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KNOWLEDGE ENGINEERING TOOLS FOR EXPERT SYSTEMS

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Advances in the technology of expert systems have made it possible to implement and operate cost-effective systems in complex domains of great practical importance. However, the knowledge engineering necessary to set up an expert system in a new domain is currently labour-intensive and requires skilled staff to elicit and codify the knowledge of an expert. This paper outlines a methodology for knowledge elicitation that has been implemented in computer programs that interact with experts to enable them to express the constructs underlying their knowledge. Some preliminary experiments on validating the system by using it to re-construct the **Business Information Analysis and Integration Technique** are outlined. Examples are given of knowledge elicitation and analysis programs in action.

KNOWLEDGE ENGINEERING

The initial success of expert system (ES) developments (Michie 1979, Gevarter 1983, Reitman 1984) and the development of a number of reasonably domain-independent software support systems for the encoding and application of knowledge (Hayes-Roth, Waterman & Lenat 1983) has opened up the possibility of widespread usage of ESs. In particular, the Japanese Fifth Generation Computing System (FGCS) development program (Moto-oka 1982, Gaines 1984) assumes this will happen and is targeted on knowledge processing rather than information processing. However, what Feigenbaum (1980) terms **knowledge engineering**, the reduction of a large body of knowledge to a precise set of facts and rules, has already become a major bottleneck impeding the application of ESs in new domains. We need to understand more about the nature of expertise in itself (Hawkins 1983) and to able to apply this knowledge to the elicitation of expertise in specific domains.

The problems of knowledge engineering have been stated clearly:

> "Knowledge acquisition is a bottleneck in the construction of expert systems. The knowledge engineer's job is to act as a go-between to help an expert build a system. Since the knowledge engineer has far less knowledge of the domain than the expert, however, communication problems impede the process of transferring expertise into a program. The vocabulary initially used by the expert to talk about the domain with a novice is often inadequate for problem-solving; thus the knowledge engineer and expert must work together to extend and refine it. 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." (Hayes-Roth, Waterman & Lenat 1983)

The problem of knowledge elicitation from a skilled person is well-known in the literature of psychology. Bainbridge (1979) 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. 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. Welbank (1983) has reviewed many of these techniques in the context of knowledge engineering.

This paper is concerned with interactive computer aids to the knowledge engineer based on Kelly's (1955) **Personal Construct Psychology** (PCP) which uses a model of the person that has strong systemic and psychological foundations (Gaines & Shaw 1981a, Shaw & Gaines 1981a). PCP provides a model of human knowledge representation, acquisition and processing that has been made operational through computer programs for interactive knowledge elicitation (Shaw 1980, 1982). These may be used in developing the expert's vocabulary and in encoding aspects of his reasoning for a rule-based system. The expert interacts with a program, PEGASUS (Shaw & Gaines 1981b, 1984a) that encourages him to make clear the distinctions he uses in applying his expertise. This helps him to structure his knowledge and identify and formalize his concepts. The program may also be used in a teaching mode in order to enable others to come to use the expert's vocabulary in the same way as he does. Some experiments are described to validate the use of PEGASUS in this way by re-constructing the basic distinctions used in the Business Information Analysis and Integration Technique (BIAIT) used to determine the accounting needs of a company (Carlson 1979, Sowa 1984).

PERSONAL CONSTRUCT PSYCHOLOGY

Kelly developed a systemic theory of human cognition based on the single primitive of a **construct**, or dichotomous distinction. For an individual, constructs are:

> "transparent templets which he creates and then attempts to fit over the realities of which the world is composed." (Kelly 1955)

He proposes that all of human activity can be seen as a process of anticipating the future by construing the replication of events:

> "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 a basis for the revision of constructs and, eventually, of whole construct systems." (Kelly 1955)

Hence his psychological model of man is strongly epistemological and concerned with the way in which man models his experience and uses this model to anticipate the future. The anticipation may be passive, as in prediction, or active, as in action.

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. This is precisely the problem of knowledge engineering noted above. His **repertory grid** (Shaw 1980) 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 ESs 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 (Shepherd & Watson 1982); to study processes of knowledge acquisition in education (Pope & Shaw 1981); and to study decision making by individuals and groups in management (Shaw 1980). PLANET (Shaw 1982) is an integrated suite of programs that operationalizes Kelly's work and may be used for the interactive elicitation and analysis of repertory grids. These programs have been widely used internationally in clinical psychology, education and management studies (Shaw 1981), and the present paper describes their application to knowledge engineering for ESs.

