamakawa did, without the cart's velocity being one of the monitored inputs. Since, in Yamakawa's demonstrations, the cart is moving back and forth when the pendulum is kept upright, it is not in the stable position; and what

makes it look stable is just illusory (Ikeda 1989; 1990).

From a slightly different perspective, Araki, who has been at Kyoto University since his student years, substituted (in a simulation) a circular rail for the straight rail used in Yamakawa's demonstrations. He showed that, by extending the rail length (the cart of Yamakawa's demonstrations moves back and forth on a rail of about a meter in length) and choosing suitable values for the parameters, the pendulum will become unstable and will eventually fall down when the cart moves some thirty meters away from the origin. One of the causes of falling-down is the friction between the cart and the rail and between the pendulum and the cart (Jang and Araki 1990).

Ikeda and Araki have been interested in the stability analysis of control systems from the early days of their academic careers (Araki 1989: 34),¹¹⁵ and their analyses, as described above, were familiar ones they have repeated countless times. For them Yamakawa's demonstrations represented the stability problem of nonlinear systems (Araki 1989; Ikeda 1990). With regards to the demonstrations, what interested them was not something a fuzzy controller could do (the feats of balancing a flower for example), but the why and how it could do so (the condition of it being stabilized). And the tool for such an inquiry was mathematical analysis of differential equations.

Both of them were participants in a small research group of Japanese control theorists, organized under the lead of Prof. Kimura Hidenori. It was in Budapest in 1984, at the ninth triennial world congress of the IFAC (International Federation of Automatic Control), the most highly regarded international society of control engineering, that several Japanese participants proposed this type of gathering, in order to advance research in control theory.¹¹⁶ As an independent gathering, it received no funds until much later, when it took funds from the Ministry of Education (*Monbushyō*), and it lasted for more than ten years. It was succeeded by the research group for theory of control systems (Katayama et al. 2001: 33).¹¹⁷ The claimed purpose of the research group, 'to pride ourselves on Japan's control theory' (Kimura 2002b: 61) echoes well a contemporary comment on the state of affairs on control engineering in Japan by several control theorists, Kimura being the youngest one among them: 'If we are asked whether Japanese control theory has made some "fundamental" contributions, many of us will answer negatively' (Kitamori et al.

¹¹⁵ Ikeda interview.

¹¹⁶ Kimura received at the congress the *Automatica* Paper Prize Award, which is given to three authors of their respective paper published in the journal *Automatica* for every three years. Kimura assumed leadership among other would-be members of the research group because of winning the prestigious prize. Kimura interview.

¹¹⁷ Ikeda interview; Kimura interview.

1984: 8). This comment throws into sharp relief the anxiety of the control theorists' circle, given that Japan had followed quickly the development of control theory from abroad, except for a short lag right after World War II due to its occupation by the Allied Powers (Kitamori et al. 1984: 6; Suda 1996: 35).

These younger Japanese control theorists cared about stability no less than their international peers. As Kimura explains, '[E]ven if all components are stable, instability can be generated if they are in a loop. Feedback is the source of instability, and we use feedback in order to control, so we always must be very careful to keep stability'.¹¹⁸ The concern for stability is not merely an indoctrinated tradition of theoretical interest; it is the inevitable trade-off of the aim to control. It derives not only from the issue of performance in designers' minds, but also from issues of safety. Thus, the question Jang and Araki ask in the opening paragraph of one of Araki's commentary articles: 'is it really all right to get fuzzy controllers applied in industry as there is no explicit guarantee on stability and performance?' (Jang and Araki 1990: 45). These control theorists maintain that 'if the system is not stable, it cannot be safe'; 'stability does not guarantee safety, but safety requires stability'.¹¹⁹ For them, this critical requirement can and should be satisfied through a mathematical approach.

The (Non-)Controversy: Anyone Can Build a Model

In this approach, models expressed in mathematical equations – the equations of motion of the inverted pendulum shown above as an example – are the starting point. The equations by which models are represented provide a mathematical realm where criteria of stability can be checked. This epistemological issue underlies these Japanese control theorists' criticisms of fuzzy control:

[A]s control theorists, we promote model-based control. The model is very important. Based on a model, we can design control systems rationally. But those fuzzy people neglect the modelling part, that's the main reason (why we criticize). So if we don't know the model, how can we guarantee stability, the most important factor in control?¹²⁰

I found that fuzzy control is very heuristic, in essence, and *there is no, no proof, so*

¹¹⁸ Kimura interview.

¹¹⁹ Ikeda interview; Kimura interview.

¹²⁰ Kimura interview.

that's why.... it may work, but there is no guarantee....It cannot catch the dynamics of the plant (emphasis mine).¹²¹

Araki's and Ikeda's articles on Yamakawa's demonstration appeared as invited 'common room' discussions in *Instrument and Control*,¹²² the official journal of the Society of Instrument and Control Engineers (SICE), in 1989 and 1990 respectively.¹²³ To their disappointment, 'we didn't receive any response from people in fuzzy control directly or indirectly'.¹²⁴ Their aim to provoke discussion also failed: '[W]e invited them to our conference, control theory conference and we organized a sort of debate. And some of our people, control theorists just showed the simulation result in front of fuzzy people, but they just kept silent'; 'They had no objection, I wanted to discuss with people in fuzzy control, but nobody wanted to'.¹²⁵ The interaction between the two groups remained at a fairly low level after the publication of the articles. In fact, Yamakawa might have agreed with those control theorists, as he noted explicitly in a book written in Japanese that his goal for the demonstration was only to balance the pole, and thus the position of the cart was not under consideration (Yamakawa 1988: 139).¹²⁶ But to do this without the inverted pendulum being stabilized – for which monitoring of the cart's velocity is a precondition – is pointless, or, according to Ikeda, equal to cheating.¹²⁷

As Yamakawa's rules of fuzzy inference show, the intuitive design method of fuzzy control contrasts sharply, as we have seen in chapter 2, with the mathematical approach in terms of precision. By utilizing the semantic imprecision of natural language, fuzzy theory forms a contrast with the 'digital analogy' model of the brain as a neural network (Nyce 1994: 415). The non-binary claim has sometimes won the fuzzy approach the name 'analogical'. For example, an article about Yamakawa was

¹²¹ Ikeda interview. As a technical term in control engineering, a 'plant' refers to the device or process at issue to be controlled.

¹²² This is the literal translation of the Japanese Journal name. The official English translation of it is *Journal of the Society of Instrument and Control Engineers*.

¹²³ SICE is the largest of the three societies of control engineers in Japan. Based in Tokyo and founded in 1961, SICE consists of more than 6,900 members as of May, 2008 (<http://www.sice.or.jp/intro/intro-e.html>). ISCIE (Institute of System, Control and Information Engineers), based in Kyoto and usually thought of as the counterpart of SICE in western Japan, was founded in 1957 with a former name 'the Japanese Association of Automatic Control Engineers' used until 1988. It consists of about 3,000 members. Its official journal is *Systems, Control and Information*, changed from the former name *Systems and Control*. Another society based in Kyushu is the Society of Instrumentation, organized in 1957 and having less than a hundred members, most of them corporate bodies (Kitamori et al. 1984).

¹²⁴ Ikeda interview.

¹²⁵ Kimura interview; Ikeda interview.

¹²⁶ The wording is different in one of his English papers. There, he uses the word 'stabilization' to describe what his devices do to the pole in the demonstration (Yamakawa 1989: 161).

¹²⁷ Ikeda interview.

titled 'The Man Who Revives Analog Computers' (Kobayashi 1989: 22); instead of using digital computers for fuzzy information processing as others have done, Yamakawa himself claimed to be employing 'intrinsic' fuzzy logic circuits in his fuzzy controller. He compared and contrasted digital computers with 'fuzzy computers', with the latter being an alternative to digital computers which work according to binary logic (Yamakawa 1988, 1989).

What Yamakawa had in mind is quite different from once-extant analog computers, such as network analyzers or differential analyzers, that were utilized as scale models of systems or differential equation solvers (Small 2001: Chap. 2&3). Yamakawa's, as it were, was an attempt to impose human thinking on machines. Human thinking is subjective and individualized, but this is not to be denigrated; on the contrary, these characteristics are celebrated:

There is only one accurate set of equations for the mathematical model (of the inverted pendulum), and everyone has to reach the same set of equations; in contrast, for linguistic model making, ten people would make different rules. Even there can be some expressions off the point or some useless expressions (if there are some redundant rules), it is still alright (Yamakawa 1988: 124-5).

The mathematical modelling approach as conceived by control theorists, on the other hand, is not as much without subjective character as people would think. A model, according to Kimura, when seen as the interface between scientific theory and reality, has both subjective and objective characteristics. Models lie between theory and art in the objective-subjective spectrum. Everyone can give a certain model a reality check against experimental data. On the other hand, a model is also subjective because it allows individuality and uncertainty in the model building process. The difficulty of model building is exemplified by a seemingly mundane system: the suspension system of automobiles. Drivers know its mechanical characteristics well through their bodily experience; however, for control purposes its model building is extremely complicated and difficult (Kimura 1998; 2002c). The lesson, painstakingly learned from the difficult model building process, is to refine a model so that the always simplified representation of reality achieves its largest usefulness (Kimura 1998: 234).¹²⁸

Nevertheless, the contrast between the two camps is clear: the former focuses on

¹²⁸ A revival of an interest in scientific models has recently drawn the attention of an audience of science and technology studies. Recent views on scientific models see a practice oriented trend that focuses on the function, construction and usage of them in scientific practices. See, for example, Morgan and Morrison (1999).

individuality and subjective experience, and the latter talks more of precision in terms of models and theories. This contrast is what was highlighted in the criticisms by control theorists. As their arguments on stability show, terms in control theory are usually defined in terms of the language of mathematical models and are not allowed to be interpreted according only to human senses.

Contrasting Ease of Communication

The differences between the two approaches, the mathematical one centred on the proofs of stability criteria and the intuitive one centred on whether it ‘works’, as epitomized by Yamakawa’s demonstrations, were reflected in their ability to communicate. Control engineering, as perceived by control theorists, has hardly been the focus of the general public (Kimura 2002a: 4). Restricted by a typically highly mathematical language, discussions of control engineering, and criticisms of fuzzy control as mentioned above, appeared largely in professional journals.

By contrast, discussions of the benefits of fuzzy control found their place in business magazines (Ikeda 1990: 70). Concerns for subjectivity and individuality, the typically claimed characteristics of fuzzy control, were translated into a language comprehensible to a broader audience. Using examples from everyday life, fuzzy control was put into easily understandable language. For instance, robustness, a technical term in control engineering, was explained by Yamakawa with the analogy of carrying a Japanese portable shrine (*Mikoshi*), a common scene in Japanese festivals. Just as a portable shrine will still remain stable even when one of its seven carriers fails to do their job well due to some unexpected problems, so the inverted pendulum in the demos keeps its balance even when one of the electronic rule boards is removed (Kobayashi 1989: 27).¹²⁹ Furthermore, by using fuzzy inference to account for what is at work when people perform various jobs (Yamakawa 1988: 114), the differences between intuition, tacit knowledge and bodily experience are erased. The analogies thus incorporate highly diverse experiences, such as pitching a baseball or driving a car.

Yamakawa’s claims catered to the interests of control engineers in some segments of industry. After World War II, with the experience of dealing with complicated non-linear systems, most notably anti-aircraft guns, theory in controller design moved beyond simply achieving stability to the goal of bringing about

¹²⁹ In contrast, although Kimura (2002a) is a book aimed for the general public, in it robustness is given as ‘even when some imprecision exists in the model, which is the link between control theory and reality, there is a design method to prevent controlled performance from deteriorating too much’ (ibid: 53).

optimal designs. Successive needs for military applications such as missiles and space vehicles drove control theory in the direction of the 'state-space' approach which ushered in the era of 'modern' control theory from the mid-1950s; control theory before that time is labelled as 'classical' control theory (Bennett 1993: viii).¹³⁰ Although successful in aerospace industries with their sophisticated mathematical techniques, modern control theory was found inadequate for use in general industry, where the models of some systems are either not available or are difficult to implement (Bennett 1996: 21-23). Industrial processes that traditionally relied on the control of experienced operators, such as 'steelmaking furnaces, cement kilns and presses in the glass industry', are said to fall in this category (Tong 1977: 559).¹³¹

These processes are 'smoothly nonlinear, highly uncertain, and of very high order, modellable only in gross approximation', and extant industrial process plants 'may involve thousands of measurements and actuators and hundreds of control loops, all the responsibility of a couple of operators. Some plant complexes occupy square miles of land....process control can be considered legitimately the largest example of a large system which deals with real goals' (Bristol 1982: 4). For fuzzy control researchers, the difficulty involved in the modelling of modern process in industry offers an argument against the primacy of stability criteria in assuring safety of control systems: safety can be achieved by various measures.¹³² The contrast between theoretical difficulties and practical workability has brought the skills of operators into focus. A psychologist describes an aspect of operator's perceptual skills:

The operator does not discriminate the process information as an isolated task but with the purpose of using it in his job. He may not mentally measure the process variables by numerical scale values but in relative terms, for instance it is more useful to know that 'power usage is well above the target' than 'power usage is now at 65'....It seems that the process variable values and their rates of change are categorized into overlapping bands with different implications for action: 'on

¹³⁰ The state-space approach was introduced by Lyapunov and applied by Russian control theorists well before the idea was known and used in the West after World War II. In dealing with the stability of non-linear systems, 'instead of concentrating on the time-domain solutions of differential equations, notoriously difficult to obtain analytically for many non-linear systems', Lyapunov 'introduced an energy-like scalar function of the state variables' (Bissell 1992: 173). Performance requirements of large complex multi-variable systems such as those that control missiles and space vehicles led control theorists to the state-space approach which symbolizes the era of modern control. For the transition to modern control, see Bennett (1993: 200-207).

¹³¹ In general process control refers to 'the control of plants which [are] manufacturing homogeneous materials and services: oil, chemicals, paper, metals, concrete, power, and the like' (Bristol 1982: 3).

¹³² Tanaka interview.

target', 'going off target', 'action required', etc. The operator's thinking and remembering are probably done in terms of this scale of categories which includes relative judgements about the state of the process and actions required, rather than in terms of actual numerical scale values (Bainbridge 1978: 241).

The 'fuzziness' of the operator's judgements, as shown in the above quote was well noted by fuzzy control researchers, and industrial processes have been the earliest fields to which fuzzy control was applied. Actual application can be traced to as early as the late 1970s. In the second congress of the IFSA in Tokyo, FRUITAX, a hardware system for fuzzy control developed by Fuji Electric Corp., was also presented in the special demonstration sessions. It was already commercialized and had been put into use for a water treatment plant (Yagishita et al., 1984). As Sugeno Michio, who provided ideas for the initiation of the project, admits, the reason why he began to put applications before his former theoretical work on fuzziness was to show its usefulness in response to criticisms that he had either received or heard of.¹³³ This strategy created an application-oriented atmosphere, which led to various demonstrations of fuzzy control – Yamakawa's was one among them that attracted much attention.

A Practical Response

Although, according to the control theorists there was no direct response, their criticism did have an effect on fuzzy control researchers. Not only was Araki's result confirmed by fuzzy control researchers (Bouslama and Ichikawa 1992), but, more significantly, Yamakawa modified his hardware to incorporate the position and velocity of the cart as monitored inputs.

According to a comment on the early demonstrations in the second edition of his book on fuzzy computing, Yamakawa himself seems to have confirmed what Araki and Ikeda said: '[A pole or a flower in the former demonstrations] is unstable with regards to position, and can only be kept upright in a certain period of time. As it were, it is no more than "kept upright approximately"' (Yamakawa 1992: 157). However, Yamakawa's modification was not only to stand a pole for any arbitrary time span but also to do a more amazing demonstration: this time a glass half-filled with wine was put on a platform on top of the pole. In order to reduce the amount of fuzzy inference rules, two new parameters 'falling down condition' and 'moving away condition' were set by linearly combining the angle and angular velocity with

¹³³ Sugeno interview.

the position and velocity of the cart respectively. Eleven to thirteen fuzzy inference rules were constructed with regards to the two parameters (Yamakawa 1992: 166-170).

The new demonstration was first set up in November 1990 by some nineteen undergraduates in engineering under Yamakawa's instruction, for the yearly university festival of the Kyushu Institute of Technology, where Yamakawa had moved from Kumamoto University in 1989. Again, Yamakawa emphasized the ease of understanding and constructing fuzzy inference rules by stating that the students had only fairly average knowledge of classical control theory, let alone any grasp of modern control theory (Yamakawa 1992: 181-184). Yamakawa also tried substituting a live mouse for the glass on the platform, and the pole was shown to be kept in balance (Yamakawa 1992: 185-187). These newly developed, more fascinating feats were repeatedly shown in laboratory trips, on television, and in domestic or international conference settings, often winning an applauding audience well into the early 1990s. They became standardized demonstrations presenting the workability of fuzzy control in Japan and abroad (McNeill and Freiberger 1993: 273; Rosental 2004: 171).

