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EXTERNALIZING THE PERSONAL WORLD: COMPUTER AIDS TO EPISTEMOLOGY

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Commences "An individual, a group of individuals, or a society, each has some basis for the acquisition, expression..."

ABSTRACT

An individual, a group of individuals, or a society, each has some basis for the acquisition, expression, and understanding of knowledge. This basis changes with time, is rarely explicit, and may contain inherent inconsistencies and conflicts. This paper considers a framework for such personal and group epistemologies which is operational in that it has been embodied in computer programs, that through interaction with the individual or group, make explicit the underlying constructs being used in acquiring and representing knowledge. It is suggested that this framework embodied in programs for personal computers can provide an important range of tools in aiding people to cope with an increasingly complex environment. System-theoretic foundations for this work in terms of epistemological studies and fuzzy set semantics are also discussed.

1 INTRODUCTION

The computer has been hailed as having a wide variety of possible social impacts (Gaines 1979) from saviour to destroyer of our civilization (and also as having virtually no impact whatsoever !). One of the most important early promises was some kind of very close relationship between computers and people in which the strengths of one compensated for the weaknesses and complemented the strengths of the other - man-machine symbiosis as Licklider (1968) so elegantly phrased it.

There is little evidence yet of such symbiosis being achieved. However, its potential significance is very great and could play an important role in what Wiener (1950) called "The Human Use of Human Beings". For example, consider the following social scenario: (1) individuals are becoming dominated in their thoughts and actions by the organizational structures of an increasingly complex world; (2) individual decision-making is increasingly restricted because the basis for comprehending the ramifications and consequences of decisions is too complex for most people; (3) only a few are capable of being truly individualistic in moving within society's framework; (4) most give in and are driven by the organization rather than driving it; (5) some opt out destructively rebelling against the complete social framework. Now consider an alternative scenario in which (1) and (2) still hold but the numbers of people in category (3) is greatly increased at the expense of categories (4) and (5) because the personal computer is available to interface between the person and the complex society in which he is embedded.

This is a very different image of the use of the computer from the current stereotype in which it is usually seen as a "technical cognitive" tool (Habermas 1968) to exert authority over man. We see the computer being used in what Habermas calls an "emancipatory" role to give greater freedom to the individual rather than further restrict it. In this respect, the emphasis on the truly personal computer is a significant one. It is not the "computer utility" (Parkhill 1966), the global network, into which everyone connects - that is too open to central control. It is rather the individual machine with its own capabilities for computation and storage that is part of a person rather than part of his environment.

The scenarios above over-simplify and over-dramatize the issues before us. However, they suggest a line of thought that a key role for the personal computer may be seen as a symbiotic one with a person in coming naturally to comprehend and control an increasingly complex environment. As De Bono remarked recently:

> "By great good fortune, and just in time, we have to hand a device that can rescue us from the mass of complexity. That device is the computer. The computer will be to the organisation revolution what steam power was to the industrial revolution. The computer can extend our organizing power in the same way as steam extended muscle power..... Of course we have to ensure that the result is more human rather than less human. Similarly we have to use the computer to reduce complexity rather than to increase complexity, by making it possible to cope with increased complexity." (De Bono 1979, pp.18-19)

This paper is concerned with that line of thought and its fundamental and practical implications.

2 THE ROLE OF SYSTEM THEORY IN MAN-COMPUTER SYMBIOSIS

The most obvious feature of the above line of thought is that it is one more in a long sequence of predictions about what we ought to be able to achieve with computers. It has very little substance in terms of what we have actually achieved. Why ? We suggest basically because the issues here are quite fundamental and have never been tackled at a sufficiently deep level in past research on man-computer symbiosis. The issues are philosophico-systemic in nature, concerned with the process of knowledge acquisition and utilization: what is it that we are doing in the world, and why ? If we had answers to these questions they would be very useful - at the very least for founding a new religion! However, we do seriously suggest that there will be little progress in man-computer symbiosis until it is analysed top-down in terms of its fundamental objectives rather than built bottom-up through a sequence of improving man-computer interaction and computer capabilities.

