ESYS: Interactive Knowledge Acquisition from Multiple Experts Using Personal Construct Theory

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Abstract: ESYS is a graphical knowledge acquisition tool based on the psychological theory of personal constructs. Several experts in the same problem domain are interviewed by ESYS to produce independent rating grids which capture their knowledge. ESYS combines their knowledge into a single consultation expert system suitable for subjective multi-criteria decision-making.

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1.Introduction

As experience in the development of expert systems has shown, it is not sufficient to provide only powerful problem solvers, it is equally important to support the knowledge acquisition process. One important reason why rather few **real-world** expert systems have been developed is that domain experts are not capable themselves of structuring and formalizing their **knowledge,** having instead to rely on **knowledge engineers** in order to develop expert systems.

ESYS is a graphical knowledge acquisition tool [Tilivea&Stancioiu 1992], exploiting the psychological **theory of personal constructs** of George Kelly [Kelly 1955]. This tool is designed to open up the domain experts possibility for transferring their expertise with only limited assistance from **knowledge engineers,** combining expertise from multiple experts in the same domain (for instance, several medical specialists in the same area with different options concerning a patient's sickness).

Currently, ESYS interviews experts, analyses the elicited knowledge, builds a knowledge base for a domain, uses feedback to help refine the knowledge base and helps the expert combine his/her knowledge with that of other experts.

To explore the issues involved in combining expertise from **multiple experts** ESYS was designed to build a system which allowed an end-user to choose which experts he/she wished to consult from among a set of experts, run a consultation based only on the expertise of the selected set and make recommendations based on a majority opinion or mean calculated opinion among selected experts.

This version represents a step toward the goal of designing a more sophisticated graphical user-interface to reflect an adequate model of knowledge familiar to the expert in terms of high-level graphical knowledge representations.

ESYS is based on psycho-therapeutic interviewing methods developed by George Kelly. Kelly's

personal construct theory provides a systemic model of cognitive and behavioural processes of the individual, interpersonal and social interaction. A person is modelled as construing his/her experience by dividing it up into chunks (**elements**) and classifying them using a system of **bipolar constructs**. In personal construct theory learning is viewed as the development of the construct system, social processes as the development of shared constructs and problem-solving as an active anticipation of the future. Since Kelly's original work many extensions and analysis methods have been applied to grid methodology [Gaines&Shaw 1980].

In computational terms the elements of personal construct theory may be seen as entities, the constructs as attributes, and the relationship between entities and attributes as values in an entity-attribute database. Kelly terms such a database as a repertory grid.

The manual elicitation of constructs is tedious, time-consuming and requires skill, practice and some sort of personality. In recent years computer-based techniques have been developed for on-line elicitation and analysis. Many of them are interactive programs which allow the user a higher degree of autonomy and larger control. One can imagine that such interactive programs are merely more convenient ways of elicitation and do not bear anything qualitatively new on the process. However, person-computer interaction can bring advantages to person-person interaction in some aspects of knowledge processing. Certain significant differences can be observed when the elicitation is made such that interpersonal interaction proves non-existing.

Kelly's methodology has been used to compare opinions of different people on the same subject. Kelly's grid methodology, embodied in ESYS, provides promising techniques for rapidly and effectively combining expertise from multiple experts [Boose 1985, Shaw&Gaines 1989].

ESYS was extended to produce consultation systems which would advise on or produce diagnosis in a domain. This can be done by running the consultation systems internally for all given combinations of expertise from the experts selected by the end-user and then presenting the consensus opinion as well as the mean calculated opinion. ESYS works best on structured selection problems and is difficult to apply it in order to elicit deep causal knowledge.

2.Design of Repertory Grids

The repertory grid is undoubtedly a very fertile instrument. With its great flexibility in design and application, it can be very stimulating for the user.

A full repertory grid contains three components: **elements,** which define the material which the grid will be based on, **constructs,** which are ways of grouping elements and differentiating among them and **linking mechanism,** which shows how each element is being assessed on each construct [Easterby-Smith 1980].

2.1. Elements

Since the remainder of the grid will be derived from these elements, an appropriate selection is obviously critical. The elements determine the focus of the grid and it is important that this focus be as specific as possible.

There are two general points to emphasize about element specification: first, the elements should be homogeneous, that is, all of them should be taken from the same category; second, the elements should make a representative coverage of the area to be investigated. It is also important that contrasting elements should be included.

2.2. Constructs

Strictly speaking, there need be no difference between the nature of constructs and the elements employed in a grid. However, it makes the design and interpretation of grids somewhat easier if a distinction is made, and one such distinction is to think of elements as being the objects of people's thought and constructs as the qualities that people assign to these objects.