Kelly's PCP is important because it develops a complete psychology of both the normal and abnormal, which has strong systemic foundations (Gaines & Shaw 1981a). In the long term these foundations may be more important to knowledge engineering than the techniques currently based on them. The next section briefly reviews the systems analysis aspects of these foundations.

EPISTEMOLOGICAL HIERARCHY

In 1955 when Kelly developed his theory there was neither the mathematics to formalize it nor the computer technology to operationalize it. He sees man's main characteristic being that he **models** the world (the **personal scientist** (Shaw 1980)) and that the basis of this model can be revized (**constructive alternativism** (Mancuso & Adams-Webber 1982)). His explication of man's modeling process is extraordinarily simple: personal constructs are dichotomous, or bipolar, distinctions; constructs themselves are construed and hence form a hierarchy or **construct system**; at the upper levels of the hierarchy there tend to be evaluative constructs that form the basis of appraisal of events, manifesting themselves in emotions and the goals for action; at the lower levels there tend to be ways of classifying experience. This hierarchy lies at the heart of modern approaches to modeling in system theory such as Klir's (1976) **epistemological hierarchy**, shown in a psychological variant (Gaines & Shaw 1981a) in Figure 1.

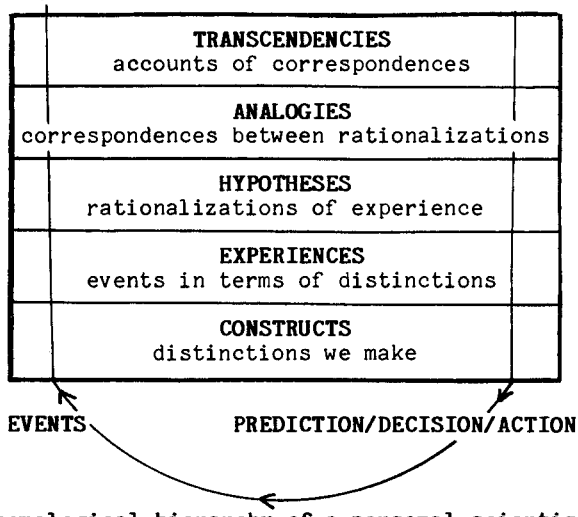

Fig. 1 Epistemological hierarchy of a personal scientist

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 happen 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** which are preconceptions underlying rationality. Interaction with the world is, therefore, mediated through the construct system to produce experience which is modeled through the higher levels and leads to predictions, decisions and actions again mediated through the construct system.

Klir (1976) has used this hierarchy as a framework for a general theory of knowledge acquisition through modeling and Gaines (1977) has shown that the processes represented may be formalized algebraically and computationally. In particular, it may be shown (Gaines & Shaw 1981a) that the calculus of distinctions developed by Brown (1969) is a formal foundation for system theory (Gaines 1980) leading naturally (Varela 1975) to the tools of fuzzy reasoning (Zadeh 1972), and category theory (Goguen 1981) applied to modeling (Ralescu 1979). The **standard uncertainty logic** arising from this analysis encompasses probabilistic and modal logics (Gaines 1983), and Quinlan (1983) has shown that the constraint systems of such non-truth-functional systems may be used as a basis for improved inference in ESs. The higher levels of the epistemological hierarchy represent the **deep** knowledge based on causal models. Current ESs use only the lower levels with rule-based inference giving a superficial basis for expertise. Advances in the technology of ESs are dependent on developing means of incoporating the higher levels and including modeling and simulation (Shaw & Gaines 1985, Gaines & Shaw 1985a). Thus, the epistemological hierarchy provides a natural framework for knowledge engineering, bridging from the psychological principles of PCP to its systemic and logical foundations.

It should be noted that the hierarchy is strongly idiosynchratic and formalization should not be taken as implying uniformity. Kelly emphasizes the **dynamic** and **personal** nature of the construct system. It is subject to change according to feedback from failure to anticipate events. It is individualistic in the constructs used, in the vocabulary used to name the construct poles, in the relations between constructs in the hierarchy, and in those constructs most likely to change when this is necessary. Knowledge engineering for ESs may be seen as a process of making overt the construct system of the expert. The problems noted in the first section arise because of the essentially individualistic nature of construct systems. A person may be able to use his construction system effectively whilst having no basis for communicating it to others. Two people may use exactly the same construct yet refer to its poles by different names. Two people may use the same names for the poles of their constructs and yet use them in different ways. Two people may use similar constructs at the lower level of the hierarchy and yet have them organized in different systems such that their reactions to the same event are quite different. Two people may have similar constructs at nearly all levels of the hierarchy and yet construe a novel event completely differently.