The problem of coping with complexity for an individual may be viewed as a three-part relationship between his ontology, epistemology and axiology leading to decision and action: within what ontological framework can he view the world; how does he model particular world data within that framework; what values does he place on states of the world; how does he determine actions that lead to more desirable states; and how does he implement them ? Gaines (1977) gives a system-theoretic framework for the epistemological process and shows how this may be implemented algorithmically for defined systems of ontology and axiology. The computer may be used to structure data into knowledge for us if our foundations for doing this are defined.

This approach however, whilst providing a rigorous mathematical formulation and solution of epistemological problems posed in very weak and general terms, serves primarily to indicate the wealth of arbitrary decisions that have to be made before we can even begin to solve the problem. It focusses attention on the primacy of how we view the world rather than how we can determine what particular worlds fit within that view or how they may be changed within that view. The examples given by Gaines (1976a) demonstrate that the complexity of epistemological problems varies by many orders of magnitude as the presuppositions that we make in solving them vary. This suggests that the use of the computer to help us understand our own ontological, epistemological and axiological frameworks, may be at least as great in importance as using it to structure data within them once defined.

The significance of this line of argument may be highlighted by contrasting some of the nominally opposing schools of scientific methodology and epistemology. Carnap's (1950) incremental accretion of confirmation through a system of logical probability is a practical method of inductive inference once the terms within the languages used for system behaviour, models, and relationships upon them and between them have been defined; Gaines' (1976a) ATOM may be seen as an implementation of a Carnapian "confirmation machine" (Erwin 1971).

However, the structuring of data into models through a confirmation machine is a tedious process whose speed greatly depends on the actual data used - the majority of relevant data does little to change the order relationship of preference (goodness of fit) on models. If we wish to speed up the process of model formation then it makes sense to deliberately seek out data that can most effect our preference order for particular models - data which can falsify that most preferred currently. Thus, Popper's (1972) emphasis on "falsification" may be seen as proposing an effective strategy for speeding induction by forcing us to search for the data most relevant to changing the order relationship (by falsifying the currently preferred model). It corresponds to the optimal strategy for data search if we are prepared to be active epistemologists and have not adopted the role of a passive observer.

However, in the present context it is Kuhn's (1962) argument that major advances in science originate through "paradigm shifts" leading to "scientific revolutions" that is most relevant. Kuhn's scenario is that a phase of "normal science" comes to a point at which the best theories have become unsatisfactory, generally by having to cover too much new data with ad hoc additions. The confirmation of the best models becomes irrelevant because all the acceptable models within the current framework have been falsified. The only way out is through a radical change in viewpoint, a shift in the way in which we construe the world. The effect of such a shift is to make irrelevant all our previous evidence on confirmation and falsification. Such a discontinuity is reasonably termed a "revolution".

Thus, in coming to deal with the complexities of the world we can envision the computer as helping the individual in a number of different ways:

(1) Modelling of data within a given framework (confirmation);

(2) Indication of search strategy for data most likely to cause a change of model (falsification);

(3) Indication of the effect of actions on the state of the model (simulation);

(4) Indication of actions most likely to lead to desired model or state of model (decision);

(5) Indication of presuppositions underlying the above four processes (paradigm);

The first three applications are very significant uses of the personal computer, but as already discussed they are overwhelmingly sensitive to the ontological, epistemological and axiological presuppositions made. A genuinely

Kelly notes that the repertory grid may be used and analysed in a number of ways, notably through some form of factoring that makes apparent relationships between constructs. Since its original description there have been many applications of the repertory grid and developments of it (Bannister & Fransella 1971). A notable extension is that of Hinkle (1965) who concentrated upon the implicational structure amongst constructs and developed a grid for eliciting entailment. Another extension generally accepted is to allow multi-point rating scales to be used in the assignment of elements to constructs so that Kelly's binary requirement is dropped. There is also a separate dimension to this in that a construct may be more or less relevant to an element - Kelly says that a construct has a "range of convenience".

A notable advance in recent years has been the use of an interactive computer terminal to elicit constructs. Boxer (1979) has developed a suite of programs, "NIPPER", for what he terms "reflective analysis" whereby a person can reflect on his own construct structures and relate them to those of others. NIPPER is run interactively from a computer terminal and may be used in a variety of ways to elicit the constructs underlying a preference relationship on a set of elements. It encourages the user to give names to groups of constructs which seem to play a special role in determining the preference structure, e.g. in analysing his preference for cars the system may show the user that the pair of terms "powerful" and "airy" has a special role for him in combination and he may decide to call this "sporty".