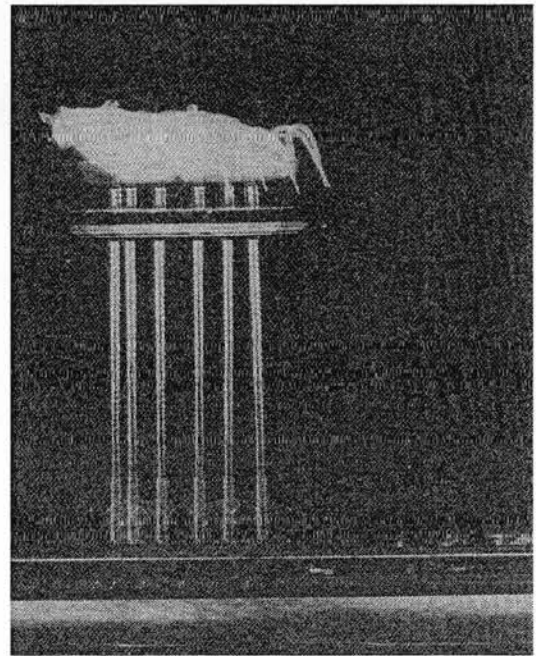
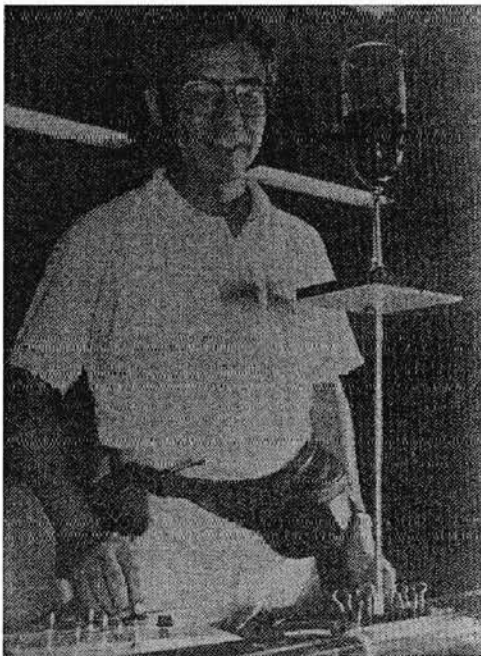


Fig. 4.4 and 4.5 Yamakawa's new demonstrations: a glass on the platform (left), and a mouse on the platform (right, stroboscopic photograph) (Yamakawa 1992: 178; 187).

As well as stimulating a response from control theorists, Yamakawa's first demonstration in 1987 meant that the stability issue of the inverted pendulum also became a recurrent theme in the yearly fuzzy system symposiums in Japan, even before Araki's and Ikeda's articles were published. More generally, in Japan, stability analysis of fuzzy systems became a major theme in symposiums and conferences from the late 1980s on.¹³⁴

This concern ran parallel to the newly developed modelling approach to fuzzy control, which originated in Japan. The first such model was proposed by Sugeno Michio and his student in 1985. The so-called 'Takagi-Sugeno model' is an altered form of fuzzy inference rules, the consequents of which ('IF...THEN') are formed as linear functions of the precedents (Takagi and Sugeno 1985). The Takagi-Sugeno model and other models were employed by fuzzy control researchers to describe systems and to pursue a more systematic method of controller design, in which – not much unlike the general practice in control engineering – stability analysis was also applied.¹³⁵ The construction of the Takagi-Sugeno model grew out of an academic concern. As Sugeno admits, 'I thought stability was the last subject of the fuzzy society, so we must solve it'.¹³⁶

As was shown above, an explicit counter-argument to Araki and Ikeda's criticisms was not offered, which implies that the meanings of 'stability' defined in the framework of control theory cannot easily be altered. Once the explanatory framework was given back to those who were seen as legitimate spokespersons, it was difficult to maintain one's claim in terms of that framework. By taking up the language of general control engineering, for example by constructing a model and doing stability analysis little by little, model-based fuzzy control had become just another approach within the whole enterprise.

Yamakawa's demonstrations, as well as other applications of fuzzy control to the process industry, prioritize workability rather than theoretical proof. However, later developments in fuzzy control have seen that the language of modelling overwhelms the language of intuitive reasoning, and have led to the situation quoted earlier: 'Although fuzzy control was initially introduced as a model-free control

¹³⁴ For example, Kawaji and Noguti (1989) examine the stabilization of an inverted pendulum balanced by fuzzy control; Terano et al. (1988) and Maeda et al. (1989) discuss the stability of fuzzy-controlled systems.

¹³⁵ For instance, Tanaka and Sugeno (1992) apply Lyapunov stability analysis to the Takagi-Sugeno model.

¹³⁶ Sugeno interview.

design method based on the knowledge of a human operator, current research is almost exclusively devoted to model-based fuzzy control methods that can guarantee stability and robustness of the closed-loop system...' (Sala et al. 2005: 433). With its aim to cater to the interests of practising engineers, the proposition of fuzzy control as a controller design method has led in the end to the separation of the practical and the theoretical. The gap between theory and practice has been a recurrent concern in control engineering: modern control theory has been criticized for being difficult to apply to general industrial settings. Before 1940, when control engineering had not yet been established, practising engineers did not rely on mathematical work such as that by Maxwell, Nyquist etc., but rather on experience.

Thus Yamakawa's demonstrations and their aftermath seem to be a re-enactment of scientification in the history of control engineering. The process of scientification, then, involves a transition of controller design from practical experience to theory, or, to use the induction/deduction distinction introduced in chapter 1, from an inductive culture of proving to a deductive culture of proving. Although the induction/deduction distinction nicely encapsulates different cultures of proving to which the two groups of researchers belong, the distinction breaks down if we consider various techniques that are in use for controller design in control engineering. Modelling by 'system identification', which amounts to input-output testing as mentioned earlier, as well as the statistical approach that plays an important role in modern control (Bryson 1996), can be put under the category of inductive approaches. In other words, not only deductive, but experiential testing and mathematically inductive approaches are all in use in control engineering – they are nevertheless differently emphasized with regards to the problem areas considered.

Saying this, however, brings into sharp relief Yamakawa's demonstrations. He performed fantastic feats by using fuzzy control on the inverted pendulum, but its dynamics were relatively easy to analyze mathematically using ready-made models, and put fuzzy control under close scrutiny by control theorists. The competence of a mathematically deductive approach was borne out by its ability to 'cover all cases' (MacKenzie 2004: 70) – to cover conditions in which the inverted pendulum could become unstable that Yamakawa had not taken into account in the beginning. However, for people in the inductive culture of proving in which the 'demo' is a core persuading tool, apart from Yamakawa's inverted pendulum, process industries as a whole offered a transformed form of counter-argument to the control theorists' criticism. These applications were there and they worked well; their sheer existence, which was claimed to have incorporated operators' intuitive capabilities, provided a demonstration.

Conclusion: Demonstration and Modelling

The contrast between mathematical modelling and intuition, as Yamakawa made explicit in his characterization of fuzzy control, was the dichotomy evoked to distinguish fuzzy approach from older approaches. Fuzzy logic, as it modelled an aspect of the ways people think, was claimed to be able to perform what older machines could not, on the grounds that the latter work according to mathematical modelling.

On the other side of the dichotomy lies ‘the skills of experts, at the level of craftsmanship, the so-called knack, intuition, or gist’ (Yamakawa 1992: 11). The working of the demonstrations (Yamakawa’s and those in other forms) is noteworthy here, as it bridges a gap between the entities doing the modelling and the entities that were modelled. Through demonstration (and successful working of control systems), fuzzy logic – ‘a... model of the semantics of human concepts’ for ‘formalizing human reasoning’ (Freska 1994: 21) – was substantiated as one the ways (i.e. knack, intuition, gist) in which human beings reason. Through demonstration, a model built upon an aspect of language use – an external expression of human reasoning – became a representation of its inner workings. The claim that fuzzy computers outperform older machines owing to the ability of the former to represent the knack and experience of skilled human operators, can be seen also from some of the advertisements for the systems with fuzzy control features.

The title of one of the advertisements (see Fig. 4.6) of Hitachi’s automatic control system for the Sendai subway, easily seen by readers as a request made from passengers as it was put alongside the picture of a woman standing on the train, carrying a baby, reads: ‘Please do also add “riding comfort” to the specification (of the system)’. At the very bottom of the advertisement lies the description of the system: ‘the knack for providing a comfortable train ride is to reduce the occurrence of sudden acceleration and application of the brake notch as much as possible...“predictive fuzzy control”...realizes a comfortable ride with few sudden accelerations and decelerations but a precise stop at the station’.

‘analogical’ design, all other fuzzy computers based their work on binary logic (Togai and Ōta 1990: 62-82).



Fig 4.7 Omron’s advertisement for its fuzzy controller (Yomiuri Shinbun 1988/03/16, reproduced from IFSA Nihon Shibu Nyūsu 1988: 25)

What received emphasis was the ability of the fuzzy computers to evince a human’s knack. As Omron’s advertisement states, ‘Similar to the case of the toy juggler, driving control for vehicles, and process control in industry, are hard to automatize. (For these) sophisticated knowledge and rich experience of an expert are necessary because data are difficult to quantify’. In fact, for Japanese authors, knack and intuition (‘kan’ and ‘kotsu’ in Japanese) have a significant role in the evaluation of the abilities of Japanese technical and art masters (Minami 1994: 221-222). In the next chapter, I will analyze the building of a link between fuzzy theory and another feature emphasized by the Japanese, by tracing the Japanese translation of the English word, ‘fuzzy’.

Chapter 5

The Translation of Fuzzy Theory into Japanese

As was shown in Chapter 3, well before fuzzy theory became widely known in Japan in the late 1980s, Terano Toshirō – then a professor at the Tokyo Institute of Technology who in 1972 initiated the Working Group of Fuzzy Systems (the first research group dedicated to fuzzy theory in Japan) – chose the word ‘aimai’ as the Japanese translation for ‘fuzzy’. From the early 1970s to the time when ‘aimai’ was gradually replaced by the Japanese transliteration of ‘fuzzy’ (pronounced as ‘fajyi’) in the late 1980s, ‘aimai’ had served as a frequently used adjective for all the subfields under the banner fuzzy theory in Japanese.¹³⁷ For instance, fuzzy set had been represented as ‘aimai shūgō’, fuzzy logic as ‘aimai ronri’, fuzzy measures as ‘aimai sokudō’, and fuzzy control as ‘aimai seigyō’. In addition to translating fuzzy into aimai, Terano also coined ‘aimai kōgaku’ (aimai engineering), a term the counterpart of which in English is not found in Zadeh’s writings.

Terano promoted his viewpoints by broadening the scope of fuzzy set theory far beyond its original version. As we have seen in chapter 3, Terano tried to emphasize subjective sensations and feelings that had largely been disregarded in handling problems in systems composed of humans and machines, and fuzzy set theory was one of the approaches of aimai engineering. Yet Terano used the same word, aimai, to represent both a new kind of engineering and Zadeh’s fuzzy set theory. This made fuzzy set theory, already an international endeavour in the early 1970s, a springboard for Terano’s own project. On the other hand, through the establishment of the equivalence between ‘aimai’ and ‘fuzzy’, aimai engineering then turned out to be a prototype of talking about fuzzy theory in a particularly Japanese way, partly because of what the word ‘aimai’ implied in the Japanese context. Following a short introduction of the Japanese writing system and the etymology of the word ‘aimai’, this chapter aims to disclose the role that ‘aimai’ played in this process by analyzing the efforts at science popularization carried out by Terano and his student and colleague, Sugeno Michio – one of the most influential figures in the development of fuzzy research in Japan.

The Word Chosen for ‘Fuzzy’ in the Context of Translation in Japanese Writing

In Japanese, ‘aimai’ (both an adjective and a noun) can be written with either a

¹³⁷ Occasionally the English word ‘fuzzy’ rendered intact was used instead. See below.

combination of two ‘kanji’ (Chinese ideograms) or with four characters from Japanese syllabaries. Japanese characters were once used only as diacritical marks put alongside kanji (Montgomery 2000: 193).¹³⁸ Although the two kanji that represent ‘aimai’ are not in the list of ‘Chinese characters for daily use’ – therefore the term ‘aimai’ is nowadays usually written with hiragana (cursive characters from one of the two Japanese syllabaries) – the term itself is a loanword from China in the distant past.

In addition to kanji and kana, modern Japanese scientific writing also utilizes terms in English and numbers in Arabic symbols extensively (Montgomery 2000: 199-201). This can also be seen in the content of Terano’s own writings on fuzzy theory (e.g. Terano 1984: 1765).¹³⁹ So why did Terano not render ‘fuzzy’ in its original English form as he did with some other technical terms? A possible answer is that mathematics is one of a few fields ‘where the use of kanji tends to dominate’ (Montgomery 2000: 199). Before fuzzy theory was introduced into Japan, many technical terms in mathematics that would later be closely related to it had been rendered with translations using kanji. For instance, Japanese translations of ‘set’, ‘logic’, ‘function’, ‘measure’ (shūgō, ronri, kansū, and sokudō respectively) have all been rendered in kanji. Multi-valued logic serves as a close comparison to the translation of fuzzy logic. It was translated into ‘tachironri’ with both ‘tachi’ (multi-valued) and ‘ronri’ (logic) rendered in kanji (e.g. Nihon no sūgaku hyakunen-shi henshyū iin-kai 1983: 239). Following the example of multi-valued logic, it might be that ‘aimai’ was thought to be less abrupt and thus fit better as an

¹³⁸ The Japanese language is well known for its complicated writing system. Chinese was introduced into Japan around about the fifth century. Since then, many Chinese terms had not only remained as loanwords (represented by original or slightly changed forms of Chinese ideograms), but some Chinese ideograms were also changed in shape to serve as diacritical marks for reading kanji and to phonetically represent native Japanese words. These marks, ‘kana’, form the Japanese phonetic syllabary. In Japanese, each syllable can be symbolized by either one of the two differently shaped kana that represent it. According to their shapes, kana in ‘square’ form are called katakana, and kana in ‘cursive’ form are called hiragana. Katakana were once used mainly by men, and were ‘at a time the standard typescript form for public writing’. Now they are used as ‘phonetic spelling of Japanese words for emphasis (similar to Western italics), and more importantly, the phonetic rendering of foreign words, especially, beginning in the sixteenth century, those derived from the Western languages’. Hiragana, on the other hand, were once used largely by women, and from the late nineteenth century ‘had become generally acceptable as typescript in newspapers, journals, and books’ (Howland 2002: 205; Montgomery 2000: 190-194). Beginning from the later half of the nineteenth century when Japan turned her back on China in favour of Europe as a new model of development, a few suggestions regarding Japanese script reform had been proposed. Some argued for a total dispense of kanji, and some even went so far as proposing to discard both kanji and kana and use romaji (Roman alphabets) instead for achieving a higher level of literacy. After WWII, with the pressure from the GHQ (General Headquarters), the Japanese government prescribed that the number of kanji for daily use be limited to less than 2,000 (compared to about 5,000 an educated person should have known in the late 1920s) (Montgomery 2000: 197-198).

¹³⁹ The case referred to here is the term ‘ill-defined’ rendered in English.

adjective in terms of language rendering than the original English word ‘fuzzy’ did. However, combining original English terms with Japanese ones in rendering technical compound words was not rare in the early 1970s.¹⁴⁰ Fuzzy theory researchers Mizumoto and Mukaidono, for example, had been using ‘fuzzy daisū’ and ‘fail-safe ronri’ – both combinations of English and kanji – to represent ‘fuzzy algebra’ and ‘fail-safe logic’ respectively (Mizumoto, Toyoda and Tanaka 1970; Mukaidono 1970). In contrast, Asai *et al.* chose ‘aimai ōtomaton’, a combination of a translation given by hiragana and a transliteration given by katakana, to represent ‘fuzzy automaton’ (Asai, Kitajima and Hirai 1970: 551). Accordingly, in the early days of fuzzy research both ‘fuzzy’ rendered intact, and ‘aimai’, stood for the word fuzzy in Japanese literature. Perhaps not coincidentally, the difference in usage preferences is linked to age difference – both Mizumoto and Mukaidono were born during WWII, about a generation younger than Asai and Terano, and were thus possibly more accustomed to the practice of keeping English terms intact.¹⁴¹

The logic of translating ‘fuzzy’ is different from the same act as applied to other terms. Translations of mathematical terms such as ‘set’, ‘logic’, etc. mentioned above can arguably said to be part of Japanese history of science. Beginning from eighteenth century, the practice of creatively translating Western scientific terms by using kanji, which was once the way that Japanese scholars had to choose in order to strike a balance between Western science and traditional learning when Chinese classics still dominated, was followed by many well into the late nineteenth century (Montgomery 2000: 202-250).¹⁴² However, the issue of translating ‘fuzzy’, as it were, is not to be sought in the interpretations of an abstract Chinese philosophy. Instead, it is a re-interpretation of characteristics of the Japanese language and Japanese people, a consequence of complicated encounters between Japan and the West.

