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# Development of a Participant Construct System

*Final Report*

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# Executive Summary


- This report documents a design study for the development of a *participant construct system.*
- The overall objective of the study is to further develop and refine the concept of a participant system through the analysis of a particular one based on *personal construct psychology*, and the design, development and application of such a participant construct system.
- A *participant system* is a computer-based communication system for multiple users that is essential to the performance of their mutual task, rather than merely incidental to their use of a computer network.
- Personal construct psychology is a theory of *cognitive science* that has deep systemic foundations, models the person as an anticipatory system, and has been operationalized through computer programs that have proved very powerful in expert system development.
- A survey has been made of the literature on cognitive psychology, personal construct psychology, repertory grid techniques, and their computer elicitation, analysis and applications.
- The survey results are presented in this report as a cognitive model, the *communal scientist*, underlying human knowledge processes and the design of a participant construct system.
- This study takes place in the context of the major world-wide initiatives in the development of knowledge-based computing systems, the *fifth* and *sixth generation* computing research programs with objectives of:
  —developing *knowledge-based* computing systems to aid the transition from information processing to knowledge processing;
  —improving *human-computer* interaction to the effective use of computing systems by all people;
  —involving *multi-disciplinary collaboration* between neurologists, psychologists, linguists, logicians and computer scientists.
- This study is consistent with these objectives in combining four of the most significant uses of computing systems: facilitating communications between people; aiding human problem-solving; eliciting human expertise; and encoding human expertise to make it widely available.
- The *participant construct system* design developed in this report integrates major components of all four applications to provide a system for computer-aided problem-solving by a group of people participating through a network of personal computers.

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## 1 Objectives of Study

This study takes place in the context of the major world-wide initiatives in the development of knowledge-based computing systems triggered by the Japanese *fifth generation* research program (Moto-oka 1982). The objectives of this program (Gaines 1984b) are:

1) The development of *knowledge-based* computing systems aiding the transition from information processing to knowledge processing;

2) The improvement of human-computer interaction aiding the effective use of computing systems by all people.

These objectives each involve improved understanding of the knowledge processes of people and the role of computing in these processes, both in emulating human knowledge processing and in supporting it through interaction. The advances necessary in our understanding of human cognition are emphasized by the announcement of a Japanese sixth generation computing systems development initiative (STA 1985). This involves multi-disciplinary collaboration between neurologists, psychologists, linguists and logicians to establish foundations for the *knowledge science* underlying human creative knowledge processes (Chapman 1985, Gaines 1986).

This study is consistent with these fifth and sixth generation objectives in bringing together four of the most significant and rapidly growing uses of computer-based systems: to facilitate communications between people; to aid human problem-solving; to elicit human expertise; and to encode human expertise and make it widely available. The *participant construct system* design developed in this report integrates major components of all four applications to provide a system for computer-aided knowledge-sharing and problem-solving by a group of people participating through a network of personal computers.

The overall objective of the study is "to further develop and refine the concept of a participant system (PS) through the analysis of a particular form of PS based on personal construct psychology, and the design, development and application of such a participant construct system (PCS)." In order to provide a design framework for a PCS, a survey has been made of the literature on cognitive psychology, personal construct psychology, repertory grid techniques, and their computer elicitation, analysis and applications. This is presented in this report as a cognitive model underlying human knowledge processes leading to the design of a participant construct system.

## 2 Basis of Study

This study takes place within a framework of previous concepts and developments. These notes outline the background to the study, its expected outcome and limitations.

### 2.1 The Participant System Concept

The concept of a *participant system* is a novel one put forward by Chang (1986) to capture the notion of computer-based communication between multiple users that is essential to the performance of their tasks, rather than merely incidental to their use of a timeshared computer or computer network. The significance of this concept is best seen by contrasting it with the rationale behind the majority of current multi-user computer systems.

### 2.2 From Timesharing to Participant Systems

Interactive timeshared computers were developed in the 1960s to give each user a virtual machine that emulated personal access by that user to a dedicated computer. The design requirement was that the interaction of other users with the time-shared computer should be as far as possible not apparent. Timesharing could never fully achieve this objective since CPU availability and disk access were subject to the fluctuating demands of other users and this could be strongly apparent to a user as varying time delays that were disconcerting because they had no relation to the tasks he had initiated.

The decline in cost of computer hardware in the 1970s made it possible to provide personal computing through dedicated actual machines rather than timesharing virtual machines. Personal computers satisfy the original design requirements for timesharing systems and the only reasons, within those requirements, for a user to access another system are: access to greater computing power such as an array processor; access to greater information storage such as high-volume files; access to information updated remotely such as a centralized database.

It is interesting to note that the first two requirements, for computing power and storage, are being increasingly satisfied by personal computers. Only the third, access to remotely updated information, has a fundamental, systemic component requiring a communication capability. It is this third requirement that the concept of *participant systems* addresses—the interaction of multiple users as an essential requirement of their individual, or mutual, tasks.

Figure 1 shows a typical configuration for a participant system implemented as a network of personal computers. The group of persons who have come together to participate in the system each access it through a personal computer acting as a terminal to a distributed computing network. Terminals to a timeshared central computer could provide an alternative implementation but the delay-free interaction of personal computers is preferable in giving a highly responsive system, particularly for graphic interaction. The database shown provides storage for information that may be shared among the participants. They may communicate with the database, or one another, through the network.

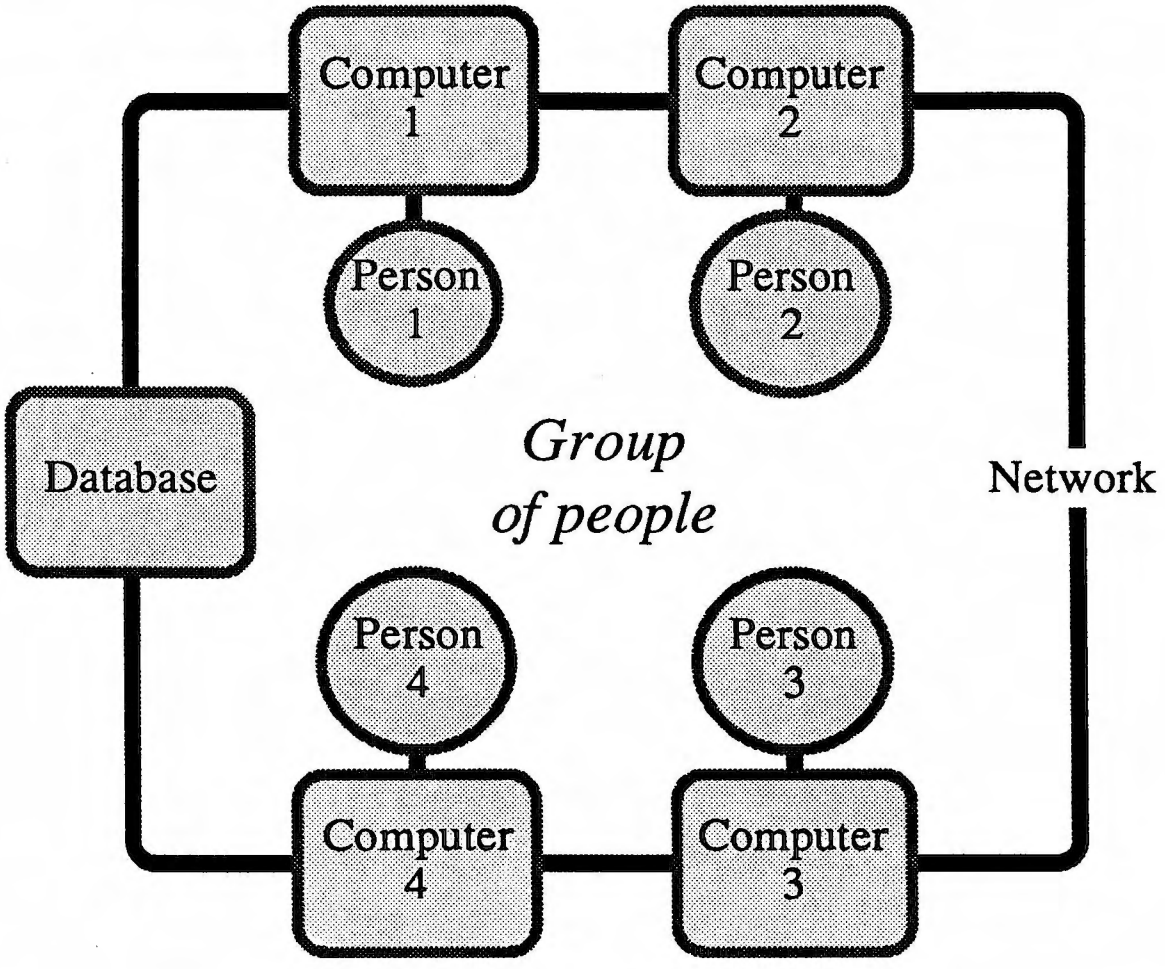


**Fig.1 Typical participant system implementation**

Note the emphasis on a *group* of people—the diagram could be of individuals, each carrying out separate activities on a computer network. However, it is the essence of a PS that those using it have some joint purpose, giving them coherence as a group.

### 2.3 Weak and Strong Notions of Participant Systems

It is useful to refine and formalize this notion of a coherent group as an essential feature of a participant system. One may distinguish a *weak* notion of a PS in which the performance of an individual task involves essential interaction with a system with which others must also interact, such as an airline reservation system. A *strong* notion of a PS is one in which the individual task is perceived by the individual as being only part of a mutual task essentially involving a number of individuals interacting through the PS.

This distinction is clearly relative in that there will always be a construction of an individual task as part of a mutual task, for example the airline reservation agents may view their task as that of filling the airline to capacity. However, there are generally natural, or consensual, constructions which determine the essential nature of the task. There are also implications for system support facilities that correspond to the differing viewpoints. Reservation system users see themselves as trying to get their customers transport rather than trying to fill aircraft. They need only indications of the space available. If they were mutually trying to fill aircraft they would need inter-communication about their individual plans to do so.

It is the strong form of PS that is of interest in this project, where the participants are using the system to further a mutual goal and the interaction of others with the system is seen by one user as being essential to the fulfilment of his individual objectives. The individual goals may be competitive or collaborative within the mutual goal. There may be multiple mutual goals that are consistent, or inconsistent, with one another.

### 2.4 Problems in the Design of Participant Systems

PSs may become extremely complex and it is reasonable to expect that the complexity will increase as they come into wider use. However, at this stage in their development there are many problems to be solved in designing PSs to operate effectively. Some of these problems arise from the technology constraints of existing hardware and software. Others are conceptual and exist because there are two few examples of PSs from which to derive a conceptual framework. Others are also conceptual and exist because the emphasis of human factors studies in particular has been on individual rather than participatory interaction.

The complexities of PSs and the conceptual difficulties in their design and implementation can be seen in perspective in Figure 2. A PS involves the essential interaction of two distinct organizations, each in itself complex. A social organization consisting of a group of people with some joint purpose is interacting with a computational organization designed to support that purpose. The design, implementation and effective operation of a PS requires understanding of the social and technical sub-systems and their mutual interaction.

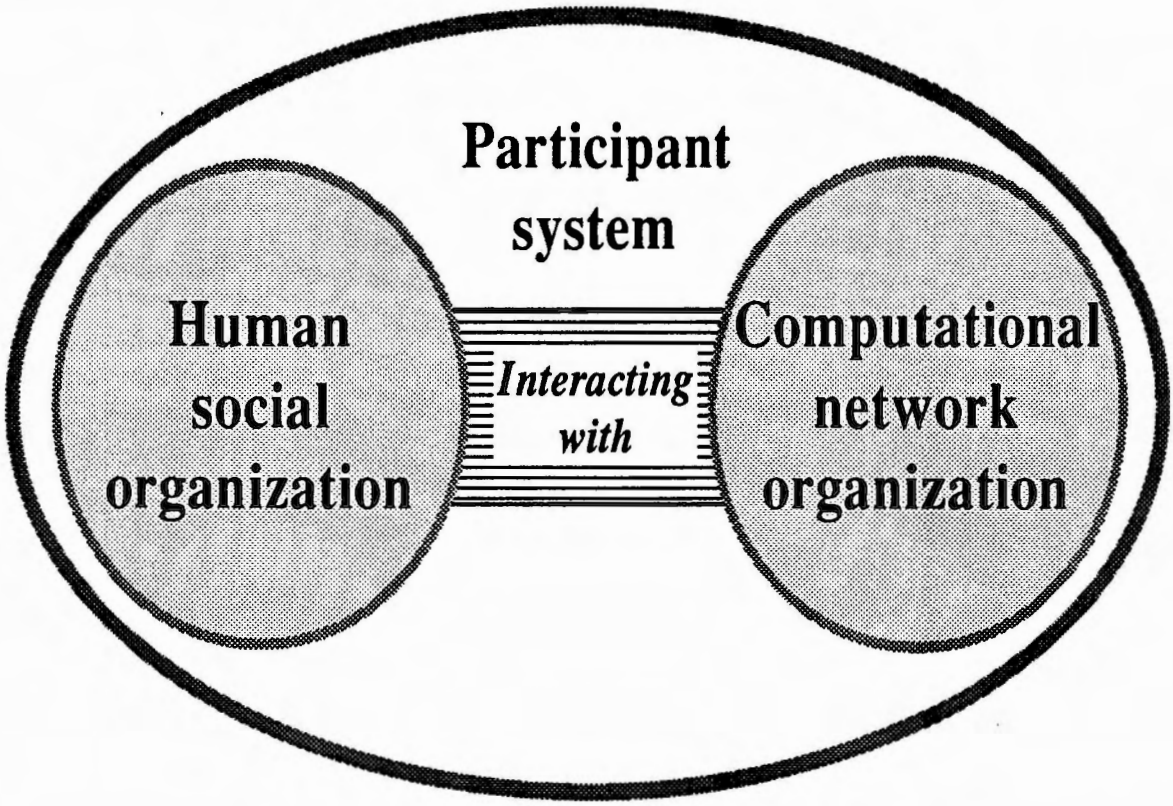


**Fig.2 Socio-technical nature of a participant system**

To clarify the design considerations in the development of PSs it is important to analyze the complete socio-technical structure of people and technologies that are involved. Figure 3 shows the conceptual structure of a PS including both the human and computer sub-systems.

The participant group at the centre consists of people in roles relevant to the group activity. They have existing social relations, direct communications not involving the PS, and are embedded in a culture of implicit and explicit values, language, and so on. The PS is interacting with this total socio-cognitive structure.

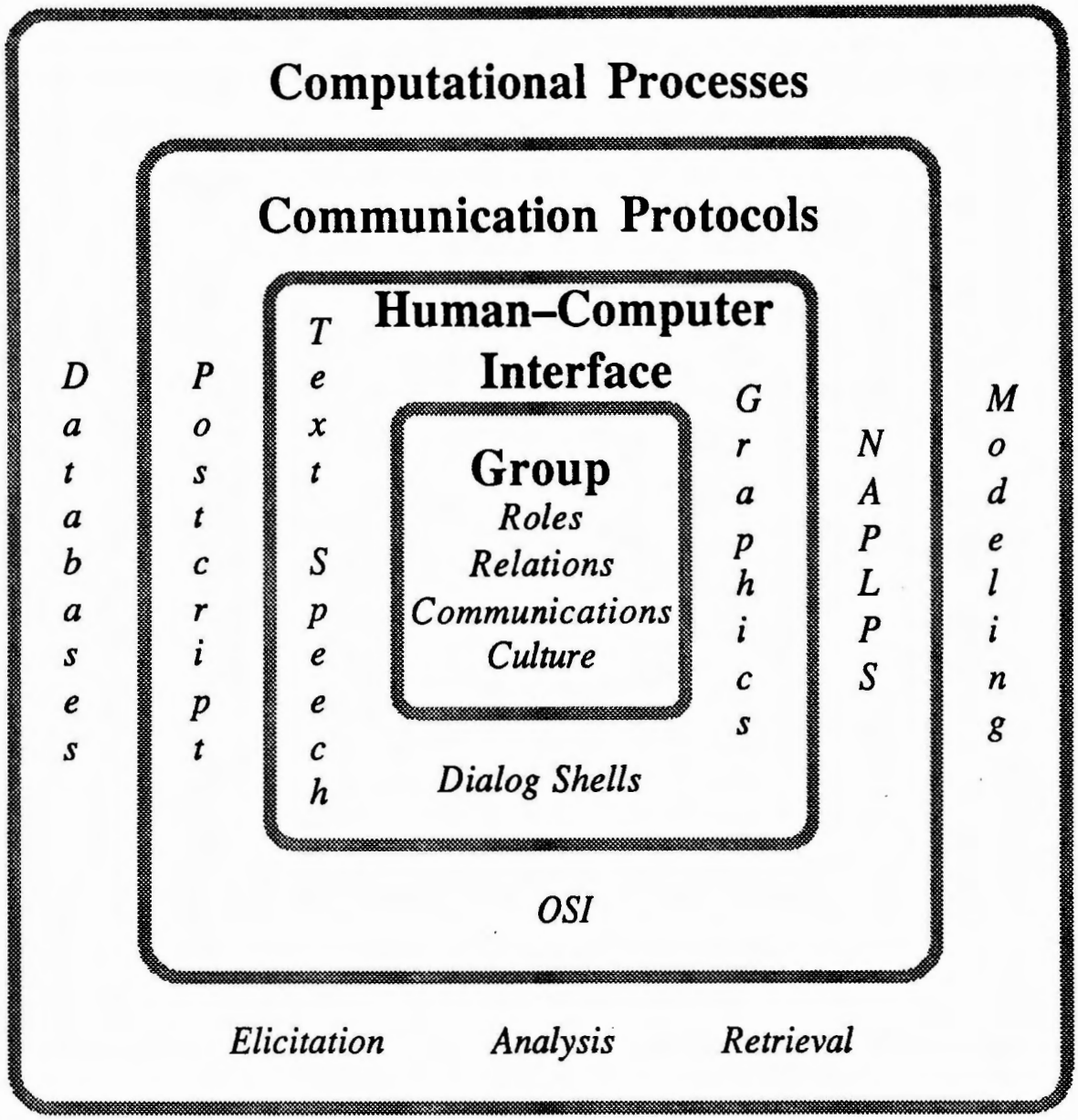


**Fig.3 Socio-technical nature of a participant system**

The people interact with the PS through a human-computer interface which may involve text, graphics and speech, engineered through dialog shells giving a uniform and consistent interface. The computers with which they interact communicate through protocols with one another and with other systems on the network. The PS is supported by computational processes such as information elicitation, analysis and retrieval, and maintenance of databases and models relating to the participative process.

## 2.5 Participant Construct Systems

The discussion of the preceeding section indicates that the design, development and application of PSs requires an understanding of both the computer technology involved and the psycho-socio-dynamics of the users. This study is intended to address this requirement by designing a specialist PS for a domain where large-scale cognitive psychological and sociological theories already exist, implementing it on a network of Apple Macintosh personal computers where an appropriate human-computer interface already exists, and studying its application. A highly structured knowledge elicitation technique has been chosen as the basis of the PS in order to draw on experience in the use of such techniques in management and expertise-transfer applications. The resulting PS will provide a working example, a potentially practical application, and an environment for a second study concerned with the human factors of the user interface.

## 2.6 Personal Construct Psychology

Kelly's (1955) *Personal Construct Psychology* (PCP) provides a systemic model of the cognitive and behavioral processes of the individual, including inter-personal and social interaction. A person is modeled as *construing* their experience by dividing it up into chunks (*elements*) and classifying these using a system of bipolar *constructs*. Constructs are themselves construed by other constructs and hence form a hierarchical system.

Construing is used to enable a person to anticipate the future as a hypothesized replication of the past. Constructs are changed as a result of errors in anticipation so that personal philosophies are seen as essentially fallibilist. A person will be more willing to change some constructs rather than other, *core,* constructs, giving a further order relation on the construct system.

In PCP, learning is seen as the development of the construct system, social processes are seen as the development of shared constructs, problem-solving is seen as the active anticipation of the future, and so on. The theory provides complete foundations for all human psychological and social processes. Hence it is possible to build technologies based upon it which are very general in concept and application. For example, an *expert system* in PCP terms is a computer-based system in which the relevant construction system of an expert has been encoded in an active form.

### 2.7 The Personal Scientist

Kelly's concept of the psychology of the person being generated by the requirement to construe experience so as to better anticipate the future is a systemic model with strong mathematical foundations and many implications. In particular there is a significant correspondence between the modeling process of the person and the expected behavior of a scientist which has led to personal construct psychology being termed that of the *personal scientist* (Shaw 1980a). The scientific process is one in which a descriptive language for data collection is established, data are gathered, a hypothesis is formed, the hypothesis is tested against further data and revized if it does not conform. The personal psychological process is one in which a descriptive system of personal constructs is established, experience is construed in terms of these constructs, hypotheses are formed as higher-level constructs, used to anticipate further experience, and revized if the anticipation proves to be invalid.

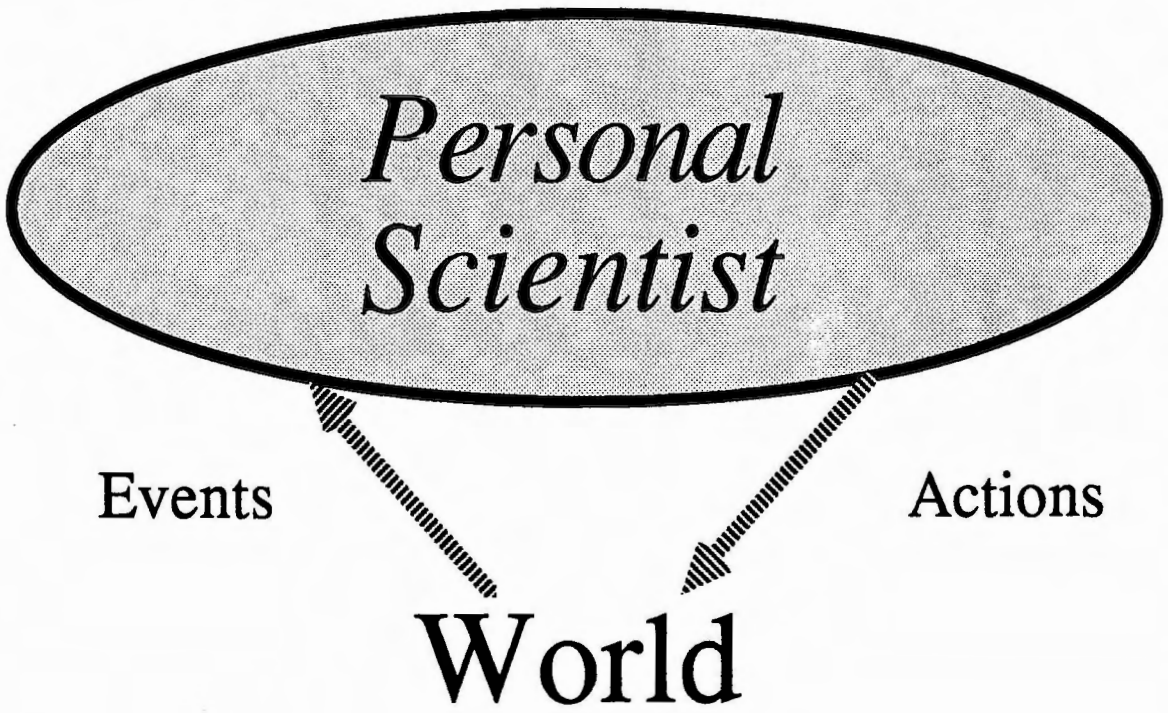


**Fig.4 Personal scientist interacting with the world**

Figure 4 shows a personal scientist interacting with the world by construing events, modeling the world, and using the model to generate actions (including predictions) in the world.