This essentially **soft** aspect of the systems analysis of expert knowledge is contrary to the normal expectation that there is a "right" answer, valid for all conditions. The next section is concerned with a framework for systems analysis that can cope with this situation and structure it for practical applications.

SOFT SYSTEMS ANALYSIS

The difficulty with eliciting the hierarchy of distinctions, or constructs, of an expert is the lack of a conceptual framework that can be expressed and used in a dialog between expert and knowledge engineer. Checkland (1981) has termed this a problem of **soft systems analysis** and emphasized

the importance of the analyst not bringing his own preconceptions to the problem domain. He has developed a number of techniques for soft systems analysis, starting with a structuring of the stages involved as shown in Figure 2.

1: The Problem Situation - Unstructured
2: The Problem Situation - Expressed
3: Root Definitions of Relevant Systems
4: Making and Testing Conceptual Models
5: Comparing Conceptual Models with Reality
6: Determining Feasible, Desirable Changes
7: Action to Improve the Problem Situation

Fig. 2. Stages in Soft Systems methodology

The importance of Stage 1 is to get back to it from Stage 2 or beyond. We should not inject preconceptions about solutions into the problem definition and need to treat any situation as unstructured no matter what structure we are given. Our framework for analysing the expert's knowledge may be such as to prevent that analysis. The expression at Stage 2 is still unstructured and it is Checkland's study of Stage 3, **root definitions** of relevant systems that provides the formal framework for a structure. His approach is particularly interesting because it emphasizes the pluralism of systems analysis, what Kelly has termed **constructive alternativism**, that it is important to examine the problem from a number of viewpoints. These may be seen as forming a nested set to which Checkland gives the mnemonic CATWOE as shown in Figure 3.

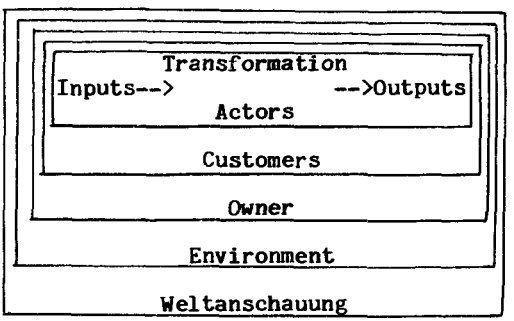

Fig. 3. Root Definitions of Relevant Systems

The system is defined through a **Transformation** carried out by people who are the **Actors** within it; it affects beneficially or adversely other people who are its **Customers** and there is some agency with power of existence over it who is its **Owner**; it has to exist within outside constraints forming its **Environment** and the whole activity of system definition takes place within an ethos or **Weltanschauung** that affects our views of it. Basden (1983) has noted the utility of Checkland's analysis in developing ESs, and we have shown how the techniques outlined in this paper may be applied to operationalizing it (Shaw & Gaines 1983).

Applying the analysis to an ES for oil exploration, we consider a **transformation** to which the **inputs** are survey data and the **outputs** are decisions to drill. The **actors** are experts concerned with making these decisions. Their **customers** are oil companies. The **owner** of the problem represents the value system and, as usual in soft systems analysis, there are several choices: the managers, directors and owners of the oil company

are possibilities, as are its customers and the government that taxes it. They have differing perceptions of the problem, risk/reward ratios, and so on. The **environment** is the physical, geographic and economic world within which extraction takes place, and the **weltanshauung** comprises energy policies, pollution concerns, and so on. These are the considerations which knowledge engineering has to take into account.

The emphasis on differing viewpoints here is fundamental. PCP is often seen as concerned with the different perspectives of individuals and knowledge engineering is often presented as concerned with **the** expert. However, particularly in complex real-life situations, it is rare to find all the expertise concentrated in an individual and we are most often concerned with skills that reside in a group or team. In fact the theory underlying PCP, the hierarchy of distinctions underlying modeling, makes no separation necessary between the individual and the group (Shaw & Gaines 1981a). We have shown elsewhere how it accounts for the way in which communities are formed by individuals and the way in which social norms in communities also act to form individuals (Shaw & Gaines 1981c). The individual can be regarded as a cross-section of the epistemological hierarchy of the community in which he is operating (Shaw 1983). These considerations are those of Pask's **conversation theory** (Pask 1975), particularly the notion of expertise distributed across a multi-person **P-Individual**, and it is notable that this theory is being used as a foundation for the development of ESs (Coombs & Alty 1984).