There are four distinct methods of generating constructs in a grid:

- The quickest way to generate constructs is simply to supply them. Thus, a participant in a course may be asked to rate the other members of the group (elements) on such dimensions as "listens well-doesn't seem to hear ", supportive of new ideas - inhibits new ideas", etc. This approach can be useful in some situations provided that the constructs supplied are known to be representative of the ones that the subject would produce spontaneously.
- The classical approach to generating constructs is to elicit them from **triads** [Shaw 1988]. This method involves selecting groups of three elements (triads) from the whole list of elements and the subject being then invited to say in what way two of the elements are alike and in what way the third element differs from the other two. This procedure is intended to produce two contrasting poles for the construct, although it is sometimes suggested that the poles should be **"opposites"**. However, the difficulty of requesting "opposites" is that it will produce logical opposites rather than opposites in meaning. For example, the logical opposite of "ambitious" is "doesn't trample on colleagues". The selection of triads may also affect the final grid. Successive triads should either be chosen on a genuinely random basis or by the investigator deciding what combinations will bring about the greatest contrast of the elements available. It is also possible to elicit constructs from **dyads** [Keen&Bell 1980]. This method is normally used when the subject finds it too hard to generate constructs from triads. Two elements are introduced at a time and the subject is asked to say whether they are alike or different, and what it is that makes them alike or different. The main reason for not using this method in preference to triading is that the resulting constructs tend to incorporate logical opposites rather than opposites in meaning.
- Some people criticize the grid for being unnecessarily verbal. Verbal labels are not particularly important, being possible to design totally non- verbal grids based on **"cards sorts"**. The elements are written onto cards and the subject is asked to sort the cards into piles of similar cards. He/she may then be asked to say what are the similarities within each pile. Alternatively, the subject is simply asked to repeat the procedure using some other basis for sorting.
- The final method is known as **"laddering"** and this is normally used in conjunction with one of the other methods. Thus, a few constructs may have been elicited by triading and the subject is to be asked to look more closely at the first construct. He/she is asked about which end of the construct is preferable and why this is so. In this way a series of new constructs of greater generality can be generated from any of the original constructs.

We have implemented in ESYS the following:

- elicitation from **triads** illustrated in Figures 5,6,7 by a set of three questions; the choice of triads is at random; domain elements must be supplied before commencing the triadic dialogue (the domain must contain at least six elements);
- elicitation by **dyads** illustrated in Figure 1,2,3,4 by a set of four questions; the elements and constructs may be supplied by dyadic dialog.

2.3. Linking Constructs to Elements

This is the way the construct is used in relation to the elements indicating the meaning of the labels given to each pole. The normal method is via some kind of rating scales. The rating scales can be seen in a continuum ranging from dichotomous scoring to ranking,involving increasingly fine differentiations in each case. Dichotomous (2-points) scales tend to be more useful if hand analysis is required, or if the grid is to be used for discussion purposes. Rating on 5-or-7-points scales allow for slightly more discrimination on each construct.

ESYS enables any choice of rating scales and a graphical method for elements rating (Figure 8).

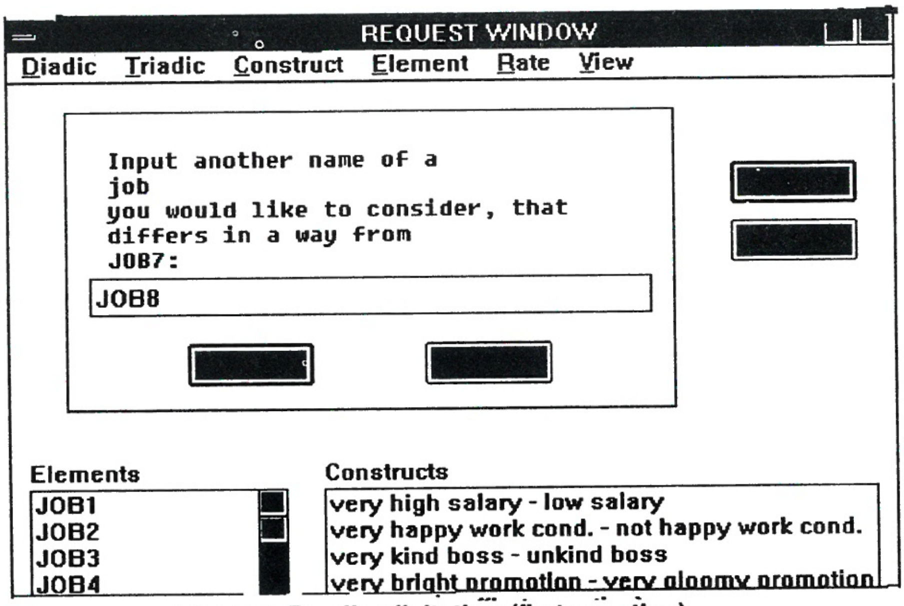

Figure 1. Dyadic elicitation (first question)