### 2.8 Repertory Grids

In computational terms the elements in PCP may be seen as *entities*, the constructs as *attributes* and the relation between elements and entities as *values* in an entity-attribute database. Kelly terms such a database a *repertory grid* and Fig.5 shows how a typical grid may be represented. The elements in this grid are people represented by their initials. The three constructs illustrate the mix between subjective and objective possible in personal constructs.

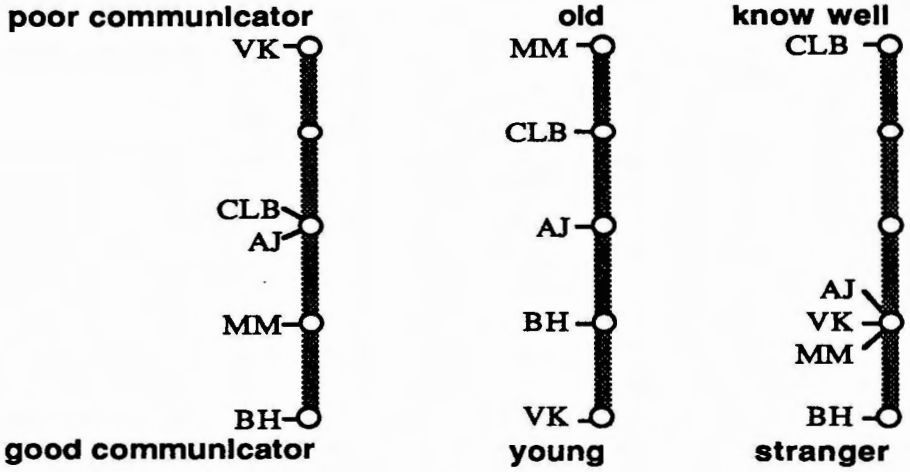


**Fig.5 A repertory grid of people on three constructs**

Kelly developed techniques to elicit such grids and to analyse the results. The clinical significance is that the construct system of an individual determines their personality and many aspects of their behavior. However, people have strong *cognitive defences* against awareness of the detailed dynamics of their behavior and do not have ready access to their own construct systems. Kelly's treatment for psychopathological problems was to make the workings of a person's construct system overt and accessible to them. His rationale was that they then might find alternative construction systems that obviated their problems.

Since their development in the context of clinical psychology, repertory grid techniques have found a wide range of applications in education, management and expert systems development. A similar rationale applies: in education the learner is attempting to acquire a specific construct system for the subject matter; in management people with different construct systems are attempting to work together towards common objectives; in expert systems development the knowledge engineer is attempting to make overt and encode the relevant construction system of an expert.

## 2.9 Computer-Based Participant Construct Systems

The manual elicitation of construct systems using structured interview techniques is tedious, time-consuming, and requires skill, practice and an appropriate personality. In recent years computer-based techniques have been developed for on-line elicitation and analysis of construct systems. These have proved very successful and are now in widespread use (Shaw 1980a, 1981a). One of the most interesting developments of such systems has been to attempt to combine the construct systems of a number of people, make them accessible to all and hence share their knowledge and skills. This may be seen as the development of a PS which is more structured than those originally envisioned but which exemplifies the basic definition and objectives of a PS.

This is the objective of this study: the development of a PS in which a number of individuals interact through networked personal computers to develop mutual understanding of a problem domain through the use of repertory grid techniques. The users of such a system will be attempting to extend and understand their own thinking and problem-solving capabilities by interacting with other people. They should be able to:

- see the relationship of their points of view to those of others;
- explore differing terminology for the same constructs;
- become aware of differing constructs having the same terminology;
- extend their own construct systems with those of others;
- provide others with constructs they have found valuable;
- explore a problem-solving domain using the full group resources.

## 2.10 Scope and Limitations of the Study

This initial study has broad objectives and a time-span of only four months. It encompasses a literature survey, system design,and an implementation suitable for application studies. The time limitations imply that the PCS developed will be an example prototype rather than a fully operational and applicable system. However, the concept of a PS is itself new and the PCS will: first, provide a further example of a different type of PS; second, make available within ARC the concepts, literature and techniques of personal construct psychology. One outcome of this preliminary study will be to make available facts and results on which a later decision about the pursuit of this line of research may be made on an informed basis.

## 3 Personal Construct Psychology as a Basis for Cognitive Science

The development of participant construct systems, and indeed participant systems in general, finds its theoretical foundations in cognitive science, the study of the cognitive processes of people, their modeling and emulation. It has been noted that *personal construct psychology* provides a systemic model of the cognitive processes of the individual. In this section the PCP model is extended to the types of social process that may be expected in PSs, and developed in detail based on the related literature.

### 3.1 Knowledge and the Life-World

The PCP model emphasizes the personal nature of the individual construction system and accounts for the very wide range of variation possible in personal views of the world. However, this emphasis on individuality leaves open the question of how we communicate, agree on widely accepted constructs and use them in mutually compatible ways. To account for social behavior, communication and language, the PCP model needs to be extended to interacting communities of people.

Sociologists and social psychologists have long held that human behavior, and that of human society, can only be understood in the context of the total social milieu. The individual must be seen as embedded in the *life-world* constituted by the social processes of other individuals and made explicit through cultural pressures, social norms, language, literature and the total knowledge base accreted by society and stored in a variety of media (Schutz and Luckman 1973). In recent years this concept has been extended to the knowledge acquisition process itself, and it has been noted that the processes of science can be best understood as social cognitive dynamics (Rubinstein, Laughlin & McManus 1984).

This examination of human cognitive behavior, the processes of science and the dynamics of knowledge acquisition have led to increasingly formal and operational theories. Popper (1968), has noted that knowledge itself forms a "world" with an ontological status equivalent to that of the physical world which he terms *world 3*. Luhmann (1979), has used systems theory to formalize the dynamics of social knowledge, such as *trust* and *power*, commencing with the survival drive and noting the peculiar problems presented to one individual by the cognitive processes of another. Wojciechowski (1983), has proposed a set of laws for the underlying processes of knowledge formation in human civilization human knowledge, and promoted the concept of an *ecology of knowledge*.

### 3.2 Inductive Inference and Reflective Equilibrium

These large-scale analyses of the knowledge processes of society have been paralleled by more specific studies of the individual carrying out the inductive inference processes of knowledge acquisition. A link between these micro-inductive processes of the individual and the macro-inductive processes of the life-world was established recently which provides new foundations for knowledge-based systems (Shaw & Gaines 1986a). This links the logic of induction with the social construct of expertise.

Whereas the deductive inference that underlies the operation of computers is well-understood and well-founded, the inductive inference that underlies human learning is not. Deduction guarantees to take us from valid data to valid inferences, but the inferences are thereby part of the data—no new knowledge is generated. Induction takes us from valid data to models of that data that go beyond it—by predicting data we have not yet observed, and by giving explanations of the data in terms of concepts that are unobservable. Induction generates new knowledge but, as Hume (1739) pointed out , the process is not deductively valid and it is a circular argument to claim that it is inductively valid.

Philosophers have continued to debate Hume's arguments and search for justification of the inductive process. Goodman (1973) proposed that we accept the circularity but note that it involves a dynamic equilibrium between data and inference rules as shown in Figure 6: "A rule is amended if it yields an inference we are unwilling to accept; an inference is rejected if it violates a rule we are unwilling to amend." Rawls (1971) in his theory of justice terms this a *reflective equilibrium.* Recently Stich and Nisbett (1984) noted flaws in Goodman's argument and repaired them by proposing that the equilibrium is social not individual: "a rule of inference is justified if it captures the reflective practice not of the person using it but of the appropriate experts in our society."

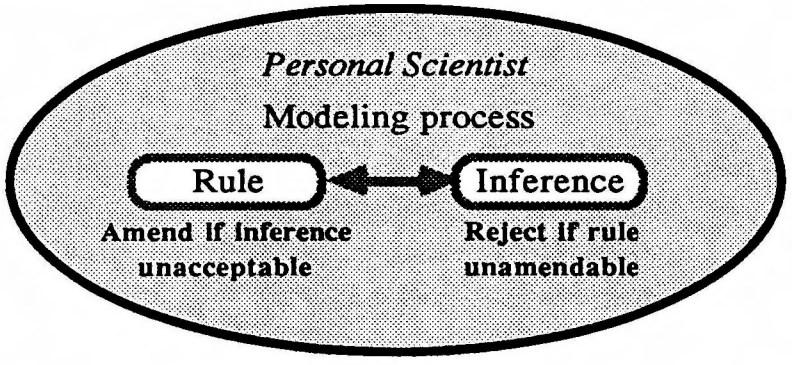


**Fig.6 Reflective equilibrium in inductive reasoning**

### 3.3 Reflective Equilibrium and Knowledge Engineering

The reflective equilibrium model of inductive inference is particularly interesting for its links to the problem of *knowledge engineering* for expert systems (Feigenbaum 1980). Knowledge engineering may be defined as the acquisition, elicitation, structuring and encoding of knowledge for application in inferential, goal-directed, explanatory, decision and action support systems. The nature of the problems involved are well-described:

> "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 concept of knowledge engineering has arisen in the industries concerned with the development of computer-based expert systems. However, the problems are not peculiar to computer technology. Most of them have their roots in the systemic principles underlying the dynamics of knowledge processes, and have long been studied in philosophy, psychology, sociology and system theory (Gaines 1977).

In particular, the early practitioners of knowledge engineering have come to realize that many problems are arising through lack of an adequate conception of the nature of expertise (Hawkins 1983). In recent years, with the breakdown of many social structures, interest has increased among sociologists and philosophers in the phenomena of expertise, authority, professions and disciplines (Haskell 1984). It is the context of this literature that Stich and Nisbett suggested the role of reflective equilibrium as overcoming the weakness of present theories of expertise:

> "The role of experts and authorities in our cognitive lives has been all but ignored by modern epistemologists. Yet it is a hallmark of an educated and reflective person that he recognizes, consults and defers to authority on a wide range of topics. We defer to the judgement of experts not only in assessing inference, but on factual questions as well, in medicine, science, history, and many other areas... it is our suspicion that one of the principle effects of education is to socialize people to defer to cognitive authorities." (Stich & Nisbett 1984)

### 3.4 Societies as Learning Systems

Stich and Nisbett's reflective equilibrium model derives from their analysis the role of experts in the knowledge process, and they see it as both solving the problem of justifying inductive reasoning and illuminating the role of experts. Although the basic idea is very simple, it has profound consequences when incorporated in the personal scientist model of personal construct psychology. The anticipatory system construing and modeling the world can now be taken to be human civilization. Individuals within human society act as distributed knowledge processors carrying out the construing and modeling process. They each have the characteristics of an anticipatory system but this can be treated as derivative from their roles within the overall social system.

These concepts are related to the social and scientific theories of Dewey (1920) who viewed scientific progress as a social process dependent on a critical community. Kuhn (1962) has termed the inferential practices of such communities *paradigms*, and sees the rules of normal science being in reflective equilibrium with the paradigms of the scientific community. He argues for the crucial role of paradigms in accounting for both the continued acceptance of theories despite contrary evidence and also the occurrence of rapid paradigm shifts in which new theories become widely accepted without adequate confirmatory evidence.

These models of a social epistemology of knowledge acquisition and dissemination that were propounded by Dewey and Kuhn have become of increasing interest as the weaknesses of the positivist approach to science have become apparent (Crane 1972). However, there are as yet inadequate links between the psychology of the inquiring individual and the social dynamics of knowledge creation. It is these links which would provide the foundations of a science of knowledge engineering and the nature of expertise. Personal construct psychology provides such foundations and, through its systemic and psychological foundations, provides an operational form of the philosophical arguments that is applicable to human cognitive processses. Kelly (1955) attributes much of his own philosophical approach to the influence of Dewey, in particular their mutual emphasis on the role of anticipation in driving the dynamics of knowledge creation. For Dewey the formation of scientific communities was effective because it provided a critical environment in which to refine hypotheses anticipating the future. For Kelly the formation of construct systems was effective in so much as it provided improved anticipation of the future.

One can summarize the positions of Dewey, Kuhn, Stich and Nisbett by noting that they take the basic anticipatory system to be not an individual but rather a society. The individual is a component in a learning society. Viewing human society as a learning system has proved very powerful in accounting for the dynamics of science, technology and economics:

> "The concept of a learning society, with its implications on the ecological Volterra equations, represents a very powerful tool in organizing social behavior and hints to the possibility of a unified theory for genetic evolution, ecology, sociology and economics." (Marchetti 1981)

In recent years Luhmann's (1979) model for the dynamics of society has provided a systemic formulation of the learning society and social foundations of inductive inference. He postulates *complexity-reduction* as the fundamental motivation for all our social institutions:

> "The world is overwhelmingly complex for every kind of real system... Its possibilities exceed those to which the system has the capacity to respond. A system locates itself in a selectively constituted 'environment' and will disintegrate in the case of disjunction between environment and 'world'. Human beings, however, and they alone, are conscious of the world's complexity and therefore of the possibility of selecting their environment—something which poses fundamental questions of self-preservation. Man has the capacity to comprehend the world, can see alternatives, possibilities, can realize his own ignorance, and can perceive himself as one who must make decisions."

Lumann also notes the peculiar problems of inter-personal relationships in increasing the complexity of the world:

> "we invoke a whole new dimension of complexity: the subjective 'I-ness' of other human beings which we experience (perceive) and understand. Since other people have their own first-hand access to the world, and can experience things differently they may consequently be a source of profound insecurity for me."

De Bono (1979) has described the role of computers in terms which are particularly meaningful in the context of Luhmann's complexity model:

> "By great good fortune, and just in time, we have to hand a device that can rescue us from the mass of complexity. That device is the computer. The computer will be to the organization revolution what steam power was to the industrial revolution. The computer can extend our organizing power in the same way as steam extended muscle power."

In the following formulation of the foundations of cognitive science we give substance to these statements about society and information technology by extending the notion of a personal scientist modeling the world (Shaw 1980a) to that of a society acquiring knowledge, a communal scientist (Shaw & Gaines 1986a). This social formulation of inductive inference is a important to the foundations of knowledge-based systems in computer science because:

1) It suggests that the basic cognitive system that should be considered is a social organization, rather than an individual;

2) It gives an operational model of the notion of expertise and the role it plays in our society, and hence provides formal foundations for expert systems;

3) It emphasizes the social nature of expertise and suggests that we should be considering groups of experts rather than individual experts in developing expert systems;

4) It provides an operational model for the growth of knowledge in a society involving the differentiation into "disciplines" corresponding to the reflective equilibria of different areas of expertise—and hence supports knowledge science encompassing the complete process and necessarily crossing disciplinary boundaries;

5) It provides a model for the role of media in communicating and storing knowledge with a continuity from classical media to present computer-based systems;

6) The computational models of inductive inference already developed can be applied directly to the social model;

7) There are links between these models and neurological processes in the brain;

8) The emphasis on the social nature of knowledge processes make the theory naturally applicable to the design of participant systems.

The following sections present cognitive science based on the fundamental principle that the human society is an anticipatory system based on a distributed modeling process, use this to account for the role of media and information technology in society, and extend it to design principles for participant systems.

### 3.5 From the Personal Scientist to the Communal Scientist

The basic model that will be used to develop a model of human knowledge processes is shown in Figure 7 as an update to Figure 4, replacing personal scientist with communal scientist. The personal construct psychology concepts still apply, but it is now the overall social system that construes its experience by looking at the "world through transparent templets" which it "creates and then attempts to fit over the realities of which the world is composed" (Kelly 1955 pp.8-9). The anticipatory process is no different for society than for the individual:

> "Constructs are used for predictions of things to come, and the world keeps on rolling on and revealing these predictions to be either correct or misleading. This fact provides the basis for the revision of constructs and, eventually, of whole construct systems." (Kelly 1955 p.14)

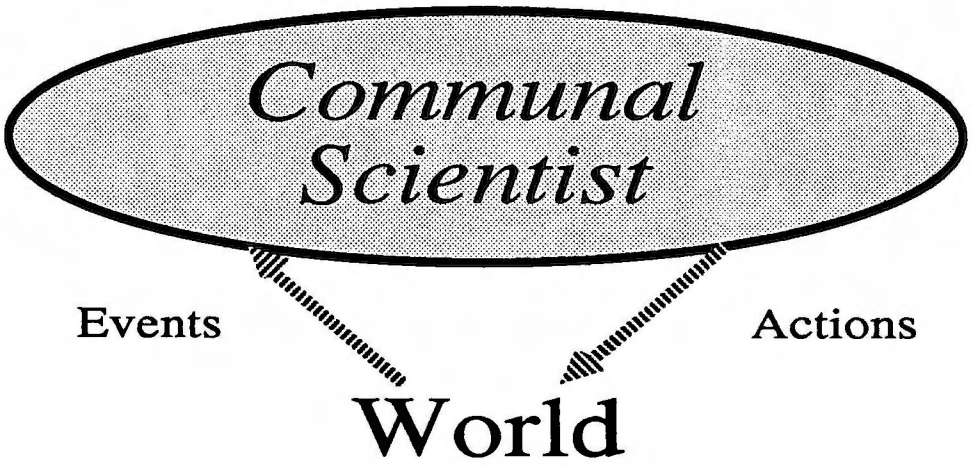


**Fig.7 Communal scientist interacting with the world**

The key concept behind Fig.7 is that the primary goal of living organisations is survival and this manifests itself in a drive to anticipate the future by modeling the world. Action is accounted for as active anticipation which acts upon the world to change it to make it more predictable and project survival further into the future. The development of a cognitive model of human knowledge processes involves analyses of the phenomena encapsulated in Figure 7 in two different ways. First, developing a formal model of the modeling process that demonstrates the generality of the notion of constructs being the foundation of anticipatory systems, and the possibility of expressing this operationally through algorithms. Second, developing a formal model of the structure of a distributed modeling system that clarifies the role of people, groups, media and information technology in carrying out knowledge processes.

### 3.6 Making Distinctions

The primitive notion underlying modeling is that of *making a distinction* introduced by Brown (1969) in his book *Laws of Form*:

> "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."

Figure 8 illustrates the essential concept of making a distinction, that some part of a world is separated out, or *marked*. At an abstract level, making a distinction is essentially a unipolar operation defining the marked region. However, the unmarked region is sometimes sufficiently well defined (if the world itself is well distinguished) for it to be treated as an opposite to the marked region and the distinction is then perceived as bipolar.

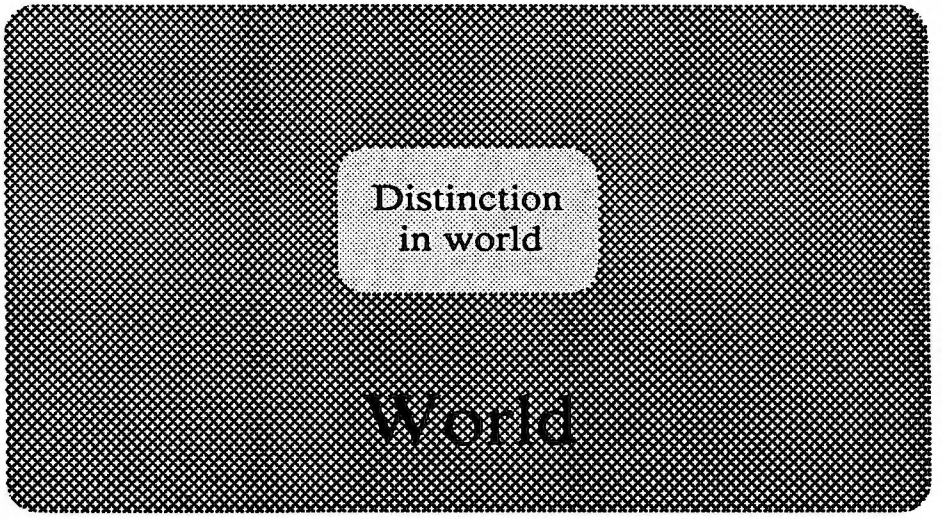


**Fig.8 Making a distinction in a world**

The theory of modeling based on distinctions is equivalent to basing set theory on an axiom of unrestricted predication and developing logics consistent with this. This is not the standard and familiar approach since unrestricted predication leads to the inconsistency that Russell discovered in Frege's (1884) *Foundations of Arithmetic*, although logicians such as Fitch (1952) have argued for the logic being changed rather than the axiom, and this makes it misleading to translate the notions into classical logic and set theory. Distinctions define a basis of knowledge which is prior to both and from which logic and set theory must be derived.

Luhmann (1979) relates the process of making a distinction to the formation of a system and its resultant complexity:

> "The concept of complexity has therefore to be defined in very abstract terms. This can be done straightforwardly in terms of a distinction between system and environment and in terms of a system's potential for actualization. The concept then signifies a number of possibilities which can be opened up through system formation."

Gaines (1980) illustrates the duality between distinctions and systems and the relation of both to complexity.

*Definition:* A *system* is what is *distinguished* as a system.

At first sight this looks a non-statement—systems are whatever we like to distinguish as systems—has anything been said? "What is peculiarly systemic about this definition?", might be asked. "Could it not equally well be applied it to all other objects one might wish to define, for example:

*Definition*: A *rabbit* is what is distinguished as a rabbit."

"Ah, but", goes the reply, "the first definition is adequate to define a system but the second is not adequate to define a rabbit." In this lies the essence of systems theory: that to distinguish some entity as a system is a necessary and sufficient criterion for its being one and this is uniquely true for systems. Whereas to distinguish some entity as anything else is a necessary criterion to its being that something but not a sufficient one.

What then are some of the characteristics that we do associate with the notion of a system, some form of coherence and some degree of complexity? 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." However, any other such characteristics arise out of the process of which making a distinction is often a part, and are some form of post hoc rationalization of the distinction we have made. 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. Distinguish the words on this page that contain an "e" from those which do not. This is a system and can be studied to rationalize why that distinction was made, how it can be explained, why it is useful. However, none of the post-distinction rationalizations and studies of the "coherency" and "complexity" of the system distinguished is intrinsically necessary to it being a system. They are just activities that naturally follow on from making a distinction when it is noted that it has been done and an explanation is wanted.

### 3.7 The Logic of Distinctions

Brown (1969) proposes a calculus of distinctions as a new basis for a logic more closely matching human knowledge processing, and it is reasonable to assume that "illogical" human reasoning (Wason & Johnson-Laird 1972) will not readily fit the framework of logics designed for mathematics and deliberately avoiding psychological connotations (Mohanty 1982). Kelly's personal construct psychology and Brown's calculus of distinctions both point to a knowledge representation system based on unrestricted predication as a primitive. The significance of such an axiom is that it forces us to develop system theories that do not run into the problems of this axiom in conventional mathematics. In set theory such predication allows self-reference and leads to the inconsistency already noted.

A solution to the inconsistency problem within the framework of standard predicate calculus requires the axiom of comprehension to be severely restricted by a complex set of rules defining a hierarchy of types (Copi 1971). However, this limits the naturality and applicability of logic and some logicians have attempted to develop systems that allow unrestricted predication and change the underlying logic (Fitch 1952, Martin 1970). One view is that the inconsistency may be better ascribed to the law of contradiction in standard logic: that the same predicate cannot be both true and false about the same proposition. Maydole (1975) proved that most contenders for an alternative logic led to inconsistencies in set theory, and White (1979) showed that Lukasiewicz infinitely valued logic gives a consistent set theory.

This was a particularly important result in bringing theory and practice together because it was just this logic that: Zadeh (1965) takes as a basis for fuzzy sets theory; Mamdani and Assilian (1981) used in one of the breakthrough expert systems for process control; and many later system developers have used as a basis for reasoning with uncertainty in expert systems (Gupta, Kandel, Badler & Kiszka 1985). The links from a calculus of distinctions to Lukasiewicz logic have been established: Goguen (1981) gives a model of concept formation based on a category-theoretic formulation of fuzzy reasoning; Varela (1975) used the calculus of distinctions to analyse self-referential systems using a construction based on Russell's paradox which gave a 3-valued logic; Gaines (1976) used a recursive form of this construction to generate the infinite valued Lukasiewicz logic; and Gaines (1983) shows that the Lukasiewicz axioms encompass modal, probability and fuzzy logics.

