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Sarah Voss



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# Fuzzy Logic in Health Care Settings: Moral Math for Value-Laden Choices

Sarah Voss

*http://www/PiZine.org*
sarahvoss@cox.net

**Synopsis**

This essay is intended as an example of "moral math", i.e., ideas culled from mathematics which can positively impact social behavior. Specifically, it combines fuzzy logic with the ethical decisions which hospital staff and others are sometimes forced to make about health care (e.g., euthanasia issues following Hurricane Katrina). The assumption is that such decisions involve value-laden choices which lend themselves to "fuzzy" or "smart" protocols. The article discusses the history of fuzzy logic — what it is, how it is used, and how it might be even better-used as a support basis for making difficult choices in the health care setting.

## 1. Introduction

As a contract chaplain with the pastoral services department at a local hospital, I am often involved with life and death issues that require multi-faceted choices and which sometimes result in ambiguous levels of satisfaction with those choices. For instance, I sometimes visit with patients about using artificial support (e.g., breathing tubes, mechanical respiration, and forced feeding). Most patients elect to forego some or all such support when and if they have lapsed into a persistent vegetative state that is deemed by medical professionals to be terminal in a relatively short duration. The medical staff usually encourage this choice if there is little likelihood that the patient will ever resume a fully aware and high quality life. Those "if's" are significant qualifiers even in normal situations, but they can become full-fledged stumbling blocks during times of natural disaster, war, epidemic disease, or other calamity. Under such extreme conditions, hospital resources may be drastically limited or may even disappear altogether, and decisions about ethical allocation of reduced resources (who gets what treatments?) can essentially turn hospital staff into death squads.

In *Five Days at Memorial* [5], a 2013 eye-opening book about one hospital's struggles in New Orleans following the 2005 hurricane Katrina, journalist Sheri Fink gives a Pulitzer Prize-winning account of the ethical dilemmas which can arise in such life-and-death situations. In the epilogue to her book, Fink notes that failures to adequately plan for triage needs[1] have continued to occur in many other places since Katrina. "Emergencies," she writes, "are crucibles that contain and reveal the daily, slower-burning problems of medicine and beyond — our vulnerabilities: our trouble grappling with uncertainty, how we die, how we prioritize and divide what is most precious and vital and limited; even our biases and blindnesses [5, page 464]."

These human vulnerabilities can be challenging. Fink's delicate and sensitive handling of them in her journalism is an attempt to speak to the horse on the dining room table that nobody wants to mention. Since Katrina, federal agencies have begun insisting (as a requirement for certain funding) that state and local health departments in the U.S. develop new triage protocols to address some of these issues, but at best this can be a slow process. These are value-laden considerations. A few of the efforts to address them have included public input, but most have not, even though, as Fink puts it in regard to one program for public engagement, "regular citizens showed they were able to gather, engage, discuss these issues, and learn from one another. They easily grasped ethical concepts that some health officials had assumed were the province of experts only" [5, page 479].

This is the point where my own interests and work come into play. Throughout my active ministry, I cultivated a two-fold position which prompts this article:

1. the general public deserves to be informed about and have a voice in the making of important ethical decisions, such as those in the rapidly changing area of health care, and

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[1] *Triage* comes from a French term "trier," meaning to choose, split, or classify. It was first used in the Napoleonic wars and persisted as a way to classify patients in terms of urgency [9, page 1].

2. the process of decision making about social and moral issues can often be positively enhanced by concepts which are rooted in mathematics.

To this end, I've developed and run a series of workshops on "moral math" designed to make mathematical ideas accessible to the lay individual and to demonstrate how math can help promote positive social behavior [12]. Fuzzy logic is one such mathematical area; it has, for example, potential as a significant tool in the triage situation mentioned above. To grasp this potential fully, we need at least some understanding of how fuzzy logic works.

## 2. What Is Fuzzy Logic?

The first thing to understand is that some of the ideas stated in this essay are partially true and partially false.

Let me elaborate. Western science — our science — grew up under the strong influence of Aristotle, that ancient Greek philosopher who insisted that truth is a *yes* or *no* creature. In the Aristotelian view, a proposition is either true, or it's not-true. A color is red, or else it's not-red. Water boils at 212 degrees Fahrenheit, or it doesn't boil at 212 degrees Fahrenheit. A light is switched on, or it's off. You love mathematics, or you don't love mathematics. In such classical thinking there are no grays, no in-betweens, no partial truths, no middle-ground. For most of its existence, Western science has championed this law of the "excluded" middle.

