14. EPISTEMOLOGICAL HIERARCHIES IN KNOWLEDGE AND EXPERT SYSTEMS

Mildred L. G. Shaw

SUMMARY

Increasingly computers are being used as tools for aiding knowledge acquisition and decision making, either alone or in some form of man-machine symbiosis. This has culminated in the development of *expert systems* in which the computer acts as a medium for access to encoded expert knowledge. It is possible to give a system-theoretic framework for much of the operation of such computer-based systems enabling suitable algorithms to be formally derived. Most practical systems commence with some inbuilt vocabulary for the problem area for which they are designed and this itself is not subject to modification either by the computer or by the user. The author demonstrates a computer-based method of obtaining such vocabulary through the elicitation of personal constructs. This method allows the user to modify these knowledge structures in an interactive mode as they are obtained.

INTRODUCTION

Some degree of pre-supposed terminology is common to all problem-solving environments even when automation is not involved. If we take a problem to an 'expert' then we first of all have to express it in such a way that he can understand it. We may well find, however, that this task is itself the most difficult of all.

This paper argues first of all for the importance of this terminological level in any form of knowledge acquisition and decision making system, and shows its significance in terms of Klir's[1] *epistemological hierarchy*. This is related to Kelly's[2] work on *personal construct* systems and to Shaw's[3] techniques for *computer-based elicitation* of constructs and their analysis using Zadeh's[4] *fuzzy sets*. The operational value of this approach is demonstrated through an example of the computer program *PEGASUS* applied to a problem of eliciting the basic vocabulary and knowledge structures used in a defined problem area.

LEVELS OF KNOWLEDGE AND FUZZY SETS

One of the most useful frameworks within which to discuss knowledge structures is Klir's[1] *epistemological hierarchy*. Figure 1 shows the cycle of events→*modelling*→*prediction/decision/action*→*events* passing through this hierarchy.

The lowest level is one of *source systems*, effectively one of data terminology definition whereby the way in which any interaction with or discussion about a system of knowledge is defined and agreed. The next level is one of *data systems*, effectively one of basic knowledge acquisition, whereby the behaviour of some system is described in terms of the agreed domain of discourse at level zero. Levels above these

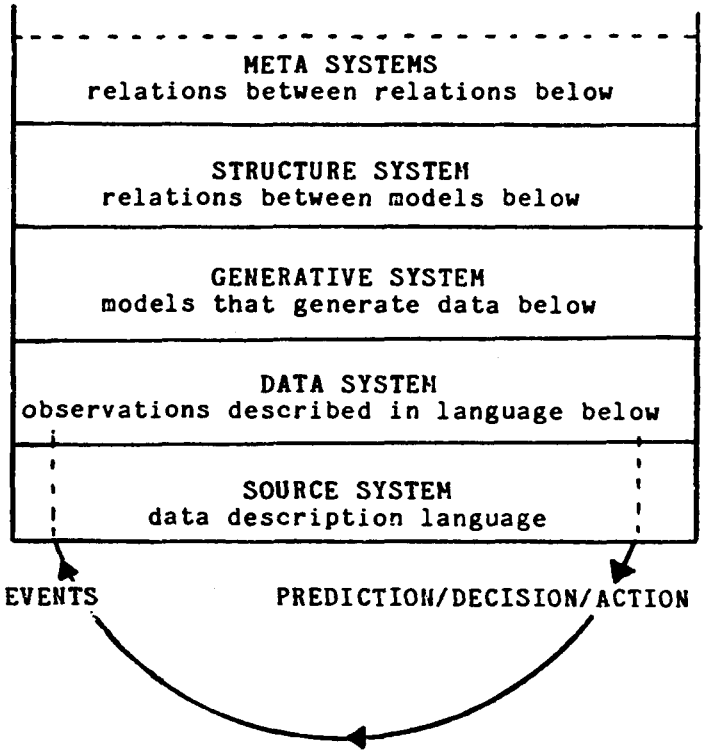

Fig. 1. The Epistemological Hierarchy (Klir[11]).