Checkland's methodology structures the task of knowledge engineering and provides techniques that are widely applicable. However, it leaves the burden of analysis to a person, and has no operational form as a computer program. The next sections show how the PCP approach can automate the analysis in major part.

PLANET: A KNOWLEDGE ENGINEERING SYSTEM

The program system that we have developed for doing soft systems analysis from a variety of viewpoints and then comparing and contrasting the systems elicited is called **PLANET** (Personal Learning, Analysis, Negotiation & Elicitation Techniques) (Shaw 1982). It runs as a menu-driven suite of interactive programs on a variety of computers and, while preliminary versions were developed on the PDP10, there proved to be no difficulty in issuing PLANET for the Apple II enabling its widespread use in field studies. The programs are all concerned with repertory grid elicitation and analysis, and divide naturally into four groups:

Construct elicitation. **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. PEGASUS 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. **ARGUS** is a variant of PEGASUS that puts one individual in the position of several others and elicits his view of their viewpoints as well as his own.

Single construct system analysis. **FOCUS** provides a hierarchical clustering of an expert's construct system that preserves the data elicited from him so that the sources of the analysis are evident and can be discussed. **PRINGRID** is a non-hierarchical cluster analysis based on principal components that can be used to gauge the major dimensions along which distinctions are being made. **ENTAIL** is a logical analysis of the construct system taking the expert's distinctions to be fuzzy predicates. The entailment structure it generates can be used as a decision tree expressing

the relationship between an expert's data and his conclusions. It can also provide rules for input to an ES shell (Boose 1984, Gaines & Shaw 1985b).

Multiple construct system analysis. **MINUS** compares two grids based on the same elements and constructs to highlight the differences between them. **CORE** provides an interactive comparison of such grids to determine where there are differences and extract invariancies, e.g. over time. **SOCIOGRIDS** analyses the total construct structure generated by a number of people construing the same elements from their individual viewpoints. It produces **socionets** showing the relationships between individual construct systems within the group and a **mode grid** reflecting the constructs shared across the group.

Database administration. **DATA, INPUT, OUTPUT** and other programs within PLANET provide the facilities needed to manage the large databases of construct data generated from field studies of expertise.

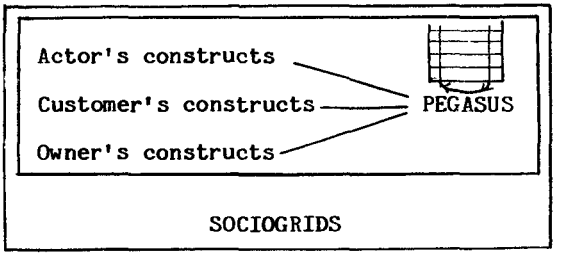

Fig. 4 PLANET automating soft system analysis

PLANET provides a set of tools for the knowledge engineer enabling him to operate at Stage 3 of Checkland's soft systems analysis semi-automatically. As shown in Figure 4, PEGASUS enables the construct systems of all those involved in the application of expertise to be elicited, SOCIOGRIDS enables the consensual structure to be derived from these, and ENTAIL enables this to be turned into a decision tree when appropriate.

The next section is concerned with validating the methodology described applied to knowledge engineering.

BIAIT: A TEST CASE FOR VALIDATION

One of the problems of evaluating any methodology for knowledge engineering is to have some clear-cut test cases where the conceptual framework of experts has been both elicited and validated. Sowa (1984) describes one such case where the record keeping needs of a business can be prescribed through the BIAIT analysis technique (Carlson 1979) based on seven features:

1. Does the supplier bill the customer, or does the customer pay cash?
2. Does the supplier deliver the product at some time in the future, or does the customer take the order with him?
3. Does the supplier keep a profile of the customer, or is every transaction a surprise?
4. Is the price negotiated or fixed?
5. Is the product rented or purchased?
6. Does the supplier keep track of the product after it is sold or not?
7. Is the product made to order or provided from stock?

Sowa notes that these features "seem almost obvious once they are presented, but finding the right features and categories may take months or years of analysis. The proper set of categories provides a structural framework that helps us organize the detailed facts and general principles

of a system. Without them, nothing seems to fit, and the resulting system is far too complex or unwieldy."