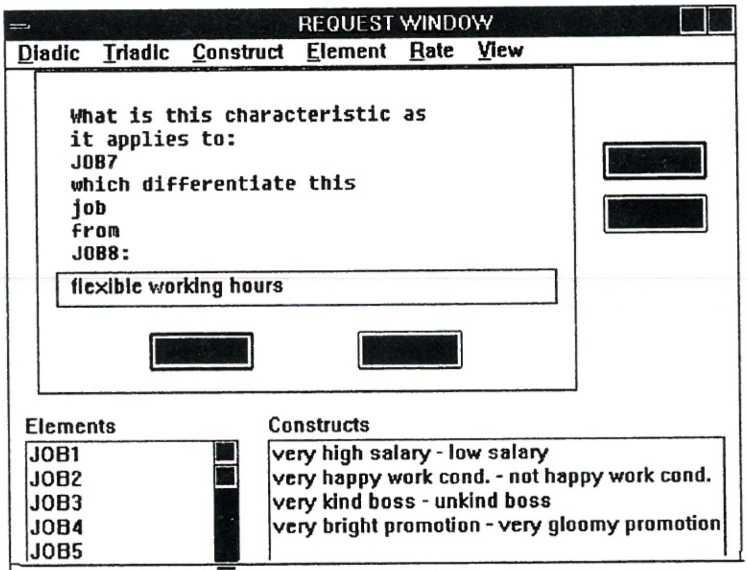

Figure 2. Dyadic elicitation (second question)

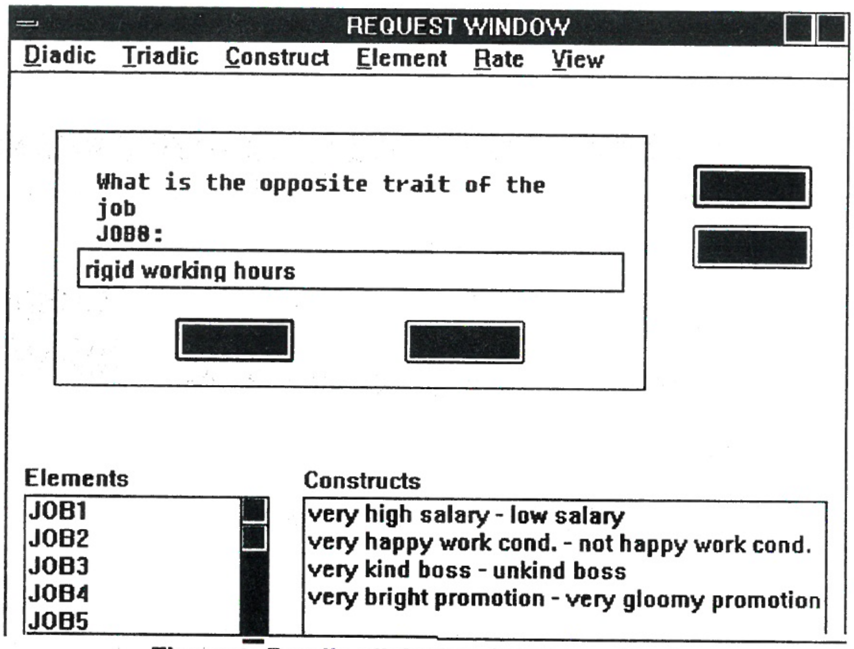

Figure 3. Dyadic elicitation (third question)

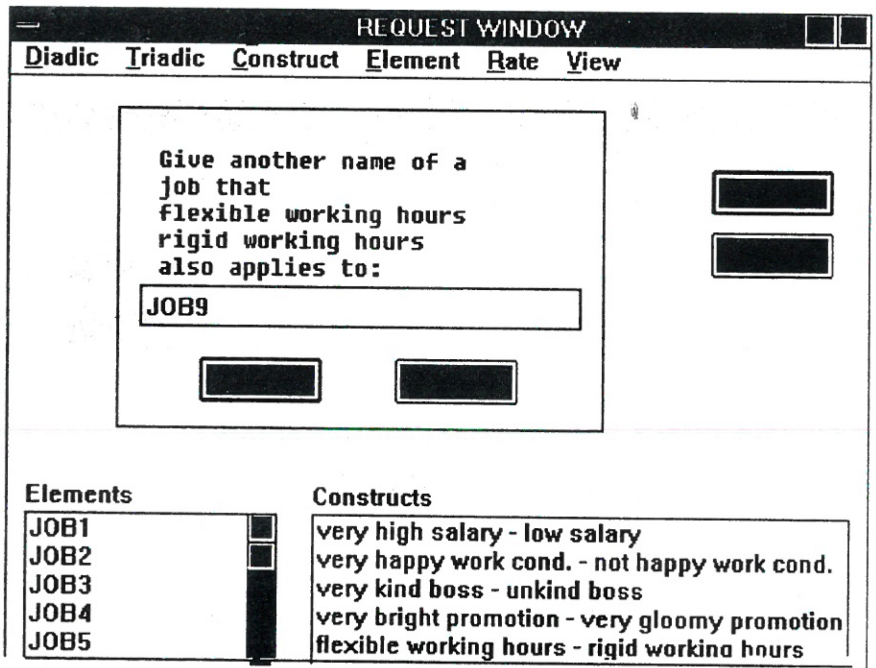

Figure 4. Dyadic elicitation (fourth question)