are concerned with models of data and their inter-relationships. Establishing any system of expert knowledge involves making a number of presuppositions at each level of this hierarchy.[5] From a formal point of view, the presuppositions taken at each level are quite distinct from one another and they are also quite arbitrary. From a practical point of view, however, the presuppositions at different levels interact with one another and are certainly not arbitrary since they determine the success of a specific expert system. If it is not explicitly realized that such presuppositions are being made and are necessary to any operational system then it is easy to become confused about the reasons for the success or failure of any particular system. It is also possible to generate fruitless debates about the merits of different approaches to decision making systems which are based on the failure to distinguish between presuppositions made at different levels in the hierarchy.

One presupposition that originates from the physical sciences and is often inappropriate to knowledge acquisition is that of *precision* in the source system and its application to create the data system. In the physical sciences the expected and preferred source system in which to represent data is one of exact measurement. We use a source system of physical quantities and their precise measurement and when we come to generalize this in knowledge acquisition we forget that the underlying

constructs of physics have been desired and refined over a very long period and are themselves of a peculiar and, perhaps, unique nature. The existence of continuous and limitless scales for physical variables of length, time, mass, charge, and so on, is an important phenomenon that marks out the constructs involved as being different from those in many other sciences. However, the existence of refined measuring schemes for some constructs should not blind us to their close relationships to other constructs for which no such physical measurement exists. For example, compare the concepts of *tallness* and *beauty*. The concept, the perception, of *tallness* exists in a more primitive sense than does the measurement of *height*. We are able to generate and follow arguments involving *tallness* without having any concept of inches, centimetres, or any other metric scales. Whilst a *scientific* analysis might conclude that there is a wide and ill-defined range of physical phenomena that combine in an extremely complex fashion to produce the subjective impression of beauty, in everyday reasoning it is as primitive a term as tallness. We certainly do not distinguish between them in statements such as: 'this ladder is too tall to put in the kitchen'; and 'this vase is too beautiful to put in the kitchen'. We are capable of decision making such as: 'he likes girls that are tall and beautiful; Mary is not very tall but very beautiful; he will probably like Mary'.[6]

Fuzzy Set Theory [4,7,8] provides a model of constructs at the source systems level which is more primitive and generally more applicable than the quantitative scales of the physical sciences. Under certain conditions measuring schemes may be available which preserve all the order relations of the fuzzy sets and obey additional axioms. Deriving these additional, higher-order constraints, is itself an important task of empirical science and the general assumption at the source level can be only that there may be predicates relevant to the problems under consideration that define fuzzy sets in relation to the entities involved. The links between the basic constructs used at the source level and fuzzy set theory have already been established. Goguen[9] takes a formal axiomatic approach to the notion of a 'concept' in natural and artificial languages and shows within a very general category-theoretic framework that one obtains generalized fuzzy sets. Gaines[10] shows that the modelling techniques based on measures of complexity and approximation that are effective for stochastic data readily generalize to data that is both fuzzy and stochastic and leads to *possibilistic* models. Thus fuzzy set theory provides a syntactic basis for source and data systems that enables decision analysis to be generalized to the imprecise data of everyday life. There are, however, possible artefacts that arise from the *semantics* of the source and data levels and are often unrecognized as major determinants of system success or failure. The terminology used in describing data is tacitly accepted and its derivation is not taken to be a significant part of establishing the expert system. However, in the literature of both arts and sciences it will be found that descriptive terminology changes both organically and discontinuously as disciplines develop and undergo various forms of *revolution*.[11] The literature on knowledge acquisition and expert systems is most often concerned with the upper levels of Klir's hierarchy, such as the relationship between a data system and the generative system that models it, rather than the language in which the data itself is described. However, all of these upper levels, where refined modelling techniques may be applied, derive their significance, if any, only from the significance of the lower levels. No amount of techniques at the

upper levels can compensate for lack of significant information expression at the lower levels. In the next section we discuss an approach to the operational analysis of these lower levels.