The Etymology of ‘Aimai’

¹⁴⁰ The use of kanji in rendering new concepts had been declining, at the latest from early 1980s according to Unger (Unger 1987: 79).

¹⁴¹ Sugeno, on the other hand, had a preference for using ‘aimai’ over the transliteration, although he is of similar age to Mizumoto and Mukaidono. The fact that he was a close colleague to Terano may serve as the explanation for the preference.

¹⁴² For instance, in physics, many Japanese translations of Western terms such as matter (busshitsu), mass (shitsuryō), and body (buntai) by using kanji have their origins in the eighteenth century and are still in use today. They bear the imprint of a blending of Chinese natural philosophy and Western science in eighteenth century Japan (Montgomery 2000: 208-209). More interesting is the fact that many of the Japanese rendering of Western terms by using kanji were later adopted as the Chinese translations of those terms (Liu 1996).

If written in the form of kanji, 'aimai' is composed of two separate kanji 'ai' and 'mai'. Both have a radical denoting the sun in the left-hand side. The Chinese reading of 'aimai' is 'aimei'. 'Ai' originally means that the sun is dimmed by clouds, and 'mei' the treetop that is difficult to see. Both have 'difficult to see because it is becoming dark' as one of their meanings. In Chinese, the compound word which means 'not clear' dates back to the seventh century, and in Chinese classics of more than two thousand years ago one finds separate usages of 'ai' and 'mei'. 'Mei' extends to imply 'conscience, moral principles, wisdom etc. are shadowed and not followed' when 'mei' is linked to words representing heart, blindness, deafness, foolishness and so on.

In modern Japanese, many compound words with 'aimai' as their beginning which were once in use find no equivalents in Chinese. These words, made up by Japanese people, came into being around the turn of the twentieth century. They are largely about 'flesh trade' disguised as legal trade. For instance, 'aimai-onna' means prostitutes disguised as those women who are not, and 'aimai-chaya', 'aimai-ya', and 'aimai-yado' all refer to brothels masked as restaurants, coffee houses, or hotels. Although meanings of these words are somewhat comparable to one of the modern meanings of 'aimei' in Chinese which denotes secret love affairs, in Chinese it does not go so far as to stand for something on the verge of illegal activities.

In current Japanese usage, these compound words with 'aimai' as their beginning are hardly seen except in literary works; they were used in the past (Sugeno 1989: 2). In contrast, in modern Chinese usage, the meaning of the compound word 'aimei' has been more or less fixed, with its applicability limited to a large extent to love affairs. Due to this kind of negative connotation, another word 'mohu' is used instead to refer to something vague for general purposes, and 'fuzzy' as in fuzzy logic was translated into 'mohu' – not 'aimei' – in Chinese.¹⁴³ But in Japanese the applicability of the word 'aimai' has remained high. A cursory search for the word 'aimai' on the websites of the two mostly read daily news pages gives hundreds of entries with it in the paragraphs. The frequently used word is employed to modify attitudes, boundaries, conditions, decisions, evidences, (facial) expressions, judgements, policies, viewpoints, standards, statements and so on.¹⁴⁴ It was also used by a Japanese Nobel laureate in literature, Ōe Kenzaburō, as the epithet to

¹⁴³ 'Mohu' also entered into Japanese as a loanword (pronunciation of which in Japanese is 'moko'), but is hardly used except when linked to 'aimai' to form a compound word 'aimai-moko'.

¹⁴⁴ The websites of the largest and the second largest Japanese daily news pages, Daily Yomiuri and the Asahi Shinbun, are <http://www.yomiuri.co.jp> and <http://www.asahi.com>. These websites are accessed by author on 8 May, 2007.

characterize his own country in his Nobel speech in 1994 (Ōe 1994).¹⁴⁵ The Japanese native word for *aimai* is 'oboroge'. The association between 'aimai' and 'oboroge' is to be found in late nineteenth century when 'oboroge' was used as diacritic marks for 'aimai' written in the form of kanji (Nakajima 2006: 5). Nowadays 'oboroge' is used primarily to modify the word 'memory' and is much less used than 'aimai' is.

Unlike the word 'fuzzy', which was first elevated from the status of a colloquial to a technical term by Zadeh, 'aimai' in the Japanese context was not without precedent in academic circles. It was chosen by philosophers to translate the word 'ambiguous' both before and after the mid 1960s when Zadeh proposed fuzzy sets. In contrast, Japanese philosophers tended to use the word 'bakuzen' to translate 'vague', a former concept which has a comparable meaning to 'fuzzy' (Nakajima 2006: 10-11). Perhaps because of the promotion efforts by Terano and others as stated below, 'aimai' has become widely used for translation purposes and the distinction between 'vague' and 'ambiguous' in English has been blurred in Japanese translation – they have gradually all been translated into 'aimai'.

Why 'Aimai'?

Before exploring the specificity of translating 'fuzzy' into 'aimai' in the Japanese context, it would be fruitful first to see why the word 'fuzzy' was introduced as in fuzzy logic. Instead of choosing extant terms such as 'vague', 'many-valued', 'multi-valued', or 'infinite-valued' that predate 'fuzzy' and convey a similar idea, Zadeh proposed to use a word which does not conform to a general rule of emphasising technicality in naming within academic circles. In fact, philosopher Max Black who explored issues on vagueness later substituted 'loose' for the word 'vague' that he had used because of derogative connotations of the latter (Nakajima 2006: 155). According to Zadeh, the term 'fuzzy logic' came from considerations of publicizing. He states that the word 'fuzzy', which is often associated with negative connotations, can arouse hostility, which serves as one of the ways to get publicity.

¹⁴⁵ For Ōe, *aimaina* – another adjective form of *aimai* – can be translated into English by using either *vague* or *ambiguous*. Ōe's speech is to a great extent a rejoinder to the 1968 Nobel lecture 'Japan, the Beautiful, and Myself' of Kawabata Yasunari, the first Japanese Nobel laureate in literature. In contrast to Kawabata's emphasis on the mysterious beauty of Japanese poems, Ōe stresses an ambiguous condition of an endless oscillation between the modern and the traditional, and between democracy and militarism that characterizes the country since modernization. The English title of Ōe's speech is 'Japan, the Ambiguous, and Myself' (Kawabata 1968; Ōe 1994). For an analysis of Kawabata's view on Japanese aesthetics as expressed in the game of 'go' (the East Asian board game), see Feenberg (1995: chap. 9).

And the word 'logic' was chosen for a similar reason: although the whole enterprise of fuzzy theory rests more on an alternative idea of sets than of logic, the name 'logic' makes more sense to ordinary people than does 'set', which is more mathematically implicated and thus more distant (McNeill and Freiburger 1993: 49).

It is said that Terano chose 'aimai' as the Japanese translation of fuzzy because he intended to arouse reactions against it out of its negative connotations, just as Zadeh did by choosing 'fuzzy' as a way of publicizing his theory.¹⁴⁶

However, such a choice incurred a cost. While Zadeh did arouse some criticisms partly because of the word he chose, an explanation has to be offered for the real merits that go beyond mere naming. What Zadeh usually offers is couched in an engineering tone of trade-off:

It is important to observe that there is an intimate connection between fuzziness and complexity. Thus, a basic characteristic of the human brain, a characteristic shared in varying degrees with all information processing systems, is its limited capacity to handle classes of high cardinality, that is, classes having a large number of members. Consequently, when we are presented with a class of very high cardinality, we tend to group its elements together into subclasses in such a way as to reduce the complexity of the information processing task involved. When a point is reached where the cardinality of the class of subclasses exceeded the information handling capacity of the human brain, the boundaries of the subclasses are forced to become imprecise and fuzziness becomes a manifestation of this imprecision. This is the reason why the limited vocabulary we have for the description of colors makes it necessary that the names of colors such as red, green, blue, purple, etc., be, in effect, names of fuzzy rather than non-fuzzy sets. This is also why natural languages, which are much higher in level than programming languages, are fuzzy whereas programming languages are not.

Fuzziness, then, is a concomitant of complexity. This implies that as the complexity of a task, or of a system for performing that task, exceeds a certain threshold, the system must necessarily become fuzzy in nature. Thus, with the rapid increase in the complexity of the information processing tasks which the computers are called upon to perform, we are reaching a point where computers will have to be designed for processing of information in fuzzy form. In fact, it is the capability to manipulate fuzzy concepts that distinguishes human intelligence

¹⁴⁶ Information on this was obtained from Prof. Nakajima's presentation in the 21st Fuzzy Systems Symposium held in Tokyo on September 7-9, 2005.

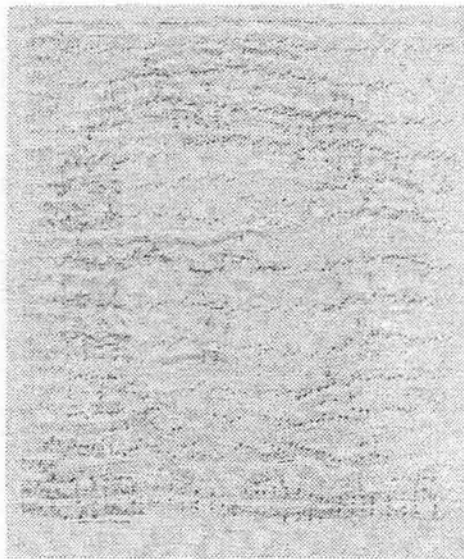
from the machine intelligence of current generation computers (Zadeh 1990a: 99-100).

In other words, for Zadeh natural language usage provides an instance exemplifying the mechanism by which the human brain actually works. As if fuzziness is the token that we are unwilling to embrace but have to bring to enter into negotiations with the complex worlds; fuzziness is the necessary evil, in the positive sense of the term. The engineering tone of trade-off is the reply to the inevitable consequences of an ever-developing world, a world with ever-increasing complexity. Although Zadeh was criticized for his 'unscientific' attitude, as we have seen in chapter 2, from this quotation it can be argued that Zadeh's thought on fuzzy theory is still in the rationalistic line: his mentioning of precision – a supposedly disadvantageous characteristic of an entrenched science – is for the trade-off; nothing is mysterious beyond this everyday practice of engineering as a profession. And the meaning of the word 'fuzzy' in the context of fuzzy theory can be said to be based on this engineering interpretation.

Although Terano was no less practical – he did claim that he put more emphasis on using 'aimaisa' (the quality of being aimai) than on inquiring into its essence (Terano 1981: 15) – much of what he offered is beyond rationalistic calculation. In an article on aimai engineering, Terano lists three arguments for why aimaisa is needed. First, in dealing with large complex systems, people tend not to be able to see the wood for the trees because they pay too much attention to detail. Secondly, human beings, as constitutive parts in systems, are not easily modelled by e.g. statistical analysis; their subjective values and feelings – which are aimai – should be taken into consideration. Lastly, in order not to become subordinate to computer-centred information systems (for Terano, Charles Chaplin's movie *Modern Times* makes a case for the situation), aimaisa is needed for a better human-computer interaction. These points exemplify Terano's view on the effects of computers on what would be called an information society. A society too dependent on computers is no less than a society operated on strict logic. Even rule-like laws and institutions allow for interpretations – a space where aimaisa resides – to work. Aimaisa, in other words, is an antidote to the malaise of a society impinged upon by computers understood as working on strict binary logic (Terano 1978: 92-93).

For Terano, 'aimaisa' means much more than non-binary logic or non-crisp set. Pictures aiming to demonstrate a Gestalt switch, a score showing Beethoven's face when looked at from a distance, results of Rorschach tests from which something

like a human face emerges,¹⁴⁷ or portraits by caricaturists are some of the favoured examples in his writings. That these pictures can be recognized by people as certain faces shows the ability of human beings to ‘see the wood’, although these pictures are aimai and difficult to analyze. This kind of ability is utilized as a new form of human-computer interaction by ‘face graphs’ developed by Hara Fumio, one of the participants of the Working Group of Fuzzy Systems, to represent multi-dimensional data.¹⁴⁸ The ability to sense both overall features and nuances (both wood and trees) of human faces is made equivalent to the ability of an experienced operator to sense what goes wrong in an industrial plant. Thus it can be used for system diagnosis – if translating various measured data of a process into continuously changing face graphs, even an inexperienced operator can tell whether an industrial plant is in good condition by sensing changes in facial expressions of face graphs (Terano 1978: 96-97).



1 図 ベートーヴェンの楽譜と肖像。近くではわからない
遠くから見ると全体像の特徴が現われる (中央公論社『世
の音楽』宮内省マタートリ)

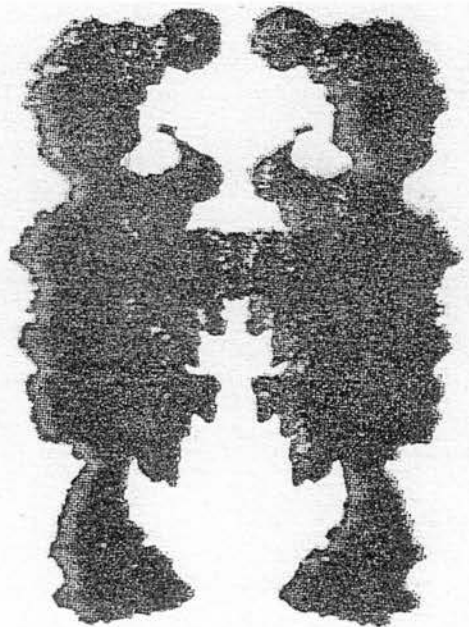


Fig. 5.1 A score showing Beethoven's face and a Rorschach test result (Terano 1978: 93)

¹⁴⁷ For an analysis on the subjective/objective aspects of Rorschach tests, see Galison (2004).

¹⁴⁸ Hara's face graphs were preceded by Herman Chernoff's facial visualization of multivariate fossil data (Chernoff 1973). Hara applied face graphs to diagnose malfunctions of an experimentally modelled heat exchanger and a group of rotary machines (Terano 1981: 160-170). Hara is now an internationally well-known researcher in facial expressions of humanoid robots. For his current work, see Menzel and A'luisio (2000: 72-76).

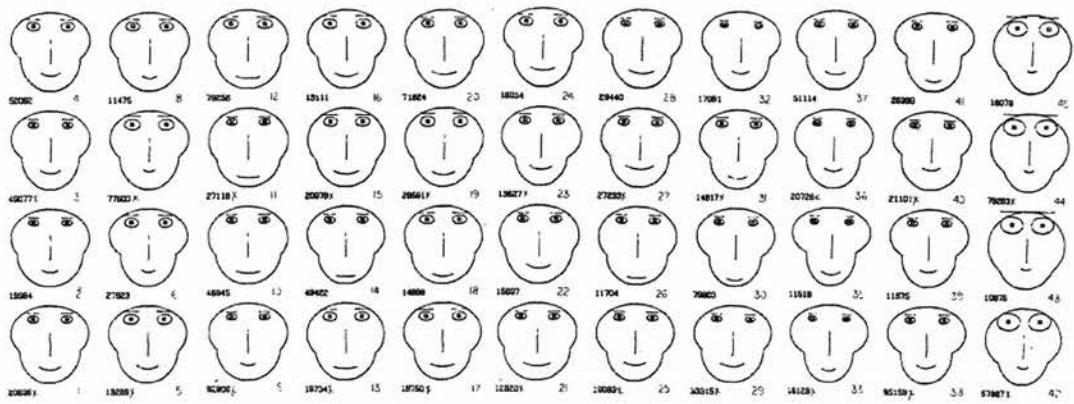


Fig. 5.2 Chernoff's faces illustration (Chernoff 1973: 362)

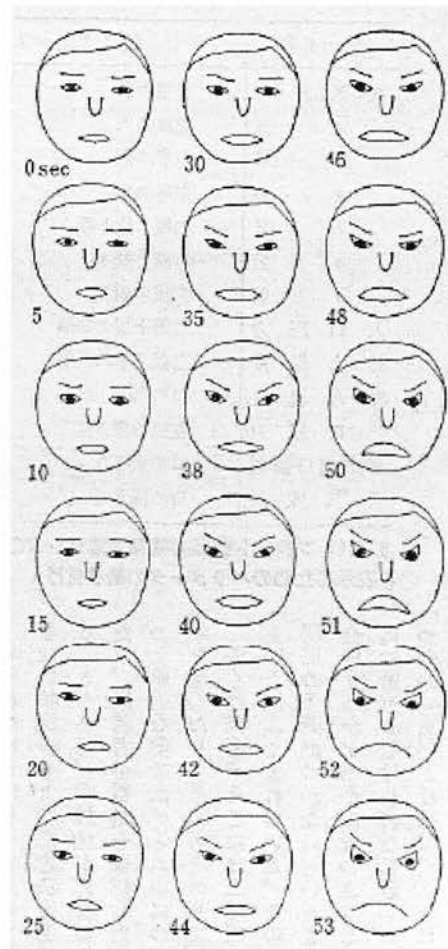


Fig. 5.3 Hara's face graphs for system diagnosis (Terano 1981: 170)

As shown above, for Terano what 'aimaisa' covers is far beyond the idea of fuzziness as interpreted by Zadeh. Abilities such as intuition, synthesis, and some others that cannot be done by computers are all said to be linked to aimaisa. According to Terano, aimaisa is so universally present in everyday life that it will not

and should not be shadowed by the mechanical operations of computers.

