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**INTELLIGENT VIRTUAL REALITY**  
**in the**  
**SETTING OF FUZZY SETS**

by

John Dockery  
Center for Excellence in C3I<sup>1</sup>  
George Mason University, Fairfax, Virginia 22030

and

David Littman  
Computer Science Department  
George Mason University, Fairfax, Virginia 22030

**Abstract**

*The authors have previously introduced the concept of virtual reality worlds governed by artificial intelligence. Creation of an intelligent virtual reality was further proposed as a universal interface for the handicapped. This paper extends consideration of intelligent virtual reality to a context in which fuzzy set principles are explored as a major tool for implementing theory in the domain of applications to the disabled.*

**Introduction and Motivation**

This paper is intended as part of an exercise in the generation of requirements from an emergent system design. Following directly upon a brief sketch of the design proposal, design requirements, previously identified, are interpreted in the context of fuzzy sets as potential applications of said subject.

Recently the potential benefits of virtual reality for the disabled have begun to be explored. [CSUN, 1992; Weghorst, 1991] Independent consideration of the potential use of virtual reality to aid the handicapped is being developed by the authors. [Dockery and Littman, 1992] We have proposed the implementation of what we call intelligent virtual reality as a universal interface for the handicapped. The intelligent aspect emerges from what we see as a requirement to wrap such an interface virtual world in an artificial intelligence shell. We shall begin by reviewing the need for such a requirement. Embedded in an end-to-end systems design, it would yield a *total prosthetic environment*.. However, before spinning out requirements for a very advanced virtual world, a reality check on virtual worlds may be in order.

What exists presently? The first applications of virtual reality have been primarily in the entertainment field although scientific uses are beginning to be reported in connection with data visualization. For example theoretical chemists use virtual reality to "dock" large molecular species. [Anon., 1992] Likewise NASA is experimenting with telerobotics and remote handling of hazardous materials. Regardless it remains difficult to separate the true promise from the hype.

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<sup>1</sup> On an Intergovernmental Personnel Act assignment from the Defense Information Systems Agency at GMU on a part time basis.

What is the current technology of virtual reality? With virtual reality the user becomes a participant in the computer display being observed. In virtual reality the user is surrounded by the display. The technology is a mating of high speed graphics, sensors, and fast computing. Introduction of special input devices has opened up the technology to a steadily expanding group of users. Some of these devices include the "data glove", with which the user can control his interaction with the virtual world, or the "eyephones" [sic] by which the user achieves stereo-optical observation of the display.

What differentiates a virtual from a real world? From an environmental viewpoint the essential feature of any virtual world is the designer's ability to suspend the conventional laws of nature and replace them with his own. Thus, users can fly; objects can shrink and expand at will; things can fall up instead of down. In such a world, a handicapped person could reach across a room to pick up an object without ever leaving his place. Why not, then, build a virtual world which compensates for a particular disability by replacing troublesome laws of nature? This is clearly the answer, but on reflection only part of it. That latter portion of the answer lies with the conception of the intelligent virtual reality interface as primarily a device for *intent amplification*. We anticipate an interface communication language which is strongly metaphoric in design. For example, consider an intelligent virtual reality action of "pulling the blinds". It could mean just that. But as a metaphor for controlling intensity, it could mean shutting down a reactor--in an extreme case--depending on context.

The authors also ran a reality check on themselves and their proposal for intelligent virtual reality for the handicapped. Is such a system currently practical? The answer: it can not be done with current technology. Why then propose such a system? The answer: without a conceptual framework for such a design the best the disabled can hope for is some kind of trickle down technology from the entertainment applications which are here now. If everything is so preliminary, then why focus on fuzzy sets? The answer: we will need a strong conceptual framework for stating requirements and for system modelling both of which are amenable to transcription into fuzzy sets as we shall shortly argue.

### **Intelligent Virtual Reality and the Disabled**

For purposes of initial theory development we have assumed the disabled person to have a full and intact cognitive map although this is not an inherent limitation on what we propose. The problem with even a tailored virtual world for the disabled lies with the question of manipulation of that virtual world to some end. Given a limited repertoire of physical moves, a limit on manipulation of a virtual world is anticipated. In fact it could become a further barrier if badly designed. We may set the design situation as follows. Imagine someone with extensive physical handicaps but effectively functioning cognitive and sensory capacities. That is, the person can plan, set goals, monitor the unfolding of a plan, etc., but has great difficulty executing and controlling the motor movements necessary to achieve goals.