The BIAIT features are examples of constructs applied to orders placed between a customer and supplier. They provide a useful test case with which to evaluate the personal construct elicitation methodology provided in PLANET. An empirical study is being carried out to determine whether PEGASUS can be used to elicit the BIAIT distinctions from those with some accounting or business knowledge. It is particularly interesting to determine how open such a study may be: can the knowledge engineer start at Checkland's Stage 1 and operate in a completely unstructured way or does he have to "seed" the solution by a process of selection. We usually assume that even if we cannot comprehend the expertise we can recognize an expert, and hence a key strategy for knowledge engineering is the selection of experts with whom to collaborate. This has strong prima facie validity but it would also be interesting to demonstrate it empirically. To do so through the PLANET analysis would itself be an indication of the validity of the methodology.

Hence, the initial experiments have been based on taking a spectrum of those with assumed expertise in business record keeping, from businessmen and accountants, to accounting students at various stages of their education, and using PEGASUS to elicit their constructs relating to business transactions. Again, in the interests of an initial open-ended approach, the construing has not been tightly constrained to relate to the record-keeping aspects of the transactions. It has been interesting to determine what distinctions are made that do not relate to record-keeping, or relate to it in ways different from BIAIT.

PEGASUS IN ACTION

PEGASUS commences its interaction by asking for the purpose of the elicitation and then for a set of elements relevant to this purpose. In the dialog the computer output is shown in normal face and the human input in **bold**:

```
Type in your purpose for doing this grid?examining
business record keeping

You must choose a set of six elements keeping in mind
why you want to do this grid. They could be people,
events, pieces of music, pictures, books, or what you
want but whatever you choose they must be of the same
type and each must be well known to you. Try to
choose specific things. Now type each one after each
question mark.

Element 1?selling newspapers from a stand
Element 2?selling antiques in a market
Element 3?selling custom drapes
Element 4?selling large appliances
Element 5?hiring out a car to a customer
Element 6?providing TV rental services
Element 7?selling car insurance
Element 8?providing electricity for home
Element 9?providing dental services
Element 10?being agent for home purchase
```

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 from 1 to 5

 2 selling antiques in a market     1
 3 selling custom drapes            1
 1 selling newspapers from a stand  5
 4 selling large appliances        ?3
 5 hiring out a car to a customer  ?1
 6 providing TV rental services    ?2
 7 selling car insurance           ?4
 8 providing electricity for home  ?5
 9 providing dental services       ?2
10 being agent for home purchase   ?3
```

Another technique is that of matching the ratings given to elements and asking for a construct that differentiates between two highly matched elements:

```
The two elements 1 selling newspapers from a stand
and 8 providing electricity for home are matched at
the 87 percent level. This means that so far you have
not distinguished between selling newspapers from a
stand and providing electricity for home.
Do you want to split these?Y

Think of a construct which separates these two
elements, with selling newspapers from a stand on the
left pole and providing electricity for home on the
right pole.

left pole rated 1 --?supplied one at a time
right pole rated 5 --?direct delivery
```

of a system. Without them, nothing seems to fit, and the resulting system is far too complex or unwieldy."

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Element 10?being agent for home purchase
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One technique used by PEGASUS to elicit constructs is that of triadic comparison:

```
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 selling newspapers from a stand  1
 8 providing electricity for home   5
 2 selling antiques in a market    ?1
 3 selling custom drapes           ?2
 4 selling large appliances        ?1
 5 hiring out a car to a customer  ?1
 6 providing TV rental services    ?4
 7 selling car insurance           ?3
 9 providing dental services       ?1
10 being agent for home purchase   ?1
```

A technique that allows PEGASUS to elicit additional elements is to match constructs across elements and ask for a new element that differentiates between two highly matched constructs:

```
The two constructs you called
5 direct delivery -- supplied one at a time
9 'hands-on' delivery -- nonpersonal delivery
are matched at the 75 percent level