However, such broadening of the meaning of 'aimaisa' also has a cost, less because the word has negative connotations than because it is difficult for the word to convey that for which it is intended. In an interview on the 'what' of aimai engineering, Terano gives chess playing as an example. Although experienced players have thousands of tested formulas in their mind, a new game can be totally different from those that have been experienced. In these situations, players do not play according to formulas but play according to intuition and common sense that a robot lacks. When the interviewer admits that common sense is surely aimai but complains that common sense is too broad to be analyzed, Terano responds by limiting aimai theory (purported fuzzy theory) to that which is not different from fuzzy inference, i.e., an inference in which conclusions can still be derived from the premises even if these premises are somewhat fuzzy and different from established ones installed in computers. When pressed by the objection that this is not exactly what can be imagined from the word aimaisa and that 'flexibility' is a better word, Terano admits that perhaps he has chosen a wrong word (Terano 1985: 21-22). He agrees with the interlocutor that aimaisa, as suggested by aimai engineering, should be differentiated from the kind of aimaisa that is implied in the statements of politicians. The latter is to be equivocal about one's real intentions, while the former is to deal actively with ill-defined problems (Terano 1985: 24-25).

The confusion arises because the word 'aimai', chosen as the translation of many Western terms, is present not only in analytical philosophy but also in discussions on cross-cultural communications. This facilitates Terano's fusion of meanings of 'aimaisa' in the fuzzy sense of the term and in the Japanese sense of the term. In fuzzy theory, fuzziness of language usage mainly refers to the inexactness of adjectives and adverbs. Thus, in the fuzzy sense of the term, aimaisa originates from the fact that our words for describing the world are much less than what we want to describe – a deficiency of words to seize the world (Terano 1981: 59; Zadeh 1990a: 100). However, in the Japanese sense of the term, 'aimai' had been used by non-Japanese as well as by Japanese themselves to characterize distinctive features of Japanese culture. For instance, Donald Keene, a prominent U.S. Japanologist specializing in Japanese literature, suggests the role that aimaisa plays in Japanese aesthetical expressions. He points out that there are four features of Japanese aesthetics: suggestion, irregularity, simplicity, and perishability. In discussing the first one, suggestion, Keene links it to traits of the Japanese language, and uses ancient poems to demonstrate their 'power of suggesting unspoken implications'. The power of suggestion rests on a feature that he argues characterizes the Japanese

language: ambiguity (translated into Japanese as *aimaisa*). As ‘a well-known feature of Japanese language’, ambiguity for him refers to the omission of subjects of sentences, and ‘the lack of distinctions between singular and plural or between definite and indefinite’ in Japanese language (Keene 1969: 294-296). Similar kinds of characterization of the Japanese language have been used to generalize the character of the Japanese people from their language usages, and have entered into popular books on cross-cultural communications aimed at those who intend to acquire a general grasp of the disposition of the Japanese people. For instance, ‘*aimai*’ is listed as one of the keywords in a book on Japanese culture: ‘the Japanese are generally tolerant of ambiguity, so much so that it is considered by many to be characteristic of Japanese culture. Although the Japanese may not be conscious of *aimai*, its use is regarded as a virtue in Japan, and the Japanese language puts more emphasis on ambiguity than most, for to express oneself ambiguously and indirectly is expected in Japanese society’ (Davies and Ikeno 2002: 9).¹⁴⁹

Although Terano did mention that promoting ‘*aimaisa*’ does not necessarily imply an emphasis on the particularity of Japanese culture since *aimaisa* is universal, in various places he could not help stating that the language usages and everyday practices of the Japanese people are more *aimai* than they are in Western cultures. That Japanese people do not give a clearly positive or negative answer was given as evidence for such *aimaisa* that distinctively belongs to the Japanese language (Terano *et al.* 1981: 61-62). On these occasions, *aimaisa* in the fuzzy sense of the term gives way to *aimaisa* in the ambiguous (equivocal) and particularly Japanese sense of the term (Terano 1981: 61-62; 94-98), and, in turn, the Japanese people are given an advantageous status of developing an engineering utilizing *aimaisa* since they are accustomed to it (Terano 1981: 690-691).

This is why in his presentation of *aimai* engineering Terano said that ‘in the end, perhaps we are fascinated by the mystery of the word “*aimai*” so as to become dream-chasing romanticists’ (Terano 1978: 101). Terano’s self declaration corresponds quite closely to Keene’s identification of the mysterious power of suggestion in Japanese poems. For Terano, why Japanese people can understand each other even if there are so many *aimai* expressions remains mysterious; to infer one’s interlocutors’ intentions by one’s knowledge and by considering relationships between oneself and them is to the same as enjoying suggestive expressions and the reverberations of poems and articles, and to read between the lines (Terano 1981: 62; 1989: 204). ‘*Aimai*’ in the particularly Japanese sense of the term then feeds back to

¹⁴⁹ For a comment on Keene’s overemphasis on the ambiguity of Japanese language and his characterization of Japanese aesthetics basing on that ambiguity, see Suzuki (2003: 150-151).

the characterization of computers, and becomes universalized beyond the Japanese context; therefore, compared to communications between human beings, what robots or artificial intelligence in general lack, is the ability to understand *aimai*. This is the argument as to why the key to those stumbling blocks of artificial intelligence, i.e. common sense, contexts etc., is said to be no more than the ability to manage *aimaisa*.

Sugeno's Philosophy on 'Aimaisa'

By way of translating and introducing fuzzy theory, the expression '*aimai*' or '*aimasa*' had become the keyword not only for making remarks on human-machine interaction or artificial intelligence in particular, but also for discussing the role of subjectivity in general science. This line of comment is exemplified by the writings of Sugeno Michio, Terano's student and colleague.

Sugeno was the most outspoken in arguing the importance of *aimaisa* in science in a more philosophical way. His employment of *aimaisa* in discussing science in general dated back as early as in late 1970s (Sugeno 1979), more than a decade before books with similar characterizations of fuzziness were published (Kosko 1993; McNeill and Freiburger 1993).¹⁵⁰ Sugeno's philosophical inclination came from the experience of participating in labour unions and a study, and then denial, of Marxism in and beyond his student years (Tahara and Sugeno 1988: 52). With an acquaintance with philosophy that is seldom seen among engineers, he tried to identify the position of *aimaisa* in the history of science in general. The problem of *aimaisa*, for Sugeno, can be traced to the French scientist and philosopher Blaise Pascal, whose contemplation of subjectivity assumes an alternative to Descartes' scientific methodology. For him, 'modernist rationality', of which Descartes' work is representative, has been so sweeping as to permeate all spheres of thinking, from mathematical sciences to Marx's materialism, economics, and to the theories of Darwin, Freud, and Chomsky. Both Marx and Descartes are incarnations of 'modernist rationality' as applied to society and science respectively (Sugeno 1979: 11-12; 1989: 19, 27-33).

Although the modernist rationality has been highly successful, its failure can be seen from the development of quantum mechanics and the revisionism that occurred

¹⁵⁰ Coincidentally or not, as was already mentioned in chapter 1, two books that try to combine modern physics with Eastern thoughts, Fritjof Capra's *The Tao of Physics* and Gary Zukav's *The Dancing of Wu Lin Masters*, were also published in the late 1970s (1976 and 1979 respectively). Interesting enough, Zubav's is a re-interpretation of modern physics through 'Wu Li', the Chinese translation of the term 'physics'.

in such fields as economics and biochemistry (Sugeno 1979: 12). The fact that fuzzy theory became popular is exactly another instance showing the bankruptcy of the modernist rationality. With an aim of deemphasising 'modernist rationality' in mind, Sugeno actively participated in round table discussions on fuzzy theory in the late 1980s. One of his discussions on it (with scholar of religion Nakazawa Shinichi, and prominent philosopher science Murakami Yōichirō under the subject of 'Fajyi and Modern Thought') was later included as a chapter in the book *Fajyi: The Development of a New Episteme*. In this way, Sugeno and others presented fuzzy theory as a restoration of subjectivity that had been dismissed in the West from the seventeenth century.

From 'Aimai' to 'Fajyi': The Retention of 'Aimaisa'

For Sugeno as well as for Terano, the research on 'aimaisa' of which fuzzy theory is a part is a restoration of human subjectivity in science and engineering (Sugeno 1979: 12; Terano 1988: 4). Also, the affinity between fuzzy theory and Japanese thought or more generally East Asian thought, is established by the way in which both are seen as emphasising a presumably shared quality – aimaisa; this affinity then serves as the explanation for why a smooth acceptance of fuzzy theory took place in this region (Sugeno 1989: 46-50; Sugeno, Nakazawa, and Murakami 1989: 84-85).

After the beginning of commercial operation of the Sendai subway, the holding of the Second Congress of the International Fuzzy Systems Association in Tokyo, and a subsequent 'fuzzy boom' in 1987, the transliteration of 'fuzzy', 'fajyi', has become much more frequently used in Japan than the former translation 'aimai' when referring to fuzzy theory. After the fuzzy boom, the theme of restoring human subjectivity was still referred to in books with the transliteration 'fajyi' in their titles (e.g. Sugeno 1989). Although Sugeno later differentiated aimaisa into several categories to which it applies and admitted that fuzzy theory, as a mathematical approach after all can only be applied to the category of language and concept (Sugeno 1989: 166; Sugeno, Nakazawa, and Murakami 1989: 86), 'fajyi' had largely inherited the philosophical status to which aimai was assigned in the earlier stage.

As the transliteration of 'fuzzy', 'fajyi' was for a time more specific than 'aimai' in spite of the philosophical status it received from the latter. However, through acquiring new meanings, 'fajyi' turned out to be a word which simultaneously meant less and more than 'aimai' did. This took place at the time when consumer products using fuzzy control went into the market, to which we now turn.

Chapter 6

The Cassette Effect: From 'Aimai' to 'Fajyi'

'Fajī-kun' (Mr. Fajī), a newly coined term that first appeared in the editorial column of Asahi News on December 27, 1990, was listed and defined in the 1991 edition of the yearly *Chiezō* (*The Asahi Encyclopaedia of Current Terms*).¹⁵¹ Adaptability to urbanization, the information society, and technology, as well as flexibility in attitude and action, were emphasized in the definition of 'Fajī-kun' (Asahi Shinbun 1990/12/27: p12). Although one of the meanings of 'fajyi' that bore a negative connotation, derived from the original word 'fuzzy' or its antecedent translation 'aimai', was also intended in phrases such as 'fajyi attitude' and 'fajyi election' (Tanaka and Ichihashi 1992: 17), a positive connotation of 'fajyi' was established among the general public. As two fuzzy researchers remarked, few words that came from science and technology enjoyed such wide popularity as did 'fajyi' (ibid: 17).¹⁵²

From the late 1980s, the word 'aimai' had become less frequently used when referring to fuzzy theory; in newspaper reports more frequently it was relegated to a space between a pair of round brackets located after the transliterated word 'fajyi' for which it offered an explanation. As was noted in the last chapter, as a phonetic rendering of 'fuzzy', 'fajyi' is written in katakana, which reminds readers of its immediate foreign origin, whereas 'aimai' is written in hiragana, implying its traditional character – although it also has a foreign, albeit much more remote, origin. But if a full equivalence of the word 'fajyi' in front of the parentheses, and the word 'aimai' housed in the round brackets, was assumed, why did the word 'fajyi' have to be used? This chapter tries to analyse how the word 'fajyi' entered the public scene, acquired new meanings there through a special narrative, and became a representation of some assumed characteristics.

Although fuzzy control had been applied to several products of consumer electronics and home appliances before 1990, the word 'fajyi' was not frequently

¹⁵¹ Although in Japanese 'kun' can be used to refer to friends or acquaintances, who are of about the same age to or younger than the speaker is, regardless of sex, it is predominantly used to refer to those who are male. Therefore I choose 'Mr.' as the translation of 'kun'.

¹⁵² Before fuzzy technology was frequently reported, in Japanese writing system, 'fajyi' (with a short vowel at the end) was the standard academic usage. Afterwards other variants of 'fajyi' appeared. For instance, 'fajī' (with a long vowel at the end) was frequently seen especially in the news; 'fajyī' (with a short vowel and a long vowel at the end) was also used sometimes. Information on this was obtained from the interview with Tanaka Kazuo. In this chapter, 'fajyi' will be used to stand for the transliteration of 'fuzzy' except for in quotes from Japanese materials.

used explicitly in promotional materials by manufacturers of those products. Fuzzy theory researcher Hirota Kaoru asked, by imaging a scene, what customers would think if they bumped into a camera new to the market with promotional copy which reads 'fajyi auto-focus?' They might translate it as 'boke auto-focus' if the equivalence of 'fajyi = boke' holds for them (as once one of the candidates for the translation of 'fuzzy', the Japanese word 'boke' means senile or defocusing). If so, then even saleable products become unsaleable (Hirota 1993a: 108-109). The case is the same if 'fajyi' was considered to be equal to 'aimai' (Mukaidono 1991: 15-16). There was even a joke concerning this issue of naming. The word 'fuzzy' bears negative connotations in English just as 'aimai' does in Japanese. It follows that, one way to keep fuzzy theory from attacks in the U.S. might be to substitute an unfamiliar word for fuzzy. If 'fajyi', as originally an unfamiliar word to Japanese people, can get rid off the negative connotations that the word 'aimai' is considered to have, how about substituting 'aimai' theory for 'fuzzy' theory in English (ibid: 16)?

However, in the year 1990, home appliances manufacturers began to use 'fajyi' explicitly for the promotion of their fuzzy-controlled products, and with those products hitting the market (Asahi Shinbun: 1990/11/30 p3), the word 'fajyi' won the gold award for the 'new word of the year'.¹⁵³ As Tobiōka Ken and Ōtsuka Keiichi, authors of a book on fuzzy logic for a general audience remark:

Some time ago 'fajyi' was translated as 'aimai theory', and a book titled 'aimai engineering' was published, but it (the word aimai) was not very remarkable. The reason why it was not popular is that, contrary to what it refers to, the meaning of the word 'aimai' itself is not ambiguous but clearly known. However, if the loanword 'fajyi', of the same meaning with 'aimai' is used instead, since to Japanese people its content is not known yet, it seems that people will be drawn to it out of a sense of its unknown mystery (Tobiōka and Ōtsuka 1991: 21).

The Cassette Effect

The above interpretation points to the 'cassette effect' consequent upon the creation of neologisms for translation, as put forward by Japanese translation theorist

¹⁵³ The yearly new words and popular words awards have been held since 1984 by a publisher, Jiyū-kokumin-sha. In the same year as 'fajyi' won the gold award for the new word of the year in 1990, the term 'bubble economy' won the silver award for popular words of the year. The new and popular words of each year since the award was given can be found at <http://www.jiyu.co.jp/singo/index.html>.

Yanabu Akira. Anthropologist Fukushima Masato sums up the ‘cassette effect’ as follows:

[A] neologism is attractive precisely because it is semantically empty. Like a good-looking cassette, the term fascinates its speakers by its sheer appearance as a term, insinuating that there might be something good in inside[*sic*], and its semantic emptiness paradoxically encourages its users to fill the semantic vacuum by projecting their images stimulated by the term itself (Fukushima 2005: 63)

Contrary to the common view that a word in the host language (the language doing the translation) is a practical but incomplete substitute for its counterpart in the guest language (the language to be translated), Yanabu argues that a cassette word (a word that induces the cassette effect) achieves a status in the host language as if it has acquired full meaning. Thus, the equivalence of a word doing the translation and a word that is translated can always be established, no matter what the context in which the translating word appears in the host language is (Yanabu 1976: 38-41).¹⁵⁴ Yanabu’s argument is therefore comparable to what translation theorist Lydia Liu claims: ‘Meanings...are not so much “transformed” when concepts pass from the guest language to the host language as invented within the local environment of the latter’ (Liu 1996: 26).

The ‘cassette effect’ of the neologism ‘fajyi’ is exemplified by responses of several women when they were asked about their impression upon coming across the word, by Tobiōka and Ōtsuka, authors of the quote at the end of the last section. Although few of the respondents knew the original meaning of the corresponding English word, what struck many of them about the word ‘fajyi’ was a feeling of softness and warmth given by it. Other replies included a feel of kindness and likelihood (Tobiōka and Ōtsuka 1991: 20).