The significance of this construction is shown in Figure 9: the axioms are taken first as defining a non-truth-functional standard uncertainty logic; fuzzy logic is then derived by adding the constraint that the logic be truth functional; probability logic is derived by the alternative constraint that the law of contradiction applies; adding either converse constraint leads to the standard predicate calculus.

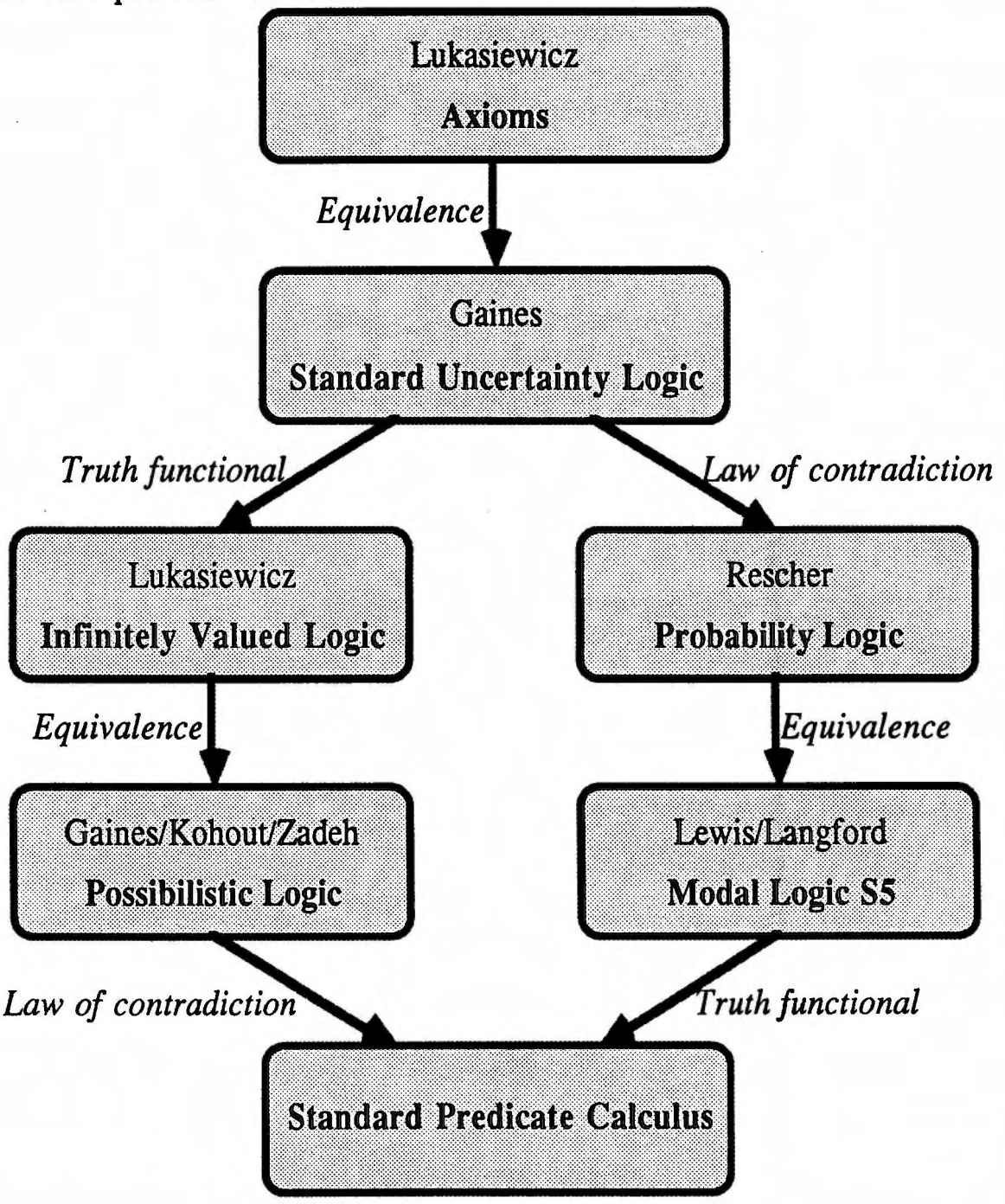


**Fig.9 Logics of uncertainty generated by distinctions**

The need for a system adequate to represent knowledge to encompass both imprecision and non-truth-functionality is obvious in retrospect. Most of the distinctions we make in everyday life do not have hard boundaries. The notion of a red rose is totally unambiguous and acceptable in human communication and reasoning. However, the set of red roses is not a standard set. It has boundary cases which are neither precisely red nor not-red. Yet we can not exclude these borderline cases from being considered as red roses. The laws of contradiction and the excluded middle do not apply. This is not to say that they never apply. There are many crisp contexts in which these laws are derivable in a set theory based on Lukasiewicz logic, for example that an entity either is a number or it is not is derivable for the set of numbers defined according to the standard successor relation (White 1979).

Non-truth-functionality arises in the logic underlying uncertain reasoning because it is not possible to ascribe truth-values to the conjunction and disjunction of uncertain events without further information about their relationship. In probability theory this is well-known: if it is 50% certain you will phone today and 50% certain that I will be out of the office, what is the certainty that you will phone when I am out of the office? The answer can range from 0% if we have pre-arranged, through 50% if the two events are not causally connected, to 100% if I do not want to talk to you. It is possible to compute the constraints upon the result but not to compute a single-valued result.

Quinlan (1983) has shown that the constraint systems of such non-truth-functional logics may be used as a basis for improved inference in expert systems with uncertain rules and data. Giles (1985) has derived related results for a theorem prover for Lukasiewicz logic that uses linear programming techniques to satisfy the constraints. Fuzzy logic can be seen as resulting from the requirement to avoid the calculation of such constraints by imposing truth-functionality. The common assumption of independence of events in probabilistic situations is an alternative way of forcing truth-functionality. Both these approaches are expedients whose utility depends on the problem domain.

Much work remains to be done on the reasoning processes deriving from the modeling hierarchy and the logics that may be seen as underlying them. Whatever model results will be characterized by taking unrestricted predication as a basic requirement and hence going beyond current standard predicate calculus.

### 3.8 The Modeling Hierarchy

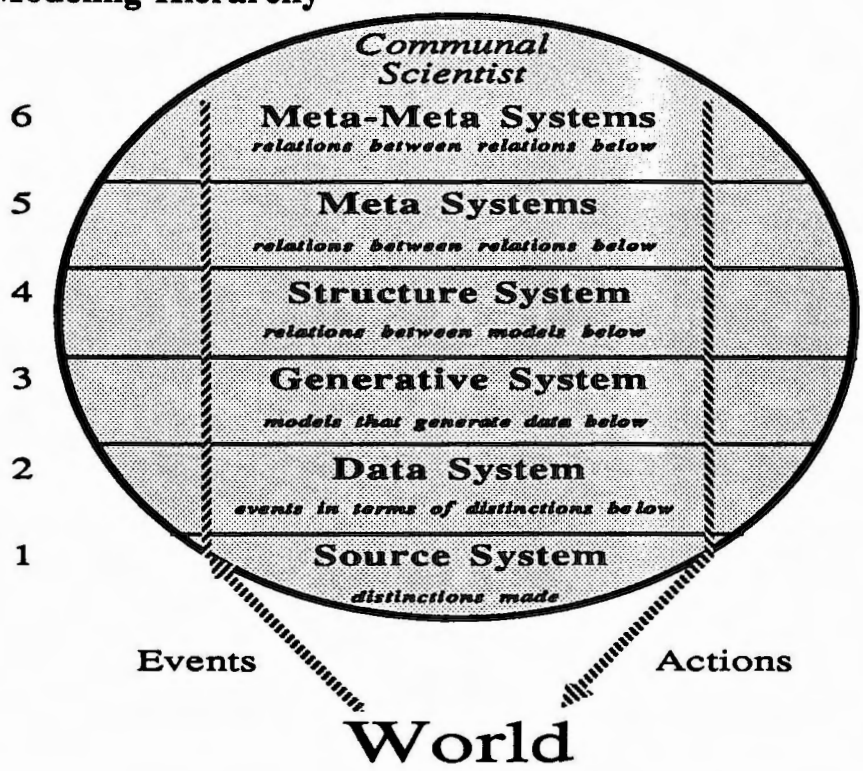


**Fig.10 Distinctions in the modeling hierarchy**

The foundational role of distinctions in knowledge acquisition is evident in the general modeling schema of Figure 10. This hierarchy does not introduce any additional primitives beyond that of making a distinction—the levels are the results of distinctions that we make. Thus, in Klir's (1976, 1985) terminology, the *source* system is distinguished as those distinctions that the particular modeling system makes; it is a distinction about distinctions defining the construct system of an individual. The *data* system is distinguished as those distinctions that have been made about a particular event; again a distinction about distinctions defining an event. The *generative* system is distinguished as a set of distinctions that also defines an event; these are model-generated rather than event-generated. It is the match between the model-generated and event-generated distinctions that determines the degree of approximation of the model to the world; this is a distinction about distinctions among distinctions that defines goodness of fit. The *structure* system is distinguished as a set of distinctions that compare models. The *meta* system is distinguished as a set of distinctions that specify the basis of these comparisons. The *meta-meta* system, and higher levels, are distinguished as sets of distinctions that specify further relations among the distinctions on the level below.

### 3.9 Learning in the Hierarchy

The hierarchy of Figure 10 accounts for learning as the modeling of events enabling prediction/action (Gaines & Shaw 1981a). In prediction the key distinction is whether a level can account for the information flowing through it and this may be called one of *surprise* (Gaines 1977), borrowing the term from the economist Shackle (1955). Surprise goes in opposition to the degree of membership (Zadeh 1965) of a predicted event to an actual event and the expected surprise is a form of entropy. Surprise at the lowest level of the hierarchy corresponds to distinctions being inadequate to capture events; at the next level to inadequate variety to experience events; at the next to inadequate approximation to predict events; at the next to inadequate simplicity to explain events; at the next to inadequate comprehensiveness to account for events.

The formal theory of modeling is one in which models are selected at each level down the hierarchy to minimize the rate at which surprise is passing up the hierarchy. The criteria for model selection independent of the data are generally termed ones of *simplicity/complexity*—of two models which fit the data equally well choose the simplest. However, notions of simplicity/complexity are not well-defined nor intrinsic to the class of models. The simplicity/complexity ordering is arbitrary and in its most general form is just one of *preference*. Hence the general modeling schema is one in which surprise flows up the hierarchy and preference flows down. In situations that are mathematically well-defined, such as determining the structure of a stochastic automaton from its behavior, such a model schema gives the correct results (Gaines 1977). Conversely, the success of the schema in stabilizing with regard to a given world defines the characteristics of that world.

Thus the basic modeling schema for learning from experience is one in which surprise flows up the hierarchy and preferences flow down. In primitive organisms only the lower levels of the hierarchy are developed, surprise is generated from experience and preference is genetically encoded. In higher organisms the modeling process generalizes both surprise and preference to cope with novel environments. Human life has developed the upper levels of the hierarchy and detached surprise from experience and preference from its genetic roots. Surprise can flow up from a level without flowing into it from below because the processes at that level have generated novelty. Preference can be generated at a high level detached from both experience and genetic origins and flow down to affect the relations of the organism to the world.

### 3.10 Psychological Interpretation of the Hierarchy

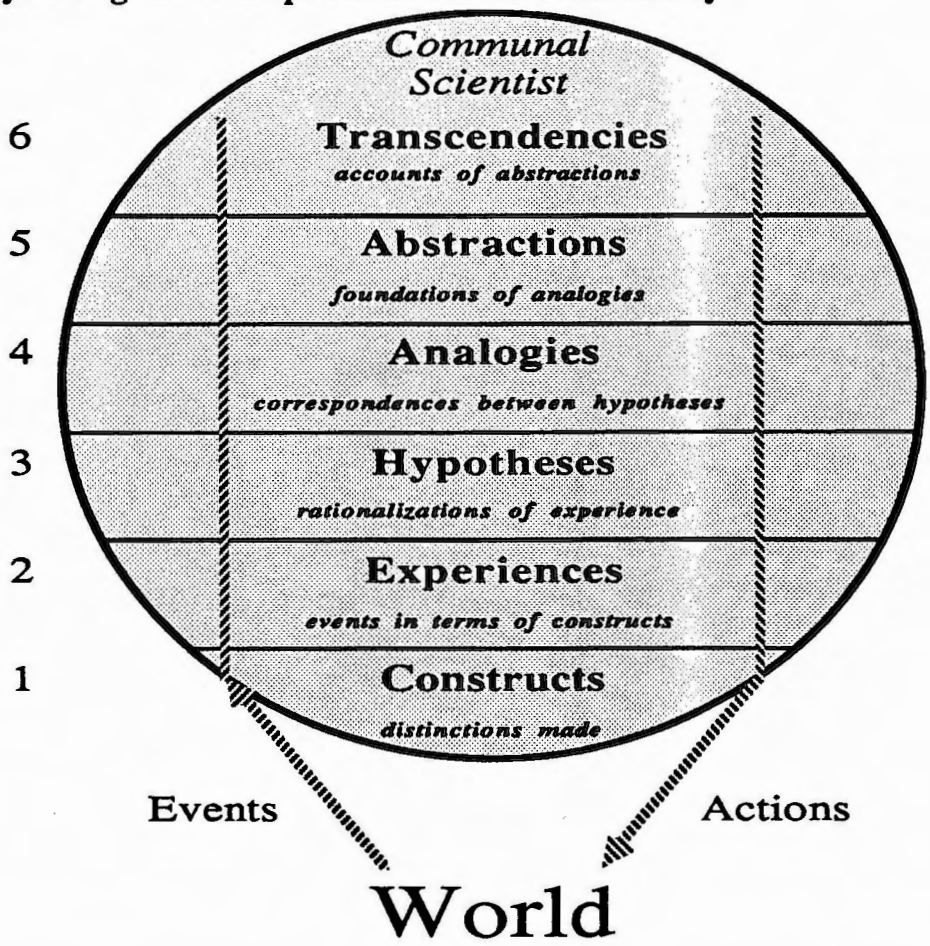


**Fig.11 Construction hierarchy of communal scientist**

The loop in Figure 10 from events up through the modeling hierarchy and then down again to predictions and actions characterizes the communal scientist. The systemic hierarchy of Figure 10 has an analog in psychological terminology as shown in Figure 11. The source level is one of *constructs*, distinctions made in interacting with the world. The data level is one of *experiences*, events which happen, and are made to happen, in terms of the distinctions already made. The generative level is one of *hypotheses* which are rationalizations of experience. The structure level is one of *analogies* which are correspondences between these rationalizations. The meta level is one of *abstractions* which are foundations of analogies. The meta-meta level is one of *transcendencies* which are accounts of abstractions. Interaction with the world is 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.

### 3.11 Action in the Hierarchy

In interpreting the hierarchy of Figures 10 and 11 it is important to note that distinctions and constructs are not just static partitions of experience. They may be operations: actions in psychological terms; processes in computational terms. Whether a system finds a distinction in the world, imposes it passively as a view of the world, or imposes it actively as a change in the world, is irrelevant to the basic modeling theory. It makes no difference to the theory whether distinctions are instantiated through sensation or action. We can make a distinction passively or actively. We can sense some condition already in the world or we can act to establish some condition in the world. In system-theoretic terms there is no intrinsic distinction between prediction and control. In scientific terms the predictive goals of scientific investigation and the normative goals of technological change are basically indistinguishable. In biological terms, a living system may discover a comfortable niche, create one, or combine the two processes. Figure 12 shows the basis for action at different levels in the modeling hierarchy.

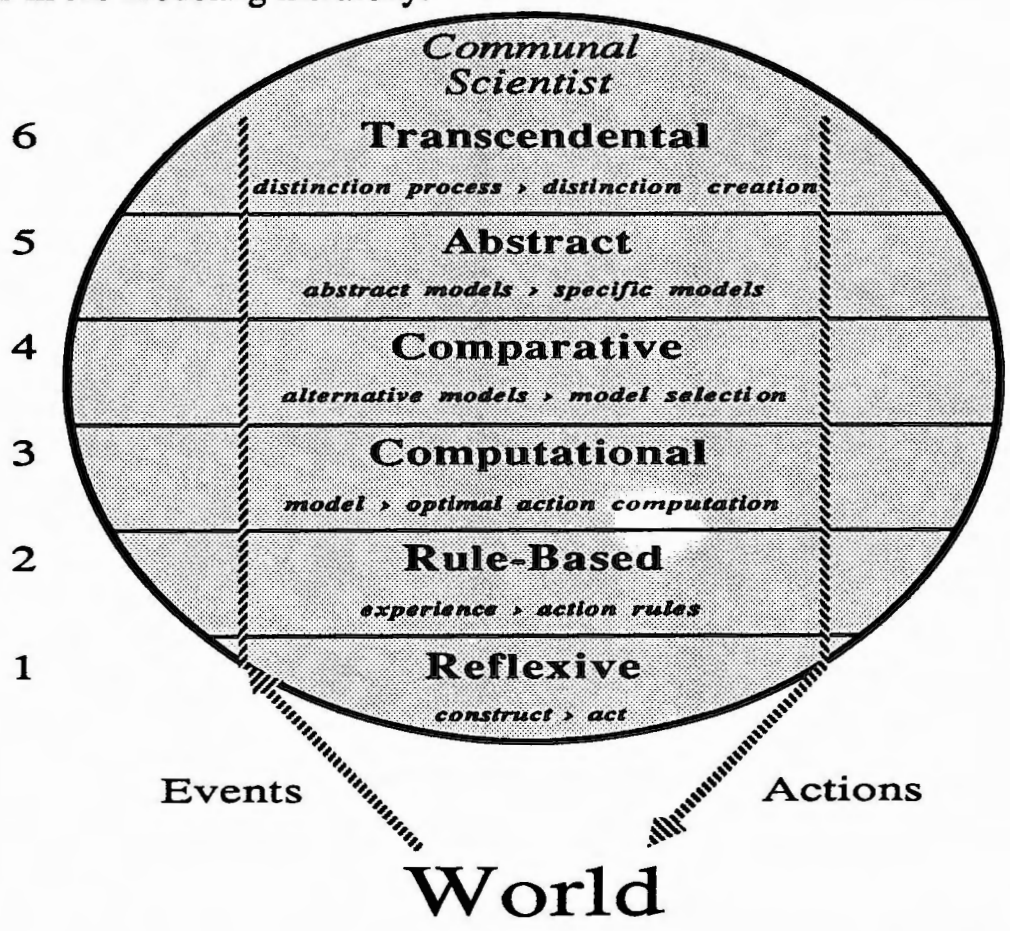


**Fig.12 Action hierarchy of a communal scientist**

At level one, the activation of a construct may be linked directly to a primitive act, another construct. This corresponds to reflex actions and stimulus-response connections. In system-theoretic terms this level might be implemented by conditional probability calculations giving confirmation-theoretic inductive inference.

At level two, constellations of experience may be linked to complete action sequences through rules derived from similar experience. In system-theoretic terms this level might be implemented by fuzzy production rules giving generalization-based inductive inference.

At level three, a generative model of experience may be used to compute an optimal action sequence. In system-theoretic terms this level might be implemented by a state-based modeling scheme giving model-based inductive inference.

At level four, a variety of alternative models may be compared as a basis for selecting one appropriate to the required goals. In system-theoretic terms this level might be implemented by a category-theoretic functional analysis scheme giving analogical inductive inference.

At level five, generalized abstract models may be used as templets from which to instantiate one appropriate to the required goals. In system-theoretic terms this level might be implemented by a category-theoretic factoring scheme abstracting the mathematical form of an analogy and giving abstractional inductive inference.

At level six, the entire process described may be transcended through a recognition that it is based on distinctions being made at various level, and an attempt to rationalize these distinctions and create new ones. In system-theoretic terms this level might be implemented by a distinction-based analysis scheme giving what might be termed transcendental inductive inference.

It is an interesting comment on computer science that it has proceeded "middle-outward" in representing knowledge at different levels of the hierarchy. In the past it has been primarily concerned with level three activities, and is only now beginning through expert system developments to emulate level two activities. The primitive sensation-action modes of learning at level one require the large-scale parallel processing essential to the emulation of human vision and locomotion, and will be emulated in the next generation of robotic systems. The higher level functions of levels four and five are being studied in artificial intelligence but require advances in mathematics and system theory for their full realization.

### 3.12 Psycho-Social Processes Within a Communal Scientist

The individual within society is a cross-section of the modeling hierarchy of Figure 10 (Shaw & Gaines 1981a, Shaw 1985). Figure 13 shows three personal scientists differentiated within the communal scientist. Each personal scientist is a hierarchical modeling system as shown for Personal Scientist 1, and together they form the hierarchical modeling system of the communal scientist of which they are cross-sections.

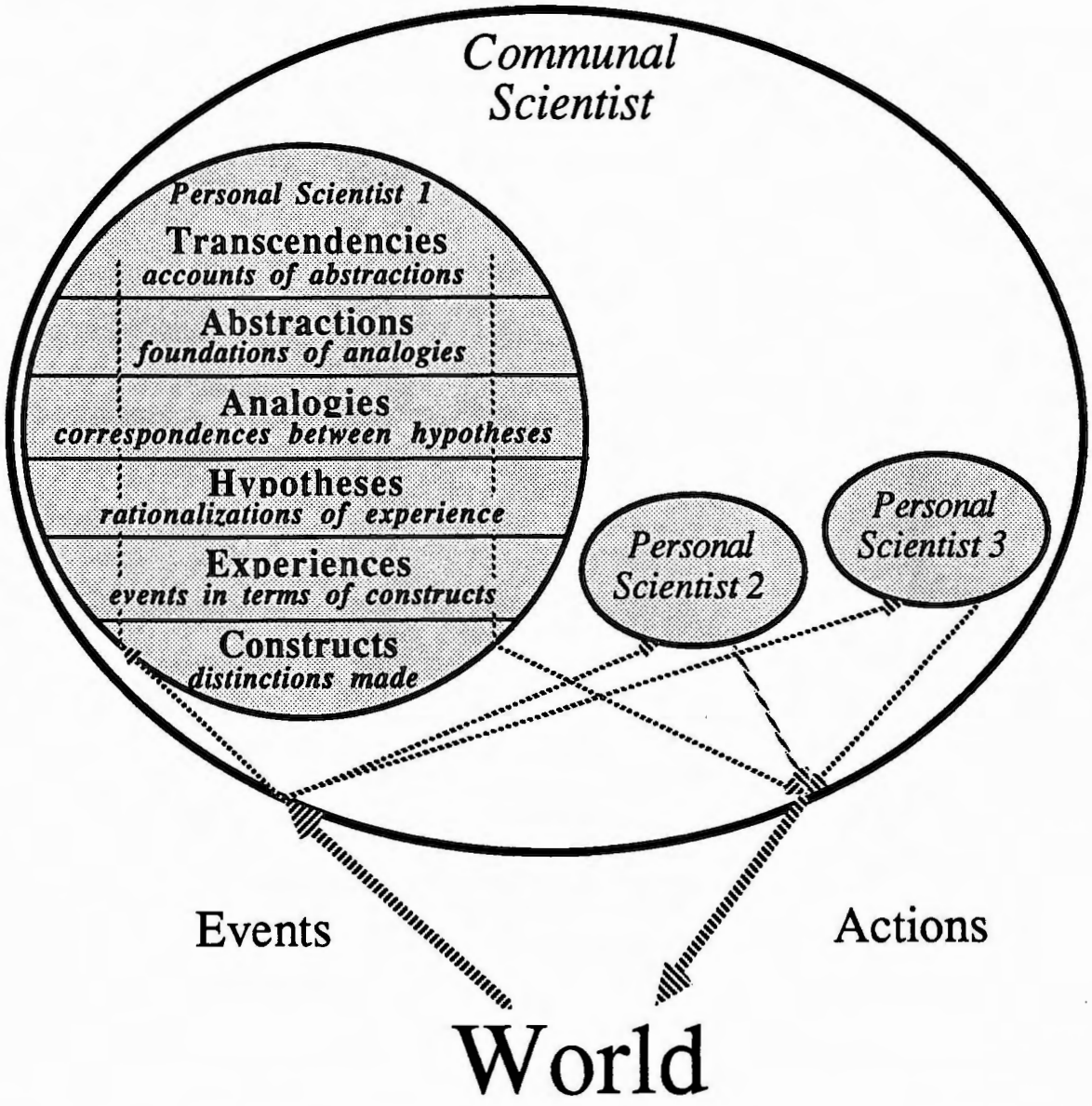


**Fig.13 Differentiated personal scientists in a communal scientist interacting with the world**

The differentiation shown in Figure 13 is inadequate in itself for the representation of the individual within the personal scientist. The personal scientist is properly conceived not as *person* but rather as a *role*. The significance of this distinction is clarified by Parsons (in Grinker 1956 p.328):

> "In the limiting conception a society is composed of human individuals, organisms; but a social system is not, and for a very important reason, namely, that the unit of a partial social system is a role and not an indovidual... A social system is a behavioral system. It is an organized set of behaviors of persons interacting with each other: a pattern of roles. The roles are the units of a social system. We say, 'John Jones is Mary Jones' husband.' He is the same person who is the mail carrier, but when we are talking about the mail carrier we are abstracting from his marriage relationship."