This means that most of the time you are saying
direct delivery you are also saying 'hands-on'
delivery and most of the time you are saying supplied
one at a time you are also saying nonpersonal
delivery. Think of another element which is either
direct delivery and nonpersonal delivery or 'hands-
on' delivery and supplied one at a time. 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?
```

Through a combination of triadic comparison, element matching, and construct matching, a PEGASUS interaction elicits from the user his system of constructs relating to the topic being studied.

ENTAIL IN ACTION

ENTAIL (Gaines & Shaw 1981b, 1985b, Shaw & Gaines 1982) gives a dependency analysis of the grid by listing logical entailments consistent with the data. The dependency analysis is also being extended to be interactive so that it may lead to the elicitation of further elements if the system suggests dependencies with which the expert disagrees, or to the modification of ratings if the expert suggests dependencies which are not possible according to the data he has entered. The overall objective is to allow the expert to explore the dimensions of his conceptual structure, testing it against specific cases, and discussing its implications, until he is comfortable that the representation elicited reasonably represents his knowledge.

Figure 5 is a composite grid in which the top seven constructs are those from BIAIT applied to a standard set of elements related to business record

keeping. The remaining 9 constructs were elicited from a businessman using PEGASUS. Figure 6 shows the ENTAIL analyis of this composite grid. The entailments are shown with two values, the first a truth value from 0 to 100 (e.g. L 7 > L 8 truth 75), and the second the uncertainty reduction generated by asserting this entailment, again in the range from 0 to 100 (e.g. L 7 > L 8 with truth 75 reduces the uncertainty in L 8 by 57). The uncertainty reduction measures the information carried by the assertion and is used to ensure that trivial entailments consistent with the data are pruned (Gaines & Shaw 1985b).

		1	2	3	4	5	6	7	8	9	10		
Billed	1	5	5	3	4	3	1	2	1	2	3	1	Pay cash
Deliver product	2	5	5	3	1	5	1	2	1	5	3	2	Customer takes
Keep cust. profile	3	5	5	3	5	3	2	1	1	1	3	3	Each trans. surprise
Price negotiated	4	5	1	4	5	5	5	5	5	5	1	4	Price fixed
Product rented	5	5	5	5	5	1	1	5	5	5	5	5	Product purchased
Supplier tracks product	6	5	5	3	2	1	1	2	3	3	4	6	Supplier forgets product
Made to order	7	5	5	1	5	5	5	3	4	2	4	7	Provided from stock
STANDARD PRODUCT	8	1	2	5	1	1	1	2	1	3	2	8	SPECIAL PRODUCT
SEND BILL	9	5	5	2	1	2	1	1	1	1	3	9	COLLECT CASH
CUSTOMER OWNS	10	1	1	1	1	5	5	1	1	1	1	10	WE OWN
SHORT TERM RELATIONSHIP	11	1	1	2	1	1	4	2	5	4	2	11	LONG TERM RELATIONSHIP
FIXED PRICE	12	1	5	2	2	2	1	1	1	1	4	12	HAGGLE
CHOICE	13	1	1	1	1	1	1	1	5	2	1	13	MONOPOLY
DELIVER	14	5	4	4	1	5	1	5	1	5	3	14	TAKE
CUSTOMER LOOKS AFTER	15	1	1	2	1	5	5	1	3	2	1	15	WE LOOK AFTER
EXPENSIVE	16	5	2	2	2	3	4	2	3	2	1	16	LOW-COST

* * * * * * * * * 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

Fig. 5 Composite Repertory Grid: BIAIT Constructs at Top; Constructs Elicited from Businessman by PEGASUS at Bottom

In this example the ENTAIL analysis is being used to see which BIAIT constructs may be recovered from the businessman. Usually entailment analysis is used to derive relations between constructs for use in ES

shells. The entailments derived by ENTAIL can be converted directly to rules that may be loaded into a standard ES shell as Boose (1984) has shown. The truth value of the rule codes into the truth value representation used by the shell. The rules may be checked by the expert for their content but their prior evaluation for uncertainty reduction makes it unlikely that spurious rules will be generated.

```
Entail    Truth  Information (Cutoff 30)