That the cassette effect of the word ‘fajyi’ could ever be created was due to an effort made outside the circle of fuzzy theory researchers. As was shown in the previous chapter, in the practice of Japanese translation of mathematical terms, using Chinese characters or keeping original terms intact is typical. The gradual transition of the translation of the word ‘fuzzy’ from ‘aimai’ to ‘fajyi’ was consummated, not by an academic attempt to standardize its translation, but by a deliberate marketing strategy. Although in news reports on fuzzy theory or its applications, ‘aimai’ was still used to serve as an explanation of ‘fajyi’ even well into the late 1990s (e.g. Asahi Shinbun 1999/06/23 p2), the word ‘fajyi’ had already become widely known among

¹⁵⁴ Here the usage of host/guest languages is adopted from Liu (1996).

the general public through widespread advertisements of home appliances that utilized fuzzy control in 1990. 'Fajyi' is not simply a phonetic rendering of the word fuzzy in Japanese spelling system: the gap between 'fajyi' and 'fuzzy' is the space where the cassette effect of 'fajyi' resides. Full applicability of the concept of the cassette effect to the word 'fajyi', however, should not be expected. As was mentioned in the beginning of this chapter, the word 'fajyi' had also inherited from its predecessors, 'aimai' and 'fuzzy', meanings that former users attached to them.

In this chapter, I will try to explore the cassette effect of the word 'fajyi' through an examination of the design and advertising of the most famous home appliances that utilized fuzzy control – washing machines.¹⁵⁵ It was Matsushita Electric Industrial Co., Ltd. which first tried to apply fuzzy control to washing machines, and its product, 'Aisaigō (the model 'beloved wife') Day Fajyi', put on the market in February 1990 and an immediate success, was quickly followed by various home appliances manufacturers' similar products.¹⁵⁶

The Aisaigō Day Fajyi¹⁵⁷

As the first consumer washing machine model which had fuzzy inference rules installed on-board, Aisaigō Day Fajyi entered the market on February 1990. Before the washing machine, Matsushita had applied fuzzy control to a domestic hot water supply system which was put on the market in April 1989, and to a prototype robot vacuum cleaner for governing its moving path. The prototype of the former was put on the demonstration sessions in the second congress of the International Fuzzy Systems Association (IFSA) held in Tokyo in 1987, as mentioned earlier in chapter 4 (Mukaidono 1988: 70). The latter, however, did not go into the market because of safety considerations concerning the risk of hitting users and objects and causing injuries and damage. Inside Matsushita, fuzzy control was made known to various sections of consumer products design and production through presentations by researchers of its Chūō-kenkyū-jo (Central Research Laboratory).¹⁵⁸ The ease of

¹⁵⁵ For an analysis of advertisements in the history of computing, see Aspray and Beaver (1986).

¹⁵⁶ Established by Matsushita Kōnosuke in 1918, Matsushita Electric Industrial Co., Ltd. is now a large company of electronics and home appliances in Japan as well as internationally. It has created several brands for national and international markets, of which the most widely known worldwide is 'Panasonic'. In Japan it is also known as 'National'. 'Aisagō' has been a model name chiefly for washing machine by Matsushita since 1983. For a list of washing machine models by Matsushita since 1965, see http://national.jp/labo/history/product/house_hold/wash/chr_table/.

¹⁵⁷ Washing machine has become an indispensable appliance for families in Japan from the mid-1950s, as reflected by the fact that it was categorized, along with the refrigerator and the black and white television, as one of 'sanshu no jingi' (three sacred treasures) (Yoshimi 1999: 155).

¹⁵⁸ Nonaka and Takeuchi (1995, Chap 4) provide an example of product design and development

controller design by using fuzzy logic, as Yamakawa claimed by his inverted pendulum demonstration, was well acknowledged and promoted in these presentations.¹⁵⁹

Although the hot water supply system mentioned above was Matsushita's first commercial product to use fuzzy control, the word 'fajyi' was not used for marketing it. It was only with the Aisaigō Day Fajyi in which 'fajyi' appeared as a part of the name of the model that the word became a marketing strategy.

For the control of the Aisaigō Day Fajyi washing machine, fuzzy inference rules are applied to process data procured by sensors. In addition to the sensor that gives the information about the amount of clothes to be washed, a feature common for automatic washing machines, a phototransistor serving as a light sensor is mounted to the drainpipe of the Aisaigō Day Fajyi. Since it takes different time for muddy dirt and oily dirt to dissolve in water, different kinds of dirt can be differentiated according to the speed at which water pouring into the drum of the washing machine becomes muddy. The amount of dirt is informed by the same sensor according to its saturation level. Six fuzzy inference rules such as "if the saturation time is long, and the light-transmitting rate is low, then make the washing time much longer" are established according to the data acquired by the two sensors. It is claimed that such fuzzy control can save unnecessary washing time so as to save expenditure on energy and not to do damage to the clothes (Kondō and Kiuchi 1990: 112-114; Wakami 1991: 28-29).

Other large manufacturers of home appliances soon followed the example of Matsushita. In 1990, the same year in which Matsushita put the Aisaigō Day Fajyi on market, washing machines using fuzzy control produced by Hitachi, Sanyo, Mitsubishi, and Toshiba all appeared on the market. The ideas behind these products were more or less the same. That is, using sensors to procure data that is believed to be manifesting some properties of the clothes to be washed that are important to the washing cycle, and then applying fuzzy inference rules to process the data. For example, in the model that Sanyo developed, the inertia of the rotor under different loading conditions is provided by a photocoupler, which serves as the calculating basis to differentiate different types of fabric. These pre-processed data are then fed as one of the variables into fuzzy inference rules. The other variable is the weight of clothes (Kuraseko, Okada, Eihuku 1991: 29-30). Similarly, in the model that Hitachi developed, weight and types of clothes are the two variables monitored (Matsumoto

cycle inside Matsushita. For a sketch of the historical context of research organization in Matsushita in particular and in large corporations of Japan in general, see Morris-Suzuki (1994: 184-187).

¹⁵⁹ Kondō interview.

and Shikamori 1990: 493-494).

Aisaigō Day Fajyi led a fuzzy boom in home appliances beyond mere washing machines. Matsushita, Hitachi, Sanyo, Mitsubishi, and Toshiba, as mentioned above, were joined by Canon and Sharp to form a wave of companies applying fuzzy control to their various products: from video cameras, vacuum cleaners, air conditioners, heaters, microwave ovens, rice cookers, to dryers, etc. As the copy of a commercial by Matsushita reads, 'there are all kinds of fajyi products by National' (Japan Radio and Television Commercial Council 1992: 167).

At the corporate level, the fully automatic nature of Aisaigō Day Fajyi fitted well with the marketing concept of Matsushita: 'Human Electronics'. Proposed by its chief executive officer in 1986 as the umbrella concept for product design, 'Human Electronics' aimed to develop easily used products that cater for the needs of customers. Derived from the umbrella concept was the objective of applying 'humanware technology' that makes products more human-like, and fuzzy logic was deemed as one such technology (Nonaka and Takeuchi 1995: 111-115). The user-centred product concept was also emphasized by other manufacturers, and in the case of marketing the washing machine, it was claimed critical to cater to the needs of 'working housewives', i.e., those 'housewives' who are employed (Kuraseko, Okada, Eihuku 1991: 28; Matsumoto and Shikamori 1999:40; Wakami 1991: 27-28).¹⁶⁰ Their proportion to all 'housewives' in Japan increased from 45 percent in 1975 to 54 percent in 1988. As mainly responsible for domestic chores when off work, their much shorter time available for housekeeping than that of 'professional housewives' called for fully-automatic washing machines (Matsushita denki 1990).

That these washing machines which utilized fuzzy control appeared at the time when there was a perceived need for fully-automatic washing machines influenced the advertising strategies of the home appliances manufacturers. For example, Hitachi attached a slogan 'korekkiri botan' (once-and-for-all button) alongside 'fajyi' for advertising its fuzzy washing machines. The once-and-for-all button implies that there is no need for the customers to worry about anything – load, fabric, etc., – all of them will be taken care of automatically once the button is pushed.

The application of fuzzy control to washing machines was facilitated by the new sensors used alongside fuzzy control. That is, if it is the case, as their manufacturers claimed, that the fuzzy-controlled washing machines outperformed earlier models which were without fuzzy control feature, it can not be credited solely to the efficacy of fuzzy control without acknowledging the contribution of those new sensors.

¹⁶⁰ I adopt 'housewife' as the English translation of the Japanese word 'shufu'. In Japan, the word 'shufu' in which 'fu' means a woman, is predominantly used when referring to female homemakers.

Although this was well acknowledged by Wakami Noboru, a researcher of fuzzy control at Matsushita's Central Research Laboratory, to others the point had been deemphasized due to the advertising campaign for the efficacy of fuzzy control (Shin 1992: 51; Wakami 1991: 29).¹⁶¹

Advertisements of Fuzzy-Controlled Washing Machines

The cassette effect of the word 'fajyi' – a transliteration employed in the mass media – was furnished by commercials broadcast between programs on television and radio, and advertisements in print materials. In the following, I will put commercials and advertisements under scrutiny to see what was implicated in these materials in producing the cassette effect of the word.

That 'fajyi' won the gold award of the new word of the year 1990 owed much to the extensive advertising activities of home appliances manufacturers, among which Matsushita was not only the first to produce washing machines with a fuzzy control feature, but also the most innovative in its advertising strategy. Matsushita's set of advertisements for the Aisaigō Day Fajyi was one of a series promoting four products: washing machine, air conditioner, refrigerator, and microwave oven. The series featured as the catchphrases for the advertising campaign either the technologies applied or the names of some special parts of the products themselves (Tokuda 1990: 44). For the case of the Aisaigō Day Fajyi, in its two-paged newspaper advertisement, the most visible bold-typed phrase housed in brackets in the centre is 'fajyi washing machine'. Alongside the catchphrase, to the right of it lies the elaboration: 'the first smart washing machine that gets the subtle knack and intuition of human beings'. As we have seen at the end of chapter 4, human's knack and intuition had been emphasized as what fuzzy computers were able to imitate. What is more noteworthy here is that 'smart' (orikō) is attached as an encompassing feature of the washing machine.¹⁶²

¹⁶¹ Shin interview.

¹⁶² The Japanese word 'orikō' is a variant of 'rikō'. 'Rikō' is used generally for attributions like clever, bright, or wise. On the other hand, 'orikō' refers also more specifically to a child who is reasonable and amenable.



Fig. 6.1 Matsushita's advertisement for the washing machine Aisaigō Day Fajyi (Asahi Shinbun 1990/02/10 p16 and 17)

The 'smartness' is derived from a narrowing of a gap between machines and human beings, the gap characterized by knack, intuition, and experience – hardly measures of 'smartness' as far as human beings are concerned. The bridging of the gap is shown in a ready-made reply to a question, supposedly to be asked by targeted customers, about the meaning of the word fajyi. Located inside a small column in the far left hand side of the advertisement, it reads:

'Fajyi' is the computerized control *close to human senses*. It is not a control based on a simple answer derived from a piece of information, but on an overall judgement of much information – through which it realizes minute control with a method close to human experience, intuition or knack. Before now machines were unable to do this.

Subtle control is feasible. Those adopted 'fajyi' include, for example, the realization of computerized control in subway system that put veteran drivers' experiences to account. It is by now a theory commanding attention (Asahi Shinbun 1990/02/10: pp16-17, original emphases).

These technical explanations were complemented with a cultural account of the affinity between fuzzy technology and Japanese people. In another advertisement on

the meanings of the word fajyi, posted in magazines by Matsushita, the contrast of the word ‘iie’ (no) in white colour on a black background and the word ‘hai’ (yes) in black colour on a white background was used to highlight the boundary between the two extreme colours.



Fig. 6.2 Matsushita’s advertisement for its appliances with fuzzy technology on board (Tokyo Copywriters Club 1991: 194)

The title of the copy was ‘Fajyi – grew up in a country in which black and white are not clearly defined’. It reads:

The real answer in mind lies between ‘yes’ and ‘no’. That’s fajyi technology. Japanese people are, if anything, poor at answering ‘yes’ or ‘no’. However, the answer between ‘yes’ and ‘no’ is valued – it can be said to be Japanese-like. Fajyi technology is exactly so. The origin of fajyi lies in the idea to achieve a proper judgement on the basis not of ‘yes’ or ‘no’, but of a subtle sense between them. Matsushita has adopted this for washing machines and vacuum cleaners etc. and made them human-friendly. And we are now using fajyi technology to persistently make human-friendly products, in the hope of providing an answer closer to you between ‘yes’ and ‘no’. (Tokyo Copywriters Club 1991: 194)

Although the claimed Japanese cultural trait was mentioned in elaborating the meanings of fajyi technology, the word 'aimai', in which that cultural trait had been epitomized, was not seen at all; in contrast, a slogan 'orikō-fajyi' (smart fajyi), surrounded by an oval, appeared in an immediately apparent place. The cassette effect of the word fajyi depended to a large extent on a semantic hollow into which attributes such as human-friendly and smart could be filled. It seems to be difficult for the word 'aimai', which has negative connotations, to incorporate these attributes.

In the advertisements of the Aisaigō Day Fajyi, not surprisingly, a stereotypically gendered role in which women were assumed responsibility for doing laundry was used as narrative strategy. Therefore the main characters in these advertisements were generally 'housewives'. For instance, in the following spot advertisement inserted between radio programs, a conversation between a background voice and a 'housewife' is intended to say what a 'fajyi'washing machine is:

Characters: Housewife (H), Background voice 1 (B1), and Background voice 2 (B2)

H: Oh, this shirt is quite dirty.

B1: 'Quite'? To what extent is it dirty?

H: It has to be rather strongly washed.

B1: 'Strongly'? To what extent is it strong?

B2: National [the manufacturer] is thinking with nyūro-fajyi (neuro-fuzzy).

H: That's enough (original Japanese: iikagen) ...

B2: No,

B1: It's properly (original Japanese: yoikagen) ...

B2: Doing the laundry. National washing machine – Aisaigō (Japan Radio and Television Commercial Council 1992: 166)

The background voice 1 is practising a 'breaching experiment', known to social scientists by the experiments that ethnomethodologist Harold Garfinkel and students did to emphasize the role of common knowledge in facilitating everyday conversation (Garfinkel 1967: 35-75). By repeatedly asking the 'housewife' the meanings of adverbs she uses, the questioning of background voice 1 leads to a situation that background voice 2 can take advantage of: the 'housewife' is about to be angered by the breaching of an order in which meanings of adverbs are commonly shared in a language (i.e. Japanese) community. The responsibility of the breaching

of a linguistic order in the human world is imputed to the emergence of washing machines that National produces. Difference in conceiving the human/machine divide is the key that the advertisement plays with here: for the background voices, a washing machine can think like a human – understanding adverbs in this case – thus it breaks the order of human/machine distinction.

The order is then displaced by a pun. Here it plays with multiple meanings that Japanese phrase ‘iikagen’ has. It means ‘to a certain degree’, but can also be used in the meaning of ‘to a degree that is more than enough’ in a negative sense as a mild or strong reprimand. It also means a half-hearted, perfunctory, irresponsible, or vague attitude. In contrast, ‘yoikagen’ is used to refer to ‘to a certain degree’ with a positive meaning. The background voices nicely transform a mild reprimand (‘iikagen’ here can also be understood as ‘no kidding’ or ‘you are joking’) to an attribute with which the fuzzy washing machine is claimed to be equipped. The background voices reply to the reprimand ‘iikagen’ by pretending to understand it not by the meaning that the ‘housewife’ has in mind (‘that’s enough’), and deliberately explaining it as if the ‘housewife’ is referring to certain negative attributes of the washing machine, and transform it into positive meaning.¹⁶³

Similarly, the main theme of the following spot advertisement centred on the responsibility of a housewife for doing laundry:

Child: A dad is...

Dad: A child is, after all, the one who plays with mud all over.

Child: Because you’ve said this, I’ve got muddy when back home, but mom will...

Mom: Why you’ve got so dirty?

Child: See, I’ve made her angry. Um, I’m in trouble.

Background voice: Washing machines by National are equipped with scrubbing wash program. It’s OK even if the child gets muddy. But, now the house will be surrounded only by concrete (Japan Radio and Television Commercial Council 1992: 164).

The strategy of Matsushita’s advertisements for products using fuzzy control rested on the user-friendliness of those machines, which was said to be coming from the smartness of fuzzy technology – thus the slogan ‘orikō-fajyi’ (smart fajyi). As the above copy implies, that smartness would surely ease the burden of ‘housewives’

¹⁶³ The contrast stems from the difference between the adjectives ‘ii’ and ‘yoi’, respective part of ‘iikagen’ and ‘yoikagen’. Although both ‘ii’ and ‘yoi’ refer to something good, ‘ii’ can be used in a negative or sarcastic way in which ‘yoi’ can not.

through the washing machine's ability to distinguish different kinds of dirt to which it chooses proper washing programs in response. If this smartness would ease the burden of 'housewives', then it would also make the daily drill easy for men – stereotypically not the chore takers and not familiar with washing machines. This is exactly the advertising strategy of another manufacturer, Hitachi. In one of Hitachi's advertisements for its fuzzy controlled washing machine posted in magazines, a male figure on the upper side looks troubled by the question of how to choose a washing program:

A pair of pyjamas, five towels, and four T-shirts, the amount of clothes to be washed today, is it many or not? What fabric are they made of? Should I use the scrubbing wash program? Or the gentle wash program? How long should it take?...such and such.