The role-person distinction is very significant for cognitive science and has been put in systemic terms, and further developed by Pask (1975, 1976, 1980) in his *conversation theory*. Pask defines an individual in cognitive terms as a psychological process, or psychologically characterized individual (*P-Individual*). He notes that the brain carrying out this process may be seen as a psychological processor which he terms a mechanically characterized individual (*M-Individual*). Pask (1975) notes that an M-Individual is characterized as:

> "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, qua processor."

He also notes that whilst an M-Individual may support many P-Individuals, that is, a person may play many roles, it is also possible that a P-Individual may be distributed over many M-Individuals, that is, a social unit may require the interplay of several persons.

These concepts allow more complex psychological and social structures to be shown in terms of the communal scientist and modeling hierarchy by taking into account the possibilities of timesharing, process switching and distributed processing with psychological processors. For example, one person may assume many psychological roles (process switching), whereas a group of people working together may act as a single goal-seeking entity and hence behave as one process (distributed processing).

Figure 14 shows two people, each with two roles, forming a group. The original communal scientist, CS1, and the personal scientists, PS1 through PS4, are all psychological processes. Person A and Person B as physical entities are psychological processors. Symbolic communication is important in co-ordinating psychological processes. In Figure 14 PS1 and PS2 are shown as having internal communication. PS3 and PS4 are shown not to have such communication and can only coordinate by monitoring one another's actions as events in the world. PS2 and PS3 have external communication corresponding to the use of language. The role of language in the communal sciemtist is very important and will be discussed in more detail following an example of roles and groups.

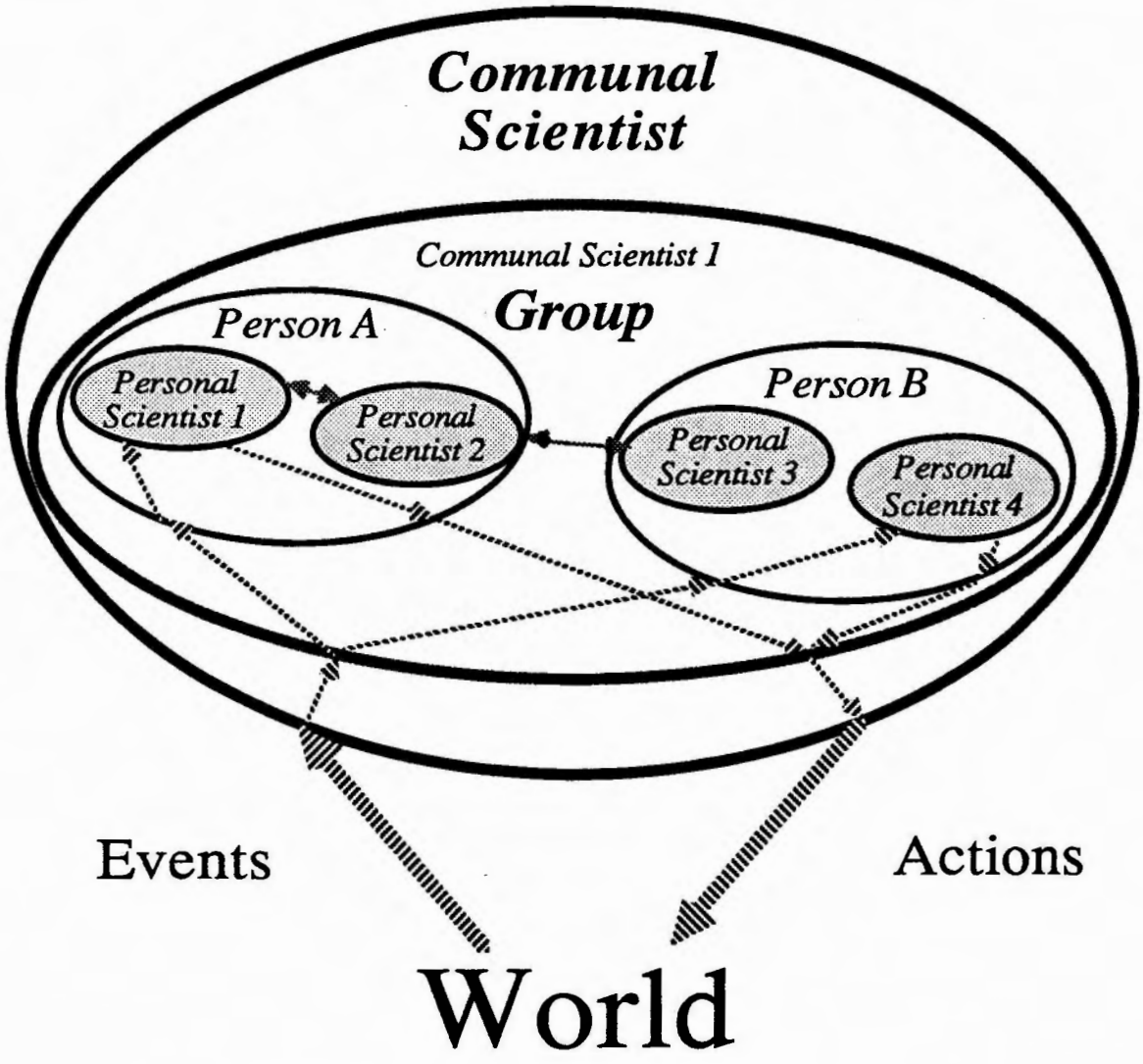


**Fig.14 People, roles and groups**

### 3.13 An Illustration of Roles and Groups

The concepts of Figure 14 are exemplified in more concrete terms in Figure 15 showing people in a number of roles and groups (Shaw 1985). The personal scientists, or roles, or elementary P-Individuals, are shown as shaded ovals within each named person, or M-Individual. The functional groups, or compound P-Individuals, are shown by the deeper shaded lines grouping roles within different people. Figure 15 exemplifies Parson's remark quoted previously that the roles, not the people, are the units of a social system.

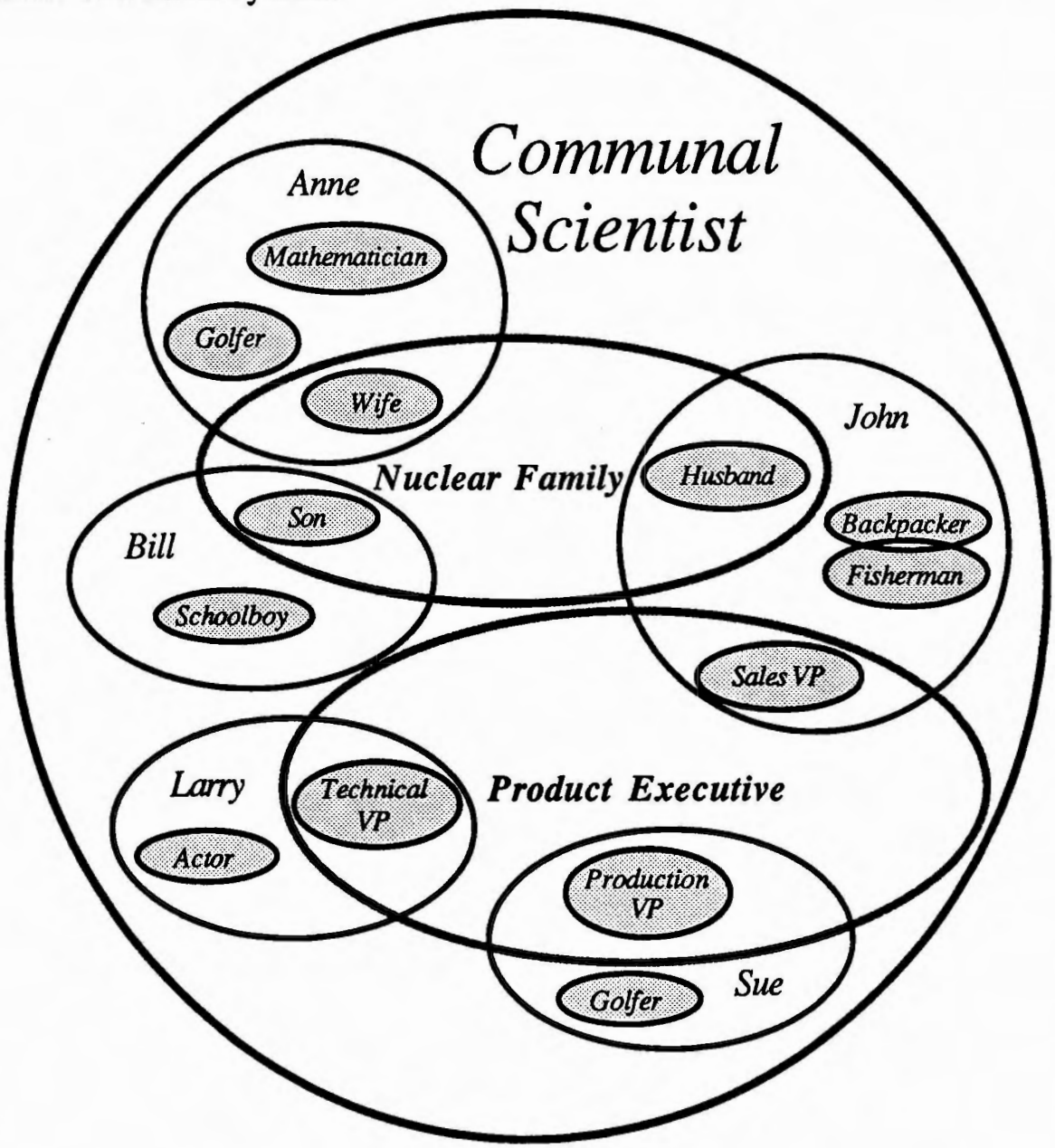


**Fig.15 Examples of people, roles and groups**

In Figure 15, John is a person with roles as a husband, a sales Vice President of his company, a backpacker and a fisherman. John uses different constructs when he is in the role of husband from when he is in the role of fisherman, and the personal scientists corresponding to these roles are shown as distinct. However, some of the constructs he uses in the role of fisherman are also used in the role of backpacker and this is shown as the corresponding personal scientists overlapping.

Anne is a second person shown as having three roles, as John's wife, as a mathematician and as a golfer.

Bill is a third person shown as having two roles, as the son of John and Anne, and a schoolboy.

Larry is a fourth person shown as having two roles, as the technical Vice President in John's company and as an actor as a hobby.

Sue is a fifth person shown as having two roles, as the production Vice President and as another golfer.

Each of these roles, personal scientists or P-Individuals, is distinguished and characterized by the construct system driving its processes, the distinctions it makes. All of the people shown will have many more roles but these are sufficient for purposes of illustration.

Pask's concept of a P-Individual distributed over several people may be illustrated by functional social groupings of the people shown. John may act with his wife, son or colleagues to form group processes that have some constructs that are shared between participants and others that arise from only one of them. The group, like a role, is a cross-section of the communal scientist and its knowledge processes, but it happens to involve several M-Individuals coordinated as a distributed process.

For example, John, Anne and Bill form a nuclear family. This is a distributed process which has legal rights, specific behaviour, concepts and language which go beyond those of its sub-processes (Reiss 1981).

John, Larry and Sue form the product executive of the company which is another distributed process which has authority, responsibility, and behaviour which is unique to the entity and not that of any one of its participants (Deal & Kennedy 1982).

Anne in her role as mathematician is attempting to become part of a communal scientist which has a much longer history of existence and again sets standards and uses language which is quite different from those of the other groups shown (Wilder 1981).

### 3.14 Symbolic Communication Within a Communal Scientist

It was noted in discussing Figure 14 that symbolic communication coordinates the activities of personal scientists within the communal scientist. Language is a difficult phenomenon to model—positions range from Skinner's (1957) analysis of language as behavior generated like any other behavior, to the so-called Sapir-Whorf hypothesis that language determines thought (Pinxten 1976). The communal scientist model puts language in a new perspective, as the coordinating mechanism for a hierarchical modeling system operating on distributed processors. The problem of modeling language is substantially reduced if we see the society, not the person, as the basic knowledge acquiring entity.

There is an evolutionary rationale for the selective encouragement of linguistic processes in enabling the human species to perform as a social anticipatory system while operating as physically separate entities with a high degree of autonomy. The communal brain in splitting into separate physical entities needs a mechanism for coordinating its parts and uses symbolic communication through language. Emotional communication at the limbic level through body language, or other forms of inter-individual communication, are inadequate for processes at the cortical level. It is reasonable, although not necessary, for inter-individual communication to mimic intra-individual communication and hence language to relate to "thinking". It is also reasonable to expect language to be multi-level, multi-purpose and diverse in its features since it coordinates activities at multiple levels for different purposes between a variety of entities.

The sequence above does not describe a physical process in evolution since, as far as is known, the individual brain did not split off from a group brain. However, in phylogenetic terms, a species developing mechanisms that enable it to act as a group brain while consisting of distinct and highly mobile physical entities would have such a great advantage that it would rapidly come to dominate all others. Group coordination occurs in some lower organisms such as slime molds and ant colonies but no other species has developed symbolic communication at the level of human language. If we assume that language arose late in evolution as a mechanism to extend human societies' capabilities to act as a distributed brain, then the emphasis changes to the brain with language being just one mechanism, not necessarily paramount. Questions as to whether language is necessary to individual thinking are answered in the negative. It is important in co-ordinating group thinking, particularly with the group extended in time and space—human transcendence of time is unique.

Pre-linguistic group communication develops into language as individuals with greater skills in communication set up evolutionary niches for others with the capability to mimic such skills to gain from their better group coordination. Language may coordinate the group brain in a diversity of ways—there is no single integrated language system. Syntax and other such formality arises as language becomes divorced from more direct forms of discourse. If we lose the expressiveness of speech and body movement then we need greater structure—a means of "telling" when we have no feedback as to the receiver's understanding.

This analysis does not diminish the role and significance of language but it emphasizes that distinctions rather than language determine thought processes. Consider Sapir's (1921 p.75) original statement:

> "Human beings do not live in the object world alone, nor alone in the world of social activity as ordinarily understood, but are very much at the mercy of the particular language which has become a medium of expression for their society. It is quite an illusion to imagine that one adjusts to reality essentially without the use of language and that language is merely an incidental means of solving specific problems of communication or reflection. The fact of the matter is that the 'real world' is to a large extent unconsciously built up on the language habits of the group."

This is consistent with our analysis but the interpretation goes too far if, as often occurs, it is taken to imply that language is the dominant determinant of knowledge processes. Sapir's student and interpreter, Whorf (1942 in Carroll 1956 p.252), brings this out in a footnote:

> "'thinking in a language' does not necessarily have to use WORDS. An uncultivated Choctaw can as easily as the most skilled litterateur contrast the tenses or the genders of two experiences, though he has never heard of any WORDS like 'tense' or 'gender' for such contrasts. Much thinking never brings in words at all, but manipulates whole paradigms, word classes, and such grammatical orders 'behind' or 'above' the focus of personal consciousness."

This notion of "language" is far closer to our notion of distinctions than to the conventional stereotype of language as essentially composed of words. The communal scientist analysis is supportive of the Sapir-Whorf arguments but not their common interpretation of linguistic determinism —the determinism of distinctions is axiomatic in the theory of the modeling hiearchy underlying the communal scientist but relatively few cognitive distinctions correspond to words.

### 3.15 Language and Culture in Knowledge Acquisition

The creation of new knowledge takes place through the surprise and preference flows within the hierarchy and it is these that determine the rate of knowledge acquisition. The human capability for an entire society to act as a distributed knowledge acquisition system is dependent on the role of communication processes in coordinating activity at a given level of the hierarchy across different people. These processes whereby individuals do not have to undertake all aspects of the inductive process but can share the results of such processing by others comprise what is generally termed the *culture* of a society. People use language for much of this communication but they also have in common with other animals the capability to communicate cultural information without the use of language, for example, mimicry is an important mechanism for knowledge acquisition as is reinforcement through reward and punishment.

The human development of language enables coordination to take place in a rich and subtle fashion that greatly enhances, but does not replace, the more basic mechanisms in common with other species. It is particularly important at the upper levels of the hierarchy where direct expression is difficult. From an individual point of view, language is a way of by-passing the normal modeling procedures and interacting directly with the system at any level. In particular it can directly affect the preference system. Even when language cannot mediate the direct transmission of knowledge it may be used to achieve the same effect by the indirect support of other mechanisms, for example, one can describe a good learning environment, or a behavior in sufficient detail for mimicry.

Figure 16 shows the cultural support for knowledge acquisition in the modeling hierarchy. The reflexive knowledge at level one has no verbal component and comes directly from experience, often that of mimicking the behavior of others. It has been termed *informal* to correspond to Hall's (1959) definition of cultural transmission of behavior of this type.

The rule-based knowledge at level two is usually transmitted by reinforcement of behavior, verbal rules, or is induced from the patterns of knowledge at level 1. This level has been termed *formal* to correspond to Hall's definition of cultural transmission of behavior of this type.

The computational knowledge at level three is usually transmitted by technical explanation, or is induced from the patterns of knowledge at level two. This level has been termed *technical* to correspond to Hall's definition of cultural transmission of behavior of this type.

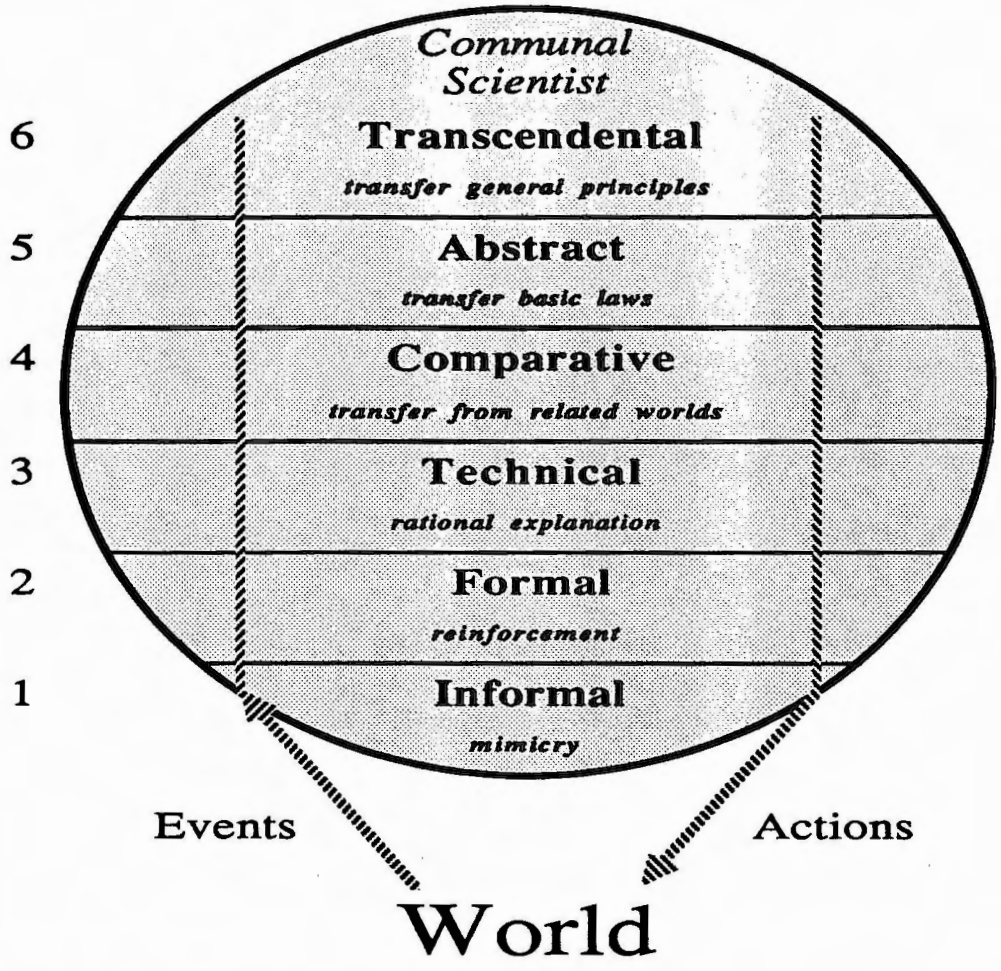


**Fig.16 Cultural communication in the hierarchy**

The analogical knowledge at level four is usually transmitted by simile and metaphorical analysis, or is induced from the patterns of knowledge at level three. Hall does give a name to this level but the term *comparative* captures his own activity of highlighting the features of one culture by contrasting it with others.

The *abstract* knowledge at level five is usually transmitted through mathematical representation, or is induced from the patterns of knowledge at level four.

The *transcendental* knowledge at level six is usually transmitted by general system-theoretic analysis, or is induced from the patterns of knowledge at level five. Many mystical and consciousness-raising techniques may be seen as attempts to communicate knowledge at this level when formal analysis is impossible. It involves moving outside the framework established at the lower levels. Pope (1984) has given examples of this process in a wide range of cultures.

### 3.16 The Dynamics of Construct Formation

It is fairly straightforward to analyse the operations of P-Individuals once they exist. Psychology and sociology have systemic foundations in the theory of personal constructs and the calculus of distinctions. However this leaves open the generic question of how such unities form and change. Kelly (1955) places the major emphasis of his work on the notion of *constructive alternativism*, that we have choice in our construct systems at every level in the hierarchy and that problems may often be solved by exercising this choice. Note that this should not be interpreted as an idealist position that ascribes all phenomena to our interpretation of them. Changes in the construct hierarchy may affect the real world, and some changes may be impossible. The theory is neutral to philosophical stances such as idealism versus realism; it is the distinctions which a philosopher makes that determines his stance and these can be analyzed in terms of the modeling hierarchy. Kelly saw his theory as reflexive and the only fundamental principle, apart from that of a construct itself, being that of constructive alternativism (Mancuso & Adams-Webber 1982).

In psychological terms, emotional processes play an important role in the formation of P-Individuals, although as Norman (1980) notes their role has been neglected in cognitive psychology. Melges (1982) notes that:

> "the normal function of emotions is to attune the person to overall discrepancies between the present and the future so that he adjusts his plans of action to his future images."