L 7 > R 8   75   57 Made to order > SPECIAL PRODUCT
R 3 > R 1   75   53 Each trans. surprise > Pay cash
R 9 > R 1  100   52 COLLECT CASH > Pay cash
L 1 = L 3   75   51 Billed  = Keep cust. profile
R11 > L 1  100   51 LONG TERM RELATIONSHIP > Billed
R11 > L 3  100   51 LONG TERM RELATIONSHIP > Keep cust. profile
R 1 = R 3   75   51 Pay cash  = Each trans. surprise
R15 > L 6  100   50 WE LOOK AFTER > Supplier tracks product
R 3 > L11  100   49 Each trans. surprise > SHORT TERM RELATIONSHIP
R 9 > R 3  100   45 COLLECT CASH > Each trans. surprise
L 1 > R11   50   43 Billed  > LONG TERM RELATIONSHIP
R 1 > L11  100   43 Pay cash  > SHORT TERM RELATIONSHIP
L14 > L 2   75   41 DELIVER > Deliver product
L 5 > L 6  100   40 Product rented > Supplier tracks product
L 6 > L 5   50   40 Supplier tracks product > Product rented
L 4 > R12   75   40 Price negotiated > HAGGLE
L 5 > R10  100   40 Product rented > WE OWN
L 5 > R15  100   40 Product rented > WE LOOK AFTER
L 6 > R10   50   40 Supplier tracks product > WE OWN
R10 > L 5  100   40 WE OWN > Product rented
R10 > L 6  100   40 WE OWN > Supplier tracks product
R12 > L 4   75   40 HAGGLE > Price negotiated
R15 > L 5   50   40 WE LOOK AFTER > Product rented
R10 > R15  100   40 WE OWN > WE LOOK AFTER
R15 > R10   50   40 WE LOOK AFTER > WE OWN
L 3 > L 9  100   39 Keep cust. profile > SEND BILL
R 6 > R 9   50   39 Supplier forgets product > COLLECT CASH
L 8 = R 7   75   38 STANDARD PRODUCT = Provided from stock
R 7 = L 8   75   38 Provided from stock = STANDARD PRODUCT
R 9 > R 2  100   38 COLLECT CASH > Customer takes
L 1 > L 9  100   37 Billed  > SEND BILL
L 2 > L 9  100   36 Deliver product  > SEND BILL
R 6 > L15  100   36 Supplier forgets product > CUSTOMER LOOKS AFTER
R12 > R 9   75   35 HAGGLE > COLLECT CASH
R13 > R11  100   35 MONOPOLY > LONG TERM RELATIONSHIP
```

Fig. 6 Entailments Derived by ENTAIL for Grid of Figure 5

SOCIOGRIDS IN ACTION

The construct elicitation described in the previous section is being carried out with a number of subjects from those experienced in business record-keeping to students with some knowledge of accounting. It is clearly possible to analyse for each subject whether the BIAIT constructs are among those elicited, how closely they are mimiced, and which ones are missing, and this analysis is being done. However, as noted earlier, one can also attempt to validate the methodology by seeing whether it is possible to reconstruct the ranking in expertise of the subjects through a SOCIOGRIDS analysis. For example, in an earlier study (Shaw 1980) of quality control for a garment company the SOCIOGRIDS analysis reconstructed the management hierarchy of the firm from the construct systems of staff involved in construing garment faults.