Fig. 6.3 Hitachi's advertisement for its fuzzy washing machine (Tokyo Copywriters Club 1991: 194)

The same figure on the bottom, however, looks relieved by finding the solution: 'it is easier just pushing the button than worrying'. This refers to Hitachi's slogan for its fuzzy controlled washing machines: the 'once-and-for-all button' (korekkiri botan) (Tokyo Copywriters Club 1991: 194). Similar to Matsushita's advertisements, the theme that 'fajyi' is akin to human-friendly was also utilized by Hitachi for promoting neuro-fuzzy technology, epitomized in this case by the 'once-and-for-all-button'. The theme was also exploited in the following

advertisement:



Fig. 6.4 Hitachi's advertisement for its neuro-fuzzy washing machine (Tokyo Copywriters Club 1992: 166)

The title of the copy reads 'You are giving care (to your work) to the extent that I am sorrowful':

Shift of stain, and washing time

Remaining amount of detergent, and rinse condition

Washing programs that fit fabric types

And spin-dry condition, and amount of water...

You are by yourself monitoring all these

I incline my head forward

Impeccably thinking towards the goal, oh!

You are giving care to the extent that I am sorrowful

Quiet and rigorous figure when at work
Although receiving nothing
You are so diligent

Dear washing machine
How closely you are
To follow human beings?

To what extent, if that exists
Even if you do not change from the form of a machine (Tokyo Copywriters Club
1992: 211)

Concluding Remarks

As such, through the promotion of fuzzy-controlled home appliances, 'fajyi' had acquired meanings that are akin to smart or human-friendly. Moreover, it was through these promotional campaigns that an idea of 'fajyi' as representing the ability of judgement, a crucial attribute of human beings, was instilled into the minds of a general public. This can be shown by an article which appeared in the reader's column in Asahi Shinbun.

The title of the article is 'A horrible generation that doesn't know "fajyi" – present-day youngsters'. The author, a female civil servant, complained about the response she got when she asked a student neighbour to turn down the volume of his/or her stereo. The student replied, put up with it since you also make noise! The author grumbled that she did not ask the student not to make any sound at any time, but the student could only think of either a total freedom or a total restriction. She commented that the student was lacking the ability to judge under these circumstances, and that young people in the workplace thought in the same way. She noted that this way of thinking was common among contemporary youngsters and it resulted from the fact that they were brought up without being given chances to judge by themselves. For the author, the meaning of 'fajyi' appears to be coming from advertisements of home appliances, as she said that home appliances had already been installed with the 'fajyi' function to have the ability to do what in the past could only be done by people, the ability that 'veteran housewives take into consideration of the circumstances'. In summing up her point, she lamented that 'fajyi' has been taught to computers but at the same time we have taken away 'fajyi' from our children (Asahi Shinbun: 1993/03/01 p12).

Through the mass media, the word 'fajyi' was associated with attributes such as smart, human-friendly, and having the ability to judge and make right decisions. As the above example shows, being 'fajyi' had become a significant measure of humanity. Since we have delegated part of our discretionary power to these machines, the technology on which these machines were based, then, had brought into sharp relief that part of the discretionary power that we have renounced. This is the moral lesson 'fajyi' gave, in terms of ideas on the human/machine divide.

Chapter 7

Conclusion

As was noted in the previous chapter, in 1990 the word 'fajyi' won the gold award for the new word of the year. In the same year, the term 'baburu keizai (bubble economy)' won the silver award for the most popular words of the year. This latter term is used to refer to the period of economic boom that spanned from 1986 to 1990 in Japan. The first fuzzy boom also occurred within that period, with the second fuzzy boom occurring when the economic boom was about to come to an end. This period was succeeded by 'the lost decade' of economic recession; the bursting of the bubble in 1990 influenced many things, including the personnel and resources available for Japanese fuzzy research. The remark of a university professor made vivid the impact of the end of bubble economy on academic life: 'in the late 1980s there were many postgraduate students coming to my lab to pursue fuzzy research...in the early 1990s, however, with the burst of the bubble, all corporations cut their budgets for research – including fuzzy research'.¹⁶⁴

The second fuzzy boom, characterized by the extensive application of fuzzy control to home appliances and consumer electronics, was so strong that it was 'as if home appliances couldn't do without fuzzy' (Nakayashiki 1993: 2). As the fuzzy bandwagon was gathering speed, criticisms by those who were already aboard also began to emerge. As early as the latter part of 1990, Terano Toshirō, former professor of TIT and one of the few Japanese who had initially promoted fuzzy theory, warned that many consumer products that utilized fuzzy technology could do without it. The existing state of affairs went contrary to his idea of how fuzzy technology should be used: which should only be for those cases that could not do without it (Terano 1990: 26). Disagreements on the appropriateness of utilizing fuzzy technology, as well as reports on the decline of the boom in its use, can be seen in the news reports from 1991. For instance, Matsushita Electronics Co. introduced a review measure to assess whether fuzzy technology and the term 'fajyi' were pertinently used for candidate products (Asahi Shinbun 1991/06/08: p8), and it was reported that testing of fuzzy washing machines produced by major manufacturers showed that differences in performance between these and other automatic washing machines lacking fuzzy technology were insignificant (Mori 1993; Asahi Shinbun 1991/11/14: p19).¹⁶⁵

¹⁶⁴ Hirota interview.

¹⁶⁵ A test on fuzzy rice cookers, washing machines, and vacuum cleaners conducted from the viewpoint of users showed that, performances of those machines, far from being relatively independent of users' choices of programs and procedures, as promotional copies of them imply,

These were preludes to the fading from public sight of the term 'fajyi'. The media coverage on fuzzy-related news shrunk quickly after 1991 (Sangalli 1998: 35). Instead, coverage was redirected to those sciences and technologies which came after fuzzy technology, such as neural networks and chaos theory (Nakayashiki 1993: 2)

The gradual abatement of the fuzzy booms, and the decrease of corporate funding for fuzzy research due to economic recession, eventually led to the changes in name of the Japan Society for Fuzzy Theory and Systems (SOFT) and its official journal, *Journal of Japan Society for Fuzzy Theory and Systems* in 2003. In its incipency in early 1990, the society had had about a thousand members, around fifty of which were corporate members. The number rose quickly to over 1,900 in 1991, and reached and remained at an apex from late 1992 to early 1994 with a figure of over two thousand, about one hundred of which were corporate members. After that, the membership decreased gradually to about 1,400 in late 2001. The number of corporation members decreased substantially to less than thirty. If those who did not pay membership fees were not taken into consideration, acting members numbered about one thousand in late 2001 (Hirota 2002). It is against this background that a change in name for the society was proposed. With the acronym of the society remaining unchanged, the name of the society changed to the Japan Society for Fuzzy Theory and Intelligent Informatics. The official journal also gained a new title, with *Intelligence and Information* added before the journal's old name (Hirota 2002). That the new title catered to a broader range of interests of AI and computer science researchers implies that the word 'fuzzy' had ceased to be attractive to those researchers, or according to the comments that Hirota Kaoru heard from some other fuzzy researchers, fuzzy research 'has been established',¹⁶⁶ where 'established' is a euphemism for 'finished'.

Whether this really marks the end of fuzzy research in Japan remains to be seen, but what is clear is that the Japanese context did provide a distinctively different setting in which this specialty prospered for a while. This success came especially when industry took up the fuzzy approach after it had been pursued in academic circles for about a decade. For fuzzy research both in academic circles and in industry, language and the translation of fuzziness into Japanese were central.

What's in a Name: Translating Fuzzy Research into Japanese

As was mentioned in Chapter 5, translation is a critical theme in the travelling

depended heavily on users' decisions (Mori 1993).

¹⁶⁶ Hirota interview.

of fuzzy theory from the U.S. to Japan, and its subsequent development in Japan. This, among other things, can be seen from the interpretation of the popularity that fuzzy theory enjoyed in journalistic accounts. It has been argued that an affinity between fuzzy theory and Japanese thought styles resulted in the smooth acceptance of fuzzy theory in Japan (McNeill and Freiburger 1993). However, this affinity is itself partly a consequence of translation. As we have seen in chapter 5, 'aimai' is often seen as a noted feature in Japanese language and in the behaviour of Japanese people. The choosing of the word 'aimai' by Terano Toshirō to translate 'fuzzy' contributed to the perceived affinity between fuzzy theory and Japanese thought styles.

For fuzzy research, the name matters. Imagine if Zadeh had used a more technical term, akin to 'multiple-valued' or 'multi-valued' for example, instead of the word 'fuzzy' to describe his conceptual innovation in set theory. Certainly, at least some of the criticisms mentioned in chapter 2 might not have been levelled at him.

The name matters, too, in Japan, in a double sense. Like the word fuzzy, 'aimai' is colloquial, and both have negative connotations. However, not only did Terano add more into the word 'aimai' than simply transporting fuzzy theory to Japan, but the very meaning of the word 'aimai' in the context of Japanese language, in turn, had an influence on the interpretation of fuzzy theory. As we have seen in chapter 3, in the early years of fuzzy research in Japan, Terano saw fuzzy theory as one of the tools in the toolbox for handling his concern with system engineering. Yet, he used the word 'aimai', presumably the Japanese substitute for the word 'fuzzy', as an encompassing term for his concern. The result, aimai engineering, not only incorporated fuzzy theory as one of its components, but also included those qualities not processable by computers that were beyond the scope of fuzzy theory. Terano's broad concern with systems engineering led to the wide spectrum of participants and seminar themes of the working group that he and Shibata Heki, former professor of the University of Tokyo, formed. This can be shown, for example, by the research on face graphs in expressing results of multivariate analysis, one of the main themes often seen in the seminar series of the Working Group on Fuzzy Systems. Although the origin of face graphs can be traced to Chernoff, a U.S. scholar, it was pursued in Japan and seen as a useful tool to serve as the interface between humans and machines, thus fitting in well with the broad concern of aimai engineering.

If 'aimai' served to broaden the scope of fuzzy theory for a academic audience, then 'fajyi', the transliteration of 'fuzzy' and successor of 'aimai' helped to promote fuzzy control to the general public. In chapter 6, the cassette effect of fajyi is investigated. The cassette effect allows users to project meanings onto newly created

words for translation. The cassette effect of fajyi was reinforced by the meanings provided in the advertisements for those home appliances that implemented fuzzy control as a feature. Through the mass media where these advertisements were shown, the word 'fajyi' was not only associated with meanings inheriting from aimai and fuzzy, but more significantly was associated with meanings akin to smart, human-friendly, and having the ability to judge.

From Academic Circles to Industry: The Shift from Theory to Application

In the early years, when fuzzy theory remained an academic enterprise, the kōza system played an important role in sustaining fuzzy research, although in rather different ways in Tokyo and Osaka, respectively. At TIT, Terano, professor of the systems theory kōza, promoted fuzzy research vigorously, and helped foster a research group in his kōza. His post later went to Sugeno Michio, a person with a strong theoretical inclination. Terano, Sugeno, and students made TIT a hub of fuzzy research. On the other hand, in Osaka, both the research scope and the extent to which kōza professors engaged in fuzzy research were different from those in Tokyo. Research in Osaka, although it included the application of fuzzy theory in wide areas such as automata theory, information sciences, and operations research etc., tended to follow the international agenda to a larger degree. Research along these lines was largely theoretical – often seen as analogous to unpractical, aiming for explications of the properties of proposed fuzzy systems. In contrast, research in Tokyo had a broader agenda under the name of aimai engineering.

The change of research interests of Tanaka Kōkichi, a powerful kōza professor in Osaka, to symbolic artificial intelligence, as we have seen in chapter 3, partly resulted in the postponement of forming the Fuzzy Science Research Association in Osaka. This again shows the important role the kōza system played in the development of fuzzy research: in Osaka, the divergence in interests between the early fuzzy researchers such as Asai and Mizumoto, and their kōza professors, led to the diffusion of fuzzy research to less prestigious universities.

Fuzzy research in Japan in the early years fits to some extent the way Whitley characterizes the fields of engineering and artificial intelligence, where (1) technical task uncertainty is low, since techniques and skills required were commonly seen in neighbouring specialties; (2) strategic task uncertainty is high, because intellectual priorities and goals are rather varied; (3) degree of functional dependence is high, because researchers have to use the results of other fellow specialists; and (4) degree of strategic dependence is low, since there is little need for one to convince others of

the centrality of one's approach (Whitley 2000). However, although material and resource requirements for early fuzzy research were low, and the *kōza* system in general serves to lower strategic dependence because it provides evenly distributed funding to each *kōza*, since fuzzy research had to compete for reputation with systems science, and especially with symbolic artificial intelligence, strategic dependence for early fuzzy research was not that low.

The application of fuzzy theory to control systems allowed fuzzy research to go beyond the confines of the *kōza* system which distributes reputational rewards in academia. In the late 1970s, the English researcher Mamdani, who first applied fuzzy theory to control purposes, was invited to TIT as a visiting scholar. As we have seen in chapter 4, the promotional effort by Sugeno Michio played a significant role in realizing two large scale civil projects of fuzzy control – the water treatment control system developed by Fuji Electric Co., and the automatic driving control of the Sendai subway trains initiated by Hitachi. In the demonstrations in fuzzy control undertaken by Yamakawa and others, the efficacy of fuzzy theory was demonstrated through the operations of the 'fuzzy computers' that were in charge.

The three cases analyzed in chapter 4 capture the process of a gradual change of emphasis to knack or intuition over mathematical modelling in the design of fuzzy controllers. Both Fuji's fuzzy controller for water treatment process and Hitachi's automatic train operation (ATO) system depended on extracting skilled operators' knowledge for controller design. As we have seen, in the case of Fuji's controller, fuzzy control was applied as a complement to a statistical model based on data collected from past operations. In the case of Hitachi's fuzzy ATO system, in contrast, the design of the fuzzy controller depended more fully upon constructing 'fuzzy IF-THEN rules' from drivers' knowledge. In the case of Yamakawa's inverted pendulum, moreover, far simpler rules were constructed according to the everyday bodily knowledge of a general person. If the working of the first two cases brings to the fore the pre-eminence of skilled operators' knowledge over mathematical modelling, the third case extended that pre-eminence to cover everyday practices, adding an esoteric colour to them – explicitly in the name of knack or intuition.

This emphasis on knack or intuition in designing fuzzy controllers was reminiscent of the history of control engineering before 1940 when a gap existed between theory and practice, or, to use the deductive/inductive distinction, between deductive and inductive cultures of proving (MacKenzie 1996; 2001). Although mathematical, deductive approach 'can claim to cover all cases' and offers proofs to stability criteria (MacKenzie 2004: 70), in practice, design relied on experience and emphasized workability.

However, the first two cases and the last case mentioned above differ in the ease with which control theory addresses them. As we have seen in chapter 4, industrial processes that rely on the control of skilled operators are difficult for the modelling approach. The water treatment plant precisely falls into this category. On the other hand, ATO systems have been the application area of the modelling approach. The last case, the inverted pendulum, has also been dealt with by the modelling approach. Moreover, unlike the first two cases, in which stability is not a goal of control, stability is the major concern of the inverted pendulum problem in control engineering. It is against this background that Yamakawa's demonstration became a disputed experiment for some leading Japanese control theorists. The concern of these control theorists with stability ran parallel to an academic trend that saw stability of fuzzy systems as a major issue. Therefore, while on the practical side, demos provide instances of an inductive culture of proving, on the academic side, a deductive culture of proving emerged in the area of fuzzy control.

Reflections on Research Process and Findings

In the following sections, I will try to clarify some conceptual and methodological issues concerning the presentation of this thesis. They will be dealt in three parts. Firstly, I will clarify the overall conceptual model which links the three theoretical perspectives that I used to analyze the development of fuzzy logic in Japan, and discuss the applicability of this overall conceptual model. Secondly, I will reflect upon research design choices by addressing the question of how the cases in this thesis were chosen. This question will be dealt by discussing a methodological issue concerning case studies. Lastly, I will clarify the application of the concept of (inductive/deductive) cultures of proving to demarcate the two sides of the controversy presented in chapter 4, by considering local epistemologies of the actors who were involved in that controversy.

Overall Conceptual Model

In this section, I will show that the overall conceptual model of this thesis can be stated as the differentiation of the trustworthiness in the audience of the claims of fuzzy logic. Seen through this conceptual model, the three periods can be characterized in terms of evaluation criteria that the main audience used respectively. While the evaluation criteria moved from theoretical, to technical, and to cultural ones, thus reflecting the concerns of larger and larger audiences (those in the

academy, in industry, and in the public), I will show that theoretical concerns were still underway in the second period. In discussing the applicability of the conceptual model, I will point out that, as a unique contribution, the third stage of the model can deepen our understanding of the cultural production of AI-related fields in Japan.

