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KNOWLEDGE ENGINEERING FOR EXPERT SYSTEMS

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The Japanese fifth generation computer development program is targeted on knowledge processing rather than information processing. Expert system developments have demonstrated that knowledge can be represented and processed to replicate human skills, but have also focused attention on the difficulties of knowledge engineering, of eliciting and representing human knowledge and its processing. This paper presents a system for interactive elicitation of expert knowledge that is based on a systemic psychological model of human knowledge acquisition and processing. The need for normative tests of such methodologies is emphasized and an experimental study studies on reproducing a standard business record-keeping methodology is described.

1. KNOWLEDGE ENGINEERING

The human-computer interface (HCI) plays an ever more important role in computer system design. In particular, the Japanese **Fifth Generation** proposal stresses the transition from information systems used by specialists to knowledge systems accessible by everyone [23]. This emphasis shows in the "conceptual diagram" of fifth generation systems with its 3 rings of hardware, software and human applications [23 p.29]. However, as Gaines [10] remarks in these Proceedings, one notable feature of this diagram is that the hardware and software rings are full of detailed architecture, but the human ring is not. Logically, that ring should contain a psychological architecture of the person that is relevant to HCI. It does not, probably because we have no such definitive structure. There is much candidate material in human information processing studies [20] but Norman, in summarizing the current state of **cognitive science**, notes that there are major gaps in the underlying theory [24].

There is already evidence that the fifth generation objectives are reasonable. Expert system developments have led to a number of reasonably domain-independent software support systems for the encoding and application of knowledge [22]. However, the lack of detail in the third ring, of an account of human knowledge acquisition and processing, has created problems in what Feigenbaum [6] terms **knowledge engineering**, the reduction of a large body of knowledge to a precise set of facts and rules. As Hayes-Roth, Waterman and Lenat note:

> "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." [16].

We need to understand more about the nature of expertise in itself [15] and to able to apply this knowledge to the elicitation of expertise in specific domains.

The problem of knowledge elicitation from a skilled person is well-known in the literature of psychology. Bainbridge [1] has reviewed the difficulties of verbal de-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 [38] has reviewed many of these techniques in the context of knowledge engineering.

This paper describes systemic and psychological foundations for a model of human knowledge representation, acquisition and processing, that can be used to fill in the third ring, and has been made operational through computer programs for interactive knowledge elicitation. Some experiments on validating these techniques applied to knowledge engineering for business record keeping are briefly described.

2. DISTINCTION-MAKING AND PERSONAL CONSTRUCTS

Clinical psychology is the prime source of literature on techniques for by-passing cognitive defenses. In particular, Kelly's **Personal Construct Psychology** (PCP) is significant because it develops a complete psychology of both the normal and abnormal, which has strong systemic foundations [11] and has been operationalized through computer programs [29]. PCP models a person as using **personal constructs** as distinctions made about experience:

> "transparent templets which he creates and then attempts to fit over the realities of which the world is composed." [17]

and emphasizes the fallible use of constructs as a basis for knowledge acquisition:

> "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." [17]

In 1955 when Kelly developed his theory there was neither the mathematics to formalize it nor the computer technology to operationalize it. Despite this, PCP has developed to become a major psychological theory [21] and to provide a variety of techniques [30] used in clinical [35], educational [26] and managerial [29] psychology. In recent years strong links with system theory have developed that give formal foundations for PCP. Brown bases his logical system in **Laws of Form** on the notion underlying personal constructs of **making a distinction:**

> "The theme of this book is that a universe comes into being when a space is severed or taken apart...By tracing the way we represent such a severance, we can begin to reconstruct, with an accuracy and coverage that appear almost uncanny, the basic forms underlying linguistic, mathematical, physical and biological science, and can begin to see how the familiar laws of our own experience follow inexorably from the original act of severance." [3].

Gaines derives the foundations of system theory using a similar approach:

> "A system is what is distinguished as a system... In this lies the essence of systems theory: that to distinguish some entity as being a system is a necessary and sufficient criterion for its being a system and this is uniquely true for systems... The Oxford English Dictionary has it that a system is 'a group, set or aggregate of things, natural or artificial, forming a connected or complex whole.' One set of things is treated as distinct from another and it is that which gives them their coherence; it is that also which increases their complexity by giving them one more characteristic than they had before - that they have now been distinguished." [8].

Varela [37] extended Brown's logic to cover self-referential systems using a construction based on Russell's paradox. Kohout and Pinkava [19] showed that both systems could be embedded in a logical system that was consistent and complete. Gaines [9] has given a framework for these systems that encompasses modal, probability and fuzzy logics, and does not lead to inconsistency when unrestricted predication is allowed in set theory [39]. Quinlan [27] has shown recently that the constraint systems of such non-truth-functional logics may be used as a basis for improved inference in expert systems using uncertain rules and data.