Here in the West we tend to believe that when we think rationally or "reasonably," we are thinking *logically*, by which we consciously or unconsciously mean we are thinking with crisp Aristotelian logic. In reality, however, about 99.9% of everyday human reasoning is not Aristotelian. Most of us think most of the time that most things are partially true and partially false. Our thinking, in effect, is *fuzzy*.

Fuzzy thinking can be fun thinking — like the little boy who was trying to memorize the Ten Commandments. When he got to "Thou shalt not commit adultery," his mother asked him what he thought the commandment meant. The child thought a moment, then replied, "It means you shouldn't want to be an adult."

Traditional logic says there is a right answer and a wrong answer to the mother's question about the commandment, but the little boy picked a middle answer, something that was sort of true. Fuzzy logic pays attention to that excluded middle.

Fuzzy logic can be traced back to 1965 when Iranian-born Lofti Zadeh, then a Berkeley professor of electrical engineering, wrote a landmark paper titled "Fuzzy Sets" [13]. Humans, of course, used fuzzy reasoning before 1965, but after Zadeh's paper appeared, this very human thought process acquired a new name and an entirely new mathematical framework.

There is nothing fuzzy or vague or uncertain, however, about the mathematical framework of fuzzy logic. The math of fuzzy logic is as explicit as "Two plus two equals four [7, page 15]." It's about as interesting, too. Which necessarily means it's also boring to some degree. Mathaphobes think fuzzy logic is boring to degree 1 and interesting to degree 0. Fuzzy logicians think fuzzy logic is boring to degree 0 and interesting to degree 1. For most of the rest of us it's probably moderately interesting, say, maybe "halfway" interesting, or interesting to degree .5. In fuzzy logic things are assumed to be true *to some degree*, and simultaneously false *to some degree*, where, by mutual agreement, a numerical value between (or including) 0 and 1 is arbitrarily assigned to represent that degree. Because the number selected is purely subjective, the choice sometimes leads to dissension. Generally, however, we can do a surprisingly good job of quantifying vagueness. We can even quantify the fuzziness of purely linguistic notions such as "surprisingly" or "somewhat" or "quite."

A while ago, I asked Joe Doe, my favorite mathaphobe, if he'd help me out with the research for this essay. Joe promptly replied, "Yes." I asked Joe, whom I perceive as somewhat old and quite tall, the following five questions:

- What age are you?
- At what age do you consider a person "old"?
- What height are you?
- At what height do you consider a man "tall"?
- On a scale of 0 to 10, how handsome are you?

Joe Doe, it turns out, is 79 years old and 5 foot nine and a half inches tall. That was very helpful. Just what I wanted, in fact.

Joe, it also turns out, considers "old" a *mind* thing, which means he thinks "a person is old when they quit doing things that they want to do." Joe has seen people who are old at 50 and also who are over 90 and still not old. By his own reasoning, Joe is *not* old, because he can still do things he wants to. "It's just harder," he says. Furthermore, Joe thinks "you are tall if you are over nine and a half inches."

These answers were not at all what I wanted, and I was just about to say Joe Doe was a lost cause when I had an alternative idea. I asked my scientific, biochemist husband Dan how old a person has to be to be "old" and how tall a person has to be to be "tall." Being embedded in Western science, Dan immediately gave me what I wanted. Dan considers a person "old" at age 100 and "tall" at 6 feet.

Now, using Joe Doe's factual data and Dan's definitions of old and tall, I pulled out my trusty hand calculator and figured out that Joe is old to degree .79, that is, he is 79% old. He is also 85% tall, or tall to degree .85. So, you see, with Dan's assistance, we assigned numerical values that are surprisingly consistent with the perception that Joe is somewhat old and quite tall.

It is easy to misinterpret fuzzy thinking as probabilistic thinking because, after all, we are trying to numerically interpret the level of certainty to which, say, Joe is old. However, probabilistic thinking maintains the law of the excluded middle and hence belongs to classical logic, not fuzzy logic. When we say Joe has a 79% chance of being old, we are talking about the *probability* that Joe is old, which still means either Joe is old or he isn't. No middle ground here. Just a better *chance* that he is old than that he isn't. Black and white. But when we are thinking according to fuzzy logic we say that Joe is *partially old*, or, more precisely, that Joe's membership within the set of "old" people is .79. The mathematical rules for operations on fuzzy quantities are different from the rules for operations on probabilities, so while the numerical relationships between probabilistic and fuzzy thinking bear a superficial resemblance to each other, they are still two very different species of math.

