KNOWLEDGE ENGINEERING FOR EXPERT SYSTEMS

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This paper outlines a methodology for knowledge elicitation that has been implemented in a computer program that interacts with an expert to enable him to express the constructs underlying his knowledge. Automatic construct elicitation and analysis may be used to pump-prime an expert system shell with initial rules that are derived from an expert. The system can then be further developed using the techniques of the shell itself. The techniques described are useful for eliciting the expert vocabulary and aiding the expert in coming to structure the knowledge domain.

Knowledge Engineering

Examples of practical expert systems [ESs] and the availability of domain-independent ES shells has generated widespread interest in ES applications. However, what Feigenbaum [4] terms **knowledge engineering**, the reduction of a large body of knowledge to a precise set of facts and rules, has become a major bottleneck impeding the application of ESs in new domains. Hayes-Roth, Waterman and Lenat outline the communication problems impeding the process of transferring expertise into a program [7]. They note that the vocabulary initially used by the expert to talk about the domain with a novice is often inadequate for problem-solving and the knowledge engineer and expert must work together to extend and refine it. They emphasize that one of the most difficult aspects of the knowledge engineer's task is helping the expert to structure the domain knowledge, to identify and formalize the domain concepts.

The problem of knowledge elicitation from a skilled person is well-known in the literature of psychology. Bainbridge has reviewed the difficulties of verbal debriefing and notes that there is no necessary correlation between verbal reports and mental behavior, and that many psychologists feel strongly that verbal data are useless [1]. However, this remark must be taken in the context of experimental psychologists working within a positivist, behavioral paradigm. Other schools of psychology have developed techniques for making use of verbal interaction, for example through interviewing techniques that attempt to by-pass cognitive defenses, including those resulting from automization of skilled behavior.

This paper is concerned with interactive computer aids to the knowledge engineer based on Kelly's **Personal Construct Psychology** (PCP) [8] which uses a model of the person that has strong systemic and psychological foundations [5,9,14]. However, as knowledge engineering tools the programs can be used without committment to the underlying theory. Pragmatically, they are techniques for eliciting the expert's vocabulary and structuring some aspects of the domain knowledge. Shaw and Gaines have reported experiments on eliciting constructs related to expertise in business record-keeping [15]. Boose has reported success in a wide range of ES developments at Boeing using these techniques to set up an initial system very rapidly [2].

Personal Construct Psychology

Kelly [8] developed a theory of human cognition based on the primitive notion of constructs, or dichotomous distinctions, which are "templets" that a person "creates and then attempts to fit over the realities of which the world is composed." He proposes that all of human activity can be seen as a process of anticipating the future by construing the replication of events, and revising constructs according to the success of this anticipation. Kelly developed his theory in the context of clinical psychology and hence was concerned to have techniques which used it to by-pass cognitive defenses and elicit the construct systems underlying behavior. In a non-clinical context this is the problem of knowledge engineering discussed above.

Kelly's **repertory grid** is a way of representing personal constructs as a set of distinctions made about elements relevant to the problem domain. In clinical psychology this domain will often be personal relationships and the elements may be family members and friends. In the development of expert systems the elements will be key entities in the problem domain such as oil-well sites or business transactions. Repertory grids have been widely used: in clinical psychology [12,16]; to study processes of knowledge acquisition in education [10]; and to study decision making by individuals and groups in management [11].

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Figure 1 shows a repertory grid elicited from a businessman on the topic of "examining business record keeping." The **elements** he is construing are all business situations in which records might be required and are shown as the columns of a matrix. The **constructs** he is using to make bipolar distinctions between these elements are shown as the columns of the matrix. A rating scale from one through five is being used to enable him to make more precise distinctions in situations where he does not wish to allocate an element definitely to one pole of a construct. A rating of 1 means definitely at the left-hand pole (LHP), and of 5 definitely at the right-hand pole (RHP).

The importance of the repertory grid in clinical psychology is that it can be elicited without the client considering the overall grid and the relations between the constructs. Discussion between the therapist and client concentrates on the elements, which are generally actual people or situations, and the ways in which they are distinguished. It is only after the grid has been obtained that the therapist analyses it for relations between constructs of which the client may be unaware and which may be the source of problems.