Boxer notes that the structural analysis of the constructs has four aims:

> "(1) To identify anchor groups of concepts which correspond to significant dimensions of construing."
>
> "(2) To ground those groups on the content of experience with concepts that arise directly out of experience."
>
> "(3) To spread the concept structure over as wide an area of construing as possible."
>
> "(4) To be able to make a normative statement relating all of the concepts back to the individual's aggregate evaluation/preference point of view." (Boxer 1978)

He developed NIPPER for use in management and notes that the purpose of "reflective analysis" is to make explicit the personal content of managers' theories and to aid communication with others.

Shaw and Thomas (1978) have also developed a range of programs for the elicitation and analysis of personal constructs and applied them to a wide range of educational, clinical and management situations (Shaw 1979). PEGASUS (Shaw 1979) is a program for interactively eliciting construct structures that gives the user great flexibility in analysing and modifying the structure as it is being elicited. In particular it feeds back relationships between constructs and prompts the user for more data to establish whether they are fortuitous or substantial. The following dialogue with PEGASUS in the context of "exploring learning situations" demonstrates this process in action:

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THE TWO CONSTRUCTS YOU CALLED
 1 INVOLVEMENT--REMOTENESS
 2 FLEXIBLE--RIGID
ARE MATCHED AT THE 75 PERCENT LEVEL
THIS MEANS THAT MOST OF THE TIME YOU ARE SAYING
INVOLVEMENT YOU ARE ALSO SAYING
FLEXIBLE
AND MOST OF THE TIME YOU ARE SAYING
REMOTENESS YOU ARE ALSO SAYING
RIGID
THINK OF ANOTHER ELEMENT WHICH IS EITHER
INVOLEMENT AND RIGID
OR FLEXIBLE AND REMOTENESS
IF YOU REALLY CANNOT DO THIS THEN JUST PRESS
RETURN AFTER THE FIRST QUESTION MARK, BUT
PLEASE TRY. THEN YOU MUST GIVE THIS
ELEMENT A RATING VALUE ON EACH CONSTRUCT
IN TURN. TYPE A VALUE FROM 1 TO 5 AFTER EACH
QUESTION MARK.

WHAT IS YOUR ELEMENT?PROGRAMMED TEXT
RATINGS :
INVOLVEMENT--REMOTENESS?2
FLEXIBLE--RIGID?5                    (Shaw 1979)
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Shaw (1979) also describes programs for analysing the hierarchical structure of constructs (FOCUS); providing an "expert" grid which is used to provide commentary about how the user's constructs relate to those of the "expert" (PEGASUS-BANK); analysing a set of grids elicited from a group of people to produce socionets (SOCIOGRIDS); eliciting a set of grids simultaneously from one person in several roles (ARGUS); and eliciting a relationship between a pair of grids (CORE).

It would be easy to assume that such interactive programs are merely more convenient ways of eliciting construct systems through extensions of Kelly's repertory grid and do not themselves add anything qualitatively new to the process. However, such an assumption would be missing certain crucial psychological factors in the man-computer situation and its differences from the man-man situation. We have observed informally in making PEGASUS available to a wide range of people in a variety of situations that those coming to it for the first time often seem to find it a very dramatic experience. They react to it intensely and become gripped by the interactive process of construct elicitation. They also feel that they are learning something new from the process and are prepared to use this in determing their behaviour.

Probably such involvement is also significant in the elicitation of construct systems by people rather than computer interaction. However, we believe there are certain quite fundamental differences when the elicitation is done in such a way that interpersonal interaction is clearly absent. In particular, when a person is feeding

back comments and guidance it is a natural and ready assumption that they are injecting the constructs rather than eliciting them. It is easy to believe that the elicited constructs do not come from oneself but that one is in a tutorial or debating situation with another person. One has to be persuaded that this is not so and the persuasion has to be stronger the more striking and significant the constructs elicited. However, when a computer is the tool by which one's construct structure is being reflected or laid bare then such an assumption of outside injection and interference is far less tenable (note how this suggests the need for the computer to be clearly simple and neutral - a little "PET" is better than a terminal to a remote powerful machine that may be 'artificially intelligent' !).