PERSONAL CONSTRUCTS AND FUZZY SETS

One of the most detailed studies of the operational role and significance of the source system level on personal decision making arises from the psycho-philosophical work of the clinical psychologist George Kelly. In his seminal work, *The Psychology of Personal Constructs*[2] he notes that:

> 'Man looks at his world through transparent patterns or templets which he creates and then attempts to fit over the realities of which the world is composed.' (pp.8-9).

Kelly emphasizes the epistemological role of these constructs in predicting and controlling the world and their ontological status as personal conjectures rather than reality-derived absolutes:

> 'Constructs are used for predictions of things to come, and the world keeps rolling on and revealing these predictions to be either correct or misleading. This fact provides the basis for the revision of constructs and, eventually, of whole construct systems.' (p.14).

This capability to revise construct systems in the light of experience and the pluralism of possible construct systems was the basis of Kelly's *constructive alternativism:* that we are not necessarily bound by our construct systems but can revise them to see the same problem from a new viewpoint. At a fundamental level we can see Kelly's *constructive alternativism* as being based on the primitive operation that Spencer Brown calls *making a distinction.* Brown commences his seminal work on *Laws of Form*[12] by noting:

> 'A universe comes into being when a space is severed or taken apart . . . The act is itself already remembered, even if unconsciously, as our first attempt to distinguish different things in a world where, in the first place, the boundaries can be drawn anywhere we please. At this stage the universe cannot be distinguished from how we act upon it, and the world may seem like shifting sand beneath our feet . . . Although all forms, and thus all universes, are possible, and any particular form is mutable, it becomes evident that the laws relating such forms are the same in any universe.' (p.v).

Thus, for both Kelly and Brown, all models at higher levels are fundamentally dependent on the distinctions made — the constructs used — at the source level. In designing expert systems we have a basic requirement to determine what these distinctions are, or should be, before proceeding with the analysis. Kelly terms this the *elicitation* of a construct system.

To show the significance of this in terms of the epistemological hierarchy, it can be redrawn with Klir's terminology of a *source* system replaced by Kelly's of a *construct* system.

Figure 2 shows this together with a more psychological interpretation of the upper levels of the hierarchy[13] which is useful in understanding an individual's acquisition

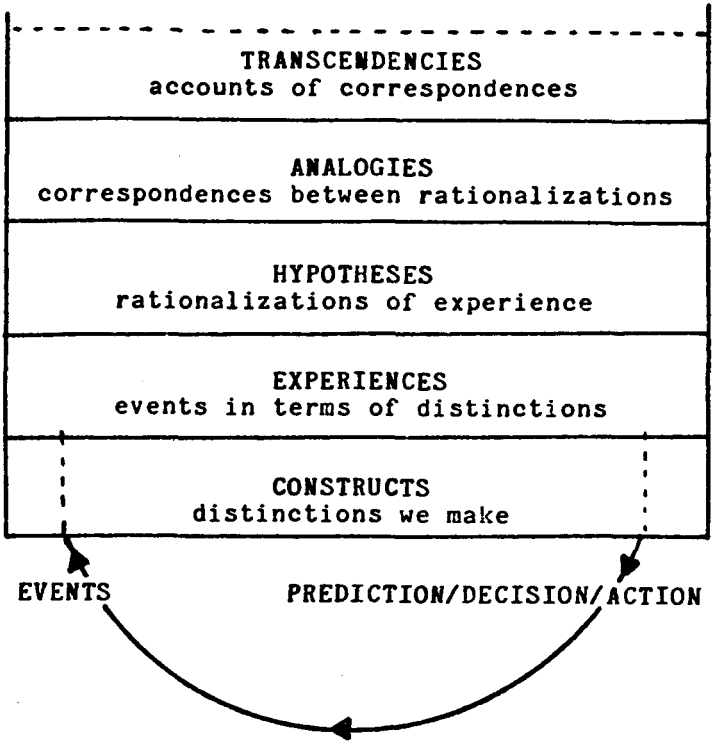

Fig. 2. The Epistemological Hierarchy (Gaines & Shaw[6]).

and application of expertise i.e. those of the personal scientist.[3] In this Figure the lowest level is one of the *constructs* or the *distinctions* made in interacting with the world. The next level is one of the *experiences* of events which happens to us, and we make happen, in terms of the distinctions already made. Levels above these are *hypotheses* which are rationalizations of experience, *analogies* between these rationalizations and *transcendencies*. Interaction with the world is, therefore, mediated through the construct system to produce experience which is modelled through the higher levels and leads to predictions, decisions and actions again mediated through the construct system.