Oh, but we're forgetting about Joe Doe's handsomeness. Remember my fifth question to Joe: "On a scale of 0 to 10, how handsome are you?" I even gave him guidelines for interpreting the endpoints. *Zero*, I said, means "flat out horrid ugly" and *ten* means "absolute gorgeous hunk of a guy." Now Dan and I immediately agreed that Joe is handsome to degree .98, that is, Joe is very handsome. Thus, fuzzy logic yields the following conclusions: Joe is somewhat old, quite tall, very handsome, and decidedly modest. The modest part is a natural language interpretation of Joe's disinclination to assign himself any value whatsoever on the "handsome" scale, which is to say that first he totally ignored my question and, when pushed, he assigned himself only "7."

About now you might be wondering if fuzzy logic is good for anything other than describing Joe Doe as somewhat old, quite tall, very handsome, and decidedly modest. The answer is "yes."

The first commercial application of fuzzy logic was the development in 1980 of an improved cement kiln, one which effectively managed the highly complex set of chemical interactions involved in the cement-making process. This improved process, fuzzy though it was, efficiently monitored four different internal states of the kiln and managed four dozen or so "rules of thumb" about their relationships. To instruct the kiln what to do, the fuzzy system used rules such as "If the oxygen percentage is *high* and the temperature is *high* then *slightly reduce* the coal feed rate" (emphasis added), see [3] and [7, page 16]. "High" and "slightly reduce," of course, were translated into numbers between 0 and 1.

Other early applications of fuzzy logic in engineering include fuzzy control of the extraordinarily smooth Tokyo subway, baggage handling at Denver International Airport, and a meterological system in China for identifying the best places to plant rubber tree orchards. We find fuzzy thinking in the production of automated cars, traffic light controllers, robot graspers, TV tuners, graphics, automated police sketchers, washing machines (which automatically adjust for size and amount of dirt), self-focusing cameras (which consider multiple targets), "smart" ovens (which provide more uniform cooking), "smart" weapons (which provide more accurate "hits"), the thermostat on your air conditioner and the water setting on your shower (which keep the temperature "just right"). See, for instance, [2, pages 114-117].

Fuzzy thinking is also effective in all sorts of decision-support systems, including financial planning, diagnostic systems for determining soybean pathology, biomedical applications to diagnose breast cancer, rheumatoid arthritis, post-menopausal osteoporosis, and heart disease. In hospitals, fuzzy logic helps monitor anesthesia, blood pressure, insulin for diabetes, and post-operative pain control. In medical situations there have been new fuzzy protocols developed for such things as reducing overall harm during rescue efforts for natural disasters, for monitoring unattended patients in overcrowded emergency rooms and disaster sites, for automated remote triage on military battlefields, and for assigning triage levels of urgency in a hospital setting. There are also fuzzy applications in geography, ecology, nuclear science, the stock market, handwriting analysis, and even the weather. Moreover, for the past couple of decades fuzzy logicians have been applying this new mathematical tool to human social behavior and issues of ethics.

## 3. Inside a Fuzzy Textbook

The mathematical symbolism that fuzzy logicians sometimes use to express these subjective and often non-explicit concepts mirrors the syntax of classical Boolean (i.e., true or false) logic. For example, the definition of a fuzzy set $A$ in a nonempty set $X$ is characterized "by its membership function $\mu_A : X \to [0,1]$ and $\mu_A(x)$ is interpreted as the degree of membership of element $x$ in fuzzy set $A$ for each $x \in X$."[2] The union of two *triangular fuzzy numbers* $A$ and $B$, for instance, can be defined as

$$(A \cup B)(t) = \max A(t), B(t) - A(t) \wedge B(t) \text{ for all } t \in X.$$

Likewise, a fuzzy set A is called a *trapezoidal fuzzy number with tolerance interval* $[a,b]$, *left width* $\alpha$, *and right width* $\beta$, "if its membership function has the following form:

$$A(t) = \begin{cases} 1 - (a-t)/\alpha & \text{if } a - \alpha \le t \le a \\ 1 & \text{if } a \le t \le b \\ 1 - (t-b)/\beta & \text{if } b \le t \le b + \beta \\ 0 & \text{otherwise,} \end{cases}$$

and we use the notation $A = (a, b, \alpha, \beta)$". As one can see, the descriptions are always using the same logical-mathematical syntax.