Now imagine that the person's environment is populated with intelligent objects, whose purpose is to identify and to carry out the person's intentions. The person communicates intentions to the intelligent objects through an artificially intelligent interface. The latter gives the person access to a combination of (1) computer-generated artificial reality and (2) information captured from the person's environment. The user projects himself into the interface and commands the intelligent objects to do his bidding. In Figure 1 we illustrate the logical flow from which a requirements analysis can begin.

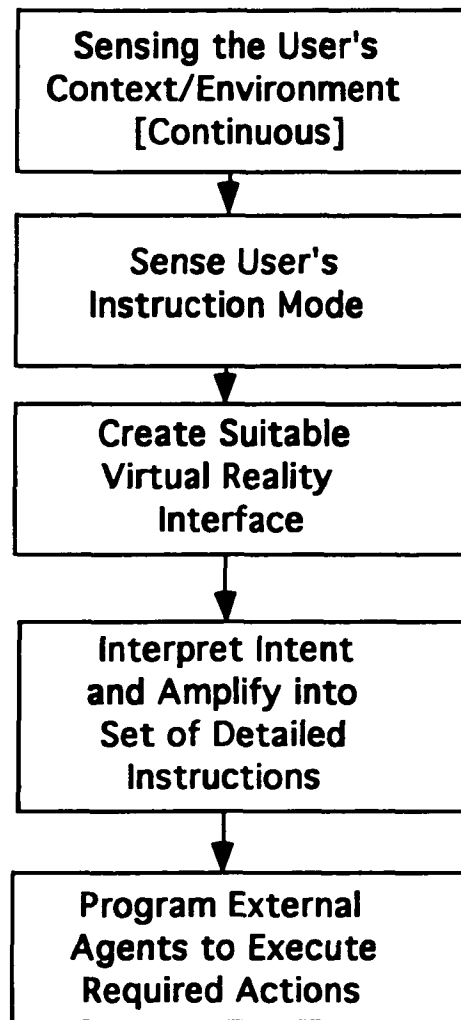


Figure 1: Sequence of Events Necessary to Effect Interaction with the Proposed Intelligent Virtual Reality Interface

The first two boxes in Figure 1 seem straightforward enough, but they mask considerable complexity. One might continue to argue for non-fuzzy implementations if the tasks were simple. When either, or both, the user environment and instruction mode get complex, fuzzy set implementations seem indicated from the outset. The case for fuzzy design principles becomes, if possible, stronger when we remove the restriction for an intact cognitive repertoire. Consider for instance the loss of short term memory. The intelligent virtual reality interface would then have to extract the missing information from records or the environment (real and virtual) after first sensing that amplification of the divined intent required such information.

The second set of two boxes in Figure 1 call for a formal model of intent amplification. We are currently working on an evidence based model. [Dockery and Littman, 1993]. The last box could be considered controversial since robotics has not developed in this direction. However, this paper is an exercise in the statement of requirements; and "smart" external agents are necessary to the concept.