Brown defined a distinction as a binary cut and Kelly also presented constructs as binary categories and based his own methodology for eliciting them on this. However, later workers found the need for shades of grey between the two poles of a construct and Kelly notes that this is consistent with his notion of a construct:

> "The construct, of itself, is the kind of contrast one perceives . . . while constructs do not represent or symbolize events, they do enable us to cope with events, which is a statement of a quite different order . . . They also enable us to put events into arrays or scales, if we wish."[14] (pp.13-14).

The interpolation within the basic bipolar distinction that has been made can be

generated through logical operations that correspond to paradoxes of *self-reference* in classical logic. Varela[15] shows how a three-valued logical calculus arises from acceptance of a single self-referential form in Brown's calculus of distinctions. Gaines[6] shows how such 'primitive paradoxes' may be iterated to given an indefinite number of distinctions between the poles of those originally made, and hence how the fuzzy truth value of an arbitary proposition may be derived through a Dedekind section.

Kelly himself developed an elaborate but fairly informal epistemology based on his constructive alternativism and its consequences stated as a fundamental postulate and a set of 'corollaries'. He also developed techniques for eliciting the personal construct structure of particular individuals and it is this aspect of his work which has been primarily developed by later workers, mainly in the context of clinical psychology, that is, of people with abnormal construct systems. In recent years, applications of Kelly's ideas in management science has led to an interest in the personal construct systems of professional staff, and interactive programs have been developed that elicit an individual's construct system within a definite context.[3,16] Shaw and Gaines[17] have discussed such systems within the framework of general knowledge acquisition and the personal computer, and have given a fuzzy semantic model for the personal construct structures.

AUTOMATION OF CONSTRUCT ELICITATION — PEGASUS

To show how the methodology may be applied to the problem of the formation of a Citizen's Service Department (CSD), Shaw and Gaines[18] considered the attitudes of potential *Customers* to the *Actors* who currently carry out system activities related to the customer's address[19].

Figure 3 shows a repertory grid elicited from a person contemplating a change of address: the elements are different groups who should be notified and the constructs are significant distinctions between them. A '1' in the matrix indicates that left-hand description on the row applies to the element on that column; a '5' that the right-hand description applies; and intermediate values that the element lies between the two descriptions. This grid was derived by the computer program *PEGASUS* (Program Elicits Grids and Sorts Using Similarities)[3] which elicits a grid interactively from an individual, simultaneously acting as a psychological reflector for heightening his awareness and deeping his understanding of himself and his processes. This is done by continual commentary on related elements or constructs, together with the encouragement to differentiate between them.

Before choosing his elements, the user is asked to think about his purpose for eliciting the grid. Here it was stated to be 'who to inform when I change address'. This is of great importance for the interaction which is to follow, as it enables him to choose elements which are dependent on the purpose and then to distinguish between them through constructs which are relevant and representative of the topic area.

The *PEGASUS* program uses a standard triadic elicitation method to obtain the first few constructs as shown in the following dialogue:

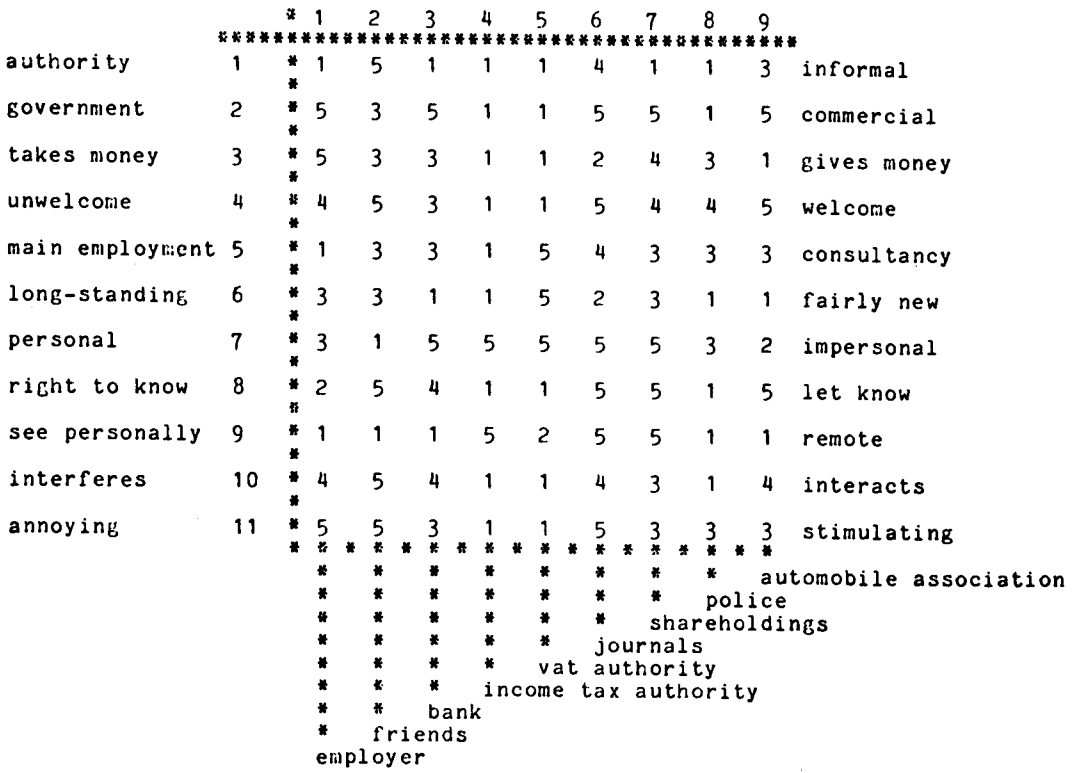

Fig. 3. Grid elicited by PEGASUS from Person Contemplating a Change of Address.

```
TRIAD FOR ELICITATION OF CONSTRUCT 1
 1 employer
 2 friends
 3 bank

CAN YOU CHOOSE TWO OF THIS TRIAD OF ELEMENTS WHICH ARE
IN SOME WAY ALIKE AND DIFFERENT FROM THE OTHER ONE

WHAT IS THE NUMBER OF THE ONE WHICH IS DIFFERENT?2

NOW I WANT YOU TO THINK ABOUT WHAT YOU HAVE IN MIND
WHEN YOU SEPARATE THE PAIR FROM THE OTHER ONE.
HOW CAN YOU DESCRIBE THE TWO ENDS OR POLES OF THE
SCALE WHICH DISCRIMINATE employer AND bank ON THE
LEFT POLE FROM friends ON THE RIGHT POLE.

JUST TYPE ONE OR TWO WORDS FOR EACH POLE TO REMIND YOU WHAT
YOU ARE THINKING OR FEELING WHEN YOU USE THIS CONSTRUCT.

LEFT POLE RATED 1 -- ?authority
RIGHT POLE RATED 5 -- ?informal

NOW ASSUME THAT employer AND bank ARE ASSIGNED THE VALUE 1
AND friends IS ASSIGNED THE VALUE 5.

ACCORDING TO HOW YOU FEEL ABOUT THEM PLEASE ASSIGN TO EACH
OF THE OTHER ELEMENTS IN TURN A PROVISIONAL VALUE FROM 1 TO 5

 1 employer              1
 3 bank                  1
 2 friends               5
 4 income tax authority  ?1
 5 vat authority         ?1
 6 journals              ?4

POLE 1 --authority

 1 employer              1
 3 bank                  1
 4 income tax authority  1
 5 vat authority         1

 6 journals              4

 2 friends               5

POLE 5 --informal

DO YOU WANT TO CHANGE ANY OF THESE VALUES ? no
DO YOU WANT TO CHANGE THE POLE NAMES ?no
```