However, all of this detailed notation is commonly supplanted with or even completely replaced by a much more intuitive graphic, such as the one shown in Figure 1 which represents the fuzzy control system for the temperature of a room.

[2]This definition and the notation in the next two sentences are typical of the way fuzzy math is conveyed. See, for example [6, pages 6, 15, 22].

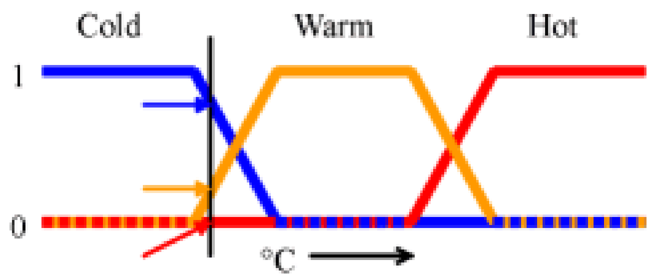


Figure 1: An example of a fuzzy logic member function. Image by: `fullofstars`, licensed under the Creative Commons Attribution-Share Alike 3.0 license, available at https://commons.wikimedia.org/wiki/File:Warm_fuzzy_logic_member_function.gif, accessed on July 26, 2016.

Figure 1 shows three overlapping trapezoidal fuzzy sets representing the fuzzy notions of cold, warm, and hot. The vertical line represents a "crisp" number which has simultaneous membership in two of the sets, such that it might be described as being fairly cold and slightly warm.

A variation on this iconic graph which is directly relevant to critical health care can be found in "Applying Fuzzy Logic to Medical Decision Making in the Intensive Care Unit," a 2003 article by H. T. Bates and Michael P. Young [1]. In this essay the authors walk the reader through a three-step process designed to aid physician decisions regarding the rate at which intravenous fluids should be given to a selected patient. There are multiple factors which physicians take into consideration in making such a decision, but for purposes of illustration, the authors describe a process which is limited to only two variables, viz., the mean arterial blood pressure and the hourly urine output for the patient. Just as the temperature in the graph presented in Figure 1 had regions denoted as cold, warm, or hot, the blood pressure and urine output measurements were classified low, normal or high. The uncertainty regions (e.g., measurements which might or might not be "normal") correspond to the overlap areas in the trapezoidal graphs.

In Step 1, the possible blood pressure and urine output measurements were "fuzzified." That is, a graph similar to that in Figure 1 (and/or its set-notation equivalent) was created such that the "overlap" regions had numerical boundaries corresponding to uncertainties about the degree of membership which a particular measurement might have in, say, the category of "normal." In Step 2, a table was created to show what action should be taken for every possible combination of the two measurements. In this illustration, the designated action was giving the patient some "appropriate" level of intravenous fluid. In Step 3, the controlled quantity, i.e., the intravenous fluid rate, was similarly "fuzzified," in this instance by being divided into five overlapping fuzzy sets, such that the rate of intravenous fluid delivery could be considered low, maintained, moderate, high, or very high. Thus, precise measurements of the blood pressure and urine outputs could ultimately be linked to a precise change in the fluid rate, an outcome which in principle, could be quickly determined by a computer and implemented completely automatically without human intervention.

For a more complete understanding of the math behind fuzzy logic, interested readers (including those with limited exposure to fuzzy logic) are referred to this article [1] by Bates and Young. One gentle caution: "more complete" is a fuzzy term.

## 4. Fuzzy Logic Used as Moral Math

Here are several examples of how fuzzy considerations might impact our ethical and moral choices. I adapted these illustrations from three books, all of which I partially liked and partially disliked. The books are *Shades of Reality* [2], by Bob Bishop, who from 1992 until his death in 2014 was the "Mr. Logic" of a popular California radio show called the "Thinking Machine"; *The Fuzzy Future* [7], by Bart Kosko, a professor of electrical engineering at the University of Southern California; and *The Science of Good and Evil* [11], by Michael Shermer, the publisher of *Skeptic* magazine and a teacher of critical thinking at Occidental College, also in California. Hmmm. Maybe fuzzy writers all live in California! I suppose that conclusion is a little like the guy who ordered a pizza and was asked if he preferred to have it cut into 8 or 12 pieces. After a moment of fuzzy thought, the customer opted for the 8-piece-cut, saying he didn't believe he was hungry enough just then to eat 12 pieces. (Yes, that joke was in one of those three books, too [11, page 160].)