In systemic terms it is the surprise signal that travels up the modeling hierarchy to indicate discrepancies between the model and the data. In inductive inference terms this indication may be used either to amend the model or to reject the data. The distinctions which correspond to rules of inference that are regarded as unamendable are termed *core* constructs:

> "Core constructs are those which govern a person's maintenance processes—that is, those by which he maintains his identity and existence." Kelly (1955)

Systemically, the existence of core constructs corresponds to our not being able to re-evaluate all past experience in the light of a new model. We encapsulate that experience in a model based on distinctions to which we give inertia through reluctance to change. A system that amends its core constructs becomes detached from its own history and loses what has been learned from past experience. The optimization between readiness and reluctance to change is a function of the stability of the system's environment and part of its adaptive process.

Kelly sees negative emotions as coming from experiences that threaten to require changes in core constructs—McCoy (1981) has given a detailed taxonomy of emotions based on the type of core constructs involved. The deviation from the model indicated by the surprise signal may be seen as having adverse or beneficial consequences, being distracting, requiring attention, investigation, action, and so on. Thus human emotions may be seen as derived from surprise with the type of emotion varying according to circumstances: negative from distinctions we wish to retain and positive from those we prefer to change. From a systemic point of view human feeling tones are signals directing the inductive inference process.

Gray (1979) gives further insight into the system dynamics involved by linking the emotions with the processes of system formation. He introduces his notion of *system-forming precursors* as part of his *emotional-cognitive structure* theory for understanding creative thought processes. Emotions as integrating devices for the formation of thoughts and coding devices for memory. System formation occurs when *precursors* are brought together: *activators* initiate emergence of an organizing focus allowing entry to a group; and *blockers* inhibit emergence of an organizing focus preventing entry to a group. *Lock-out* is a situation in which blockers prevent entry to a group which may lead to the behavior of *break-in*, and *lock-in* is that in which withdrawal from a group is prevented which may lead to the behavior of *break-out*.

If we view a group as a surviving system that is dependent on its members for its own existence then the system dynamics proposed by Gray may be seen as part of the overall life cycle of the role of an individual within a group shown in Figure 17. At the first stage shown at the bottom of the diagram an individual who is not part of the group is attracted to it but resists the attraction: the pull-in—stay-out dynamics. In systemic terms there is a possibility of bringing the expertise represented by the distinction system of the group into the reflective equilibrium of the individual. In personal construct terms: the attraction is summed up in Kelly's choice corollary, that alternatives are chosen through which greater possibilities for definition and extension of the model are anticipated; the reluctance stems from the need to discard core constructs in accepting the system characterizing the group. Maslow (1971) sees the pull-in as satisfying a need to belong and the systemic model gives the process underlying that need. Gray's blockers are the core constructs which we are reluctant to discard in accepting the system of the group and his activators are those where we welcome the discard.

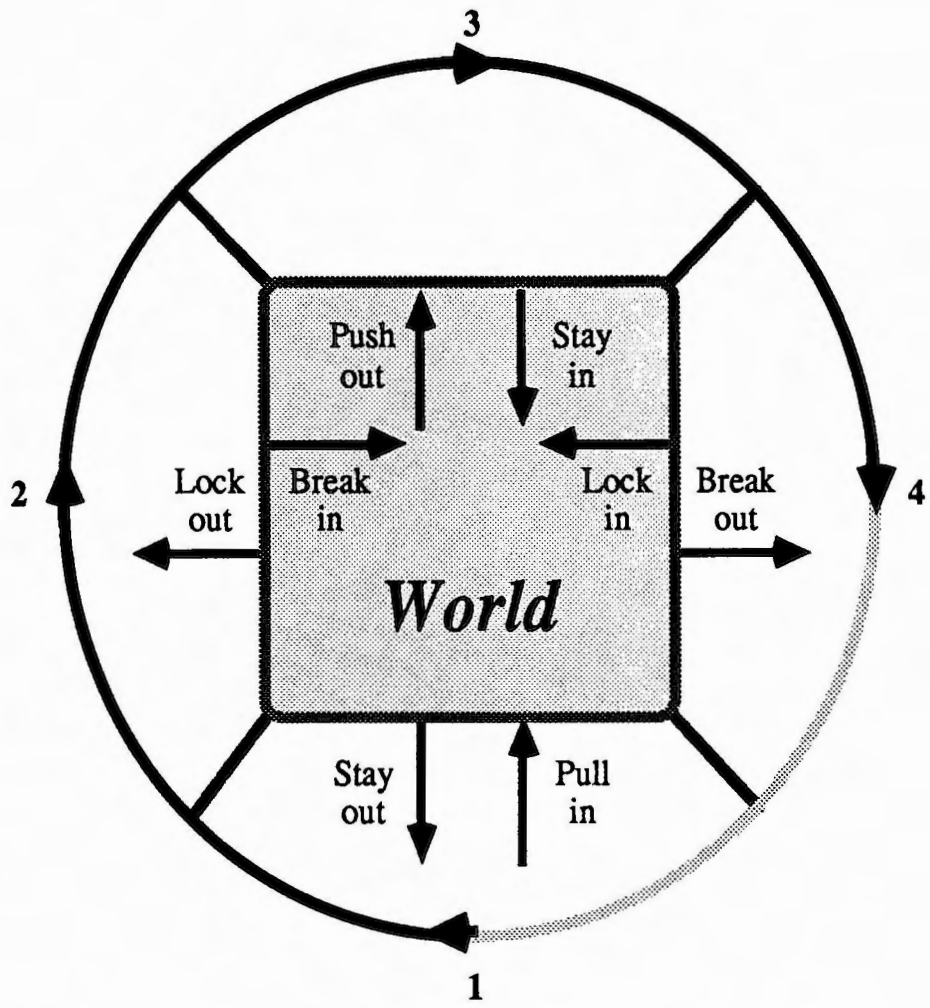


**Fig.17 The life cycle of membership in a group**

At the second stage the individual has decided to attempt to join the group but now faces the barriers to membership, the requirement to acquire the core constructs of the group in order to become recognized as a valid member and not as a *stranger* in Simmel's (1950) terminology. This constitutes the lock-out—break-in dynamics.

At the third stage the individual has become part of the group but this is not a static process since the reflective equilibrium between his inference processes and those of the group must be maintained This constitutes the push-out—stay-in dynamics.

At the fourth stage the individual has decided to reject the construct system of the group but has difficulty in ceasing to make distinctions which now correspond to his core constructs This constitutes the the lock-in—break-out dynamics.

### 3.17 Worlds Defined by Construct Systems

The life-cycle model of individuals entering and leaving groups emphasizes that the groups have an identities that are distinct from those of the individuals forming them. This is defined by the construct systems of the groups which may become sufficiently separate from those of any individual that they become regarded as an abstract set of distinctions defining a *world*. The abstract notion of a world is often used in both everyday and scientific speech but it is rarely defined and, indeed, surprisingly difficult to define.

Wolff's (1976) book about "experience and enquiry today" has much in it that is relevant to the formation of groups as communal scientists and the ways in which individuals enter into them, and bridges the gap between Gray's system-forming processes and abstract worlds. His basic model is one of *surrender* to a situation so that one may *catch* the essence of it—of becoming through surrender someone different in order to catch hold of something different—of relinquishing one's own core constructs in order to adopt those of a group. Using Wolff's terminology, we surrender ourselves to a particular role and catch its essential core constructs in order to become a physicist, a mathematician, a manager, a father, and so on.

The link between Wolff's model of surrender and catch and the notion of abstract worlds is most clearly presented in terms of his discussion of the nature of the mathematician:

> "From the standpoint of the world of everyday life, the mathematician, as we often put it, lives in the 'world of mathematics', dealing with 'nonreal' elements, notably numbers, whose relation to 'real' things, to 'reality', is not part of his concern. Analogously for the logician. What makes our subject-object approach to this attitude misleading is the fact that the subject, the student of mathematics or logic—his or her individuality, including motives and attitudes—is irrelevant for our understanding; the only thing that counts is the pursuit, with its results and questions." (Wolff 1976 pp.162-163)

Wolff makes the key point that not only does the real world, the object, disappear to be replaced by the world of mathematics, but also that in entering into this world the person doing mathematics, the subject, also disappears to be replaced by a new entity, the mathematician. That is, roles and worlds stand in a dual relationship to one another.

Popper (1968) reifies the notion of such a world, which in the discussion so far has played only a descriptive role as the construct system binding together people into a social unity, and terms it a world 3. He explains the 3 worlds model in his autobiography (Popper in Schilpp 1974 p.143) by quoting Bolzano's notion of "truths in themselves" in contradistinction to "those thought processes by which a man may...grasp truths", proposing that:

> "thoughts in the sense of contents or statements in themselves and thoughts in the sense of thought processes belong to two entirely different 'worlds'."

and making the three-fold distinction:

> "If we call the world of 'things'—of physical objects—the first world and the world of subjective experience the second world we may call the world of statements in themselves the third world (...world 3)."

This notion of a world 3 is corresponds to Wolff's object that we catch and has its own ontological status:

> "I regard the third world as being essentially the product of the human mind. It is we who create third-world objects. That these objects have their own inherent or autonomous laws which create unintended and unforseeable consequences is only one instance (although a very interesting one) of a more general rule, the rule that all our actions have such consequences." (Popper in Schilpp 1974 p.148)

Popper stresses the key role of world 3 in the development of human knowledge processes, giving two gedanken experiments on the destruction of civilization to illustrate the status of world 3:

> "(1) all machines and tools are destroyed, also all our memories of science and technology, including our subjective knowledge of machines and tools, and how to use them. But libraries and our capacity to learn from them survive... our world civilization may be restored... from the World 3 that survives...
>
> (2) in addition all libraries are destroyed ... men would be reduced to the barbarism of primitive man in early prehistory, and civilization could be restored only by the same slow and painful process that has characterized the story of man through Paleolithic times." (Popper 1968 p.334)

From a systemic point of view Popper's world 3 corresponds to the abstraction of the construct system of a group and its treatment as an entity in its own right, with its own coherence through superordinate constructs and hence its own laws.

This viewpoint is illustrated in Figure 18 where the construct systems of those forming the groups in Figure 15 are abstracted out to define the worlds of mathematics, the family and the company. The worlds of the family and company are shown as part of the communal scientist since they are regarded as parochial to the communal scientist shown. The world of mathematics is shown as extending beyond the boundaries of the communal scientist under consideration reflecting its status as the product of many contributors over a period of time that extends beyond most of our other social organizations.

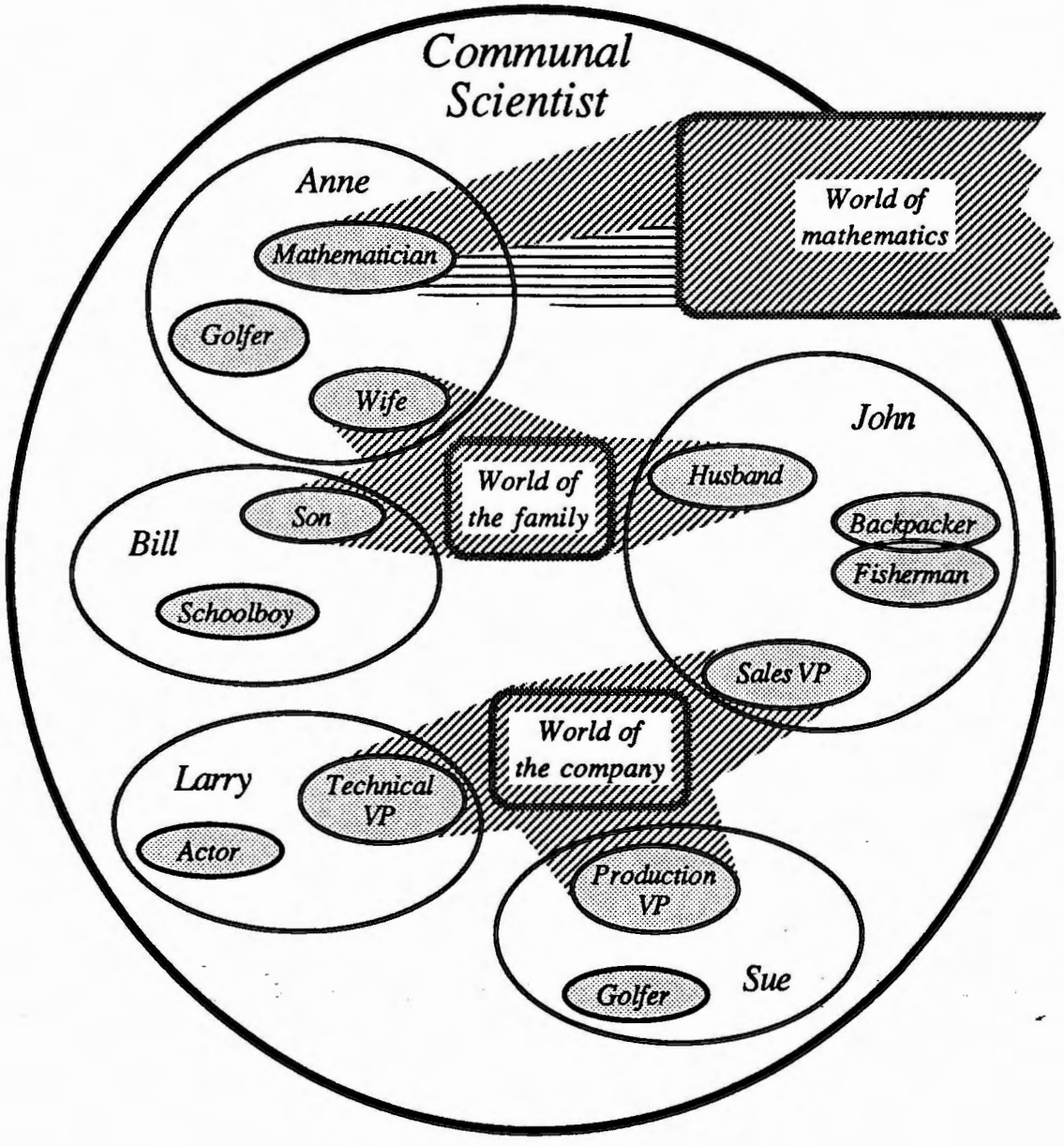


**Fig.18 Worlds accessed by groups**

Anne's access to the world of mathematics in Figure 18 is also shown as partial. She is attempting to carry over some constructs that are inappropriate and this presents her accessing the world of mathematics. Adopting a role involves the negative action of not using constructs that are not appropriate to that role just as much as it does the positive action of coming to use constructs appropriate to the role.

Anne's situation is shown in more detail in Figure 19. Her surrender to the world of mathematics is inadequate and she cannot catch it because her attempt to break in is being locked out by the inappropriate constructs.

She has surrendered to the world of the family but now wishes to break out of the situation to which she is locked in and is attempting to make familial constructs non-core and view the family unit through the constructs of an outsider.

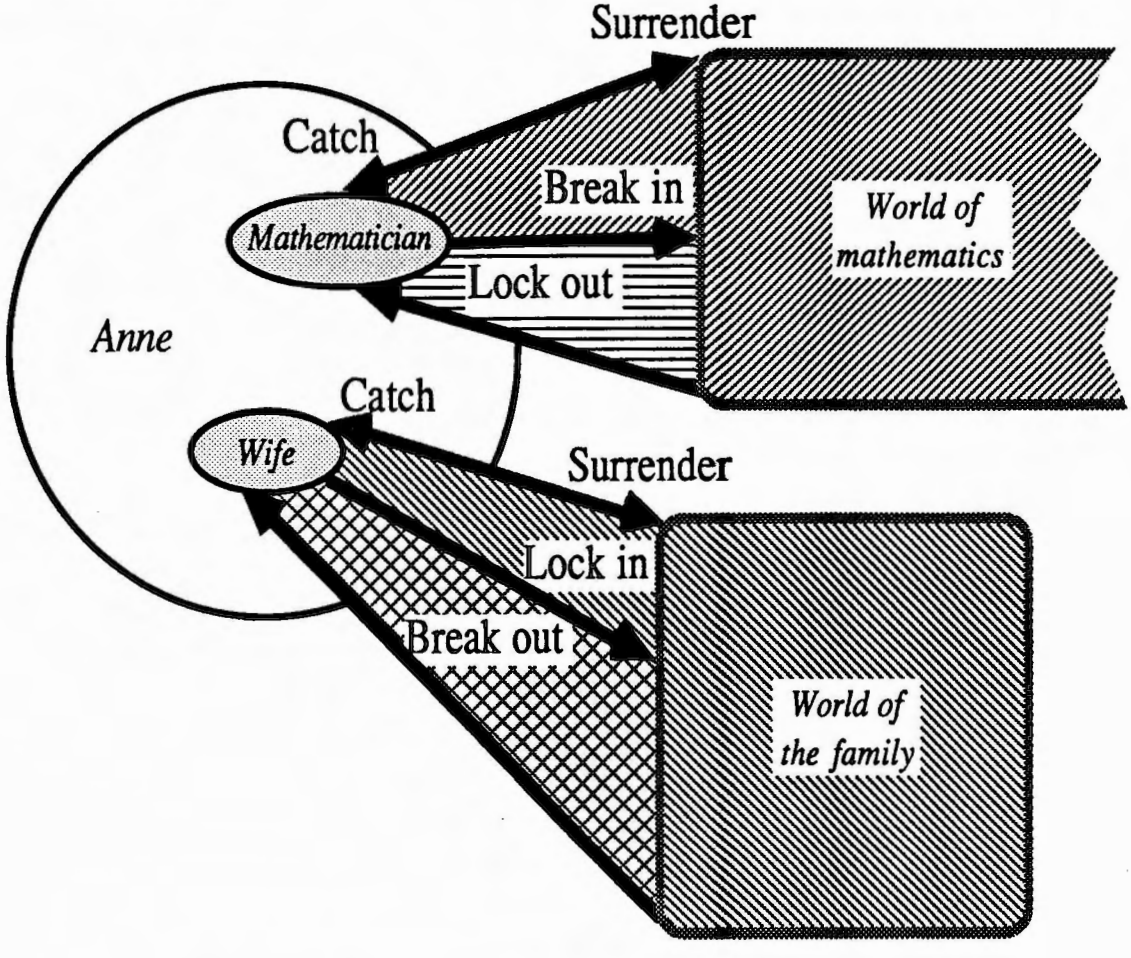


**Fig.19 Examples of lock-out/break-in, lock-in/break-out and surrender/catch**

### 3.18 Kelly's Postulate and Corollaries

Kelly (1955 Chapter 2) himself developed an elaborate but fairly informal epistemology based on his constructive alternativism and its consequences stated as a fundamental postulate and eleven "corollaries". These assertions which are worth considering in some detail in the light of the model of the communal scientist developed in this section.

***Fundamental Postulate:*** *A person's processes are psychologically channelized by the way in which he anticipates events.*

This fundamental emphasis on the role in behaviour of a view to the future is what distinguishes Kelly's particular approach to psychology. He saw man as driven by the need to cope with coming events in the world and all other aspects of behaviour as deriving from this. He notes in expanding upon this point that "a person's processes, psychologically speaking, slip into the grooves which are cut out by the mechanisms he adopts for realizing his objectives." (p.49)

***Construction Corollary:*** *A person anticipates events by construing their replications.*

He notes that "By construing we mean placing an interpretation: a person places an interpretation on what is construed. He erects a structure, within the framework of which the substance takes shape or assumes meaning." (p.50) He emphasizes that "Construing is not to be confounded with verbal formulation." (p.51) In construing or placing an interpretation on events the individual places into categories those which he or she determines to be similar to and different from others, building up a set of constructs which enable him to pick out recurring patterns that he can then use to anticipate and predict. It is this tendency which makes an adequate model an essential part of success in any field. One does not always build a new model when faced with new events, but anticipates on the basis of the models which he has already developed.

***Individuality Corollary:*** *Persons differ from each other in their constructions of events.*

This is Kelly's stress upon the personal nature of construing but he emphasizes also "persons can find common ground through construing the experiences of their neighbours along with their own", although "individuals can be found living out their existence next door to each other but in altogether different subjective worlds." (p.56) He suggests that to obtain the best explanation of a person's organization of experience or behavior one should find ways to inquire of the person who does the organizing.

***Organization Corollary:*** *Each person characteristically evolves, for his convenience of anticipating events, a construction system embracing ordinal relationships between constructs.*

Kelly noted that "Different constructs sometimes lead to incompatible predictions" (p.56) and saw a hierarchical relationship ordering constructs relative to one another as a basis for resolving such contradictions. The hierarchy is such that the stability of the upper levels allows for change in the lower ones, and the arrangement of constructs in a particular hierarchy is more a determinant of personality than the constructs used.

***Dichotomy Corollary:*** *A person's construction system is composed of a finite number of dichotomous constructs.*

Kelly saw concepts of similarity and contrast between elements forming the two "poles" of a construct. This does not necessarily involve a binary evaluation of elements since they may lie somewhere between the poles.

***Choice Corollary:*** *A person chooses for himself that alternative in a dichotomized construct through which he anticipates the greater possibility for extension and definition of his system.*

To explicate the system's functions one must keep in mind that constructs are dichotomous and they are hierarchically organized. A person locates an event at one or another end of a hierarchically interconnected construct in ways which will maintain the greatest anticipatory power of which the system is capable. This is Kelly's basis for human action which he saw as an alternative to concepts of motivation: "there is a continuing movement toward the anticipation of events, rather than a series of barters for temporal satisfactions" (p.68).

***Range Corollary:*** *A construct is convenient for the anticipation of a finite range of events only.*

Correlatively, not every construct can allow convenient anticipation of every event. *Convenience* in psychological processes refers to the extent of revision and alteration of the hierarchical structure that would be occasioned by fitting one or another event into one or another pole of a particular construct. This may be thought of as introducing a concept of *relevance* into the definition of construct systems.

***Experience Corollary:*** *A person's construction system varies as he successively construes the replications of events.*

Each of a person's anticipatory constructions represents a hypothesis to be tested not only for its anticipation, but also for its extending and defining capabilities. Experience changes the person's system, and, to

formalize his view that the resulting accomodations of the system constitute *learning*, Kelly stated the Experience Corollary. This expresses the essential fallibility and conjectural nature of constructs. They are hypotheses to be judged by their utility.

***Modulation Corollary:*** *The variation in a person's construction system is limited by the permeability of the constructs within whose ranges of convenience the variants lie.*

In a way the Modulation Corollary takes into account the metaphorizing character of a person's constructs. Novel inputs to the system will be anticipated and will change the system if the system can access permeable constructs, that is, constructs which are "so constituted that new experience and new events can be discriminatively added to those which it already embraces" (p.81).

***Fragmentation Corollary:*** *A person may successively employ a variety of construction subsystems which are inferentially incompatible with each other.*

Through this corollary Kelly allows for the operations of different psychological systems and hence different methods of inference and forms of rationality within a single individual.

Kelly completed his system of formal propositions by giving two corollaries which relate construing processes to social interaction events. Another person's constructions of events, as well as the events themselves, provide input relative to those events; and, thereby, become a part of the experience of those events.

***Commonality Corollary:*** *To the extent that one person embraces a construction of experience which is similar to that employed by another, his psychological processes are similar to those of the other person.*

This is complementary to the individuality corollary and allows for the "fact that certain groups of people behave similarly in certain respects." (p.93)

***Sociality Corollary:*** *To the extent that one person construes the construction processes of another, he may play a role in a social process involving the other person.*

Kelly is here allowing the construal processes of one person to become elements for construal by another and hence to model the process by which we anticipate the actions of others.

### 3.19 Significance of the Communal Scientist as a Cognitive Model

This section has provided a cognitive science framework for knowledge-based systems which encompasses the social and psychological processes of people as well as similar processes in computer-based systems. The foundations are based on a systemic model of inductive knowledge acquisition and the overall model accounts for the role of culture, media, experts and expert systems in the human knowledge process (developed in Section 5).