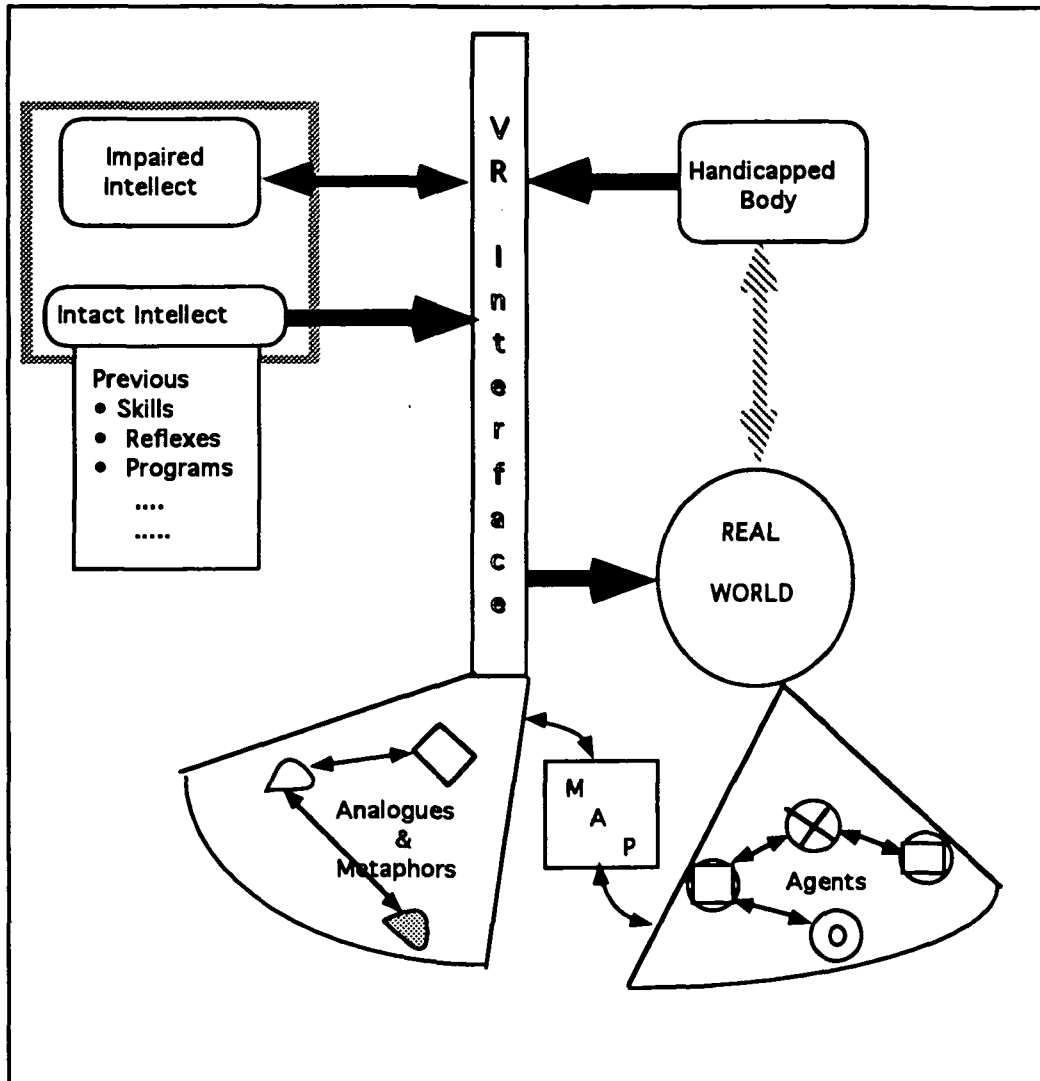


Figure 2: Dynamics of the Interactions between the User and the External World via the Intelligent Virtual Reality Interface.

Seen from a systems engineering viewpoint things are a bit more complicated. Figure 2 above from Dockery and Littman [1992] summarizes the linked intelligent virtual reality interface in more dynamical terms than Figure 1. Attention is called to the reliance on analogue reasoning and metaphorical communication. Both of these are well handled by fuzzy sets. The hatched arrow between the handicapped body and the real world is meant to indicate an impaired and fuzzy communications channel between stated intent and requisite implementation. We turn now to a systematic overview of all the possible requirements which may possibly be met within a fuzzy sets framework.

### Emergent Requirements for Fuzzy Sets Implementation

We have done some preliminary analysis of the required network of technologies necessary to bring about an intelligent virtual reality interface for the handicapped. A fragment

of such analysis can be seen in Figure 3. It shows some possible relationships between fuzzy sets and other technologies.