My first example of fuzzy morality — oops, make that fuzzy thinking *applied to* moral choices — is a consideration of the unfairness of our current tax laws. Most of us feel pretty powerless when it comes to our taxes, and quite rightly so, because, even though we theoretically live in a country where we can democratically decide how our tax dollars are spent, few of us believe we actually enjoy such choice. The truth is, as Kosko put it, "The state spends our tax money on what it wants and does not directly ask us to help it choose [7, page 49]." Such a process, as the founders of our nation well knew, can lead to a kind of political elitism which oppresses the ordinary individual.

Kosko's suggestion is to use a fuzzy tax form. Such a form would allow ordinary people to select on their IRS forms just what they would like to have their tax dollars spent on. Since there is a certain amount of common need which governments can predict, a portion of the tax money might be set aside for general revenues — perhaps half of our tax dollars, or a third or four-fifths or whatever. (Here's where the dissension comes in.) The remaining amount goes to social categories which you help choose even as you send in your portion of the total tax money. In his book, Kosko provides a sample fuzzy tax form which would clearly help those who pay have a more direct say. "I want ...............% of my tax dollars to go for ............" Fill in the blank, as in "I want 5% of my tax dollars to go for preventative health care subsidies."

Just as tax allocation may benefit from fuzzy technology, crime and punishment might become "fairer" through fuzzy decision making. All of us know of incidents where the rich don't get the same punishments as the poor do, mostly because our judicial system fails to demand across-the-board equal treatment for identical crimes. This class issue can be addressed by carefully matching the severity of the consequences to the seriousness of the crime, i.e., by using fuzzy logic.

Assume, for example, that "intoxicated" is legally defined as having a blood alcohol content of at least 0.08. As the law currently stands, a driver involved in a car accident can receive a full prison sentence if he has a blood alcohol count of, say, 0.081, while a second person gets virtually no punishment at all if his count is 0.079. Fuzzy theory could smooth out such inequities by offering a sliding scale which matches the degree of drunkenness to the degree of punishment. Two similarly intoxicated drivers would then experience similarly "realistic" law regardless of social, economic, or any other status (see [2, pages 156-58]).

A third example of how fuzzy thinking can assist our moral choices can be found in consideration of the abortion issue. Most of us will find that we are probably already using some version of fuzzy thinking when it comes to issues of life and death. It is helpful here to remember that the line between life and death is fuzzy, not crisp. Avid right-to-lifers[3] are consciously or otherwise using classic Aristotelian reasoning which sees the fetus as passing from 0% alive to 100% alive in one big jump — no middle ground.

An argument can be made that pro-choicers do the same thing, that they just draw the line between life and no-life at a spot more in that excluded middle ground. In the United States, the legal line according to Roe vs Wade is viability, that is, when a fetus is deemed viable outside the womb (generally in the range of 24 to 26 weeks). Individual states have different interpretations of course, and to get an abortion beyond the 12$^{th}$ week is often more complicated. In India, the line is at 20 weeks. In China, where in the 1990s almost half of all pregnancies ended in abortion, the state forced some abortions as late as the sixth month of pregnancy in order to meet its one-child-per-couple population goal. Regardless of where the line is drawn, fuzzy logic urges us to think proportionally. That is, one factor we could consider in assigning human rights to an unborn fetus is *the degree to which* the fetus is alive. Partial rights for partial life.

In some ways, in our country we currently give full rights for partial life. Once, at the hospital, I was called to be with a young man whose wife was giving birth prematurely. At 24 weeks, the baby was born alive but very sick. I watched as this young man, who spoke almost no English, struggled with assorted feelings. Clearly he wanted this child to be okay, to "make it." When he saw his little girl, he wept with joy that she was alive. But I also saw the grandfather, whose presence was testimony to his support for his son at this difficult time. Again, we shared no common language, but it didn't require a common language for me to see his conflict. Grandpa took one look at his tiny, tiny granddaughter, and shook his head with painful sadness. "Too soon," he said, and even though it wasn't in a language I knew, I understood what he was saying, how he was weighing all the issues ahead for this family trying to raise a child with so many strikes against her.