The logic underlying the inductive and deductive reasoning processes of the system is one based on an axiom of unrestricted predication and able to cope with uncertainty and contradiction. Physiological systems are known in the brain that appear to carry out the basic functions of arousal and activation required by the model (Tucker & Williamson 1984). Language plays the role of co-ordinating the multiple processors which are individual brains within a knowledge-acquiring society.

The communal scientist model links system-theoretic foundations of induction with the psycho-social dynamics of the human knowledge process including the essential role of emotion in cognition and the essential role of social processes in individual modeling and anticipation.

If we are to develop knowledge-based systems and artificial intelligence we must have an adequate scientific theory of knowledge, human intelligence, and their mutual interaction. The raw material required to develop a theory is available but widely dispersed through many scientific disciplines.

This section has shown the potential for bringing this material together. It has provided cognitive foundations for knowledge-based systems. These have mathematical foundations supporting computer algorithms. They also correspond to psychological, social and physiological reality.

Section 4 reviews Kelly's repertory grid technique for eliciting a person's construct system and its implementation through interactive computing systems. Section 5 examines some of the implications of the communal scientist model for the role of computing technology such as participant systems in knowledge processes. Section 6 brings all these analyses to bear on the design of a participant construct system.

## 4 The Repertory Grid

One way of applying the theory of the communal scientist to the study and aiding of human knowledge processes is to analyze the distinctions underlying a person or a group's activities in a world. Section 2 briefly discussed Kelly's (1955) development of the repertory grid as a means of representing these distinctions. This section describes repertory grids in greater detail, outlines the existing procedures for their manual and computer-based elicitation and analysis, and exemplifies their applications in a variety of problem domains.

The problem of eliciting knowledge from a 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 see the problem not as methodological but as psychological and resulting from cognitive defences that impede internal communication for a variety of reasons (Freud 1914, Rogers 1967). Clinical psychologists in particular have developed techniques for making use of verbal interaction to identify underlying cognitive processes, for example through structured interviewing techniques. These can be used to by-pass cognitive defences, including those resulting from automization of skilled behavior. Welbank (1983) has reviewed many of these techniques in the context of knowledge engineering.

Kelly developed personal construct psychology 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. His 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 management studies the domain might be subordinates and the elements again people, or it might be products and the elements could be objects manufactured by a company and its competitors. In education the domain might be part of the subject matter being taught, for example national physical geography, and the elements would be any items relevant to that topic, for example countries.

### 4.1 Elements and Constructs

A repertory grid is a two-way classification of data in which events are interlaced with abstractions in such a way as to express part of a person's system of cross-references between his personal observations or experience of the world (elements), and his personal constructs or classifications of that experience.

The elements are the things which are used to define the area of the topic, and can be concrete or abstract entities. Before choosing the set of elements, the user must think carefully about the area of the topic and relate the elements to his purpose. The elements should be of the same type and level of complexity, and span the topic as fully as possible. It is usual to start with about six to twelve elements.

The elements originally suggested by Kelly in his work as a psychotherapist were role titles such as: *Self, Mother, Father, Best Friend, Threatening Person, Rejected Teacher.* This has been carried over into industry with such role titles as: *Myself, My Boss, My Boss's Boss, Subordinate, Person Likely to Get On, Person Not Likely to Get On*, etc. The subject in both cases is required to supply names of individuals well known to her/him to fit these and other roles as closely as possible. When choosing elements care must be taken to ensure that each one is well known and pesonally meaningful to the subject.

The constructs are the terms in which the elements are similar to or different from each other. Each construct therefore has two poles, each of which has a meaning with respect to its opposite. Any construct or dimension of thinking which is important to the subject is a valid construct. For example, to distinguish between people by saying that x and y are "blue-eyed" whereas b and c are "brown eyed" may be trivial, and not concerned with the important qualities of x, y, b, and c. However, if you are an eye specialist concerned with prescribing tinted contact lenses, this may be a significant construct.

Thoughts and feelings, objective and subjective descriptions, attitudes and rules-of-thumb all constitute valid constructs. The verbal description of the construct and the labelling of the poles need not be a publically agreed meaning in the outside world, but only a memory aid to the thinking process. The mapping of the elements onto the constructs produces the two-dimensional grid of relationships. In computing science terminology this repertory grid has elements as entities, constructs as attributes and allocations of elements to poles of constructs as values (Chen 1980).

## 4.2 Methods of Construct Elicitation

The *minimum context form* or *triadic* elicitation is the most common form used. In this form elements are presented to the subject in threes—that being the minimum number which will give both a similarity and a difference—and the subject is asked to choose two of the elements which are in some important way alike, and in a similar way different from the other one. This is the emergent pole of the construct. The implicit pole may be elicited by the difference method (in what way does the singleton differ from the pair) or by the opposite method (what would be the opposite of the description of the pair). Each triad is chosen so that the elements are evenly represented, and do not occur in the same combinations too often.

As an example, thinking of the three Artificial Intelligence books *Handbook of AI*, *Winston's AI*, and *AI Applications for Business* in what way are two alike and thereby different from the other one? We might first of all say that *Handbook of AI* and *AI Applications for Business* are alike since they are multi-authored, whereas *Winston's AI* is single-authored. This is, then, the first construct with its two poles or opposite descriptions. Now all the elements in the set must be rated on this dimension as either 1 being multi-authored, or 2 being single-authored as shown in the grid below. This also shows the significance of the term personal in personal construct since it would not obviously be a publicly agreed description that *Winston & Horn's LISP* is single-authored whereas *Knowledge-Based Systems in AI* is multi-authored. In this case it reflects a single concerted effort as opposed to more than one topic.

```
          1        1  2  3  4  5  6  7        2
                   ********************

multi-authored     1  2  1  2  1  1  1   single-authored

                   ********************
                   *  *  *  *  *  *  Building Expert Systems
                   *  *  *  *  *  Logic Programming
                   *  *  *  *  Knowledge-Based Systems in AI
                   *  *  *  Winston & Horn LISP
                   *  *  AI Applications for Business
                   *  Winston's AI
                 Handbook of AI
```

Then the second and subsequent constructs are elicited in exactly the same way using different triads each time. The grid below shows the grid above with a further two constructs elicited. The third construct shown here illustrates that constructs can be factual, imaginary, emotional, or whatever is important to the person generating the grid.

```
          1        1  2  3  4  5  6  7       2
                   ******************

 multi-authored    1  2  1  2  1  1  1   single-authored

    theoretical    1  1  2  1  2  1  2   building systems

    fun to read    1  2  1  2  1  1  2   hard work

                   ******************
                   *  *  *  *  *  *  Building Expert Systems
                   *  *  *  *  *  Logic Programming
                   *  *  *  *  Knowledge-Based Systems in AI
                   *  *  *  Winston & Horn LISP
                   *  *  AI Applications for Business
                   *  Winston's AI
                   Handbook of AI
```

A scale allowing more distinctions may be used. If a 1 to 5 scale is used then the above example might become the grid shown below. Thus, in this case, the third construct means that *Logic Programming* and *Knowledge-Based Systems in AI* are considered the most fun to read books, *Winston's AI* is both fun to read and hard work, and *Building Expert Systems* and *Winston & Horn LISP* are the most hard work.

```
          1        1  2  3  4  5  6  7       5
                   ******************

 multi-authored    1  5  1  3  2  1  1   single-authored

    theoretical    1  1  4  2  4  1  5   building systems

    fun to read    2  3  2  5  1  1  5   hard work

                   ******************
                   *  *  *  *  *  *  Building Expert Systems
                   *  *  *  *  *  Logic Programming
                   *  *  *  *  Knowledge-Based Systems in AI
                   *  *  *  Winston & Horn LISP
                   *  *  AI Applications for Business
                   *  Winston's AI
                   Handbook of AI
```

Note how the use of a multi-point scale with an odd number of values allows for a central rating, in this case 3, which does not force the user to choose either pole. It may be desirable to apply more discrimination to this central rating and allow the subject the choice of the two possibilities: *neither*, that the element belongs to neither pole; or *both*, that the element belongs to both poles (Landfield 1976). It is also possible to extend these possibilities to allow separate ratings on each pole (Shaw & Gaines 1980, Gaines & Shaw 1981b).

In contrast to triadic elicitation, the full context form involves the subject considering the whole set of elements, then thinking of an important way they divide into two (or more) groups. Other methods are splitting the two most similar elements to put one on each pole of a new construct, and naming of a construct to describe the difference between the two most dissimilar elements. Variants on these methods include presenting triads as in the minimum context form, but just changing one element of the triad for each construct; including the element "self" in each triad, if relevant; and asking question about the circumstance in which the subject might be in the company of the group of elements, if appropriate.

Another useful form of construct elicitation is a technique developed by Hinkle (1965) called *laddering*. Initially, constructs are elicited using a standard method, then one construct is selected and the question asked: "Which pole is the one you would prefer to be rated on?" then "Why would you prefer that pole?", and "What is the opposite of that?" This then provides a new construct which is more *superordinate* or generalized than the original one. As this process is repeated, a hierarchy or heterarchy of superordinate constructs is elicited.

There are a number of criteria that should be applied in grid elicitation if the results are to be meaningful:

1) Constructs should be *permeable*. That is, the construct should be applicable to all the elements in the set.
2) All pre-existing constructs should be elicited as well as ones just thought of in the process of the elicitation.
3) The verbal labels given to constructs should be able to explain to someone else the ideas behind the construct.
4) The constructs should look at relations between the elements as well as the subject's relationship to the elements.
5) Constructs should be bipolar. That is, both poles of the construct should be elicited.

### 4.3 The Role of Computers in Construct Elicitation

During the past twenty years the digital computer has come to assume a role of increasing importance in psychology and in the application of psychological techniques. During this period also, the nature of available computer resources has itself changed dramatically.

In the early 1960s we submitted massive computations of analyses of variance and factor analyses to some remote computing centre that punched our data onto cards and sent back the results, often days later.

By the early 1970s we had our own minicomputers in our laboratories giving a *hands-on* system for direct experimental control, but they were so expensive that they had to be available as a shared resource to a group of researchers on a booking basis. The central computers also changed during that period to allow some form of interactive *time-sharing* whereby we could enter our own data on a local terminal and receive the analysis back reasonably rapidly on the same terminal.

In the 1980s, a further development has taken place in that so-called *personal* computers have become available, offering us great power and a wide range of facilities at such a low cost that an individual can have one or more such machines dedicated to his work.

These advances in computer technology have offered opportunities for the automation of psychological testing which have been widely taken (Elithorn & Telford, 1969; Gedye & Miller, 1969; Elwood, 1972a,b,c; Klinge & Rodiewicz, 1976; Thompson & Wilson, 1982; Volans & Levy, 1982). Direct interaction between patients and computers has now been shown to be successful and acceptable in an experimental environment (Card, Nicholson, Crean, Watkinson, Evans, Wilson, & Russell, 1974; Lucas, 1977), and it has even proved possible for the computer to act as an effective therapist (Stodolsky, 1970). Automated psychological testing has also been widely validated against experts administering the same test (Ridgway, MacCulloch, & Mills, 1982; Calvert & Waterfall, 1982; Watts, Baddeley, & Williams, 1982; Acker, 1982).

These advances in technology have also offered the opportunity for new approaches to the testing process which are dependent on having powerful computational facilities in operation during the test, fo example to analyze partial results and adapt the test on-line. It has also become possible to obtain test results speedily and presented in a manner which aids both expert interpretation and self-interpretation.

As part of this advance in psychological testing technology, researchers have developed computer techniques for the elicitation and analysis of repertory grids. Many of these are interactive programs which allow a greater degree of autonomy and more control to be given to the user. It would be easy to assume that such interactive programs are merely more convenient ways of elicitation and do not add anything qualitatively new to the process. However, this misses certain crucial psychological factors in the person-computer situation and its differences from the person-person situation. For example, Gaines and Shaw (1981b) report that in making a grid elicitation program, PEGASUS, available to a wide range of people in a variety of situations that those coming to it for the first time often seem to find it a very dramatic experience. They react to it intensely and become gripped by the interactive process of construct elicitation. They also feel that they are learning something new from the process and are prepared to use this in determining their behaviour.

Probably such involvement is also significant in the elicitation of construct systems by a person rather than by computer interaction. However, there are certain quite fundamental differences when the elicitation is done in such a way that interpersonal interaction is clearly absent. In particular, when a person is feeding back comments and guidance, it is a natural and ready assumption that the constructs are being *injected* rather than elicited. It is easy for the subject to believe that the elicited constructs do not come from himself, but that a tutorial or debating situation with another person is taking place. It is necessary to persuade him that this is not so, and the persuasion has to be stronger the more striking and significant the constructs elicited. However, when a computer is the tool by which his construct structure is being reflected or laid bare, then such an assumption of outside injection and interference is far less tenable.

When constructs are elicited by a computer program, it is more likely to be accepted that it is only oneself that is being portrayed. We 'trust' a program to be doing just what it appears to be doing without deeper motivations and without attempting to persuade us to its point of view. No one is telling the user anything. He is seeing, possibly for the first time, the basis for his own thought processes. Often extreme surprise is the first reaction. If another person were eliciting the construct structure, then the surprise would be taken as an indication that he was incorrect, and one would ignore him or argue with him. With computer elicitation, it is more likely that one will accept the reflected structures as being self-generated, and the surprise will act as motivation to know more.

The knowledge obtained from interactive grid elicitation being private to oneself is itself important. We are reluctant, as Kelly notes, to be "caught with our constructs down." With another person, we are more reluctant to expose and explore our constructs the more surprising they are; perhaps because the surprise is often the result of a conflict between our ostensive value judgments and the basis of our behaviour. Or it may just be sloppy verbal behaviour that we are naming two distinct constructs with the same label. For example, in using PEGASUS, a scientist found that he was using the word "time" to label several different elements and was generating confusion in his arguments because of this.

Another reason that we are reluctant to explore construct structures freely in interacting with another person, particularly a professional person, is that we are acutely aware of the possible 'waste' of their time. This phenomenon has been noted as accounting for the preferences expressed by patients to be interviewed through an interactive computer program rather than by their doctors (Card et al 1974, Lucas 1977). There are many pressures and artifacts of interpersonal relationships that can totally obscure and undermine such reflective processes that we require in the elicitation of personal constructs.

It is interesting to note that this argument has been put in reverse: Adams (1979) notes that children learn quickly to play games on a personal computer and conjectures that this is because of the lack of interpersonal complications. She suggests, however, that:

> "one of the benefits of game-playing is that a child learns how to behave with and towards others, how to cope with success and failure, and what effect it has on others. In the human-computer relationship the child does not learn these valuable social skills".

In grid elicitation there is a converse argument that the need for such "social skills" is a load that detracts from the exploration of the self.

This analysis of the role of the interactive computer in repertory grid elicitation suggests that it has more significance than merely reducing the labor, and improving the quality, of manual elicitation. Person-computer interaction can have advantages over person-person interaction in some aspects of knowledge processes. Participant systems not only allow people to interact more effectively but also contribute a new dimension to the knowledge process through computer participation. The theoretical foundations for this are examined in Section 5. The remaining sub-sections review techniques for computer elicitation and analysis of personal construct systems.

### 4.4 PEGASUS: Interactive Personal Construct Elicitation

PEGASUS is a system for eliciting repertory grids, and is part of the PLANET suite of construct elicitation and analysis programs (Shaw 1982). The commonly used version incorporates continual commentary on patterns in the responses. Six elements are initially chosen by the user with special attention to the purpose for eliciting the grid. The first four constructs are elicited from fixed triads and thereafter random or chosen triads are offered. Real-time processing allows feedback about highly matched constructs and elements. Options offered are: to add an element to split highly matched constructs; to replace two highly matched constructs by one; to add a construct to split highly matched elements; to delete one or more elements; to delete one or more constructs; to add a construct without using a triad; to add an element; to change the level of feedback commentary; to redefine the purpose for eliciting the grid. The flow of control around these options is shown in Figure 20.

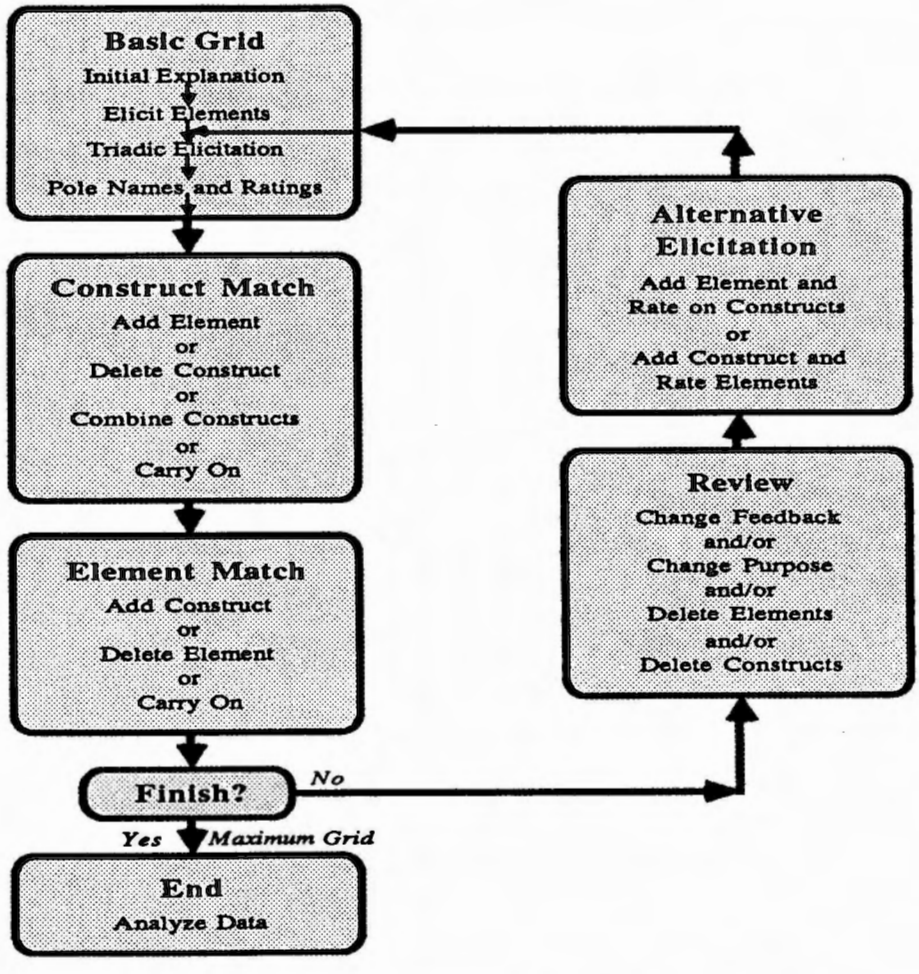


**Fig.20 PEGASUS flow of control**

PEGASUS commences its interaction by asking for the purpose of the elicitation and then explains the need for a set of elements relevant to this purpose:

```
Type in your purpose for doing this grid?staff appraisal

Name six elements.

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.

Do not forget to press the RETURN key after each.

  Element 1?S1
  Element 2?S2
  Element 3?S3
  Element 4?S4
  Element 5?S5
  Element 6?S6

Here is a list of your elements.

   1  S1
   2  S2
   3  S3
   4  S4
   5  S5
   6  S6

Do you want to change an element?no

Can you think of another element that belongs with the 6 that
you have got so far?y

  Element 7?S7
```

It is important to establish an initial context such that the person from whom the grid is being elicited selects a set of elements which are of the same type and relevant to the purpose of the elicitation. Note that in the dialog the computer output is shown in normal face and the person's input in italic. In the original elicitation the manager used the actual names of his subordinates but these have been encoded as S1, S2, and so on, for the purposes of this example.

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

```
Triad for elicitation of construct 1
  1 S1
  2 S2
  3 S3

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?3

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 S1 and
S2 on the left pole from S3 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 --?intelligent
  right pole rated 5 --?dim

Now assume that S1 and S2 are assigned the value 1 and S3 is
assigned the value 5 according to how you feel about them
please assign to each of the other elements in turn a
provisional value from 1 to 5

  1 S1     1
  2 S2     1
  3 S3     5
  4 S4    ?5
  5 S5    ?3
  6 S6    ?3
  7 S7    ?5
  8 S8    ?2
  9 S9    ?3
```

This example ilusstrates the point already discussed that a combination of three elements is necessary to establish both a similarity and a difference. Construing the three elements sets up a context, or a perspective, which corresponds to the logical notion of relevance. The two poles of the construct anchor the extremal ends of the dimension of construing that defines this relevance.

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

```
The two elements 5 S5 and 6 S6 are matched at the 90 percent
level. This means that so far you have not distinguished
between S5 and S6

Do you want to split these?y

Think of a construct which separates these two elements, with
S5 on the left pole and S6 on the right pole.

  left pole rated 1 --?self starters
  right pole rated 5 --?need a push

According to how you feel about them please assign to each of
the other elements in turn a provisional value from 1 to 5

  5 S5     1
  6 S6     5
  1 S1    ?2
  2 S2    ?1
  3 S3    ?5
  4 S4    ?5
  7 S7    ?5
  8 S8    ?3
  9 S9    ?4
 10 S10   ?5
```

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
  1 intelligent—dim
  4 little supervision reqd—need supervision
are matched at the 66 percent level

This means that most of the time you are saying intelligent
you are also saying little supervision reqd and most of the
time you are saying dim you are also saying need supervision.
Think of another element which is either intelligent and need
supervision or little supervision reqd and dim. If you really
cannot do this then just press RETURN after the first
question mark but please try.
```

```
Then 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?S10

Type in the ratings for this element on each construct.