Similar considerations apply to knowledge engineering. The businessman from whom the data of Fig. 1 was elicited had only to consider well-defined selling situations and the similarities and differences between them. In doing this he has specified a range of situations and a range of constructs which he applies to them. He has made overt much of his vocabulary in thinking about these situations and exemplified its application. The knowledge engineer can use the grid to come to an understanding of the vocabulary and constructs involved.

It is particularly significant that the processes of repertory grid elicitation and analysis can be automated can be automated through interactive computer programs. The expert can work independently of the knowledge engineer for a substantial part of the process. This is clearly important in minimizing the requirement for scarce skills and resources. However, it is has other significant advantages also:

1) It allows the expert to experiment with different approaches to his subject area without any inter-personal pressures. People are often reluctant to discuss the basis of their expertise, not because it is proprietary, but because they do not have an explicit model of it. Experts may need the opportunity to try to create such a model without feeling that they are wasting someone's time or likely to appear foolish.
2) The on-line computer elicitation of elements and constructs can be very much more effective than that by a person because the computer system can analyse the grid as it is being developed and feedback information from it that aids elicitation. The key to effective knowledge engineering is to span the relevant domain by encouraging the expert to generate elements and constructs that lead to relevant distinctions. On-line analysis is necessary for this and it is beyond the capabilities of most people.

PLANET is an integrated range of programs which operationalizes Kelly's work and may be used for the interactive elicitation and analysis of repertory grids [13]. The next section illustrates grid elicitation with PLANET and the following sections show how the data from an expert, or a group of experts, may be analysed.

Interactive Elicitation of Repertory Grids

PEGASUS is a highly interactive program that elicits constructs through a conversational dialog with an expert, generated by feedback of its ongoing analysis of his construct system [11]. It offers many options, one of which is to receive feedback from a stored bank of expert constructs, thus enabling a student to learn to use an expert's construct system. PEGASUS commences its interaction by asking for the purpose of the elicitation and then for an initial set of elements relevant to this purpose. It then goes on to elicit constructs and further elements. In the dialog the computer output is shown in normal face and the human input in **bold**:

One technique used by PEGASUS to elicit constructs is that of triadic comparison:

Triad for elicitation of construct 1
1 selling newspapers from a stand
2 selling antiques in a market
3 selling custom drapes

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?**1**

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 selling antiques in a market and selling custom drapes on the left pole from selling newspapers from a stand 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 --?**no. of different objects**
right pole rated 5 --?**same object in quantity**

Now assume that selling antiques in a market and selling custom drapes are assigned the value 1 and selling newspapers from a stand 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

individual and it is often important to combine the knowledge of multiple experts. ENTAIL may be used to analyse the construct systems of several experts construing the same elements.

SOCIOGRIDS is another PLANET program that enables knowledge from multiple experts to be compared and combined. Its operation is based on what Kelly terms the **commonality corollary** that: to the extent that one person employs a construction of experience that subsumes that of another in a given domain, that person can understand the cognitive processes of the other person in that domain. Thus, an expert system for a domain can be defined as one which subsumes the relevant constructions of experience of experts in that domain.

SOCIOGRIDS derives linkages between people (socionets) by comparing grids in pairs and calculating the average over all constructs in grid A of the similarity of the best match for each construct in grid B. This measures to what extent the system of construction modeled in grid B subsumes that modeled in grid A. These subsumption averages are ordered and used to produce socionets showing the degree to which one person's construction system subsumes that of another. SOCIOGRIDS derives a consensual construction system (mode grid) by comparing each construct in turn with those in every grid and calculating the average over all grids of the best match for the construct in each grid. This measures to what extent a given construct is represented in the construction system of every person, and hence is consensual.

Summary and Conclusions

PLANET, an interactive computer aid to expedite the initial stages of knowledge engineering has been described and illustrated through an example. The main sub-programs are: PEGASUS elicits from an expert the fundamental distinctions, or constructs, he is using in applying his expertise; SOCIOGRIDS analyses the relationships between members of a group through their differing construct systems and determines consensual constructs; ENTAIL analyses the logical dependencies between constructs and can present these as rules.