[3]The abortion issue is controversial even in the labels the opposing camps use for themselves and one another. Here I chose to use the terms that each camp chooses to use for itself.

Were the doctors right to give this partially-developed infant full rights to life, that is, to offer every assistance possible, even though it will cost hundreds of thousands of dollars and great hardship, and even then would likely leave a child who was severely handicapped? In general, I believe our protocols are pretty good in this regard, that they take into account the "fuzziness" of life. Yet, even with that confidence in our system, I still have some internal doubt. The only thing about which I had no vagueness in dealing with this family was the prayer I offered, which was as wholehearted as I could make it.

## 5. Moral Subtleties

Like all tools, of course, fuzzy logic is just that — a tool. This tool takes two basic forms: fuzzy technology and fuzzy decisions. It can serve society well or poorly, or, in keeping with fuzzy thinking, to some degree therein.

Consider, again, for example, the notion of matching degree of drunkenness to the period of time spent in jail. One problem with this approach is the severity of the crime. One day in jail involves some of the same heavyweight penalties that one year in jail does. In principle, the idea of matching partial guilt with partial punishment seems fair, but fairness does not always ensure justness. Awareness of such moral complexity has led to caution in using decision-based fuzzy logic tools: most are now suggested as decision-making *support* aids. The ultimate moral decision still rests in the collective human mind.

One thing is clear, however. Fuzzy logic adds a new and potentially powerful tool to our toolbox for making moral decisions. Michael Shermer offered an interesting take on this issue when he set forth what he called a theory of *provisional* morality. Provisional morality is not the same as absolute morality, which is what we find in fundamentalist thinking. Holding the ten commandments as absolute standards of right and wrong is an example of fundamentalist moral thinking. Provisional morality allows for exceptions. At the same time, provisional morality is not the same as relativistic morality. When I think of relative moral thinking, I think of the Non Sequitur cartoon by Wiley Miller in which Moses has been reading to his flock from the famous stone tablet. "I don't care what your lawyer said," Moses tells his flock. "They're not called the ten recommendations." Provisional ethics is not the same as relativistic ethics, either. The comparison is more like the bumper sticker, "Give me ambiguity or give me something else." As Shermer puts it, scientific facts "are conclusions confirmed to such an extent that it would be reasonable to offer our provisional agreement." Similarly, in professional ethics, "moral *or* immoral *means confirmed to such an extent it would be reasonable to offer provisional assent* [11, page 167].

This secular approach to morality is bound to certain principles. Shermer identifies four such principles: "The Ask First Principle," "The Happiness Principle," "The Liberty Principle," and "The Moderation Principle." These four principles of moral behavior translate roughly to a variation of the Golden Rule, an assumption that it is moral to seek happiness with someone else's happiness in mind and never to seek happiness when it leads to someone else's unhappiness, to seek liberty with someone else's liberty in mind and never to seek liberty when it leads to someone else's loss of liberty, and to generally seek moderation over extremism. Using these principles for making ethical decisions is a secular way of being moral ... to a degree.

## 6. Fuzzy Future

Fuzzy life issues are becoming more and more complex as new technologies arise. This happens at both ends of the life spectrum, with questions about prolonging life for the aged counterbalancing questions about who owns the rights to genome space. Fairness and justness are concerns inevitably raised in making such decisions. Who gets access to the best of modern medical techniques? Often it boils down to a matter of who has the money to buy them. The poor are usually the losers. The good news is that fuzzy scientists can facilitate non-fuzzy change in matters of equality.

Back in 1999, for instance, Kosko predicted that fuzzy logic would bring about "your own medical software agent." Such an agent, he envisioned, could track your physical condition daily by reading into your personal computer your daily bio-rhythms and bio-variables, which you would determine through inexpensive personal sensors such as blood and urine tests done at home with the assistance of computer chips. Since your medical agent would really be a set of software programs, it would search and learn, diagnose your problems, and recommend treatment at the best rates and from all available sources, including international ones. The agent would complement traditional medicine, not replace it. Notably, Kosko saw possibilities for increased fairness in the procedure:

> The poor may benefit the most as both supply of and demand for cheap smart medical agents swell and help shape health care in the digital age. The poor will be able to afford the personalized and high-quality health care that now only the better-off can afford.... Agents will be the great equalizers of the digital age [11, page 222].