Left pole rated 1, right pole rated 5.
  intelligent—dim?5
  willing—unwilling?2
  new boy—old sweats?3
  little supervision reqd—need supervision?3
```

Through a combination of these techniques, a PEGASUS interaction elicits from the user his system of constructs relating to the topic being studied. Figure 21 is the final grid of the manager.

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| intelligent | 1 | 1 | 1 | 4 | 5 | 3 | 3 | 5 | 2 | 3 | 5 | 1 | dim |
| willing | 2 | 1 | 2 | 4 | 5 | 1 | 1 | 4 | 3 | 1 | 2 | 2 | unwilling |
| new boy | 3 | 1 | 2 | 3 | 5 | 4 | 4 | 4 | 1 | 4 | 3 | 3 | old sweats |
| little supervision reqd | 4 | 3 | 1 | 4 | 5 | 2 | 1 | 5 | 2 | 2 | 3 | 4 | need supervision |
| motivated | 5 | 1 | 1 | 4 | 5 | 2 | 2 | 5 | 3 | 3 | 2 | 5 | less motivated |
| reliable | 6 | 3 | 2 | 2 | 5 | 1 | 1 | 5 | 1 | 2 | 3 | 6 | not so reliable |
| mild | 7 | 3 | 4 | 5 | 2 | 2 | 3 | 1 | 5 | 4 | 5 | 7 | abrasive |
| ideas men | 8 | 1 | 1 | 5 | 4 | 2 | 3 | 1 | 3 | 4 | 4 | 8 | staid |
| self starters | 9 | 2 | 1 | 5 | 5 | 1 | 3 | 5 | 3 | 4 | 5 | 9 | need a push |
| creative | 10 | 1 | 1 | 5 | 5 | 2 | 3 | 4 | 3 | 4 | 5 | 10 | non-creative |
| helpful | 11 | 4 | 3 | 4 | 2 | 3 | 5 | 1 | 4 | 5 | 5 | 11 | unhelpful |
| professional | 12 | 1 | 2 | 3 | 3 | 2 | 1 | 5 | 2 | 4 | 4 | 12 | less professional |
| overall rating high | 13 | 2 | 1 | 3 | 4 | 1 | 2 | 5 | 2 | 3 | 4 | 13 | overall rating low |
| messers | 14 | 2 | 2 | 5 | 4 | 3 | 5 | 1 | 5 | 3 | 1 | 14 | tidy |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | S10 |
| | | | | | | | | S9 | |
| | | | | | | | S8 | | |
| | | | | | | S7 | | | |
| | | | | | S6 | | | | |
| | | | | S5 | | | | | |
| | | | S4 | | | | | | |
| | | S3 | | | | | | | |
| | S2 | | | | | | | | |
| S1 | | | | | | | | | |

**Fig.21 Repertory grid on staff appraisal**

### 4.5 Other Computer-Based Construct Elicitation Systems

The DYAD method (Keen and Bell, 1981) does not start with an element set, but considers one element at a time, a second element being chosen as different from this first element, and a third chosen as relating in some way to this construct. The third element is then used as the first element for the second construct, and so on. This has later been superceded by the FLEXIGRID system (Tshudi, 1984) which incorporates a number of existing methods including PEGASUS and DYAD.

Boose (1984, 1985, 1986a) has built on the PEGASUS method, and designed a system, ETS, on a Lisp machine for eliciting knowledge from experts in a wide range of areas. This is based on the triadic method of construct elicitation as shown in Figure 22.

Think of an important characteristic that two of RAP, APPREC-CONCERNS-STYLE, and APPREC-CONCERNS-CONFLICT share, but that the other one does not. What is that characteristic?
ETS** STYLE AND FEELINGS

What is that characteristic's opposite as it applies in this case?
ETS** ROLE EXPECTATIONS

Think of an important trait that two of APPREC-CONCERNS-CONFLICT, RESPONSE-CHARTING, and SURVEY-FEEDBACK share, but that the other one does not. What is that trait?
ETS** DECISION MAKING

What is that trait's opposite as it applies in this case?
ETS** AFFECT

Think of an important characteristic that two of RESPONSE-CHARTING, SURVEY-FEEDBACK, and BECKHARD-CONFRONTATION-MEETING share, but that the other one does not. What is that characteristic?
ETS** GROUP DATA GATHERING

What is that characteristic's opposite as it applies in this case?
ETS** INDIVIDUAL DATA GATHERING

Think of an important attribute that two of SURVEY-FEEDBACK, BECKHARD-CONFRONTATION-MEETING, and INTERGROUP-UNDERSTANDING share, but that the other one does not. What is that attribute?
ETS** SYSTEM-WIDE PROBLEMS

What is that attribute's opposite as it applies in this case?
ETS** INTERPERSONAL PROBLEMS

Think of an important trait that two of BECKHARD-CONFRONTATION-MEETING, INTERGROUP-UNDERSTANDING, and ORG-MIRROR share, but that the other one does not. What is that trait?
ETS** INTACT WORK GROUPS

What is that trait's opposite as it applies in this case?
ETS** REPRESENTATIVES

**Fig.22 Triadic elicitation in ETS**

Boose uses the ENTAIL algorithm (Gaines & Shaw 1981b, 1986, Shaw & Gaines 1981b) to derive production rules from the grid data, and an entailment graph is automatically generated as shown in the bottom left of Figure 23. This is used for the rapid prototyping of expert systems—over 200 to date.

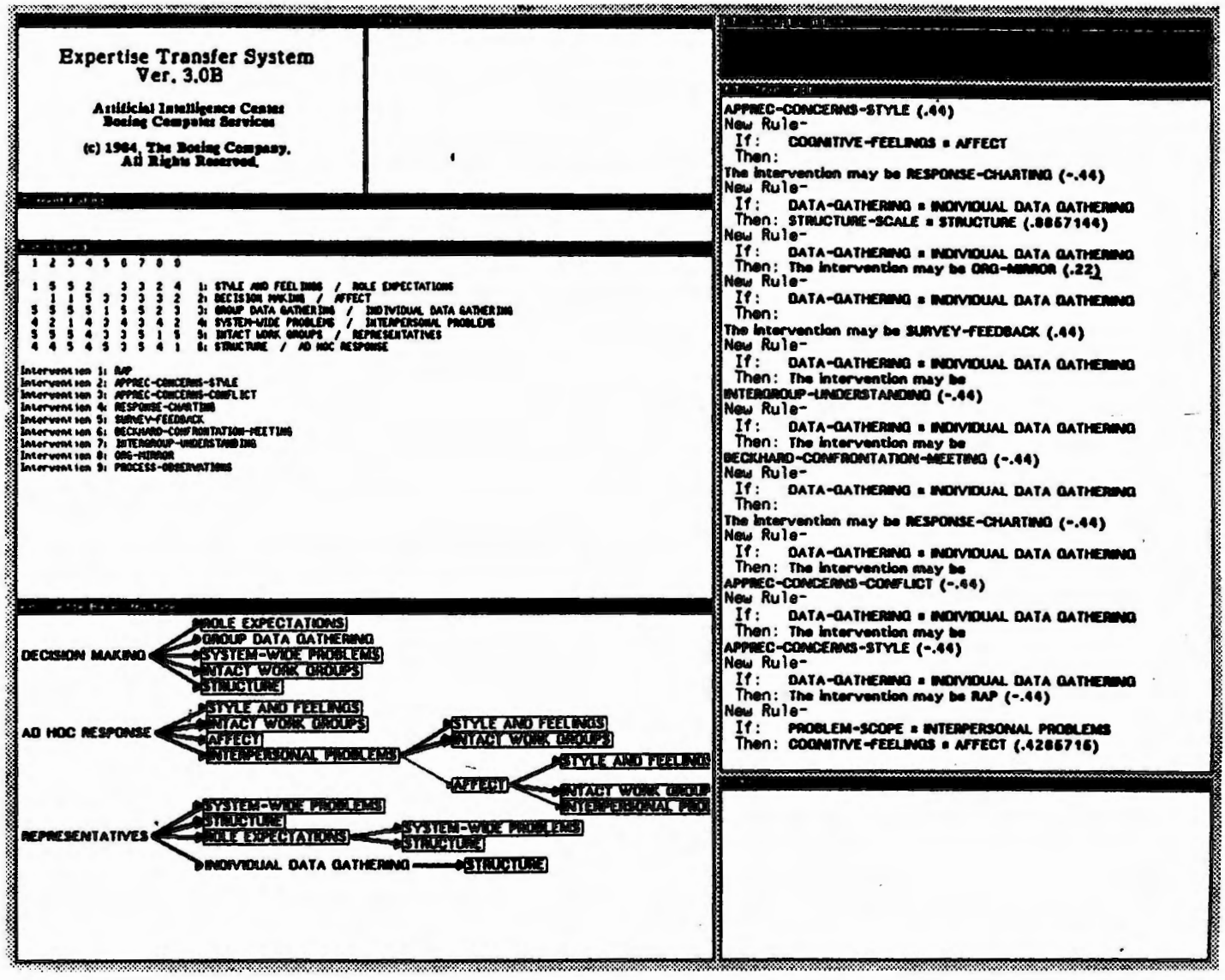


**Fig.23 Entailment graph derived by ETS**

### 4.6 Construct Elicitation from Groups of People

It is often desirable to compare constructs across groups. Shaw (1980a) discusses *exchange grids* for the measurement of understanding and agreement between either two people or one person on two occasions. For example, two people may each elicit a grid in an area of common knowledge. Each may choose his own elements independently of the other, and elicit and rate his or her constructs quite separately. Each then makes two copies of the grid, leaving out the rating values. Both these copies are filled in by the other person, one as he uses those constructs on those elements and the other as he thinks the original was completed. By comparing pairs of these grids it is possible to map the extent of overlap of the agreement and understanding between the two people.

ARGUS (Shaw 1980a, Shaw & McKnight 1981a) elicits a set of grids simultaneously from one person holding several roles or points of view. First, the elements, which are also the roles or points of view, are elicited followed by three constructs from fixed triads. These construct labels are then used for a new set of ratings to be entered for each perspective in turn, and at each stage another construct which is felt to be important for that role is added. Eventually, each perspective has a grid using construct names from all the perspectives, but with unique rating values. The final grids, all with the same element and construct labels, can be processed with the structure analysis programs, SOCIOGRIDS, CORE or MINUS.

Studies using the SOCIOGRIDS algorithms use a set of repertory grids elicited from a group construing the same elements. Constructs are elicited independently, and may differ in number for each person in the group. This technique can been used for a wide variety of purposes concerned with group structures, cultures and relationships. It has been used for investigating the relative positions of members of a small group, and the content of the shared terms and values. It has been used to investigate management hierarchies defined operationally through the interrelationships of construct systems, and in conjunction with the Delphi technique to promote common values and understanding in a group.

Boose (1986b) has studied knowledge acquisition from multiple experts in the same domain. He describes several experiments to determine a method of combining independently elicited grids using the same element set. One method combined rules, another used the same constructs but each expert rated them separately, a third showed differences between the grids using the MINUS algorithm, and, in the last, two experts elicited one grid by joint discussions of the data at each stage.

### 4.7 Repertory Grid Analysis

Repertory grids in themselves encode information about a person's way of looking at the world. This information can be used in its own right for some purposes since it is an aid to remembering the basis for decisions and actions. It can also be analysed in a variety of ways to bring out possible underlying structures, or construct systems, in a person's world view and its relationship to those of others. There are a number of forms of analysis that are widely used for different purposes and the PLANET suite of programs offers all the commonly used techniques plus, new developments of recent years (Shaw & Gaines 1986b). The form of analysis that should be used in a particular case is a matter of personal preference and of purpose. Comparisons have been made of different analyses with the same data (Gaines & Shaw 1981b).

It is convenient to divide analysis techniques into three groups: those concerned with the analysis of a single grid; those concerned with a pair of grids; and those concerned with a group of grids.

### 4.8 Analysis of a single grid

For any given construct we may regard the numbers in the grid as a *vector of values* giving the assignment of each element in turn to one or the other of the poles of the construct. From this point of view each construct becomes represented as a point in a multi-dimensional space whose dimension is the number of elements involved. A natural relation to examine between constructs is then the *distance* between them in this space. Two constructs which are zero distance apart are such that all elements are construed in the same way in relation to them, and hence we might infer that they are being used in the same way—in some sense they are *equivalent* constructs.

For constructs which are not equivalent we may analyse the entire constellation in space to determine a set of axes such that the projection of each construct onto the first axis accounts for most of the distance between them, the projection on the second axis accounts for most of the remaining distance, and so on. This is a *principal components analysis* of the construct space (Slater 1976, 1977), and it is related to the *factor analysis* of semantic space used in the study of semantic differentials (Osgood, Suci & Tannenbaum 1957). The PRINGRID algorithm in PLANET is a distance-based cluster analysis using standard principal component analysis techniques.

We may also group constructs that are close together in space, using some form of *cluster analysis*. The FOCUS algorithm (Shaw 1980a) is a distance-based hierarchical cluster analysis technique that sorts the constructs into a linear order such that constructs closest together in the space are also closest together in the order. It has the advantage in presentation that the sorting is used only to re-present the original grid re-organized by the 'neighbourness' of constructs and elements. It is left to the user to construe his own personal meaning into the result and to confirm this directly in terms of the original data.

FOCUS derives element and construct matching scores by subtracting the rating values in each position of the two elements or constructs, summing them, then mapping the result into 0%—100% similarity for the elements, and -100%—100% similarity for the constructs. Two matrices are thus formed, one for elements and one for constructs. Clusters are computed by selecting the highest numbers from these matrices, that is, the most similar in terms of the ratings given, then continuing this process for the next cluster, until all elements and constructs are incorporated. The tree diagrams show these clusters and are imposed on the re-sorted original grid data.

One very important alternative to distance-based methods of grid analysis is a logical analysis which treats constructs as predicates applying to elements. This is closer to the calculus of distinctions concepts discussed in Section 3. The ENTAIL algorithm (Gaines & Shaw 1981b) derives asymmetric entailments between the construct poles so that one can infer how a new element might be placed on one construct given how it is placed on others. This algorithm is particularly important in using repertory grid techniques in knowledge engineering for expert systems since the entailments may be used directly as rules with which to prime an expert system shell. It is also possible to apply the *surprise* measure discussed in Section 3 to give an information-theoretic analysis of the entailments as explanatory hypotheses (Gaines & Shaw 1986).

Factor analysis and its later refinement, multidimensional scaling, have also been used to analyse repertory grid data. Slater (1969) has shown factor analysis to be inappropriate, and this led to his development of the principle components method for repertory grid analysis. Two papers which discuss the advantages and disadvantages of multidimensional scaling are those by Humphreys (1973) and Tagg (1978). However, many of the problems with factor analysis are apparent in this method as well.

### 4.9 Analysis of a Pair of Grids

There are three ways in which PLANET can be used to compare two grids. The first is to concatenate grids with the same elements, and then to use the algorithms of FOCUS, ENTAIL or PRINGRID as if they were one large grid. One can then explore the interaction of ideas by examining mixed clusters of constructs from the two grids.

The MINUS algorithm (Shaw 1980a) may be used with two grids having the same element and construct names. It compares the grids to indicate where changes in construing occur by superimposing one grid on the other and subtracting the equivalent rating values. The parts of the grids which are the same are then clearly visible, as is the extent of the variation elsewhere. The result shows where there was agreement indicated by areas of blanks, and grades of difference indicated by increasing numbers.

Again starting with two grids having the same element and construct names, the CORE algorithm (Shaw 1980a) examines the most changed element and construct alternately, identifies it, and allows it to be deleted from the grids. In this way the core elements and constructs which show agreement or understanding in the two grids are identified and recorded. This method has been used to chart change over time, and to evaluate courses by examining changes in the participant rather than using the traditional method of examining behavioural objectives.

### 4.10 Analysis of a Group of Grids

The SOCIOGRIDS algorithms (Shaw 1980a, 1981b) analyse a set of repertory grids elicited from a group who share the same elements. SOCIOGRIDS compares every pair of grids using the FOCUS algorithm and produces a set of *socionets* which indicates the links of similar construing within the group. A *mode grid* is also produced showing the constructs which are readily understood by the majority of the group and this is filed for future processing on one of the structure analysis programs. Every construct which has been used is listed in order of how highly matched it is across all grids, and indicating where it originated.

SOCIOGRIDS may be regarded as measuring the applicability of the commonality corollary discussed in Section 3.18. The consensual construct system it derives from the group gives the core constructs which define the world to which thee group has surrendered. Hence the phenomena of the communal scientist can be measured and modeled using repertory grid techniques.

## 4.11 Repertory Grid Applications

Cognitive modeling techniques based on repertory grid elicitation and analysis have been used widely in many areas. The main ones to date are clinical psychology, education, management and computing science. In clinical psychology, Shepherd and Watson (1982 p.1) comment that:

> "Personal meanings arise from events and relationships which a person interprets within his most basic frame of reference—his awareness of being an individual, conscious of personal agency and personal biography."

Fransella (1982 p.47) notes "To construe is to impose meaning or interpretations upon something or some things". Clinical psychologists have used personal construct psychology to explore a patient's personal meaning system, and to make explicit the implicitly held models of the world which lead to behavior (Adams-Webber 1979, Bannister 1970, 1977, Bannister & Mair 1968, Bannister & Fransella 1971, Bonarius 1971, Bonarius, Holland & Rosenberg 1981, Duck 1973, Epting & Landfield 1985, Ibry 1984, Kelly 1965, 1970, Landfield 1971, Landfield & Leitner 1980, Maher 1969, Ryle 1975, Stringer & Bannister 1979).

In education and management, many groups are using personal construct psychology. Phillips (1981) studied the development of research skills and the styles of supervision given to doctoral students. She elicited information from the viewpoint of the students at stages during the progress of their research over three or four years, and from the viewpoint of their supervisors. Valuable insights were acquired by both parties about this process, and some interesting results were obtained. Pope and Shaw (1981) and Pope and Keen (1981) have related personal construct psychology to various philosophies or ideologies of education as they apply to school learning, and have extended this to areas of educational research and to some current issues in education. Similar applications have been made in management (Stewart & Stewart 1981).

Personal construct psychology has been found to apply equally well in helping an expert articulate her skill, as it has been in more traditional uses such as in helping a person referred for psychotherapy to articulate her problems, or a student her needs for learning. The success of expert system developments (Michie, 1979; Gevarter, 1983; Reitman, 1984) has opened up the possibility of widespread usage but left a major bottleneck in *knowledge engineering.*

Shaw and Gaines (1983a) and Boose (1984) have used personal construct psychology techniques to elicit and structure expert knowledge,

and to analyse and refine this knowledge into *production rules*. (Gaines & Shaw 1984b,c, 1985b, Shaw 1984, Shaw & Gaines 1984a). These rules can then be assembled into an expert system building tool or *shell* for immediate refinement and debugging. Boose (1985) has developed over 200 expert systems using ETS, a system based on personal construct psychology. Figure 24 shows a consultation with ETS based on the elicitation in Figures 22 and 23.

```
Generating rules:
        :
If: CLOSENESS-TO-SELF = ROLE EXPECTATIONS
Then: PROBLEM-SCOPE = SYSTEM-WIDE PROBLEMS (.89)
If: CLOSENESS-TO-SELF = ROLE EXPECTATIONS
Then: The intervention may be ORG-MIRROR (.22)
If: CLOSENESS-TO-SELF = ROLE EXPECTATIONS
Then: The intervention may be RAP (.44)
        :
62 rules were generated.

Go, Edit, Fill-in, List, etc...
ETS** TEST

This will be case number 106.

What is the CLOSENESS-TO-SELF attribute for this case (STYLE-AND-FEELINGS ROLE-EXPECTATIONS)?
ETS** STYLE-AND-FEELINGS

What is the COGNITIVE-FEELINGS attribute for this case (DECISION-MAKING AFFECT)?
ETS** AFFECT

What is the DATA-GATHERING attribute for this case (GROUP-DATA-GATHERING INDIVIDUAL-DATA-GATHERING)?
ETS** GROUP-DATA-GATHERING

What is the PROBLEM-SCOPE attribute for this case (SYSTEM-WIDE-PROBLEMS INTERPERSONAL-PROBLEMS)?
ETS** SYSTEM-WIDE-PROBLEMS .9

What is the FAMILY-COUSIN-STRANGER attribute for this case (INTACT-WORK-GROUPS REPRESENTATIVES)?
ETS** REPRESENTATIVES

What is the STRUCTURE-SCALE attribute for this case (STRUCTURE AD-HOC-RESPONSE)?
ETS** STRUCTURE

Test results for case number 106:

1 : APPREC-CONCERNS-CONFLICT ( .71 )
2 : APPREC-CONCERNS-STYLE ( .7 )
3 : BECKHARD-CONFRONTATION-MEETING ( .55 )
4 : INTERGROUP-UNDERSTANDING ( .44 )
5 : ORG-MIRROR ( .42 )
6 : SURVEY-FEEDBACK ( 0.0 )
7 : RESPONSE-CHARTING ( -.02 )
8 : RAP ( -.09 )
9 : PROCESS-OBSERVATIONS ( -.58 )