When constructs are being elicited by a computer program then one is more likely to accept that it is precisely and only oneself that is being portrayed. We 'trust' a computer program to be doing just what it appears to be doing without deeper motivations and without attempting to persuade us to its point of view. No-one is telling you anything - you are seeing, in interacting with PEGASUS, possibly for the first time the basis for your own thought processes. Very often extreme surprise is the first reaction - the person had not thought that he was viewing the world in the way portrayed. If another person were eliciting the construct structure then the surprise would be taken by the subject as an indication that the elicitor was incorrect and followed by a process of ignoring him or arguing with him. With computer elicitation the reflected structures are accepted as being self-generated and the surprise leads to a motivation to know more.

That this knowledge can be totally private to oneself is another important feature of interaction with the computer. We do not like, as Kelly put it, to be "caught with our constructs down". When another person is involved we are more reluctant to expose and explore our constructs the more surprising they are - perhaps because the surprise is often the result of a conflict between our ostensive value judgements and the basis of our behaviour. Or it may just be sloppy verbal behaviour - that we are naming two distinct constructs with the same label - a scientist may find that he is using the word "time" to label several different constructs and generating confusion in his arguments because of this.

Another reason that we are reluctant to explore construct structures freely in interacting with another person, particularly a professional person, is that we are acutely aware of the possible "waste" of their time. This phenomenon has been noted (Card et al 1974) as accounting for a major part of the preferences expressed by patients to be interviewed through an interactive computer program rather than their doctor. There are many pressures and artefacts of interpersonal relationships that can totally obscure and undermine such reflective processes as we require in the elicitation of personal constructs.

It is interesting to note that this argument has been put in reverse: Adams (1979) notes that children learn quickly to play games on a personal computer and conjectures that this is because of the lack of interpersonal complications - she suggests, however, that "one of the benefits of game-playing is that a child learns how to behave with and towards others, how to cope with success and failure, and what effect it has on others. In the human-computer relationship the child does not learn these valuable social skills." We are arguing conversely that the need to be deploying such "social skills" is a load that can seriously detract from the exploration of the self.

These are some of the key psychological factors which the use of a personal computer for the elicitation of constructs significantly different from previous manual techniques. They can be summed up by noting that one can see one's reflection most effectively in a stream if one is sure that no-one else's reflection is mixed up in it (and that no-one else is muddying the waters !). There are technical factors also, however, that add new dimensions to the computer elicitation of constructs.

The most notable technical factor is that already demonstrated in both Boxer's and Shaw's systems - that relationships between constructs may be inferred instantly and queried with the user. This immediate analysis and feedback is a key factor in most applications of interactive computers and can go way beyond what any manual analysis can accomplish. Instant feedback whilst one remembers one's line of reasoning is very different from delayed analyses that arrive at a later time when the entire context of the replies one has been giving may have been forgotten. Construct structures in particular have a high degree of context-dependence - it is often precisely the relationship between the structures elicited and the role we are adopting in answering the questions that elicit them which is of prime interest to us. Using Wolff's (1976) vocabulary, we "surrender" ourselves to a particular role and become a "physicist", a "mathematician", a "manager", a "father", etc., and it is the analysis of our construal of the world in the specific role which we are attempting to catch.

In terms of this discussion it seems reasonable to suggest that one takes an existential view of the phenomenon of computer elicitation of personal constructs regardless of one's view of Kelly's theory and methodologies based on it. The computer interaction is in itself a meaningful and significant experience for many people and they gain from it. Perhaps it is only that introspection is not a skill developed by most current educational systems - we promote the "received view" of knowledge and act as teachers to bring the minds of students into conformity with our consensual models of reality. What you think does not matter per se - only that it does not deviate from what it is "correct" to think. It is a novel experience for many people to realize that there are actually individualistic thought processes going on within them. It is even more novel for them to realize that these condition "reality" and

that different approaches to life and different reactions to the same circumstances may be ascribed to different construals of reality.

Whatever the underlying mechanism for the phenomenon of personal involvement in interactive construct elicitation, it forms a base on which to build independently of any underlying psychological theory. If people find a game worth playing then it is a valid game. If they modify their patterns of reasoning and behaviour through playing it then it forms a learning experience for them and is part of their education. In the remainder of this paper we suggest further enhancements of computer systems for construct elicitation primarily to encourage the widening of interest in, and the broadening of techniques for, what Boxer so aptly calls reflective analysis - any process wherby we enhance our understanding of our own knowledge acquisition and decision processes and their relationship to those of others.