Variants on this idea have since been developed by using fuzzy protocols. The Personal Information Carrier (PIC), for example, is one new project which provides an electronic dog tag that allows "every soldier to carry their entire medical history around his neck [8, page 7]." The device is part of an automated triage and emergency management information system that aims to shrink the death rate of soldiers who are killed in action by remotely extending the reach of the medic. The prototype system — which offers a framework for information analysis, information movement, and decision support capabilities — may also be used to monitor first responders and casualties in the civilian domain [8, page 1].

With access to the internet, you can readily find other health care developments based on fuzzy logic. One project in Australia, offering prototype mobile decision-support for hospital triage, uses linguistic terms such as *immediately* or *imminently life-threatening*, *potentially life-threatening* or *life-serious* as well as physiological attributes including *mild* or *moderate*, *pink* or *pale* to help guide a clinician's decisions when a patient presents as an ambiguous triage case [10]. Another uses fuzzy logic and decision trees to make classification of a patient's urgency level in the shortest possible time with minimum error [9]. Yet another provides a "SMART" wireless system for monitoring vital signs and locations of ambulatory but unattended patients with the goal of providing improved services at both hospital emergency departments and disaster sites [4]. This is just a sampling.

Many of these new fuzzy protocols deal with "smart" technologies which do, in fact, contribute to smart (or at least smarter) decisions. Nonetheless, decision-support opportunities in value-laden ethical situations are still in their infancy. Hospitals, as Fink noted, are only beginning to address highly value-sensitive issues such as who is euthanized when medical provisions and care are scarce or nonexistent. All too often, even these attempts do not include the voice of the general public. Fuzzy logic offers a simple way in which that public voice may be included.

For example, hospitals could seek out value-related choices along with the other information which patients (and/or their families) are routinely asked to provide when they are admitted. In the hospital where I work, the pastoral services department has recently implemented a system whereby each admitted patient selects how important a visit with a chaplain is to him/her by checking *very important*, *somewhat important*, or *not very important*. Chaplain time is limited — we are in demand. Each morning chaplains receive a printed list of patients' responses to these three simple choices, and we use them to help prioritize whom we visit and when we visit them. This is so simple that it doesn't even seem "fuzzy," but at its root, it's a logic which can benefit us all, and it is effective.

We are only a short fuzzy way from getting public input on more explicitly moral concerns, such as:

> "If medical supplies and services are scarce in an emergency, who should receive them? Prioritize 1-6, where 1 means "gets the highest priority" and 6 means "lowest priority":
>
> ____ First to arrive
>
> ____ Sickest
>
> ____ Youngest
>
> ____ Oldest
>
> ____ Those who have DNR (Do Not Resuscitate) orders
>
> ____ Other ............ (Please specify)

During non-crisis times, hospitals could offer patients and visitors an opportunity to fill out such a survey. If Pastoral Services had a role in this process, such a tool might even be useful as a "doorway" to discussing life and death issues that some people are reluctant to pass through, and, as every chaplain knows, such discussions in and of themselves are often spiritually healing. Furthermore, the results of such a survey might not only help hospital staff better prepare for difficult ethical choices in times of triage and other stressful situations, but they would likely have the additional benefit of receiving more implementation acceptance from the public. Even the hardest decisions are likely to have more total buy-in when people feel they've had a voice in making them.

## 7. Conclusion

The new frontier for making ethical decisions can be decidedly "fuzzy." Fuzzy scientists can do many "smart" things with fuzzy logic, and that includes providing decision-support for value-laden concerns. To the best of my current knowledge, "smart" moral protocols have been underused as tools in issues surrounding the moral complexities which can arise in various social situations. This is especially the case during hospital triage and other emergency situations. Moral math is part of the solution.

## Author's Note

I wrote the first version of this paper in 2004 as one of a series of "math" sermons which I gave from the pulpit. It wasn't until after I read *Five Days at Memorial* [5] (including and especially the epilogue) that the current version began to crystalize. Now a life-member of the Unitarian Universalist Ministers' Association, I continue here to explore my long interest in the relationship between math/science and religion. I am particularly grateful to the *JHM* editors who suggested the addition of what became Section 3 of this essay. Talking about math and actually citing the language are very different degrees of risk for a writer addressing an audience with multi-level math expertise, and, without the encouragement of the editors, I'd have omitted more precise math engagement.

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