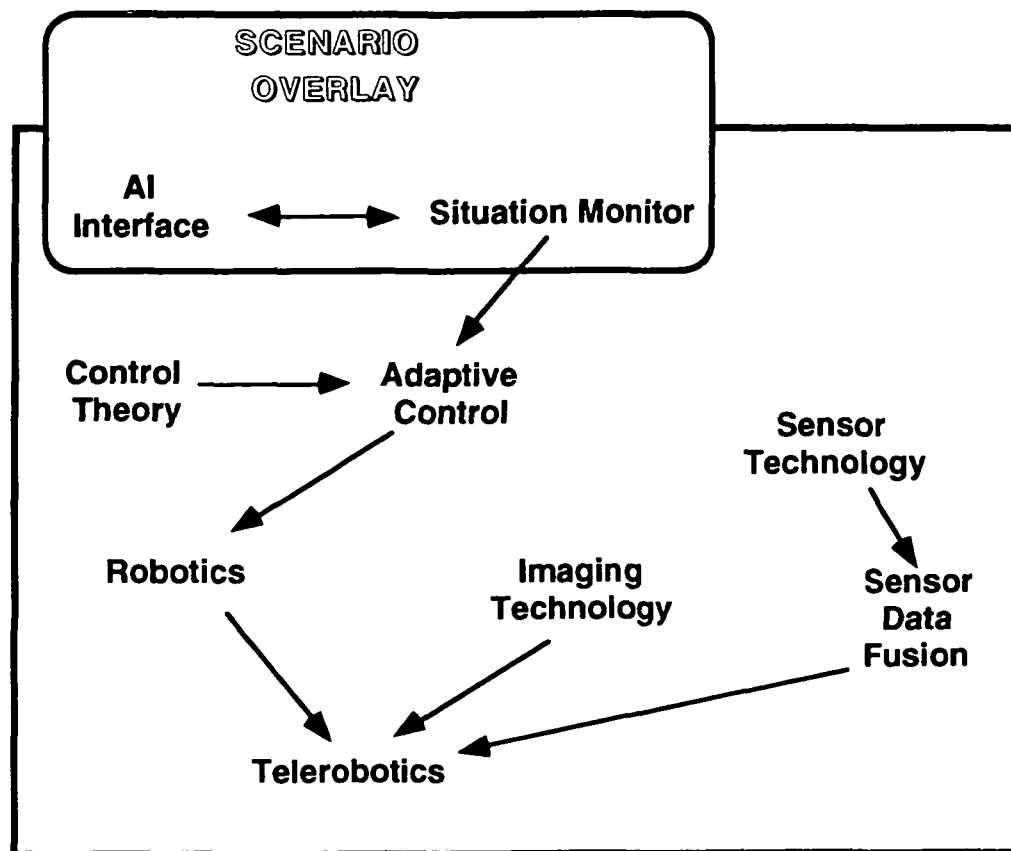


Figure 3: Example of Networked Technologies Needed to Implement an Intelligent Virtual Reality Interface for the Handicapped

To see why fuzzy set theory can be expected to play such an important role in the implementation of intelligent virtual reality for the handicapped, we look first to the assumption of intent amplification. We have already asserted that the signaling and interpretation of intent is basically a fuzzy process. Where else might the fundamental interactions be best described with the help of fuzzy sets? Including the aforementioned relationships with intent, they arise from at least the set of design foci, which are first listed in Table II, and then discussed. But first we assert that there are globally valid reasons for expecting fuzzy sets to play an important role in design of an intelligent virtual reality for the handicapped. They are summarized in Table I below.

**Table I**

**Global arguments for use of fuzzy set theory in design of an intelligent virtual reality for the handicapped.**

- Both input, e.g. intent and output, e.g. telerobotic commands are inherently multi-valued. Moreover, depending on context that may be inherently imprecise.
- Virtual reality worlds are excellent examples of instantiated possibilities rather than probable variations on real worlds. [Although the latter can not be gainsaid, the emphasis in intelligent virtual reality is the possible.]
- In the interpretation of intent there are simply too many real life instances to write rules for them all. Therefore, fuzzy reasoning is suggested for interpolating between and/or extending the rule base.
- Similarity transforms and reasoning by analogy, both well treated by fuzzy sets, are required in dealing with goal determination from intent signaling.
- Reasoning under uncertainty will certainly be important.
- Soft computing recently proposed by Zadeh [1992] appears useful for interpolation requirements sure to be present.

Some candidate design issues, which incorporate one or more of the global arguments follow in Table II. We turn finally to a series of brief expositions on emergent applications.