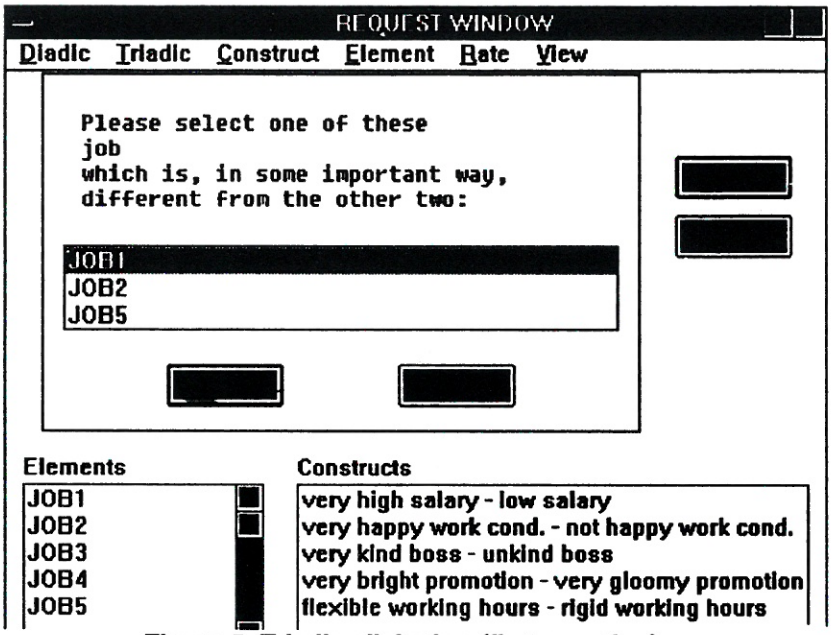

Figure 5. Triadic elicitation (first question)

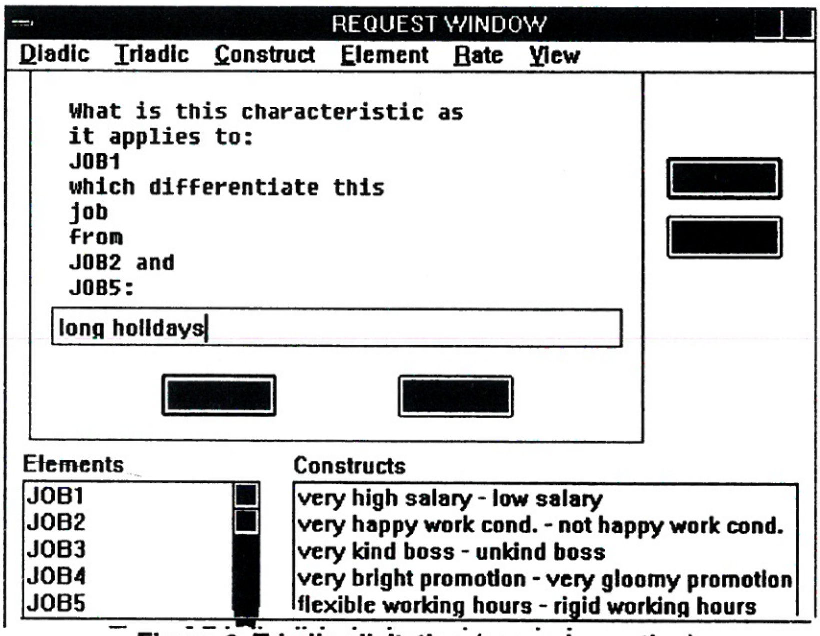

Figure 6. Triadic elicitation (second question)

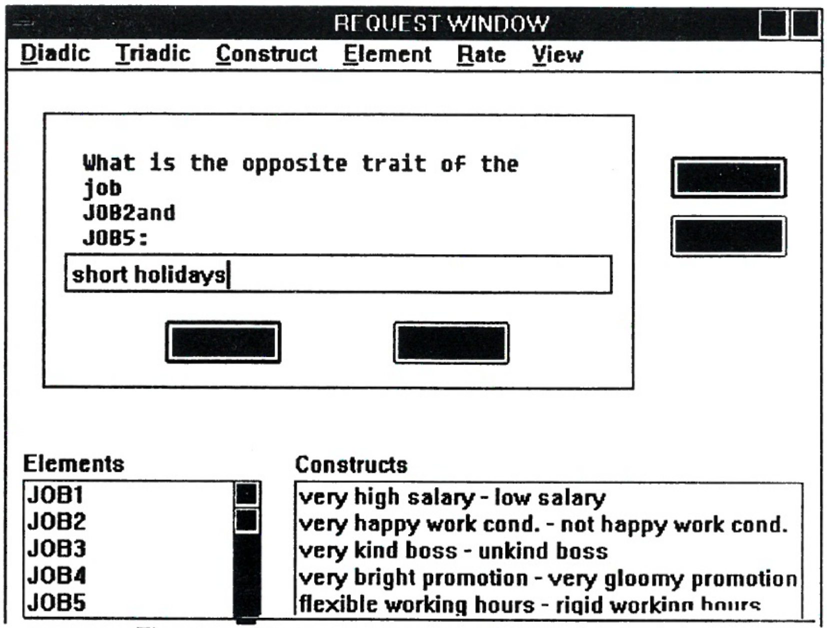

Figure 7. Triadic elicitation (third question)