As was set out early in chapter 1, the analytic angle of this thesis takes the development of fuzzy logic research in Japan as a popularization process, in which three successive periods are analyzed with regards to the ways fuzzy logic reached a growing audience. Different theoretical perspectives are utilized to characterize the distinctiveness of the three corresponding periods. These perspectives are informed by the theory of scientific organizations, work on demonstrations and proofs, and translation studies.

The three perspectives were used to analyze the most salient activities of fuzzy logic research in the three corresponding periods. Although they seem to be somewhat distant from each other, they nevertheless share a main theme that runs through the thesis and holds the three parts together. That is, the trustworthiness in the audience of the claims made by researchers as well as promoters of fuzzy logic.

In the first period, the audience was mainly from the academy. Research in this period was carried out by using a common language of system theory. Research articles usually had formal inference as their presentation format: with proofs obtained through manipulation of mathematical symbols. In the second period, a substantial research effort was devoted to technical demonstrations in order to show the usefulness of fuzzy logic to practical engineers. In the third period, new meanings were produced about fuzzy logic in order to convince a broader audience about its efficacy.

The audience in the three spheres, namely those in the academy, the engineering circle, and the public, differed in their concerns about fuzzy logic and their ability to evaluate the claims made by researchers regarding fuzzy logic. In the early years, as we have seen, researchers as well as debunkers of fuzzy logic had similar mathematical skills, skills broadly shared by those who practiced system theory. Therefore, differences in mathematical skill were not at stake; the issue was rather a kind of conceptual choice. Therefore the organization of science, epitomized in the form of the *kōza* system in this case, played a significant role in the early years of fuzzy logic research. As we have seen in chapter 3, the limited but enduring influence of the *kōza* system formed a protection belt in TIT, but led to a diaspora of researchers in the Osaka region.

In the second period, as fuzzy logic moved beyond the academy into the engineering circle, significant efforts were put into the prototyping and the building

of real systems. Technical demonstrations and large-scale working exemplars were used for promotion. The evaluation of the claims regarding the efficacy of fuzzy logic by practical engineers, as shown in the case of the Sendai subway system, was based on some technical, instead of theoretical, criteria.

The significance of the differences in the evaluation criteria can be shown by the case of Sugeno Michio, a theory-oriented researcher and also a keen promoter of industrial applications. In Japan, the industrial exploitation of fuzzy logic, just as the theory of fuzzy set itself, was an imported one. When he first heard of E. H. Mamdani's application of fuzzy logic to control in the mid 1970s, Sugeno was doubtful about its practicality. At that time, Sugeno took the position of a control engineer, and shared with those control theorists who some fifteen years later would criticize Yamakawa's demonstration the view about how control engineering should be done: 'I was working at control engineering, you see, we use plant models and we make stability analysis...[Mamdani] worked at electrical engineering, but he liked fuzzy logic, and he just wanted to apply Prof. Zadeh's idea. If I were him, I wouldn't apply fuzzy logic to control'.¹⁶⁷ The hesitation to apply fuzzy logic to control, as Sugeno claims, was overcome due to the criticisms of fuzzy theory he met when he was in Europe. These criticisms turned him into a promoter of fuzzy control application.¹⁶⁸

Sugeno's involvement in fuzzy control, as was shown in chapter 4, led directly or indirectly to the two large scale civilian applications. One of them, the Sendai subway, even featured as the key application in 'the first fuzzy boom' triggered by the Second IFSA (International Fuzzy Systems Association) Congress held in Tokyo in 1987.

On the one hand, the application of fuzzy logic to control, which made possible the first fuzzy boom, attracted a much larger audience than in the earlier period. It therefore fostered a tie between academic researchers and corporate engineers. Academic researchers would become consultants for industrial applications, and serve as supervisors to corporate engineers' thesis PhDs. This was shown in the case of Itō Osamu who developed Fuji's fuzzy controller for water purification process with the help of Sugeno. The emergence of applications was also reflected in the increase of journal articles that were devoted to the design and simulation results of fuzzy controllers.

On the other hand, as we have seen in chapter 4, the development of applications in control also facilitated the advancement of theoretical discussions

¹⁶⁷ Sugeno interview.

¹⁶⁸ Sugeno interview.

regarding fuzzy control. This was even more so after Yamakawa's demonstrations, which prompted some control theorists to make strong responses in journal articles.

The effect of industrial exploitation, overall, was to expand the reach of fuzzy theory to a wider audience. One could therefore question whether the organization of science continued to be important in the second period. Did its significance dwindle because criteria of evaluation in academic work and in engineering practicalities were different? To some extent the answer is yes. However, the organization of science was still important for those who worked with a more academic concern. This can be shown by the handling of the stability issue. Research in the so-called Takagi-Sugeno model was pursued by Sugeno and several students for several years. As the issue was somewhat detached from industrial concerns, Sugeno assigned the theoretical work to those students who followed the route of a PhD with coursework, not a thesis PhD.

At the same time the industrial exploitation allowed for the building of the research community with a wider base. Were it not for the exploitation of industrial potential of fuzzy logic, the demonstration sessions in the second IFSA congress would not have been possible, nor would the so-called 'fuzzy booms' that came immediately after. However, the academic criteria were still pursued according to the principles of the organization of science. As Sugeno said, 'I thought stability was the last subject of the fuzzy society, so we must solve it'.¹⁶⁹ The importance of the *kōza* system continued even after the fuzzy booms. Although there were many more researchers in the universities in the 1980s than there were in the 1970s, fuzzy logic researchers remained few, if not none, in the most prestigious universities such as Tokyo University and Kyoto University. This direct outcome of the working of the *kōza* system made the current situation not very different from that in the earlier period.¹⁷⁰

It was also in the process of industrial exploitation that fuzzy theory came to carry with it a cultural tinge. Through the promotion effort initiated by Terano since the mid 1970s, industrial applications took on an interpretation of fuzzy control as exploiting human's knack and intuition, instead of explaining them in terms of mathematical modelling- an interpretation favoured by control theorists. As we have seen at the end of chapter 4, the theme of the blurred distinction between human and machine emerged in the advertisements of industrial controllers. It was also associated with Japanese culture, and with the meanings that are akin to smart or human-friendly. Although Terano, followed by Sugeno, began to give fuzzy theory a

¹⁶⁹ Sugeno interview.

¹⁷⁰ Umano interview.

cultural interpretation since the mid 1970s, the interpretation was usually substituted with a more technical language in control theorists' identification. Only in books for the general public or in advertisements can this kind of interpretations be expressed without receiving much scrutiny. The role the public played therefore became significant after industrial exploitation took place.

Is the overall conceptual model, that is, the differentiation of the trustworthiness in the audience of the claims, from the academy to the industry and to the wider public, applicable to other emerging research fields? For the transition from the academy to industry, I think similar cases can well be found in history and sociology of technology. The third stage of the model is quite distinct because of its cultural specificity.

It is unique in the sense that it has to do with Japanese translation of foreign words, which has a long and complicated history. This history can only find parallels in areas which also utilize Chinese characters. In other words, although the theme of the blurred distinction of human and machine is quite common in AI related fields over the world, the long, complicated history of Japanese translation of foreign terms makes it difficult to find western counterparts to the case of fuzzy logic research in Japan.

On the other hand, however, if we take translation in broader terms, the case of fuzzy logic can be put alongside other AI-related fields in the Japanese context. A suitable case in point is robotics. Just as fuzzy researchers have associated *aimai* with Japanese characteristics, so too the proliferation of humanoid robots in contemporary Japan is said to be rooted in the tradition of making automaton ('*karakuri*' in Japanese) puppets in the Edo period (1603-1867): 'It goes without saying that the automaton puppet was the prototype of the robot that is said to be flourishing in industrial Japan today. In a sense, we can say that Japanese learnt to tame the machine by means of the *karakuri* puppet because they consider the puppet an extension and copy of the human figure, not as something sent by demons or animated by the divine' (Yamaguchi 2002: 78). As the above quote shows, 'polytheistic and animistic views of nature' are usually provoked to explain the omnipresence of humanoid robots in Japan (Ito 2003: 2). However, as Ito's analysis shows, 'attempts to naturalize robotics technology' by tracing the root of contemporary Japanese robotics to automaton puppets in the Edo period is clearly at work (Ito 2003). Therefore, the third stage of the model, which makes this thesis specific in cultural terms, presents a contribution to a case in a comparative framework of analyzing the cultural production of AI-related fields in Japan, and potentially other Asian countries.

Research Design Choices

In this section, I will reflect upon how cases in this thesis were chosen. I will present the original research design, discuss the difficulty in carrying out the original design, and present the revised design. By way of discussing a methodological issue concerning case studies—the problem of ‘case’—I will show that, while the new design does not explore the ‘user’ side of technology in great detail, it avoids the risk of losing sight of the larger picture, and opens a door for analyzing cultural interpretations of fuzzy logic—which, as I mentioned in the last section, makes a unique contribution.

The aim of understanding the process whereby fuzzy logic developed in the Japanese context required a particular research design. Because the composition of the audience differed in different periods of fuzzy logic’s development in Japan, it was necessary to adopt an approach that could follow the development. Simply to focus on one area (such as the universities or a particular industry) would have missed the larger picture.

However, it was also necessary to keep the scope of the research within practical limits and to overcome the challenges of obtaining data in some areas where there is only limited possibilities of access. The most fruitful research methodology proved to be through initial contacts with some well-known fuzzy logic researchers, and then to follow the development of fuzzy logic in Japan through several key applications and controversies. Because of their importance in the development of fuzzy logic in Japan, I relied largely on accounts of those who developed two large civilian applications and a well-known controversial demonstration. In addition, to understand how fuzzy logic was popularized, I studied the marketing strategies and advertisements for fuzzy technology applications produced by large corporations. Audiences and consumers of these accounts and advertisements were not consulted in a notable way. In other words, this thesis does not explore the ‘user’ side of technology in great detail.

The methodological issue involved here can be discussed through comparing the difference between an in-depth case study, and several case studies as this thesis has done in chapter 4. As was mentioned in chapter 1, I carried out a pilot study on the Sendai subway system developed by Hitachi. The rationale of the original research design regarding the Sendai subway system was the following. The peculiarity of this case lies in that it was a large civilian application of fuzzy logic which would later become a precursor for many following applications. Besides the

issue of historicity, the Sendai subway system is sociologically significant as well. As a civilian project, the issue of safety of a new technology is involved, and it can be placed in a theoretical context along with abundant sociological research on technological controversies and risk. The literature reveals that the implementation process of the Sendai subway system underwent several years of negotiation before its operation. The case, therefore, can be put into a comparative framework regarding the adoption of new technologies. The other suitable case in this comparative framework is the subway system in Sapporo. It was also developed by Hitachi, and the novelty of the Sapporo subway lies in its fully automatic feature by using traditional PID control. If we conduct the comparison, we might be able to know whether the criteria of the negotiation process have anything to do with the differences between fuzzy control and PID control. Thus, it serves as a foil to explore the extent to which technology resulting from fuzzy technology was deemed differently from other kinds of technology. Moreover, we could also use some sensitizing concepts such as 'variations in attitude towards different new technologies' to explore the attitudes of researchers involved.

This research design could also have been extended to include several in-depth case studies. If we had been in a position to conduct the above kind of comparison for a substantial amount of cases, time permitting, it would be possible to make inferences qualitatively from several case studies to the collective attitudes toward fuzzy logic. On the aggregate level, a combination of several in-depth case studies offers an account on the development of fuzzy logic in Japan from the users' viewpoints, and has the potential to serve as a commentary to those claimed merits of fuzzy logic by promotional efforts. It can also deepen our understanding of proliferation process of fuzzy logic that goes beyond an account that merely bases the popularization of fuzzy logic on counting up the number of applications being developed.

However, an in-depth case study or a combination of several in-depth case studies of the development and implementation process of fuzzy technology risks losing the status of a proper case of fuzzy logic. In other words, since a case study of that process would consist of various kinds of actors, a problem arises as to whether it is still a case study about the relative significance of fuzzy logic or just a case about institutional negotiations of a new technology. In other words, what is the exact place of 'fuzzy logic' in the proposed case study?

This brings us to the problem of the case in case studies. That is, is the case chosen for a case study a representative one or simply a unique historical event (Walton 1992: 131)? The issue is even more perplexing given the idea of historicity.

If we adopt the viewpoint of historicism (Wieviorka 1992: 169), then a historical case would be the ultimate goal of this research in its own regard, “idiographic” as historians have named it (Goldthorpe 1991: 211). The case is not self-evidently a historical case only because it is a past event. Neither is its sociological relevance predetermined. The question also involves the kinds of evidence we are looking for. A mere historical narrative account of an event or series of related events does not constitute a case in its own right (Blaikie 2000:217). On the other hand, since research generates data, evidence can be unduly produced according to the need of whatever theory is in hand, or in other words the problem of ‘forcing fit’: to “‘force-fit’ the data to the theory’ (Vaughan 1992: 195). From this perspective, a detailed contemporary case study of the adoption of fuzzy technology using ethnographical approach, for example, might shed some light on the intricacies of the innovation process. However, since this thesis is concerned with fuzzy logic in the past (although a quite recent past), a contemporary case study might not catch the kind of novelty that fuzzy technology had brought to bear on the cases in the 1980s and 1990s.

My pilot study of the Sendai subway system, although fruitful in terms of the data obtained, manifested the difficulty of pursuing further research following the original research design because of a practical issue: it proved difficult to access data on testing and simulation results. On the other hand, interview data from the pilot study also revealed that there might not be a long negotiation process as shown in some literature sources. When I tried to rethink the research design, the production of cultural accounts about fuzzy logic came into view. As the novelty of the Sendai subway system became a productive site of cultural accounts, I put it in a revised framework for analyzing the interpretations of the efficacy of fuzzy technology.

The other two cases in chapter 4 were chosen also because of their novelty. They not only attracted much attention and comments, but also were followed by many applications of similar kinds. Just as the Sendai subway system has descendants running at the Tokyo underground, the Fuji controller for water treatment represents a typical case of those fuzzy technologies that were applied to industrial processes. On the data collection level, more literature on them could be found than those on other less well-known small-scale applications. Although, as I alluded to earlier, data such as testing or simulation results of these applications were not accessible due to industrial secrecy or other considerations, substantial information about them were collected by acquiring literature and interviewing key persons.

Yamakawa’s demonstration also had follow-ups that were put on show in

conferences workshops. The commentaries of control theorists on Yamakawa's demonstration make it the most significant case of controversy about fuzzy logic found in Japan. The case shares with the Fuji controller and the Sendai subway system an interpretation of fuzzy control that emphasized its ability to imitate human's knack and intuition. Moreover, it provides a more complicated picture of the development of fuzzy logic research in Japan. In particular, the controversy shows the difference between groups of academic researchers in evaluating fuzzy logic, and serves as a commentary to the promotional interpretations offered by fuzzy researchers regarding fuzzy technology.

To sum up, the way that case studies in this thesis were conducted makes it difficult to understand the complex process involved in the adoption of a new technology due to difficulties in accessing certain data. These case studies, however, show a largely coherent production of interpretations of fuzzy technology by the fuzzy research community, and a difference in views within the academy.

Local Epistemologies

In this section, I will discuss the application of the concept of (inductive/deductive) cultures of proving. Using an article by historian of science Simon Schaffer as starting point, I will use interview data to explore the epistemologies of the actors in the controversy presented in chapter 4. While variations in actors' epistemologies add nuances to the picture, they do not demolish the usefulness of the concept of cultures of proving. Resorting only to demonstrations without offering analytic proofs characterizes the inductive culture of proving, in contrast to the wider range of techniques that deductive culture of proving is equipped with.

Differing interpretations of fuzzy control by fuzzy researchers led to a controversy about Yamakawa's demonstrations on the inverted pendulum. The case can be said to be the most significant case in terms of controversies of fuzzy logic in Japan because it left a traceable trajectory in written form in professional journals. According to my interview data, such an overt form of criticism is not very frequently seen in academic circles in Japan.

The controversy brought into sharp relief the emphasis put on the differences between fuzzy control and control theory. In chapter 4 I used the distinction of induction/deduction to characterize the two camps, and thought the distinction satisfactorily encapsulates two cultures of proving to which the two groups of researchers belong. However, as it was also noted in chapter 4, a wide range of

available techniques in control engineering would defy the distinction. Therefore some clarifications should be made here regarding the distinction of inductive/deductive cultures of proving.