5 FUZZY SET SEMANTICS FOR PERSONAL CONSTRUCTS

Sections 2 and 3 of this paper suggest that system-theoretic studies of epistemology and psychological studies of personal construct structures have much to gain by mutual interchange. The arguments in those sections were at a philosophical level. In this section we wish to further promote such interchange by reviewing some links between construct elicitation methodology and Zadeh's fuzzy semantics for natural language (Zadeh 1978). The suggestion here is that current methods of construct elicitation and analysis fit naturally into Zadeh's framework and that a number of extensions of these methods are then immediately apparent.

A standard extension of Kelly's repertory grid has been to use multipoint rating scales in allocating elements to the poles of constructs. An obvious interpretation of this is to take the scale as giving a "degree of membership" to the fuzzy set defined by the construct. For example we may consider the fuzzy set of "interesting" books and then ask the question, "What degree of membership does 'Dice Man' have to the set of interesting books ?". Kelly's original binary allocation then appears as the use of classical set theory and multipoint rating scales appear as the use of some form of fuzzy set theory in which graded set membership is allowed.

The following sub-sections give a framework for developing a model of personal constructs based on fuzzy sets and discuss some of the key issues in these terms.

5.1 Constructs as Predicates Defining Fuzzy Sets

We first propose the working hypothesis:

Hyp1: The basis underlying personal constructs is that a construct is a predicate defining a fuzzy set such that a construed element has a degree of membership to that set.

Note that there is no assumption that different people make use of the same construct labels or constructs, and that fuzzy sets in which the same elements have different degrees of membership are essentially different fuzzy sets and hence define different constructs. Thus the personal nature of constructs is inherently allowed for in this model. However, the assumption of defined "degrees of membership" is a strong one since it enables us to compare different fuzzy sets in a variety of ways that well-order them. These in themselves generate fuzzy sets, and hence possible constructs at a meta-level, e.g. the fuzzy set of constructs similar to construct A on some criterion.

Hyp1 takes us only a small step towards a calculus of constructs because it says nothing about the way in which the fuzzy sets may be manipulated to give us fuzzy reasoning and hence a model underlying construct generation, reasoning with constructs, etc. There are a number of possible foundations of fuzzy reasoning (Gaines 1976b) and we shall assume for purposes of this paper:

Hyp2: The fuzzy sets underlying constructs are manipulated according to an uncertainty logic (Gaines 1978).

The logics discussed in the paper referenced include those used by Zadeh in various papers, Mamdani in control studies, etc. (Gaines and Kohout 1977). It will not be necessary in the following discussion to use more than a fragment of these logics common to most of them.

We shall adopt the convention in writing formula for fuzzy reasoning in this paper that predicates are in upper case letters, logical variables are in lower case letters, and that the concatenation of a predicate and a variable is both a logical formula and the degree of membership of that variable in the fuzzy set defined by the predicate, with any ambiguity resolved by context.

5.2 Bipolarity of Constructs and Elicitation

One apparent problem with fuzzy sets in catching the nature of personal constructs is that their definition contains no reference to bipolarity which Kelly felt to be a particularly important feature of personal constructs. Hyp1 may appear to lead to precisely those defects of formal logic that Kelly warns against:

> "Now conventional logic would say that black and white should be treated as separate concepts. Moreover, it would say that the opposite of black can only be stated as not black, and the opposite of white can only be stated as not white. Thus the person whose field we mentioned would have shoes which would be just as much not white as the time of day, and he would write on paper which would be just as not black as the distance to his office." (Kelly 1955 p.106)

Part of the problem that Kelly is discussing here is one of relevance. The standard predicate calculus fails to distinguish between "not" and

"not relevant" - it is only in recent years that formal logics accounting for relevance have been established (Anderson and Belnap 1975). However, what he also brings out is the psychological role of the concept of opposite which has no logical counterpart - it is related to negation but not identical to it.