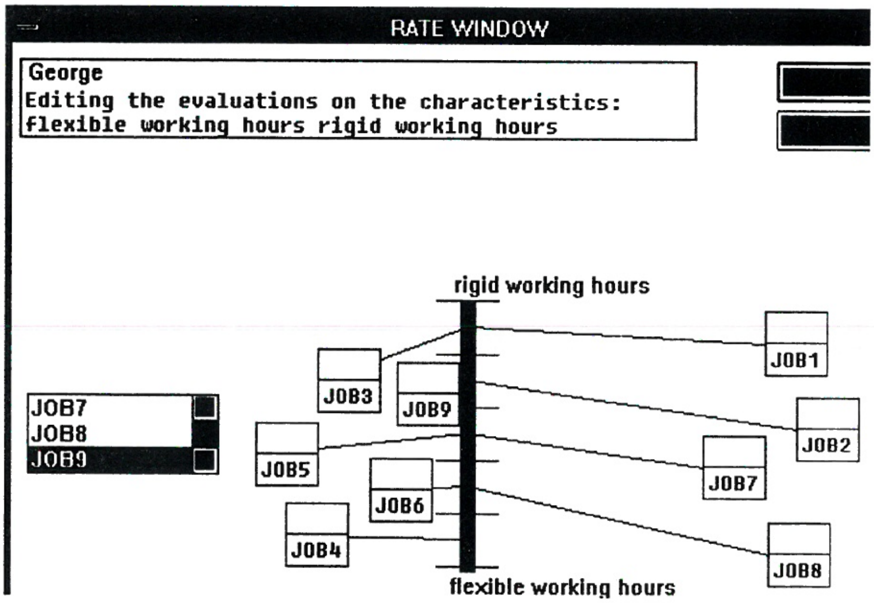

Figure 8. Rating all examples for a construct

3. Analysis and Interpretation of Grids

It is very attractive to think of having a technique that can quantify the subjective data which human judgments and decisions are based on.

The amount of work involved in analysing a grid rapidly increases with the size of the grid and the number of distances and other measures that are to be derived from it. That is why a number of software packages has been designed to generally analyse almost any grid, providing statistics about most of the features of the grid. However, before considering computer analysis it is worth reminding that this analysis does not add anything to the information available in a grid, nor does it provide any indication of the meaning of the grid. It simply reduces the amount of work required for interpretation by summarizing and condensing the data available.

There are two approaches in grid analysis:

- **Principal Component Analysis** [Slater 1974];
- **Cluster Analysis** [Pope&Shaw 1980, Gaines&Shaw 1980].

The main difference between **Principal Components and Cluster Analysis** is that the former searches out the greatest variation in the grid and imposes mathematical axes on it, while the latter relies on building up a series of hierarchical groups based on the strongest association in the matrix. An alternative way to considering what the two methods do is to imagine the star-studded sky above us. The stars represent the elements of an individual's mental map. The purpose of analysis is to find out some way of describing all these points. The **Cluster Analysis** approach looks for patterns in different zones of the sky and identifies the major groupings, like constellations. Thus, the structure of the map is built up gradually from various small groupings. The **Principal Component** analysis approach contrasts with this by looking up to the sky for identifying the main overall dimensions. Thus, one might notice that the plane of the Milky Way is the most dominant dimension in the sky as viewed from the Earth, and would then describe all other objects in terms of co-ordinates of this plane.

The INGRID package devised by Slater is based on **Principal Component Analysis** [Slater 1974] and the FOCUS program is based on **Cluster Analysis** [Gaines&Shaw 1980]. In practical terms, INGRID has the advantage of letting a visual mapping of the elements and constructs be obtained and also demonstrates the linkage between constructs and elements. FOCUS provides a very limited kind of map which does not make any explicit linkage between constructs and elements. However, its one great advantage to the highly sophisticated INGRID program is its being simple and the analysis process being easily understandable by anybody is using a grid.

Choosing one mode or another would depend on the context within which the grid is being used. **"Operational"** applications where the grid is being completed and interpreted by the subject would rather have FOCUS, while **"research"** applications where some other person is attempting to interpret the grid data would rather have INGRID.

Our choice has been **Cluster Analysis** for the first ESYS version. **Component Principal Analysis** will be implemented in a future version of ESYS.

4. Cluster Analysis in ESYS

The aim of cluster analysis is to reveal important features of the grid that might not at first sight be obvious to an end user whose experience in data analysis is not large enough. Our choice for this method is motivated by the fact that it reveals the interactions between constructs and elements directly [Tilivea&Stancioiu 1992]. The algorithm produces two distinct trees representing clusters of similar elements, and clusters of similar constructs, respectively [Keen&Bell 1980, Leach 1980]. The basic algorithm will be illustrated using the grid in Figure 9.