It appears that the repertory grid and other techniques from personal construct psychology have applications to knowledge engineering. Automatic construct elicitation and analysis may be used to pump-prime an expert system shell with initial rules that are derived from an expert. The system can then be further developed using the techniques of the shell itself.

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                        * 1  2  3  4  5  6  7  8  9 10 11 *
                        ************************************
     STANDARD PRODUCT 1 * 1  2  5  1  1  1  2  1  3  2  1 * 1 SPECIAL PRODUCT
                        *                                  *
           SEND BILL 2 * 5  5  2  1  2  1  1  1  1  3  1 * 2 COLLECT CASH
                        *                                  *
        CUSTOMER OWNS 3 * 1  1  1  1  5  5  1  1  1  1  1 * 3 WE OWN
                        *                                  *
  SHORT TERM RELATION 4 * 1  1  2  1  1  4  2  5  4  2  5 * 4 LONG TERM RELATION
                        *                                  *
          FIXED PRICE 5 * 1  5  2  2  2  1  1  1  1  4  1 * 5 HAGGLE
                        *                                  *
              CHOICE 6 * 1  1  1  1  1  1  1  5  2  1  1 * 6 MONOPOLY
                        *                                  *
             DELIVER 7 * 5  4  4  1  5  1  5  1  5  3  1 * 7 TAKE
                        *                                  *
    CUST. LOOKS AFTER 8 * 1  1  2  1  5  5  1  3  2  1  5 * 8 WE LOOK AFTER
                        *                                  *
          EXPENSIVE 9 * 5  2  2  2  3  4  2  3  2  1  2 * 9 LOW-COST
                       ************************************
                         *  *  *  *  *  *  *  *  *  *  SELLING LONG WARRANTY GOODS
                         *  *  *  *  *  *  *  *  *  BEING AGENT FOR HOME PURCHASE
                         *  *  *  *  *  *  *  *  PROVIDING DENTAL SERVICES
                         *  *  *  *  *  *  *  PROVIDING ELECTRICITY FOR HOME
                         *  *  *  *  *  *  SELLING CAR INSURANCE
                         *  *  *  *  *  PROVIDING TV RENTAL SERVICES
                         *  *  *  *  HIRING OUT A CAR TO A CUSTOMER
                         *  *  *  SELLING LARGE APPLIANCES
                         *  *  SELLING CUSTOM DRAPES
                         *  SELLING ANTIQUES IN A MARKET
                        SELLING NEWSPAPER FROM A STAND
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Fig. 1 Repertory Grid on "Examining Business Record Keeping"

Entail	Truth	Prob.	Information (Cutoff 40)	
L 4 = L13	75	100	39	little supervision reqd = overall rating high
L13 = L 6	75	100	39	overall rating high = reliable
R 1 > R 6	50	100	39	dim > not so reliable
R 6 = R13	75	100	39	not so reliable = overall rating low
R13 = R 4	75	100	39	overall rating low = need supervision
R12 > R13	75	100	38	less professional > overall rating low
R13 > R12	75	100	38	overall rating low > less professional
L 8 = L10	100	70	37	ideas men = creative
R 9 > R 4	50	100	37	need a push > need supervision
R 9 > R12	50	100	37	need a push > less professional
R 9 > R13	50	100	37	need a push > overall rating low
R10 = R 8	100	70	37	non-creative = staid
L 4 > L 5	75	100	36	little supervision reqd > motivated
L 4 > L 9	50	100	36	little supervision reqd > self starters
L12 > L 9	50	100	36	professional > self starters
L12 = L13	75	100	36	professional = overall rating high
L13 > L 5	75	100	36	overall rating high > motivated
L13 > L 9	50	100	36	overall rating high > self starters
R 2 > R 4	75	100	35	unwilling > need supervision
R 2 > R 5	75	100	35	unwilling > less motivated
R 2 > R13	75	100	35	unwilling > overall rating low
R 3 > R 1	75	100	35	old sweats > dim
R 6 > R 4	75	100	35	not so reliable > need supervision
L 1 > L 8	75	100	33	intelligent > ideas men
R 5 > R 1	75	100	33	less motivated > dim

Fig. 2 Logical Consequences Induced by ENTAIL from a repertory grid on "Staff Appraisal"