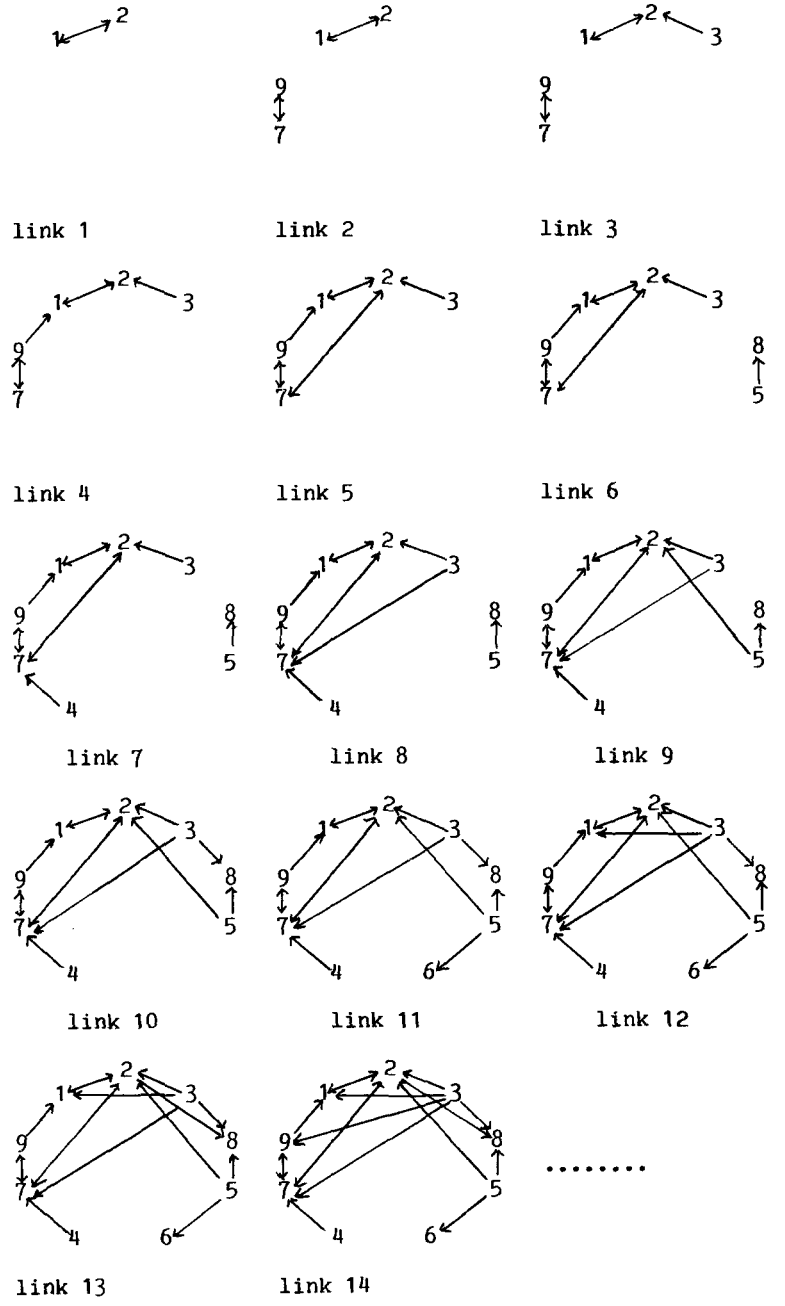

Fig. 7 Series of socionets produced by SOCIOGRIDS

The operation of SOCIOGRIDS is based on what Kelly (1955) 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 ES 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.

Link 1 in Figure 7 shows the most highly matched pair which is BIAIT and a businessman; link 2 shows another matched pair which is an economics student and a visual arts student. As the links are formed these initial pairs are joined into one group at link 4. A new subgroup is formed at link 6, then gradually the other participants are brought in and joined into one group. The nodes forming the central part of the network are BIAIT, the two businessmen, an economics student and the visual arts student. This can be seen at link 1? which is shown more completely in Figure 8.

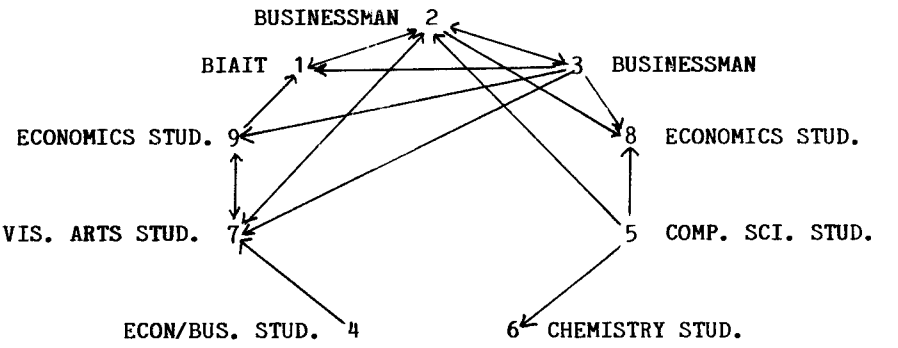

Fig. 8 Socionet produced by SOCIOGRIDS

This is mainly what one would expect, with the businessmen and the economics students closely related to BIAIT. The only disconcerting result is the position of the visual arts student who is clearly a central part of the cluster. On inquiring into the background of this student, it transpired that she had only recently become a student, having spent the previous 25 years as an administrative secretary in an insurance organization.

SUMMARY AND CONCLUSIONS

PLANET, an interactive computer aid to expedite the initial stages of knowledge engineering has been described and illustrated through an example. It is based on the personal contruct model of human knowledge acquisition and reasoning that has deep systemic and psychological foundations. The use of these foundations to operationalize the soft systems analysis at the heart of knowledge engineering has been described.

PLANET contains a number of sub-programs to do this: 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 be used to develop rules for an ES shell.

A basis for validating the methodology by eliciting knowledge in an area where an optimum structure has already been developed has been presented. An ongoing empirical trial of the techniques in a test case based on the BIAIT analysis of the record-keeping requirements of business enterprises has been described. The initial results show that the spectrum of expertise in the group of subjects used is being re-constructed in the analysis and hence that the methodology shows promise of being valid.

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