First, the analysis of the elements requires the calculation of distances or dissimilarities between all possible pairs of elements. An appropriate measure of distance between a pair of elements is the proportion of constructs on which the two elements fall on different poles. The distances between all possible pairs of elements calculated this way are shown in the elements distance matrix in Figure 10.

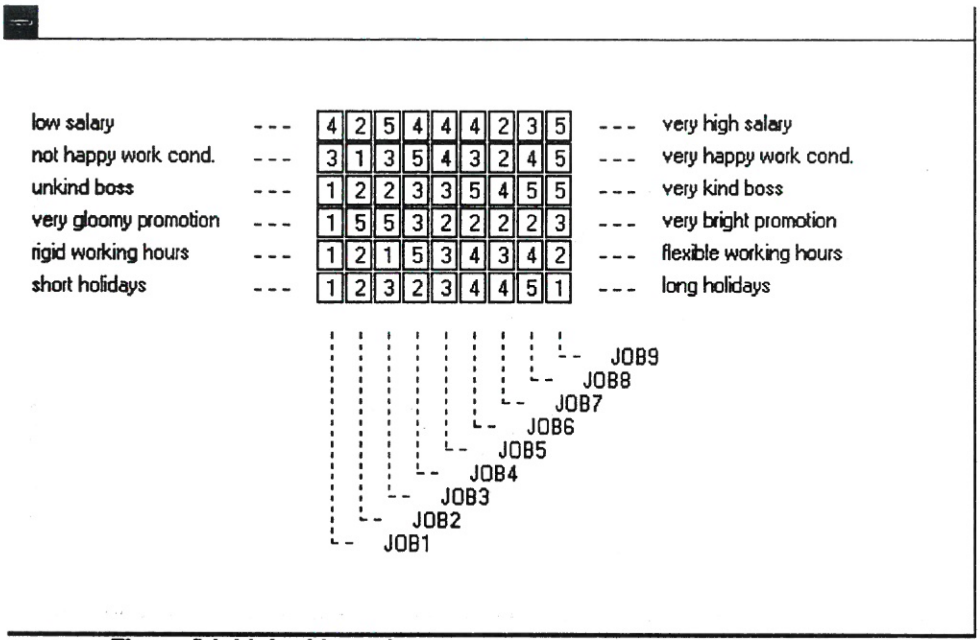

Figure 9.Initial grid matrix

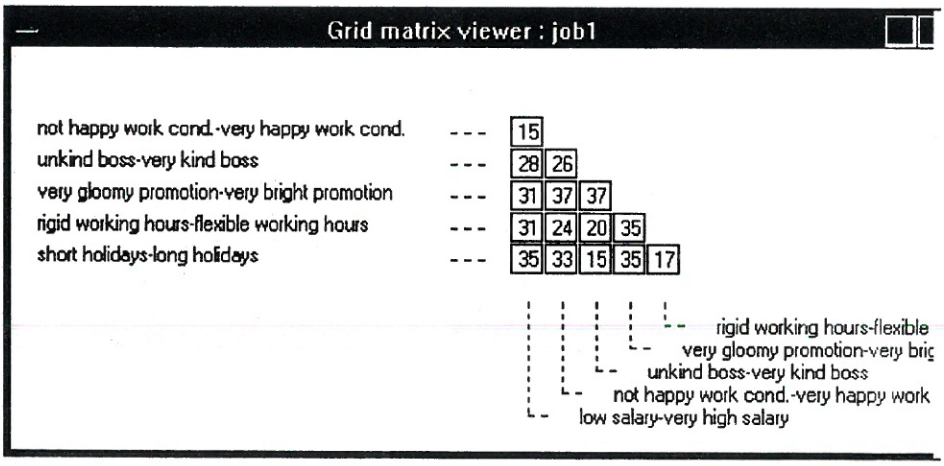

Figure 10.Constructs distance matrix

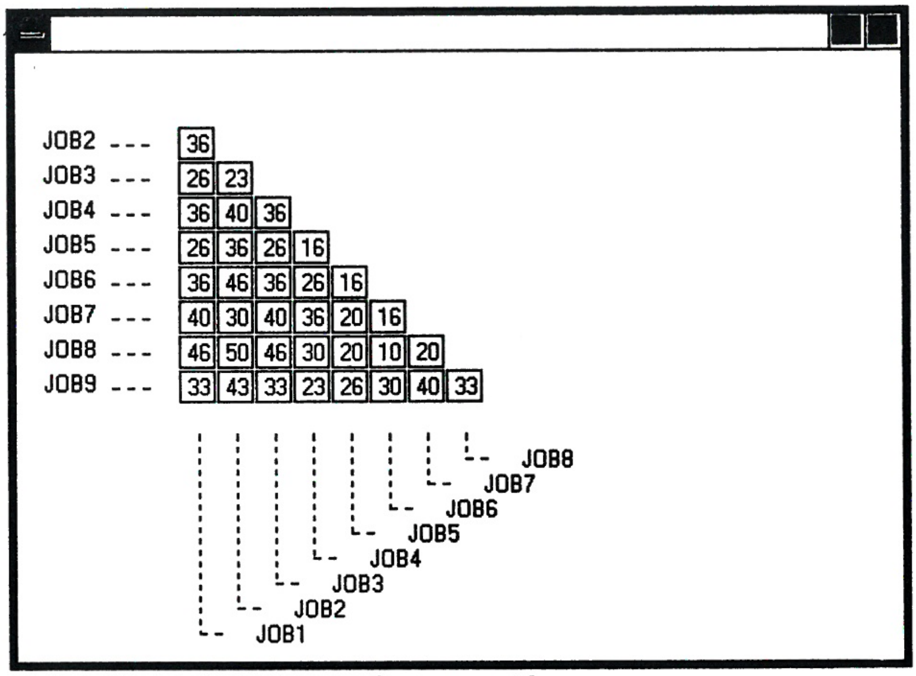

Figure 11. Elements distance matrix

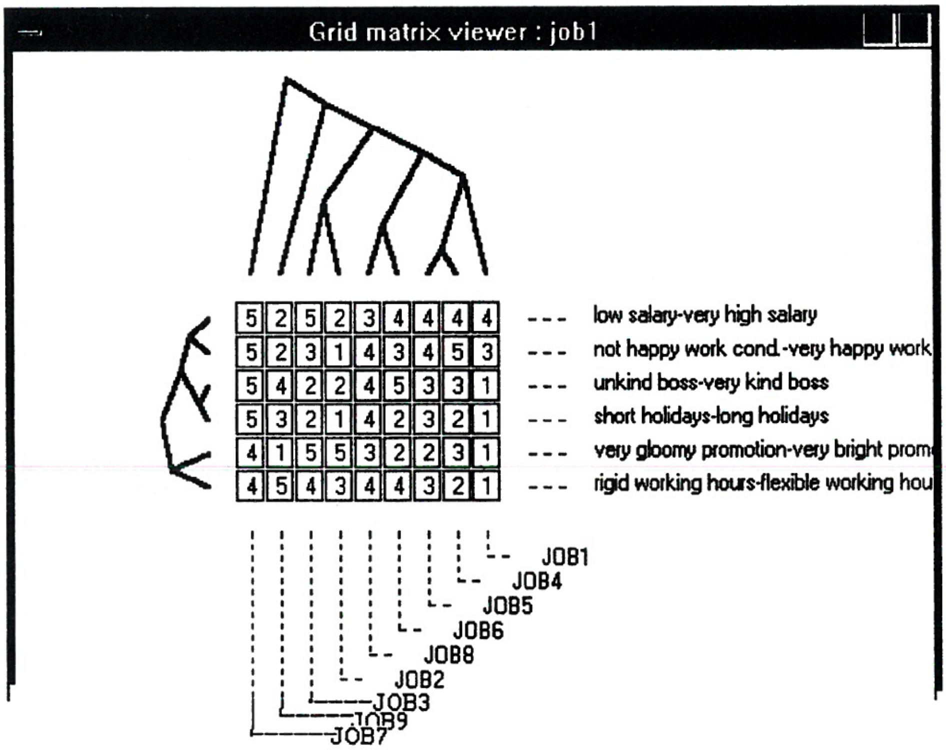

Figure 12. Constructs tree ,elements tree and rearranged grid matrix

The distance matrix is analysed using a single-link hierarchical cluster analysis. Distances are sorted out and for each value **h** in the sorted set a graph is drawn whose vertices represent the elements and whose edges join together the elements among which the distance is equal to **h**.

At each level, the connected components of the associated graph define a partition of the elements. The sequence of partitions may be drawn in tree form (Figure 12).

The analysis of the constructs proceeds on in a manner similar to that of the elements'. The first requirement is a measure of the distance between a pair of constructs. The distance matrix for constructs is shown in Figure 11. The distance matrix is now analysed using a single-link hierarchical cluster analysis in exactly the same way as with the elements in order to produce a tree reflecting similarities between constructs. The resulting constructs tree is shown in Figure 12.

5. ESYS in Operation

ESYS conforms with the WINDOWS interface philosophy in that the users can, independently of one another, activate any menus or windows.

A job selection problem was proposed for this paper. The reason for this was to show how extra criteria could be introduced into the decision space and account for similarities and differences.

In the given example the user is construing a small knowledge base about "jobs". Another user ("end-user") can ask for a consultation about these jobs, and can obtain a piece of advice about a job that best suits his /her wishes.