### **Commentary on Emergent Applications to Intelligent Virtual Reality**

#### **REASONING**

Above all the reasoning about intent and translation into overt action by agents is a hierarchical process. The process in all but the most trivial examples is non-monotonic. At the highest level is the requirement for an overall awareness function related to the imputed goal. Although crisp logic may actually drive the agents behavior, the choice of which crisp logic that is appropriate in a given time interval has been shown in simulation to be well treated by fuzzy logic. Likewise the choice of reasoning method seems to require a cross between deduction and intuition of the sort typically referred to as abductive reasoning methods. Aspects of abductive inference may benefit from fuzzy algorithms.

Adoption of various pairs of norms and co-norms effectively creates hierarchically arranged models of the decision maker operating through the intelligent virtual reality interface. Thus, the user could chose between risk taking and risk adverse solutions to goal satisfaction, itself a fuzzy concept.

**Table II**

**Candidate elements of the intelligent virtual reality for fuzzy set applications**

- Sensor fusion of real world data.
- Signaling of intent.
- Interpretation of intent by the artificial intelligence shell.
- Planning, execution, monitoring as well as replanning and adaptation.
- Design of a "forgiving" implementation of external actions resulting from interpretation of intent.
- Description of virtual reality metaphors via linguistic variables.
- Design of a virtual reality world according to fuzzy laws of nature; or equivalently, a physics with fuzzy equations.
- Incorporation of an "awareness" function at the top level of design to answer the question: "How am I [the interface system] doing."
- Strong requirement for learning which suggests linking fuzzy set controllers with neural net hardware.
- Fuzzy logic controllers for the smart robotic agents.

OPERATION OF A VIRTUAL REALITY WORLD

There appears to be a requirement for a fuzzy qualitative physics such as that discussed by Demtchenko [1991] by which to describe some of the laws of nature in the intelligent virtual reality. For example given an interpretation by the intelligent virtual reality artificial intelligence shell that force need be applied, it is anticipated that the appropriate statement is not the classical  $F = ma$  but rather "some moderate force" is required to accelerate an approximate mass to a modest velocity adequate to carry out the task, as for example forcing open a stuck door. One is reminded in this instance of why super tankers can't dock--1/4 mile per hour times a loaded super tanker mass equals trouble.

Building a world based on fuzzy qualitative physics may signal a real application for fuzzy differential equations in which both coefficients and variables are fuzzy entities. In general we will be dealing with fuzzy dynamical systems. [Buckley, 1991]

COMMUNICATION BETWEEN THE INTELLIGENT VIRTUAL REALITY ENVIRONMENT AND USER

As has already been stated, the anticipated mode of communication is by metaphor. This would almost certainly involve complex sets of similarity transforms. Since you can write your own rules in a virtual reality world, consideration of communication leads to a concept of a fuzzy

self-adaptive interface. There is no reason why the color intensity in the intelligent virtual reality could not indicate the quality of the data input to take a solution which has its answer in another design dimension. That dimension is user adaptation to some rather alien virtual reality implementation.

Whatever fuzziness appears in the interface or in the controller logic of the smart agents results in crisp actions. However, the evaluation of the crisp action in terms of movement toward the goal derived from the signaled intent is still fuzzy.

### DATA INPUT INTO THE INTELLIGENT VIRTUAL REALITY INTERFACE

Generation of events in the intelligent virtual reality interface are controlled by data fusion of real world data and possibly stored data as well. A possible military analogue is collection and evaluation of intelligence information. Real world data are by nature fuzzy since some of them will be derived by inference. Even stored data about objects in the environment are perhaps better stored as possibility functions. For example even without weighing it, it is not very possible that a book will weigh more than a couple of pounds. The question of fuzzy input data also involves practical limitations on number and precision of external sensors driving the creation and operation of the intelligent virtual reality interface world.

### RELATED TO ALLIED APPLICATIONS

Two decision science areas which may be very successfully allied to fuzzy set implementation come to mind early in the requirements generation phase.

- Neural Nets combined with fuzzy control logic to tackle questions of learning and adaptation.
- Bayesian inference net applications.

### **Summary**

We have introduced the possibility that fuzzy set theory applications could play a significant role in the design and implementation of a universal interface for the handicapped. That interface and the total system concept in which it is embedded does not exist. Therefore, this paper addressed top level requirements for such a system and interface in terms of opportunities for fuzzy set mathematics and logic.

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