Distinctions are not just static partitions of experience. They may be operations: actions in psychological terms; processes in computational terms. This shows in Goguen's [13] category-theoretic formulation of the logics, Ralescu's [28] application of these to a general theory of modeling, and Goguen's [14] development of a **OBJ**, a category-theoretic programming language. The role of distinctions at the base level of all models is evident in Klir's [18] hierarchy of modeling:

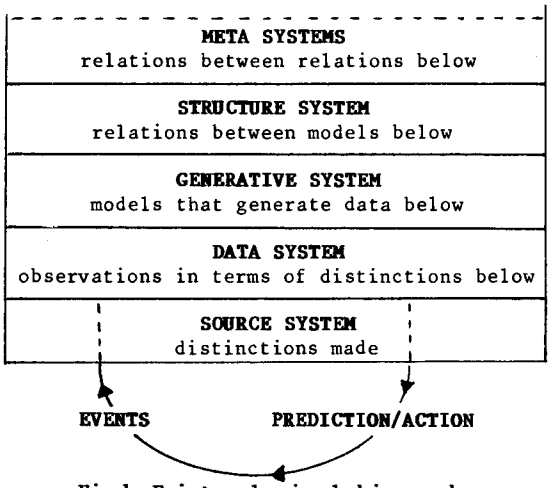

Fig.1. Epistemological hierarchy of a personal scientist

The loop from events through distinctions up through the modeling hierarchy and then down again to predictions and actions is one that I have termed the **personal scientist** [29]. Note that the upper levels of modeling are totally dependent on the system of distinctions, or personal constructs, used to express experience through the source system. Klir developed this hierarchy for work on symbolic modeling systems and Gaines [7] has shown that it forms a basis for general knowledge acquisition algorithms.

These systemic, psychological and computational foundations for a model of human cognition based on personal constructs lead to the hypothesis that the key to expertise is in the distinctions which the expert is making. The following sections examine techniques for eliciting these distinctions.

3. ELICITING CONSTRUCTS: 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 [4] 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:

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

Checkland's study of Stage 3, **root definitions** of relevant systems 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:

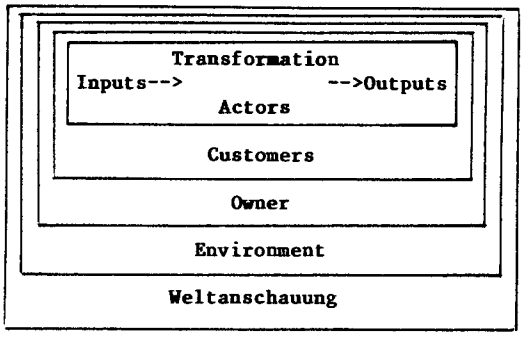

Fig. 3. Root Definitions of Relevant Systems

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 [2] has noted the utility of Checkland's analysis in developing expert systems, and I have shown how the techniques outlined in this paper may be applied to operationalizing it [33].

Applying the analysis to an expert system 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 oil extraction takes place, and the **weltanshauung** consists of energy policies, pollution concerns, and so on. These are the considerations which knowledge engineering has to take into account.

Checkland's methodology structures the task of knowledge engineering and provides techniques that are widely applicable. However, it leaves the burden of analysis with a person, and has no obvious operational form as a computer program. The next sections show how the analysis can be given these features.

4. ELICITING CONSTRUCTS: CONVERSATION THEORY

What is required to operationalize soft systems analysis is a theory of the way in which different viewpoints at different levels come together in an overall system of knowledge. Pask's **conversation theory** provides the basis for this and has been applied by Coombs and Alty [5] to the development of expert systems. Pask introduces the notion of a **P-Individual** or **psychologically characterized individual** in distinction to that of an **M-Individual** or **mechanically characterized individual.** He notes that an M-Individual is:

> "a human being (or his brain) as a biologically self-replicating system",

whereas:

> "a P-Individual...has many of the properties ascribed by anthropologists to a role, in society or industry, for example. A P-Individual is also a procedure and, as such, is run or executed in some M-Individual" [25]

He notes that while **an M-Individual may support many P-Individuals**, i.e. a person may play many roles, **a P-Individual may also be distributed over many M-Individuals**, i.e. a social unit may require the interplay of several persons.