The *Construct Match* section of *PEGASUS* provides feedback when two constructs are highly related. The user is first asked to add an element which is either at pole "1" on the first construct and pole "5" on the second, or vice versa. If he can add a new element it must be rated on all the constructs so far elicited, but if he cannot split the two constructs this way, he is asked if he would like to delete a construct, combine two constructs into one, or just carry on. Feedback from a construct match is shown in the following dialogue:

```
THE TWO CONSTRUCTS YOU CALLED
 4 unwelcome--welcome
 10 interferes--interacts
ARE MATCHED AT THE 78 PERCENT LEVEL

THIS MEANS THAT MOST OF THE TIME YOU ARE SAYING unwelcome
YOU ARE ALSO SAYING interferes AND MOST OF THE TIME YOU ARE
SAYING welcome YOU ARE ALSO SAYING interacts

THINK OF ANOTHER ELEMENT WHICH IS EITHER
unwelcome AND interacts
OR interferes AND welcome

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. AFTER EACH QUESTION MARK TYPE A VALUE FROM 1 TO 5
WHAT IS YOUR ELEMENT ?police

TYPE IN THE RATINGS FOR THIS ELEMENT ON EACH CONSTRUCT

LEFT POLE RATED 1, RIGHT POLE RATED 5

authority--informal ?1
government--commercial ?1
takes money--gives money ?3
unwelcome--welcome ?4
main employment--consultancy ?3
long-standing--fairly new ?1
personal--impersonal ?3
right to know--let know ?1
see personally--remote ?1
interferes--interacts ?1

DO YOU WANT TO CHANGE ANY OF THESE VALUES ?no
```

The *Element Match* section of *PEGASUS* provides feedback when two elements are highly related. The first choice offered is to add a new construct on which the two elements are placed at opposite poles, and then all the elements must be rated in the usual way. Alternatively, an element may be deleted, or no action may be taken. Feedback from an element match is shown in the following dialogue with *PEGASUS:*

```
THE TWO ELEMENTS 2 friends AND 6 journals ARE MATCHED AT THE 75
PERCENT LEVEL.

THIS MEANS THAT SO FAR YOU HAVE NOT DISTINGUISHED BETWEEN friends
AND journals

DO YOU WANT TO SPLIT THESE ?yes

THINK OF A CONSTRUCT WHICH SEPARATES THESE TWO ELEMENTS WITH
friends ON THE LEFT POLE AND journals ON THE RIGHT POLE

LEFT POLE RATED 1 -- ?personal
RIGHT POLE RATED 5 -- ?impersonal

ACCORDING TO HOW YOU FEEL ABOUT THEM PLEASE ASSIGN TO EACH
OF THE OTHER ELEMENTS IN TURN A PROVISIONAL VALUE FROM 1 TO 5
```

```
2 friends                  1
6 journals                 5
1 employer                 ?3
3 bank                     ?2
4 income tax authority     ?5
5 vat authority            ?1
```

When the grid reaches the maximum size allowed, or if the user chooses to finish before that, the results are analysed using the *FOCUS* procedure as shown in Figure 4. This is a two-way hierarchical cluster analytic technique which systematically reorders the row of constructs and columns of elements to produce a focused grid which shows the least variation between adjacent constructs and adjacent elements. The printout shows the trees of the elements and constructs as well as the focused grid with the element and construct labels. It can be seen from the element tree above the grid that the elements 'bank' and 'shareholdings' are seen as fairly similar despite the fact that this match appeared earlier in the interaction and the construct 'see personally — remote' was added to separate them. Also 'income tax authority' and 'vat authority' are seen to have similar characteristics. Looking at the construct tree on the right side of the grid three main clusters can be seen. Constructs 2,8,10,11 and 4 form a related cluster with 3, 5 and 6 less tightly linked, and 1,7 and 9 even more loosely grouped together. Since the *PEGASUS* feedback encourages the separation of constructs very close matches are rare.