The first step is loading the knowledge base about "jobs". In this example we take for granted that the knowledge base exists and the user must update it. To add new jobs and new information about new jobs, the user can use the following menu options from a special elicit window :

- elicit by **triads**, when user wants to introduce new constructs (attributes of jobs). For this, an user has to choose a job out of a random triad (JOB1 in Figure 5), motivate why he/she thinks JOB2 and JOB5 are alike or different from JOB1, and then produce the two poles of the construct, e.g. "short holidays - long holidays" (Figure 6 and Figure 7);
- elicit by **dyads** when an user wants to introduce new jobs and new attributes of jobs. For this he/she has to think of a new job (JOB8 in Figure 1) which differs in a way from an existing job, e.g.JOB7, and must specify what are the characteristics that, if applied to this new job, differentiate this job from the specified existing job (e.g. "flexible working hours", Figure 2). The two poles of a construct must then be produced and the user be asked to specify the opposite trait of JOB8 ("rigid working hours"). The newly introduced job (Figure 4) is chosen to produce a new dyad if the user wants to continue dyadic elicitation;
- **rating**/modify the rating of all constructs for the existing elements. The rating scale is the same for all constructs and has been specified when describing the user's grid: expert name (grid author), purpose, file name for saving knowledge base, etc. A new rating window is shown and the user must select the box which contains the name of the job and take this box to a scale, according to a rate of his/her own. The scale with element boxes looks like a tree after this operation (Figure 8).
- **cluster analysis**; the user may select view options for viewing: initial grid matrix (Figure 9), construct distance matrix(Figure 10), element distance matrix (Figure 11), and rearranged grid matrix with the two-side trees of constructs and elements (Figure 12). These trees are very suggestive due to grouping elements/constructs that are alike. Grid analysis is also possible when the grid matrix is incomplete.

Analysis results may help the user modify the knowledge base. The options made are to add an element to split highly matched constructs, replace two highly matched constructs by one construct, add a construct to split highly matched elements, delete one or more elements, delete one or more constructs, add a construct without using a triad,

Closest alternatives to the: OPTIMAL JOB

(1) - maximum consensus rate for selected experts

(2) - mean rate for selected experts

		(1)		(2)
very much alike	JOB9	94%	JOB9	93.33333333%
	JOB8	74%	JOB8	73.33333333%
	JOB3	70%	JOB7	56.66666667%
	JOB6	67%	JOB3	53.33333333%
	JOB4	64%	JOB6	51.66666667%
	JOB5	64%	JOB5	50.%
	JOB7	57%	JOB4	35.%
	JOB2	47%	JOB2	26.66666667%
totaly different	JOB1	30%	JOB1	20.%

Figure 13·A consultation for an optimal job

Closest alternatives to the: YOUR JOB

(1) - maximum consensus rate for selected experts

(2) - mean rate for selected experts

		(1)		(2)
very much alike	JOB7	84%	JOB7	84%
	JOB6	80%	JOB6	80%
	JOB8	74%	JOB8	74%
	JOB2	67%	JOB2	67%
	JOB3	64%	JOB3	64%
	JOB4	64%	JOB4	64%
	JOB5	64%	JOB5	64%
	JOB9	60%	JOB9	60%
totaly different	JOB1	50%	JOB1	50%

Figure 14. A consultation for a job meeting an user's requirements

add an element. The domain **"jobs"** can be rated by many experts. The results of elicitation will consist in several grids about this domain.

After several updatings the knowledge base may be used for a consultation. ESYS can make a recommendation about jobs and answer questions such as:

- **"Which are the most suitable jobs for me ?".** After rating **"his ideal job"** for a set of selected constructs, and by a set of selected experts, the user may consult the knowledge base (Figure 14). The table shows that the closest alternative to the **"ideal job"** of an end -user is JOB7, very closely followed by JOB6 . JOB9and JOB1 are very much alike and utterly different from the **"ideal job"** and JOB6 . Ratings are not necessarily optimal in this **"ideal job"** case. The decision-maker is allowed some degree of preference and/or compromise.
- **"Which is the optimal job?"**. After having selected interesting constructs and experts to consult (Figure 13), the optimal job results in maximal rates for a set of selected constructs. The closest alternative to the **"optimal job"** is JOB9 .

ESYS may be successfully applied to other subjective multi- criteria decision-making, and, generally, to diagnosis problem -solving.

Entity-attribute grid elicitation is an extensional approach in that individuals are asked to specify a set of entities in a domain, then make distinctions among them, naming the distinctions and classifying all the specified entities in terms of them. The extension of the distinctions determined this way is only an approximation to the underlying concept since critical entities may be missing from the classification. Elicitation techniques attempt to prompt the individual that for additional entities discriminates between related distinctions.

Knowledge acquisition is thus essentially a negotiation process leading to approximations and to conceptual structures that are adequate for some practical purpose such as system development.

6. Related Work

Personal construct theory has been widely used as a basis for developing knowledge acquisition methods in given domains:

- **KSS0** - Knowledge Support System Zero - [Gaines&Shaw 1989] helps reveal the similarities and differences in the concept systems of different experts, or of the same expert at different times, construing a domain defined through common entities or experts' attributes. It can be used in focussing experts' discussion on those differences requiring resolution and enabling experts to classify differences in terms of differing terminologies.
- **AQUINAS** [Boose 1985] performs rapid elicitation of problem- solving knowledge from several experts, conducts negotiations among experts, builds consultation systems and tests the results against the experts' expectations, combines expertise from multiple experts in the same domain or in different domains, combines expertise based on different representation techniques such as rule sets, decision tables, and frames.
- **INC2** [Hadzikadic 1991] develops an incremental concept formation system which will automate both the design and use of diagnostic knowledge-based systems by a novice, based on family resemblance theory.

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