One of the key issues is the epistemologies of the actors directly or indirectly involved in the controversy. In his research on demonstrations of the Atwood machine, Schaffer shows that there were several local epistemologies regarding the status of its demonstrations (Schaffer 1994). By the same token, therefore, for the current case, between the two cultures of proving at the far ends of the spectrum, there might be variations in actors' epistemologies regarding what counts as proof in relation to demonstrations. For example, as we have seen, Sugeno Michio, a theoretically minded researcher, developed stability criteria for fuzzy control by using mathematical modelling. However, this academic concern of Sugeno ran parallel to his efforts to develop applications for demonstration- which included voice commanded model cars and helicopters. Although he pursued research on the stability issue of fuzzy control along a mathematical line, he at the same time actively participated in the debate with control theorists about the limitations of traditional control. Another researcher, Hirota Kaoru, who had some training in control engineering, developed with MYCOM, a controller manufacturer, a demonstration similar to Yamakawa's (see the picture on p.94) after Yamakawa's original demonstration had taken place. Both Sugeno and Hirota were aware that it is not easy to introduce stability analysis to fuzzy control.¹⁷¹ The most extreme case is Yamakawa, who had little knowledge about control theory before his demonstration of the inverted pendulum. He began to take up the language of control engineering in order to understand and communicate with the control engineering community after his demonstration was commented upon.¹⁷²

How did Yamakawa see his demonstration? In my interview with him, he drew a parallel between the aim of control with the idea of going to the hospital: 'We do not go to the hospital only for a disease to be identified; we go there because we want to be healed. To control is to stabilize, but how to do it, and where the difficulty lies- those are the questions. What I want to do is to control properly. If it serves the purpose of control, then anything goes; if it cannot then it's meaningless'.¹⁷³

The following quote from the interview shows his epistemological position towards fuzzy control:

¹⁷¹ Sugeno interview; email to the author from Hirota Kaoru, 8 Aug. 2006.

¹⁷² Yamakawa interview.

¹⁷³ Yamakawa interview.

Please only see the result, and we can start from the result to investigate why it is so. Anything goes, if it can be balanced. We need only to balance it. It [the inverted pendulum] stands up to disturbance, isn't that what control is about? That's why the larger robustness is, the better, so I think of fuzzy control.¹⁷⁴

Thus, Yamakawa's idea of robustness was based on a non-theoretical notion of stability (represented by the word 'balance' in the above quote). The contrast between Yamakawa's thought on the epistemological status of the demonstration (seeing is believing), and control theorists' notion about the difference between demonstration and theoretical proof, can be clearly inferred from the above quote.

However, in the camp of control theorists, research conducted in more inductive ways was also happening. For example, control theorist Ikeda Masao conducted research on input-output testing which is inductive in spirit.¹⁷⁵ It is interesting to note that, in the controversy, control theorists emphasized the role the theoretical concept of stability had played in the history of control engineering. They worried that fuzzy control would take control engineering back to the untheoretical past (Araki 1993: 11).

Therefore, on the one hand, there was a gap between control theorists' emphasis on an official history of control engineering that put the issue of stability at the forefront, and their practical work. On the other hand, there were fine-grained variations in the epistemologies of fuzzy control researchers. These observations seem to lead to some reservations about the distinction of inductive and deductive cultures. So to what extent can we say that the inductive/deductive cultures largely delineate the boundary between the two groups?

This question brings us to the issue of proof. As we have seen in chapter 4, in control engineering there is an analytical tradition (emphasized by control theorists) of developing certain criteria regarding stable conditions. For control theorists, considering these conditions in a given system constitutes a proof to the question of stability of the system at issue. In contrast, for fuzzy control, it was not possible to perform this kind of analytic proof; only work of a trial-and-error kind could be relied on. That is why demonstrations of fuzzy control resorted to a 'seeing is believing' kind of 'proof' of the performance of fuzzy control. Take Yamakawa's demonstration for example: a more loosely defined language about stability and robustness, combined with the stunts performed, made the demonstration a 'proof' of the usefulness of imitating human reasoning in designing control systems. Here the

¹⁷⁴ Yamakawa interview.

¹⁷⁵ Ikeda interview.

use of the word ‘proof’, in contrast to the strict meaning given it in control theory, is surely slippery. Perhaps a better term is association. That is, a demonstration for fuzzy control serves as a way to associate its performance to human reasoning. In contrast, for control theorists, under the surface of the stunts performed by demonstrations lie the mathematical models—only they are seen as truly approximating the working of the reality.

AI, Tacit Knowledge, and Translation

Conflicting interpretations of the efficacy of fuzzy control, as we have seen in chapter 4, brings us to the implication of this thesis in broader terms. I would like to discuss it in relation to two theses on AI that are most frequently considered in STS related literature, that of Hubert Dreyfus and of Harry Collins, regarding the (im)possibility of realizing artificial intelligence.

Both accounts are influenced by Wittgenstein’s later philosophy (Dreyfus 1992), and both depend on the concept of tacit knowledge (Sismondo 2004: 90; Suchman 2007: 145). Whereas the concern of Collins (and later Collins and Martin Kusch) is with action, the focus of Dreyfus (and Dreyfus and his brother Stuart Dreyfus) is on knowledge. Dreyfus makes a distinction between knowledge domains that can be formalized and those that cannot. The distinction turns on whether we have explicit rules to follow in those knowledge domains. If the answer is yes, then they can be computerized. In the words of Dreyfus, ‘some domains do not have a structure that can be captured in context-free features related by laws or rules, while other domains have a structure that can be captured in this theoretical way’ (Dreyfus 1992: 717). The former domains, like chess playing or car driving, cannot be performed by following explicit rules; performing in this way in those domains is at best at the level of a novice. On the other hand, human expertise is developed by way of a process of ‘unselfconscious internalization’. Through this process, the ability to sense contextual information, and to recognize similarities and differences between situations currently faced and those that were encountered before, gets embodied (Collins 1990: 81; Sismondo 2004: 90). Viewed in this light, the skills of experienced operators, as we have seen in chapter 4, are performed in a knowledge domain that cannot be easily theorized and computerized.

On the other hand, unlike Dreyfus who focuses on the knowledge barrier that prevents AI from being completely successful, Collins takes into consideration the very social foundation in which AI could be claimed to work well. He claims, ‘I *want* intelligence to be seen as something having to do with social interaction’ (Collins

1990: 245, original italics). For Collins, “‘how does an expert system fit into a social group?’ is a more taxing question’ (ibid: 217). Collins argues that AI works in those areas when ‘the humans compensate for the deficiencies of artefacts in such a way that the social group continues to function as before’ (ibid: 215). For him, the actions that machines cannot do depend on whether they are deemed exclusively human, that is, deemed by humans as being impossible for machines to perform. Human action is dichotomized by Collins into ‘regular action’ and ‘behaviour-specific’, or ‘machine-like’, action (ibid: 216). Humans can do both, but machines can do only the latter; machines do the latter well precisely because those are the areas where humans discipline themselves to behave like machines. Collins and Kusch later replace ‘regular action’ with ‘polymorphic action’, and ‘machine-like action’ with ‘mimeomorphic action’ (Collins and Kusch 1998: 1). Writing love letters, an action so dependent on a social understanding of its appropriate context, is a representative case of polymorphic action (ibid: 34). The aspect of tacit knowledge that became emphasized in Collins’s view, it can be argued, is the social knowledge shared by the social group at issue that demarcates those actions that are deemed exclusively human from those that are not. Viewed in this light, then, the action performed by operators in the process industry is at best mimeomorphic, for it is not, strictly speaking, ‘socially situated’ (ibid: 34)

How then do we consider the claim that fuzzy control performs as well as an experienced operator? Dreyfus’s quote from Blaise Pascal’s *Pensées* at the very beginning of his book *What Computers Can’t Do* gives us a hint:

The difference between the mathematical mind (*esprit de géométrie*) and the perceptive mind (*esprit de finesse*): the reason that mathematicians are not perceptive is that they do not see what is before them, and that, accustomed to the exact and plain principles of mathematics, and not reasoning till they have well inspected and arranged their principles, they are lost in matters of perception where the principles do not allow for such arrangement...These principles are so fine and so numerous that a very delicate and very clear sense is needed to perceive them, and to judge rightly and justly when they are perceived, without for the most part being able to demonstrate them in order as in mathematics; because the principles are not known to us in the same way, and because it would be an endless matter to undertake it. We must see the matter at once, at one glance, and not by a process of reasoning, at least to a certain degree...Mathematicians wish to treat matters of perception mathematically, and make themselves ridiculous...the mind...does it tacitly, naturally, and without technical rules (Dreyfus 1979).

As we have seen in chapter 5, Michio Sugeno also resorts to Pascal's writings on the role that subjectivity plays in science to counter the 'modernist rationality' that Descartes' scientific methodology entails. While Dreyfus sees Pascal as pointing to the limit of AI, Sugeno sees fuzzy theory as furnishing Pascal's critique of a certain way of practising mathematics.

This brings us to Collins's view on AI, as reviewed in chapter 1 and above. Collins rightly raises the issue of social interaction between machines and humans as a determining factor in how successful we see AI as being. However, as Bohlin argues, Collins's account of AI is not an historical one. What is more, 'Collins addresses "intelligent machines" in a mode which is not only realist but *essentialist*, stating emphatically what their true capacities are and what views of what they are capable of doing are mistaken; his account is essentialist in that [it] consists of theoretical arguments meant to prove that the difference between human action and the behaviour of non-socialized entities is fundamental' (Bohlin 2000: 734, 736, original italics). This non-historical, essentialist stance seems to undermine the premise regarding social interaction that Collins brings up.

Bringing back the historical aspect helps to exploit the full potential of Collins's insight into AI. As we have seen in chapter 5, 'aimai' in the particular Japanese sense of the term helped to demarcate the boundary between humans and computers; this boundary was set up according to whether machines are operated on a binary basis. Since the boundary was set up in the first place, what former AI lacked is seen to be the ability to understand aimai; whatever can manage aimaisa is more human. It is against this background of boundary demarcation that human knack and intuition were brought into the scene. As was noted in chapter 4, 'fuzzy computers' were claimed to be able to memorize veteran operators' knack or intuition; it is in this ability that a fuzzy computer outperforms its predecessors. The boundary between human and machine that was demarcated by aimaisa is critical: the boundary did not shift as a result of a fuzzy computer being able to do what in the past could only be done by humans; rather, it is because a fuzzy computer was claimed to operate on a non-binary basis that we delegate humanity to it. This is why human qualities were projected onto fuzzy computers. In other words, tacit knowledge (arguably the Western counterpart of 'knack' and 'intuition' as referred to by Japanese fuzzy researchers), apart from being an analytic concept, was seen as the human quality that fell under the category of aimaisa, and was itself a piece of paraphernalia of the

interpretive enterprise of *aimaisa*.¹⁷⁶

Epilogue

In March 1999, a symposium ‘Ambiguity Brought into Focus’ took place at the International Research Centre for Japanese Studies (Nichibunken) in Kyoto. According to late Prof. and former commissioner of the Agency for Cultural Affairs (in post from 2002 to 2006) Kawai Hayao,¹⁷⁷ then director of the institute, the main theme of the symposium was decided as a result of his discussions with Piet Hut, a physicist at the Institute of Advanced Studies, Princeton, who was said to have a strong interest in Buddhism. Piet Hut was introduced to Kawai by Nakazawa Shinichi, a scholar of religion (Kawai 2003a: 3; 2003b: 305). The main theme of the symposium covered a wide spectrum of discussions on ambiguities in Japanese, as well as non-Japanese, art, literature, logic and philosophy. Along with Japanese scholars of art, literature, physics, and religion, Western scholars such as Piet Hut, system theorist John L. Casti of the Santa Fe Institute, an institute devoted to research on complexity, and historian and philosopher of science Evelyn Fox Keller, among others, were also invited to present papers on ambiguities in biology, physics, and science in general terms. Ambiguity was the translation of the Japanese word ‘*aimaisa*’ in the symposium, and papers and discussions were later translated, if the original version was not in Japanese, and collected in the book titled *Aimai no chi* (*The Wisdom of Ambiguity*)(2003). In the preface to the book, Kawai noted the ambiguity manifested in the communications of Japanese people as contrasted to Westerners (Kawai: 2003a).

The Japanese title of the book closely resembles *Fajyi – Atarashi chi no tenkai* (*Fuzzy: The Development of a New Episteme*), a book that discusses the role of fuzzy logic in science, published in 1989.¹⁷⁸ Scholar of religion Nakazawa Shinichi, who had a discussion with Kawai in the book *Aimai no chi*, had also participated in the discussion on fuzzy logic with philosopher of science Murakami Yōichirō and fuzzy theorist Sugeno Michio in the 1989 book (Kawai and Nakazawa 2003; Sugeno,

¹⁷⁶ For a critique of tacit knowledge as an analytic concept, see Turner (1994).

¹⁷⁷ The Agency for Cultural Affairs (Bunkachō) is a governmental organization under, but somewhat independent of, the Ministry of Education, Culture, Sports, Science and Technology (MEXT).

¹⁷⁸ The Japanese key word that the titles of the two books share is ‘*chi*’. The word has both Chinese and Buddhist origins and translates as wisdom, intellect, intelligence, knowledge, or episteme. ‘Wisdom’ is the word chosen as the translation of ‘*chi*’ for the 2003 book – the book has the English title put alongside the Japanese title on its front cover. The 1989 book, on the other hand, does not have an official English translation of its title, and I choose ‘episteme’ as the translation of ‘*chi*’ for its title because the Japanese title hints an epistemic breakthrough.

Nakazawa, and Murakami 1989). More than ten years later, any mention of fuzzy logic, which was once a significant element of *aimaisa*, could no longer be seen in the 2003 book. Nevertheless, discussions on *aimaisa*, expressed by examples in science, in communications, in religion etc. show similarities of scholarly interests in the two books.

These similarities provide a wider context into which history of fuzzy theory can be placed. In Japan, there was a time when fuzzy theory was discussed by way of, and put under, the concept of '*aimaisa*'. That time has, perhaps, passed, but in broader terms, the history of fuzzy logic in Japan can be considered as a case in cultural and social history of science and technology, pursued from the viewpoint of seeing it as an interplay between science and technology and the concept of *aimaisa* – itself a result of long-standing interactions between Japan and the West.

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Appendix A

List of Interviewees

(Those interviews that were recorded are noted by asterisks)

Name	Place	Date	Affiliation of the interviewee at the time of interview
Abe Kazuo; Zhang Zhi-Ming	Osaka	November 18, 2005*	ICON Co., Ltd.; EIWA Corp.
Asai Kiyoji	Osaka	March 7, 2006*	
Fukuda Toshio	Nagoya	August 25, 2005*	Nagoya Univ.
Hirose Michitaka	Tokyo	September 5, 2005*	Univ. of Tokyo
Hirota Kaoru	Yokohama	July 15, 2005 August 9, 2005*	Tokyo Inst. of Technology
Ichihashi Hidetomo	Osaka	November 21, 2005*	Osaka Prefecture Univ.
Ikeda Masao	Osaka	March 16, 2006*	Osaka Univ.
Itō Osamu	Tokyo	September 21, 2005*	FFC Ltd.
Kimura Hidenori	Nagoya	March 15, 2006*	Inst. of Physical and Chemical Research (Riken)
Kondō Shinji	Osaka	November 17, 2005* March 8, 2006*	Matsushita Electronic Co., Ltd.
Miyamoto Sadaaki	Tsukuba	February 13, 2006*	Tsukuba Univ.
Mizumoto Masaharu	Osaka	November 16, 2005*	Osaka Electro- Communication Univ.
Mukaidono Masao	Tokyo	October 13, 2005*	Meiji Univ.
Murofushi Toshiaki	Yokohama	August 19, 2005*	Tokyo Inst. of Technology
Onizawa Takehisa	Tsukuba	November 10, 2005*	Tsukuba Univ.
Anca Ralescu; Daniel Ralescu	Tokyo	September 11, 2005*	Univ. of Cincinnati
Satō-Ilic Mika	Tsukuba	February 13, 2006	Tsukuba Univ.
Sawaragi Tetsuo	Kyoto	March 9, 2006*	Kyoto Univ.
Shibata Heki	Tokyo	September 26, 2005*	

Shin Seiichi	Tokyo	February 27, 2006*	Univ. of Tokyo
Sugeno Michio	Kyoto	November 14, 2005*	Doshisha Univ.
Takahara Yasuhiko	Chiba	March 3, 2006*	Chiba Inst. of Technology
Takeda Eiji	Osaka	November 17, 2005	Osaka Univ.
Tanaka Kazuo	Tokyo	February 24, 2006*	Univ. of Electro- Communications
Tashiro Ryoji; Okuda Toshiyuki	Sendai	April 13, 2004 April 15, 2004 (with Tashiro Ryoji only)	Transportation Bureau, City of Sendai
Tsukamoto Yahachirō	Tokyo	December 3, 2005*	Meijo Univ.
Umano Motohide	Osaka	November 16, 2005*	Osaka Prefecture Univ.
Yamakawa Takeshi	Kitakyushu	March 12, 2009*	Kyushu Inst. of Technology
Yasunobu Seiji	Tsukuba	April 16, 2004*	Tsukuba Univ.
Yubazaki Naoyoshi	Kyoto	November 18, 2005*	Mycom, Inc.

Appendix B

List of those, not on the above list, with whom informal talk and email exchanges were conducted

Name	Place	Time	Affiliation
Etō Hajime	Taipei	January 27, 2008	
Nakajima Nobuyuki	Tokyo	September 9, 2005	Univ. of Toyama