As a *PEGASUS* elicitation proceeds, this *FOCUS* algorithm is used to offer to the user a possible explanation and interpretation of his meaning system in the terms of the similar patterns he uses in supposedly different circumstances. Cross-references are mapped across the grid and exhibited to the user in such a way as to offer him the facility to reconsider and change anything he feels to be inappropriate, which in turn enables him to be more aware of the links he is implicitly holding in his cognitive model.

GROUP CONSTRUCTS AND RELATIONSHIPS IN THE COMMUNITY — SOCIOGRIDS

As we begin to examine multiple construct systems, the duality becomes apparent between Kelly's extremely individualistic model of personal reality and our social stereotype of a common world shared through common ideas and language. Shaw and Gaines[20] have put forward a detailed model of how individual construct systems interact to form social construct systems, and how in doing this the individual systems are themselves changed in a way that models normative social influences. This goes a long way towards bridging the gap between the abstract epistemological hierarchy analysed by Klir and the pragmatic soft systems methodology of Checkland.[19] Again the methodology we propose has been at least partially operationalized through the program *SOCIOGRIDS*[3,16] which produces a set of *socionets* showing the capability of one person in a group to comprehend the constructions of the others when they have all construed the same elements. It also extracts from the group a set of *mode constructs* which are shared and hence form the basis of communication, consensual cognition and action amongst members of the group. *SOCIOGRIDS* has been applied in

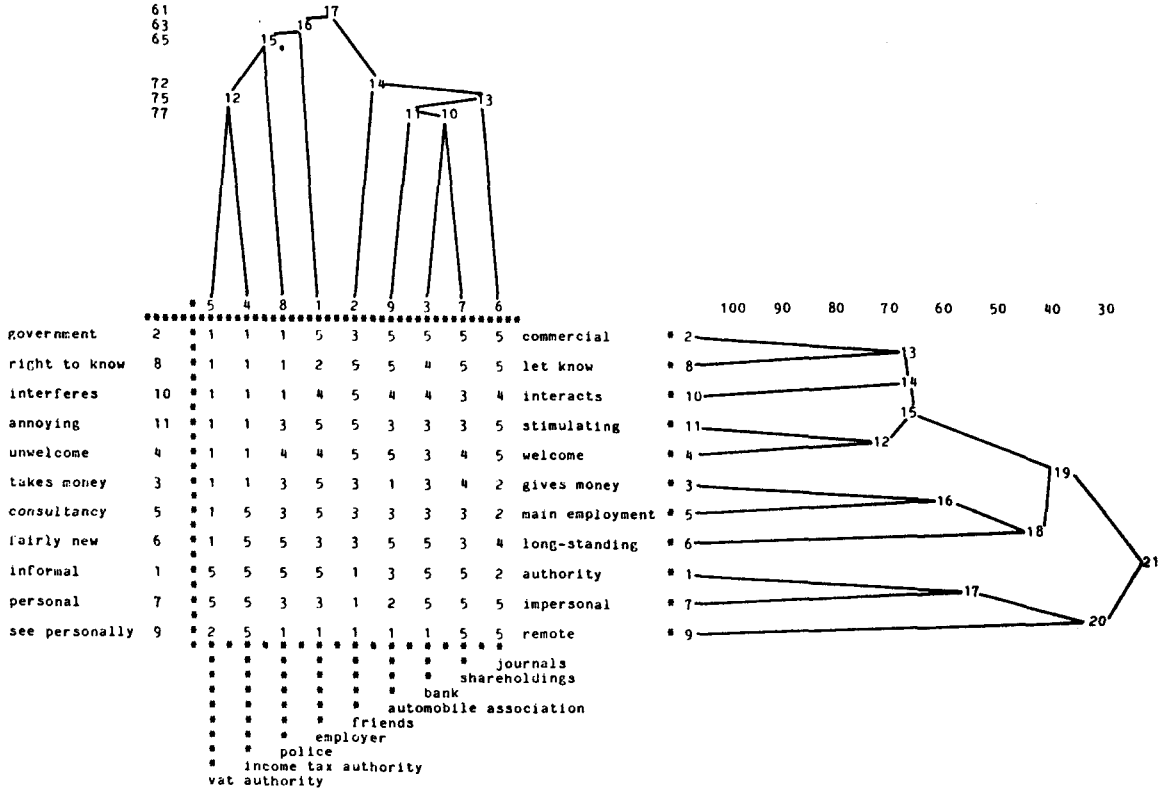

Fig. 4. Grid sorted by FOCUS to give a fuzzy hierarchical cluster analysis.