By considering only bipolar constructs, however, Kelly rules out the use of construct theory itself to analyse both logically and psychologically the nature of the concept "opposite". Logics based on fuzzy set theory do allow us to make a distinction between "negation" and "opposite" and to relate this to "relevance", thus providing the tools that Kelly needed to fully explicate these key distinctions. First, it is worth noting that Zadeh in presenting fuzzy set models of verbal reasoning makes precisely the distinction between opposite and negation that Kelly makes: the fuzzy set representing "young" is quite distinct from the fuzzy set representing "not old" (e.g. Zadeh 1976 p.290). Thus, Kelly's requirement that this distinction be made is satisfied - it is also worth noting that his argument for the intrinisic bipolarity of constructs is borne out by the extent to which such fuzzy predicates are presented in the literature as pairs of opposites.

Equally importantly, Kelly's insistence on bipolar constructs does not allow him to treat relevance within a uniform framework - he has to introduce it separarately in terms of constructs having a "range of convenience". By considering an element to have quite distinct degrees of membership to the two poles of a construct, i.e. to a construct and its "opposite" we can also capture the concept of relevance - i.e. a construct is irrelevant to an element if its degree of membership to both poles of the construct is zero. Kelly could have captured this in his binary model of constructs by noting, for example, that the construct ‹good--bad› is irrelevant to something which is both not-good and not-bad (it is clearly debatable still whether this explication of relevance captures all its psychological connotations - we would suggest not, only that it captures some key ones). Those who extended his bipolar notion to allow for multipoint rating scales also failed to allow for relevance when they made the scales a 1-dimensional interpolation between the two poles of a construct.

Clearly whilst the notion of "opposite" is not the same as that of "negation" it does have some relationship to it - the "opposite" predicate is constrained by similar but weaker constraints than the negated predicate. We would certainly require a construct and its opposite to be symmetric in their properties since the label of "opposite" could be applied to either relative to the other. Thus, if OPP PRED is the opposite of PRED, we would have the following substitution rule:

Sub1: A valid formula remains valid under the simultaneous uniform substitutions: OPP PRED → PRED and PRED → OPP PRED.

By using Sub1 in the equivalence, OPP PRED ≡ OPP PRED, we obtain:

$$\forall x \quad \text{OPP OPP PRED } x \equiv x \qquad (1)$$

which emphasizes the similarity of OPP to negation, NOT. We would also expect symmetry with respect to negation so that the negation of an opposite is the opposite of the negation, i.e. a second substitution rule:

Sub2: A valid formula remains valid under the substitution anywhere of NEG OPP for OPP NEG, and vice versa.

We would probably also feel that a predicate has to imply the negation of its opposite even if its not equivalent to it, i.e.:

$$\forall x \quad \text{PRED } x \supset \text{NOT OPP PRED } x \qquad (2)$$

which gives us in terms of degrees of membership:

$$\text{PRED } x \leq 1 - \text{OPP PRED } x$$

or

$$\text{PRED } x + \text{OPP PRED } x \leq 1 \qquad (3)$$

whereas for negation, NOT, we have:

$$\text{PRED } x + \text{NOT PRED } x = 1 \qquad (4)$$

so that a negation is an opposite, but not necessarily vice versa.

Constraint (2) does not completely capture the semantics of "opposite" since we would also want implicational relationships between different predicates on the same element to be preserved but reversed in taking opposites:

$$\forall x(\text{PRED1 } x \rightarrow \text{PRED2 } x) \rightarrow (\text{OPP PRED2 } x \rightarrow \text{OPP PRED1 } x) \qquad (5)$$

This, together with substitutions using Sub1, gives us the strong result:

$$\text{PRED1 } x - \text{PRED2 } x = \text{OPP PRED2 } x - \text{PRED1 } x \qquad (6)$$

that opposite preserves the interval structure on degrees of membership.