In terms of the discussion of Sections 2 and 3 we may view P-Individuals as cross sections of modeling hierarchies interfaced to the world through personal constructs. This gives a coherent systemic framework for the relations between the multiple viewpoints discussed in Section 4. For example, Fig. 4 shows John, a person with a number of roles. He has formed P-Individuals as a husband, a sales VP of his company, a backpacker and a fisherman. The **personal scientist** or process which is John as a husband, uses operators to make construct-forming distinctions. They are distinctions about perception, about models, about values, about action. It is with the formation of these constructs that a P-Individual comes into

being. John uses different constructs when he is in the role of husband from when he is in the role of fisherman, but some of the constructs he uses in the role of fisherman are also used in the role of backpacker and we show this as overlapping P-Individuals.

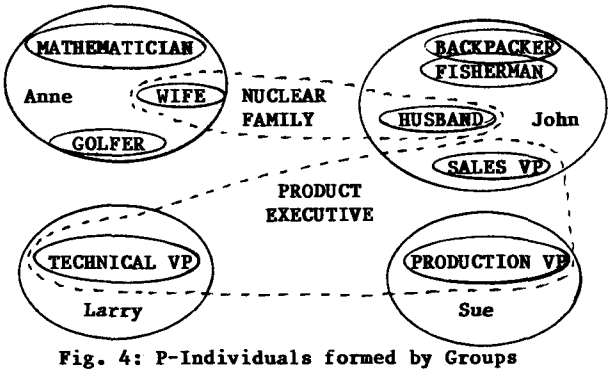

Fig. 4: P-Individuals formed by Groups

Fig. 4 includes some of John's associates: Anne is his wife, a mathematician and a golfer; Larry is the technical VP in John's company, and Sue is production VP. Sometimes John is acting with the others as a joint P-Individual that has some constructs shared between them and others that arise from only one. For example, John and Anne form a nuclear family: a P-Individual which has legal rights, behavior, concepts and language which are not those of either party alone. The product executive of the company is a P-Individual which has behavior, authority, responsibility, and language which is unique to the entity and not that of any one of its participants.

As expected from soft systems analysis, Pask's theory of multiple-person P-Individuals shows that expertise may not reside in one person. In developing an expert system for product development in a company we have to take into account all the actors shown in the product executive of Fig. 4, the objectives set by the problem owner, the constraints of the environment in which they operate, and the overall ethos for the development.

I have shown the interaction of conversation theory and soft systems analysis with personal construct psychology and how this provides a basis for computer programs for knowledge elicitation. The next section outlines briefly some computer techniques for doing this.

5. ELICITING CONSTRUCTS: PEGASUS AND SOCIOGRIDS

PLANET [31] consists of a suite of programs for eliciting personal constructs, analysing construct systems, and the common and disparate aspects of the systems of a number of people. **PEGASUS** [29] asks the user for a purpose and for elements that relate to it, and elicits different ways of construing these elements. It analyses the construct system continuously and feeds back enquiries based on this analysis to elicit further elements and constructs. The programs have been used for a wide variety of studies in management, education and clinical psychology [26,29,30,35] and recently for knowledge engineering for expert systems [34].

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 [36] describes one such case where the record keeping needs of a business can be prescribed through the BIAIT analysis technique based on seven features of the form:

> Does the supplier bill the customer, or does the customer pay cash?
>
> Does the supplier deliver the product at some time in the future, or does the customer take the order with him?

He 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."

Experiments have been done with businessmen and students at different stages in accountancy careers to determine whether **PLANET** elicits the BIAIT structure. The purpose of the elicitation was "Examining business record keeping". Typical elements were "Selling car insurance" or "Being agent for home purchase." The constructs elicited included all those of BIAIT such as "take -- deliver", but also other such as "low-cost -- expensive." A **SOCIOGRIDS** analysis of the preliminary results has been used to determine whether the BIAIT construct system is construed more readily by those with more business and accounting experience, and this shows up clearly in the results [32].

Thus, empirical studies indicate that personal construct elicitation methodology is an effective knowledge engineering technique. An experiment is now being carried out using fuzzy entailment analysis [30] to generate decision trees for record keeping from the data.

6. CONCLUSIONS

The term **expert system** has come to be applied to interactive systems which provide one person with access to another person's skills encoded in some way. Although the concepts and terminology are of recent origin, many interactive computer systems in the past have been developed with these objectives in mind and the recent focus of attention in this area is the culmination of much HCI research [12]. This paper has noted the relatively weak foundations for describing the human part of systems compared with those for hardware and software. It has outlined systemic, logical, psychological and computational approaches to providing these foundations, which have been used to develop interactive computer programs for knowledge engineering.

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