industrial studies of managers' evaluations of their subordinates and of the construct system of a quality control division in garment manufacture.[13]

What has been achieved through the interaction of an individual with the *PEGASUS* program described in this paper? From the starting position of stating the context as merely 'who to inform when I change address', we have come to a second stage where we have elicited: firstly, a set of organizations which are thought of as having to be informed; and secondly, a set of constructs that this person used in thinking about these organizations. We have done this in such a way that the person is stimulated to think about the variety of different organizations and the variety of ways he thinks about them. We have an *exploratory* program that itself has *no preconceptions* about the situation being explored — that is, one that begins to elicit the *whole* truth and *nothing but* the truth within that person's reality.

Even without any further analysis we have derived from the initial starting position a set of relevant aspects and ways of thinking about the problem. The clustering of the grid through *FOCUS* begins to give us *taxonomies* for these relevant features of the problem. By eliciting constructs from a wide range of individuals we can build up a fairly exhaustive repertoire of material on which to base our systems analysis. In the context of the CSD problem we might look at the similarities and differences between the construct systems of people in different sections of society using *SOCIOGRIDS.*

Figure 5 shows the role of the programs in relation to the problem representation for each of those playing roles in the root system and for the relationships between their construct systems. Note that Checkland's classification[19] brings into play a further hierarchical construct system based on the classification we use of people in society, and this classification can itself be explored using *PEGASUS* and *FOCUS.* Thus the methodology is truly *reflexive* and gives us the means to model ourselves and others exploring the means to model ourselves, themselves and others.

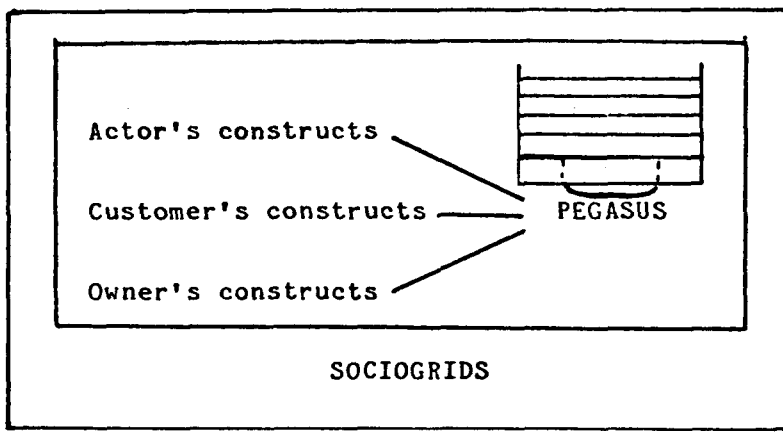

Fig. 5. Role of programs in analysing the relationships between differnt roles.

CONCLUSIONS

This paper argues for the key role of the lowest level of the epistemological hierarchy in knowledge acquisition. The source system of distinctions or constructs is a fundamental determinant of the operation, success or failure of all higher levels. It shows how the constructs being used at this lowest level may be elicited from a person through an interactive computer program, *PEGASUS*. It links the techniques described here with Checkland's soft systems methodology and the extraction of root definitions.[19] The paper also briefly indicates how the techniques can be applied to the multiple construct structures of groups and linked this with various psychosocial theories.[20] Programs related to *PEGASUS* have been developed for the analysis of group data such as *SOCIOGRIDS*,[3] which produces a *social network* based on mutual construing together with a *mode grid* of consequential construing. Thus theory and practice are bridged in providing techniques for knowledge representation and acquisition in expert systems.

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