We may now also define the relevance, REL, of a predicate to an element as the degree to which inequality (3) is an equality, i.e.:

$$\text{REL PRED } x \equiv \text{NOT OPP PRED } x \supset \text{PRED } x \qquad (7)$$

which in terms of degree of membership gives:

$$\text{REL PRED } x = \text{PRED } x + \text{NOT OPP PRED } x \qquad (8)$$

This also corresponds to the extent to which OPP and NOT are the same:

$$\text{REL PRED } x \equiv (\text{OPP PRED } x \equiv \text{NOT PRED } x) \qquad (9)$$

These definitions show the close relationships between opposite, negation and relevance that Kelly hints at in his work but did not have the formal tools to define. The discussion of this section

demonstrates that Hypl, although omitting specific mention of bipolarity, actually gives one adequate tools with which to explicate both the notions of "opposite" and "relevance" in personal construct theory. It further suggests that in the elicitation of personal constructs the bipolarity does have a significant role to play for, without information on the degree of membership to both poles of a construct, we cannot distinguish between its not applying and not being relevant. However, this also requires a change in the methodology of construct elicitation since current techniques, such as those used in PEGASUS (SHAW 1979), by forcing elements to be rated against constructs on a linear scale are automatically assuming relevance. This is not unreasonable given that both elements and constructs are elicited from the user to be mutually relevant to the context of a specifically selected topic. It suggests, however, that in a large-scale system with wide ranging applications such that uniform relevance cannot be taken for granted it would be appropriate to allow users to ascribe separate ratings to the two poles of a construct.

5.3 Analysis of Construct Structures

The analysis of data from experiments on construct elicitation is a major task in its own right. One may regard it as a problem of attempting to determine the entailment structure for a class of constructs defined extensively by the degrees of membership of a set of elements to various fuzzy sets. There is also the converse problem of determing possible relationships between elements given their co-ordinates as members of a class of fuzzy sets.

We generally need first of all to define some similarity measures such as the degree of equivalence, EQUIV, between two constructs:

$$\text{EQUIV } A\ B \equiv \forall x\ (A\ x \equiv B\ x) \qquad (10)$$

so that in terms of degree of membership:

$$\text{EQUIV } A\ B = 1 - \max_x |A\ x - B\ x| \qquad (11)$$

i.e. it is determined by the largest difference in the ratings of the same element on the two different constructs.

Equivalence between constructs is one important measure in allowing them to be clustered in terms of similarity. However, it is also of interest to investigate the implicational relationships between them, and we may define similar measures to (10) by replacing $A\ x \equiv B\ x$ with one of the four distinct implications possible: $A\ x \supset B\ x$, $B\ x \supset A\ x$, $A\ x \supset \text{NOT } B\ x$, or $B\ x \supset \text{NOT } A\ x$. This gives us a directed fuzzy graph of implications between constructs that may itself be clustered to determine the main entailment structure for the constructs.

5.4 Linguistic Elicitation and Analysis of Constructs

One major advantage of the fuzzy set approach is that there is an associated linguistic semantic model in terms of Zadeh's fuzzy "hedges", and this may be used to avoid the use of numbers in the discourse with the user if desired. For example, instead of having the user allocate books to the construct poles <serious--entertaining> on a five-point scale (Shaw 1979) one might instead allow them to make statements of the form:

"Dice Man is very entertaining"

where "very" represents one of the hedges: "absolutely", "extremely", "very", pred, "rather", "fairly", pred "and not" pred, "fairly not", etc. (where 'pred' is inserted to show a null hedge and an ambivalent hedge, respectively). These are all interpretable as degrees of membership for internal computation but allow the user to operate in 'natural language' rather than some imposed technical framework.

Such linguistic representations may also be used at for meta-level communications with the user, e.g. two constructs "are very similar" rather than "matched at the 75 percent level". Even the analysis of construct relationships and entailment structures might be best presented in this way - Rhodes and Klinger (1977) have demonstrated how effective such fuzzy semantics can be in allowing natural man-computer dialogue. It may even be possible to use this approach non-interactively to elicit construct structures from transcripts of discourse (Linde and Goguen 1978).

6 CONCLUSIONS

This paper has attempted to provide bridges between the three areas of system theory, personality theory, and the personal computer. Returning to our original theme, of "coping with complexity", we do believe that the personal computer will have a profound effect on society and play an increasingly important role in the relationships between people and the society of which they are part. Personality theory has so far been an interplay between psychology, sociology and philosophy, and its practical applications have been mediated by people. To enable the computer to play an effective role one requires greater technical understanding of the psycho-socio-philosophical processes wherby an individual assumes roles in society. We hope this paper provides some stimulus to encourage the kind of inter-disciplinary collaboration we have indicated as necessary to developments in personal computing, personal construct theory and epistemology.

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