Do you agree with the order of the test results?
ETS** YES
```

**Fig.24 A consultation with ETS**

## 5 Media, Expertise and Conversational Support Systems

The objective of this study is to develop a Participant Construct System as discussed in Section 2 based on solid foundations in cognitive science as analyzed in Section 3 and taking into account previous experience of computer-based repertory grid elicitation systems as reviewed in Section 4. This section uses the communal scientist model of Section 3 to provide an account of the use of *media* in the knowledge processes of human society. It then extends this account to encompass knowledge transfer systems such as PLANET and ETS, projects the development of such systems to support the *knowledge construct* through some form of *prosthetic brain*, and analyzes the role of participant systems within this framework.

Media have been developed to support and enhance the knowledge processes of human society and are readily modeled within a communal scientist (Shaw & Gaines 1984c). The direct experience of the world shown as the basis of the inductive modeling process in Figure 10 is very inefficient if carried out by every individual in a society. The distributed processors that make up the communal scientist need to share experience and the knowledge resulting from it (Gaines & Shaw 1983). The cultural mechanisms for this sharing at different levels of the modeling hierarchy were discussed in Section 3.15 and shown in Figure 16. They involve communication among the the individuals that comprise the communal scientist. Communication through gesture, drawing and speech is a basic mechanism for sharing experience but may not adequately represent it in a way comparable to direct experience. Direct communication is also inadequate on the scale of modern society.

### 5.1 Representational Media in the Communal Scientist

Figure 25 shows Person A interacting with the world through a representational medium such as radio or television. The interaction contrasts with that of Person B interacting directly with the world in that it is only one-way rather than two-way (Gaines & Shaw 1984a). Person A can perceive the world through the medium but not influence it.

Representational storage media such as film or videotape being used by Person C give similar access that transends time in allowing past events to be experienced but is still one-way. Note how Person C has no necessary interaction with the outside world but is experiencing a stored world encapsulated within the communal scientist. Indeed the medium may become the world as far as he is concerned.

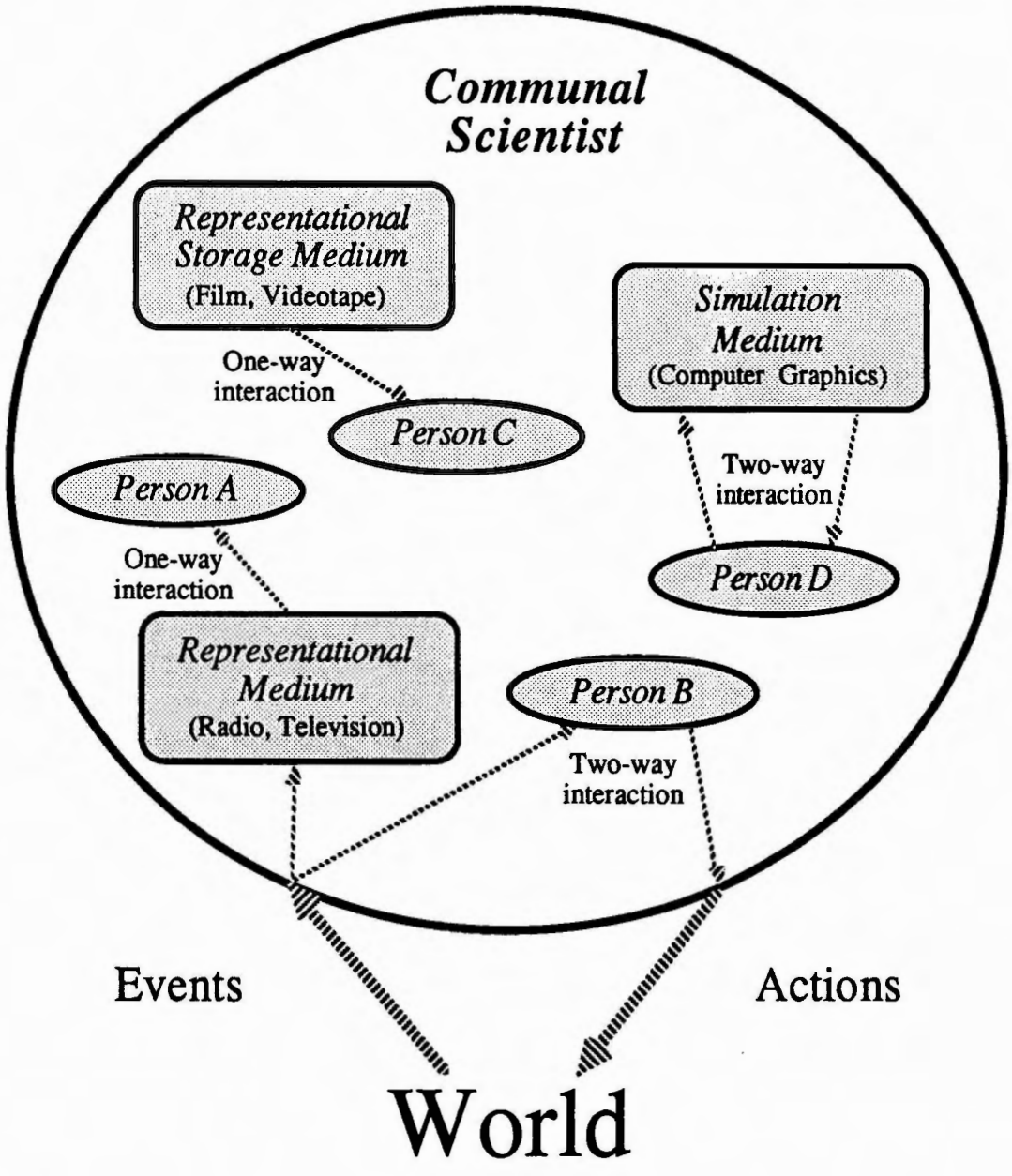


**Fig.25 Interaction with representational media**

The simulation medium based on computer graphics being used by Person D allows two-way access to a simulated world, and as such media become more realistic can increasingly replace direct experience (Gaines & Shaw 1985a). Person D also has no necessary interaction with the real world. The simulated world may be a substitute for such interaction, perhaps a safe training environment as in flight simulation, or perhaps a fantasy replacement as in video games. Computer graphic media in knowledge-based systems can give access to experience in worlds of simulated reality that may, or may not, model real world events.

**5.2 Symbolic Media and Expertise in the Communal Scientist**

The role of symbolic media may also be modeled within a communal scientist and relates with that of experts and their activities in establishing reflective equilibria. Person C in Figure 26 is carrying out a task with help from an expert advisor, Person B, who has no other interaction with the task. Person A is carrying out the task with broadcast advice from Person B, that is with expertise mediated through a symbolic medium. However, as with representational media, the mediated communication is one-way whereas the direct communication is two-way (Gaines & Shaw 1984a).

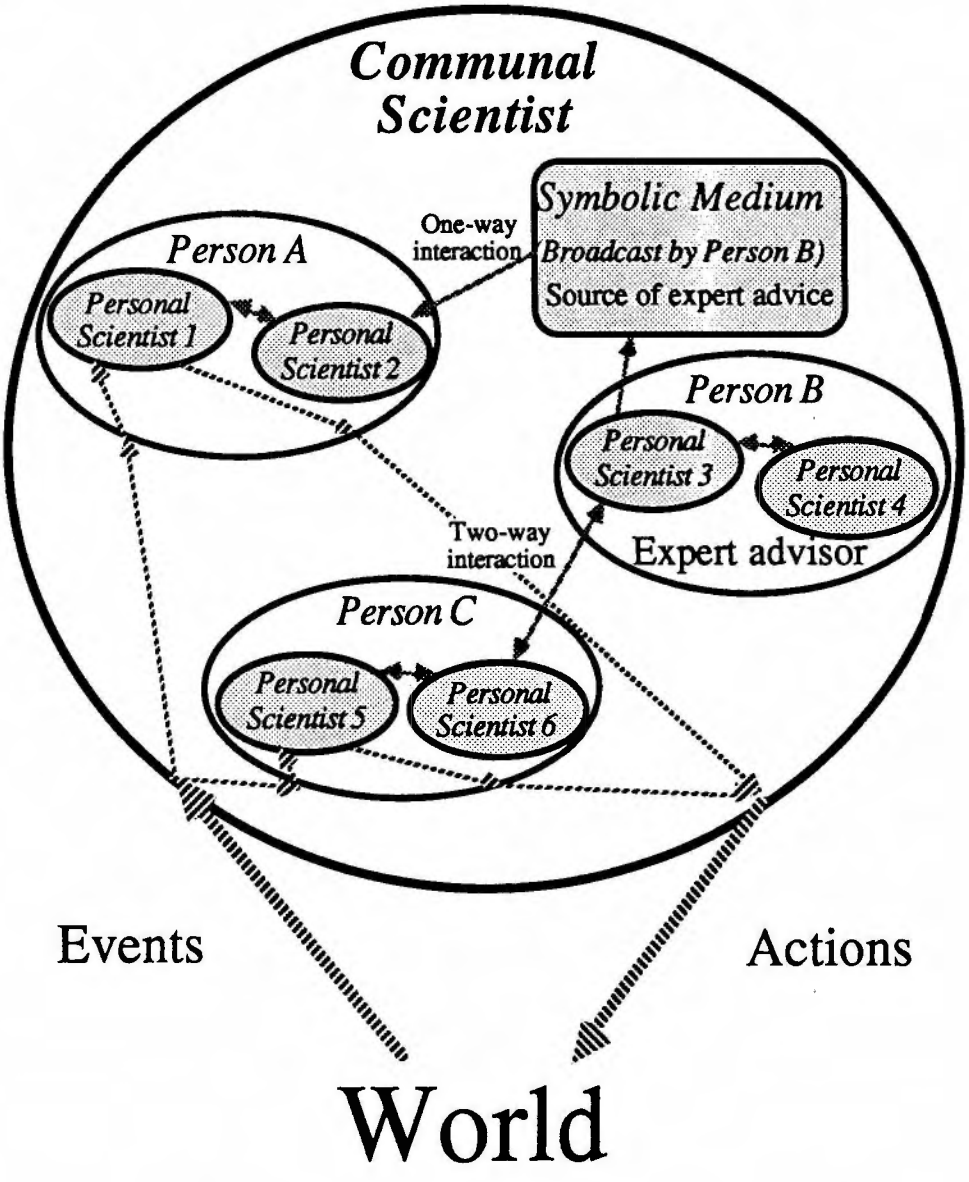


**Fig.26 Interaction with symbolic media**

Some of the problems of knowledge engineering, of transferring knowledge from experts to expert systems, are also apparent in Figure 26. PS4 is the process with the required skill in Person B and has to communicate through PS3, an external language process, but sometimes this link may be unavailable (Bainbridge 1979). Similarly PS5 requires the skill in Person C and has to be able to communicate internally with a language process PS6 which itself has to be able to communicate externally with PS3; lack of effective communication on either link will prevent knowledge transfer.

A symbolic storage medium, such as a book or paper, may replace Person B in Figure 26 to provide advice that is available even when Person B is not. However, the interaction is now essentially one-way. An expert system is a two-way symbolic storage medium that encodes the psychological processes of Person B to make his advice available interactively. The expert system has an internal structure of processes that mimic those of its source, Person B. Figure 27 shows how the concepts put forward in this study combine to structure advanced expert systems combining simulation and control. Note that the overall ES is modeled as a set of communicating P-Individuals:-

- The *advice system* satisfies the stereotype of an expert system in that it uses a *knowledge base* and *inference system* to provide expert advice.
- The associated *communication system* is of critical importance in giving access to the advice. The primary literature on successful expert system developments emphasizes the effort required to establish effective communications (e.g. TEIRESIAS, Davis & Lenat 1982).
- The *explanation system* is an important development in computing technology and distinguishes some of the pseudo expert systems now being marketed from true ones. The concept of explanation presents philosophical difficulties (Korner 1975) as advice may be explained at different levels in different terms. The mechanism in current systems is to backtrack through the processes of inference used in generating the advice and present the user with the knowledge used at each stage.
- The *simulation system* shown is absent in the current generation of expert systems. They mimic the *behavior* of an expert and lack the deep knowledge of the underlying processes on which that behavior is based. Advice from such systems can become obsolete if the world changes in unanticipated ways, for example, if a new drug becomes available in a medical context. A major development in ESs is to integrate models of the world that may be used to simulate the effects of actions on the world (Gaines & Shaw 1985a).

- The *action system* shown is also uncommon currently since the systems are being used as advisors rather than active partipants. However, it is a logical extension of the technology and consistent with previous applications of computer-based systems in control and automation.

All the sub-systems in Figure 27 have equivalent P-Individuals within a person and our knowledge of the psychology of the person is applicable to the understanding and development of the computer-based processes within expert systems. The communal scientist model provides the foundations for a sociology of anticipatory processes including the technology to support the knowledge processes within them.

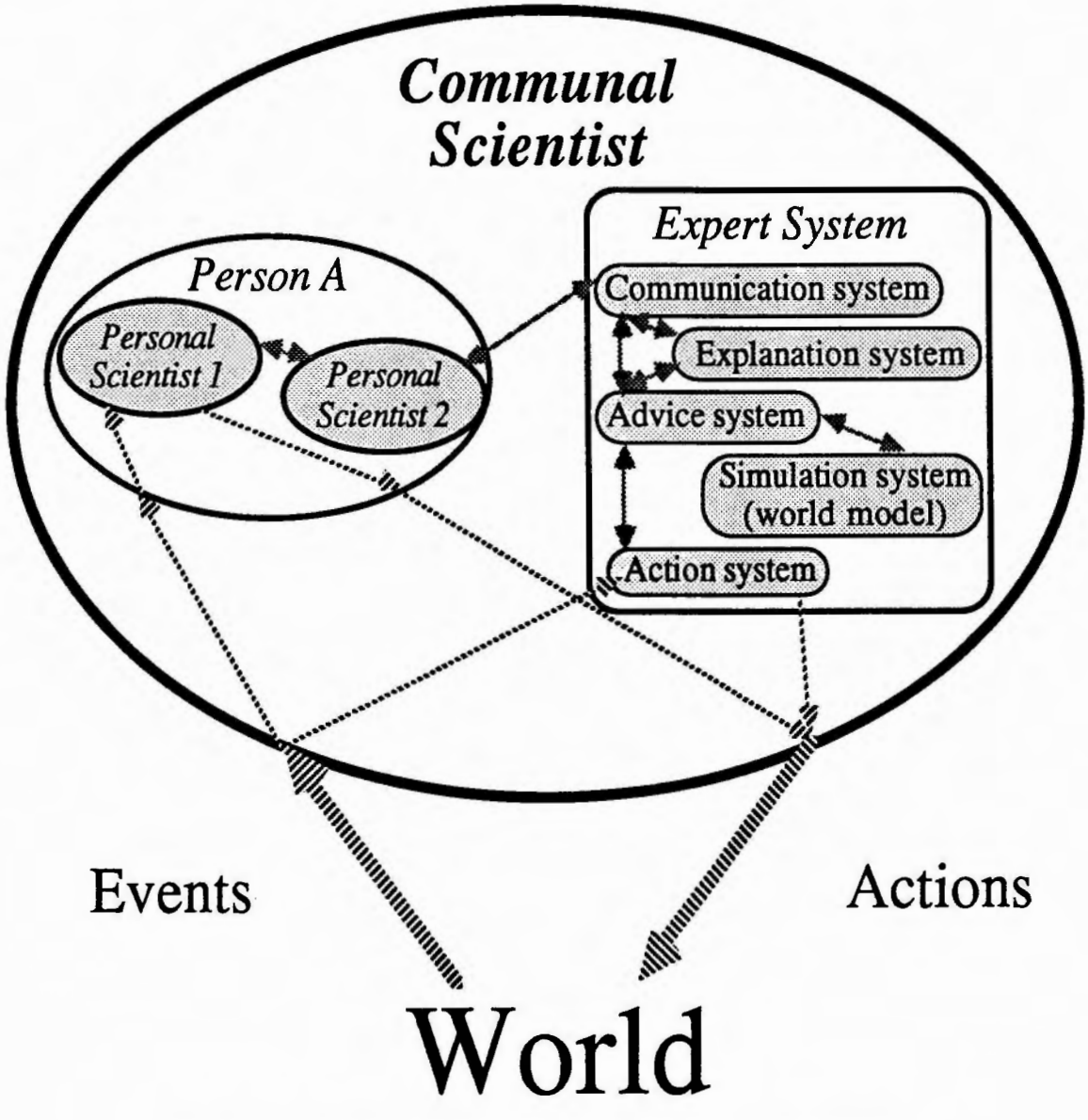


**Fig.27 Structure of an expert system**

### 5.3 Knowledge Elicitation Systems

Figure 28 shows the knowledge elicitation systems, PLANET and ETS, using repertory grid elicitation to capture personal models of the world and make them available through an expert system as described in Section 4.

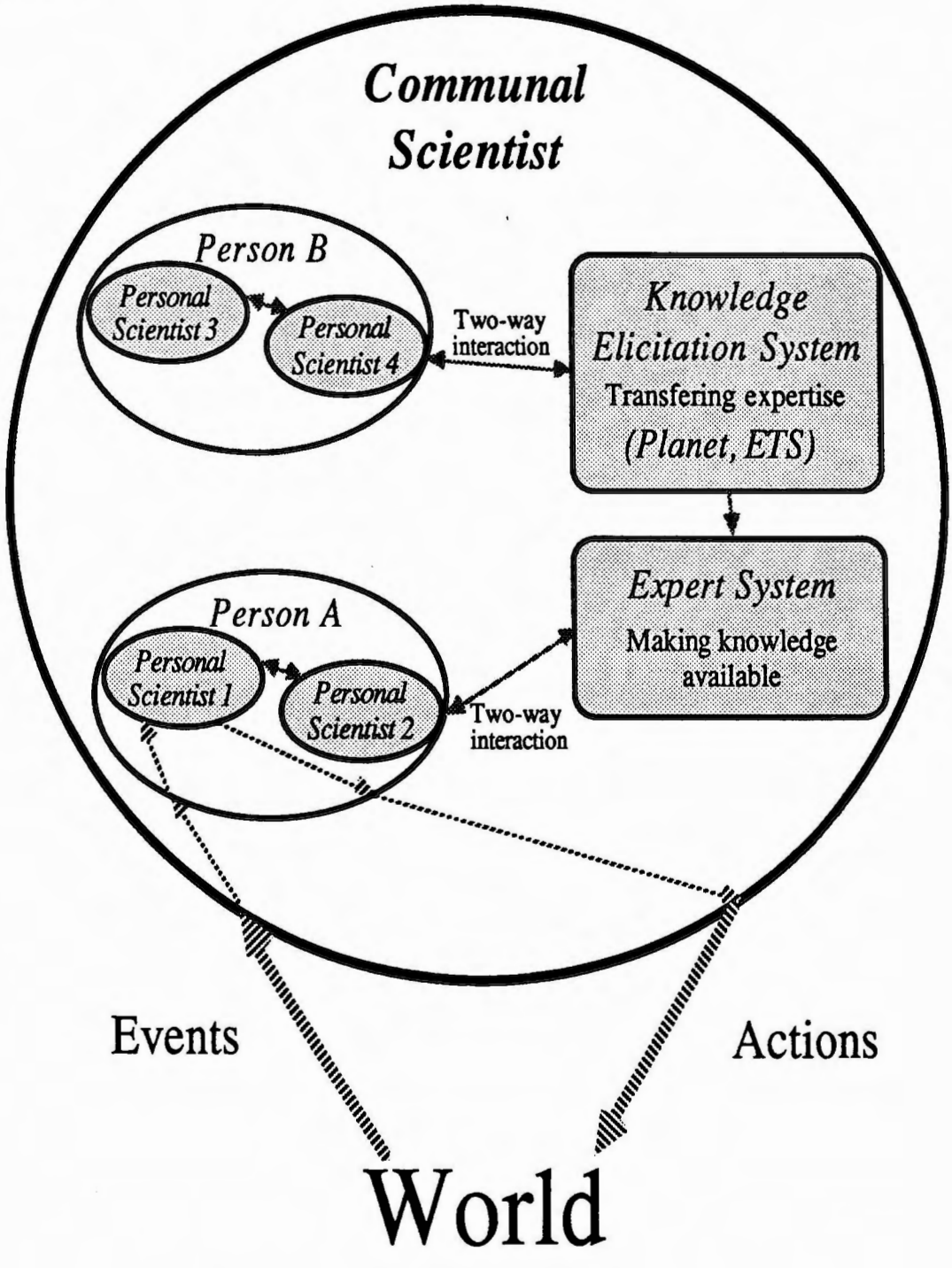


**Fig.28 Knowledge elicitation systems**

### 5.4 Participant Construct Systems

Figure 29 shows how the participant construct system may be represented in the communal scientist. Like PLANET it uses repertory grid elicitation to capture personal models of the world. It then makes comparisons of these models available to a group of people involved in a common problem-solving task. The people may have internal communication as shown between A and B, and may be using the results of their activity to interact with the world as shown for C.

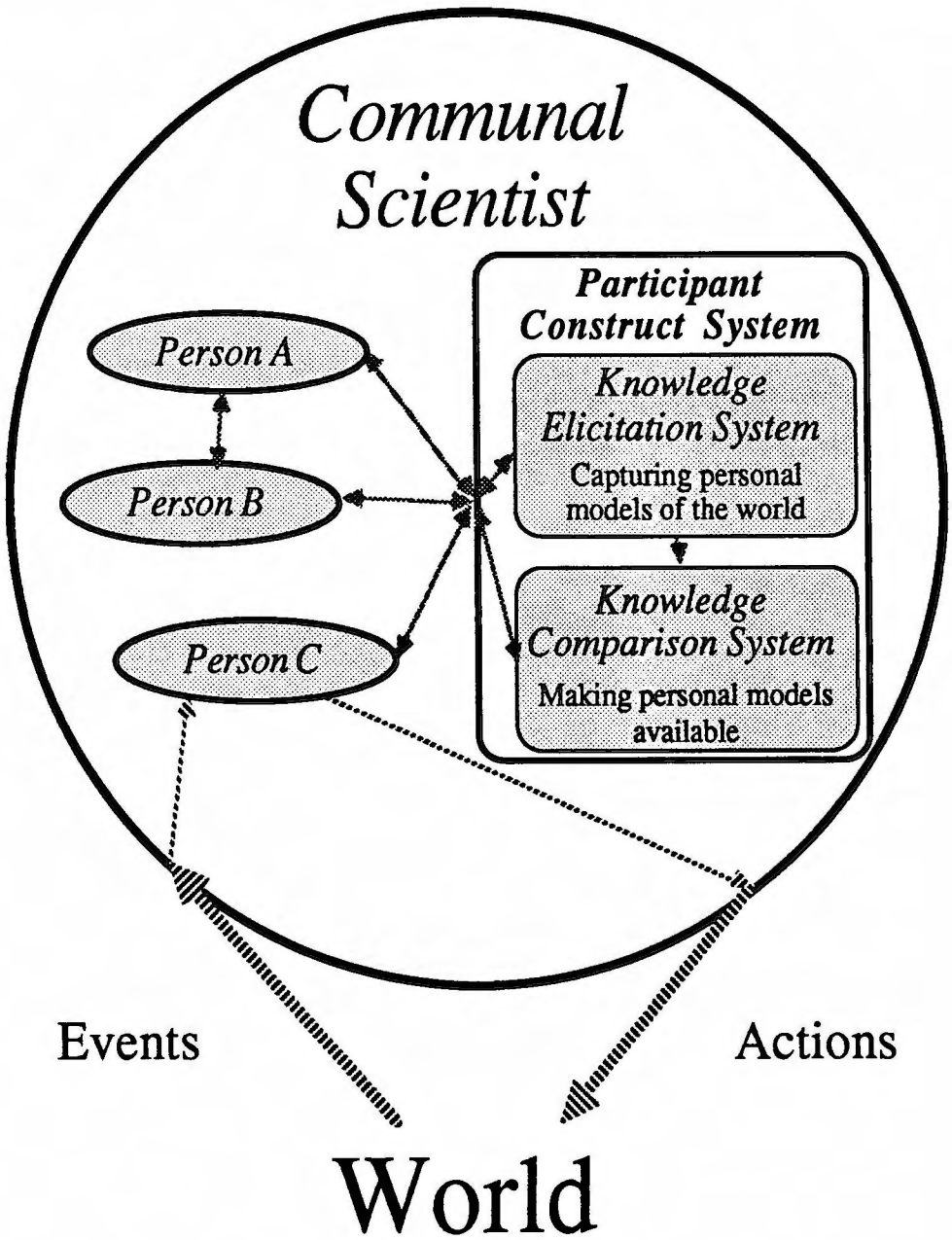


**Fig.29 A participant construct system**

### 5.5 The Knowledge Construct and World 3

PLANET, ETS, PCS, expert systems, communications networks and advanced simulation may be seen as precursors to intelligent information systems that support the knowledge processes of large-scale communities through interactive computer knowledge bases. Knowledge-based computing systems of the future will add such capabilities to the symbolic and representational storage media of current information technologies. Figure 30 shows how Wojciechowski's knowledge construct and Popper's world 3 are becoming manifest through the integration of past and present knowledge using computer and communications media. The conversational and experiential access that we have with other people and the existing world is being extended to conversational and experiential access to people and events of the past, and to knowledge and experience that correspond to possible worlds rather than reality.

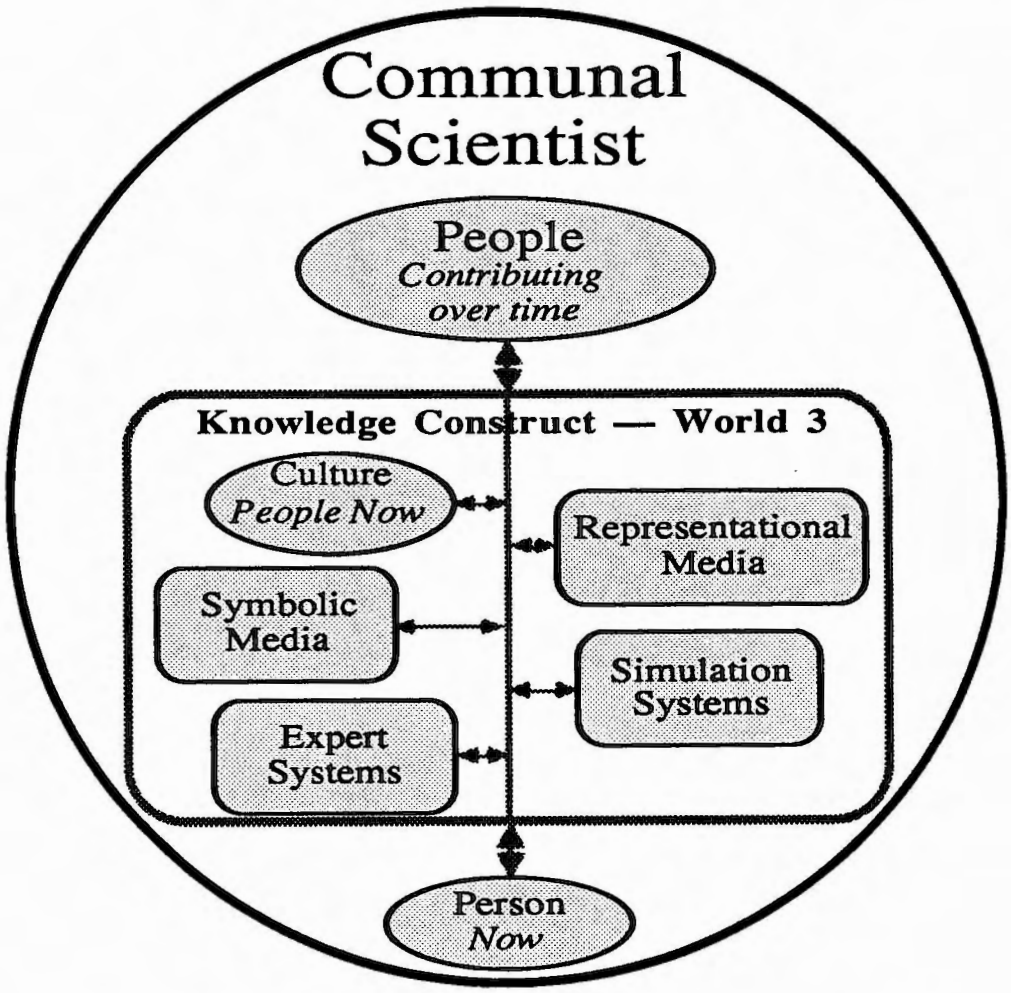


**Fig.30 The knowledge construct—world 3**

## 5.6 Towards the Prosthetic Brain

The social perspective of Figure 30 is complemented by the personal perspective of Figure 31 in which a person acquiring knowledge is seen as supported by other people, media and various forms of information technology. From the individual's point of view these may be regarded as extensions of the processes within his brain, and the total structure may be properly termed a prosthetic brain. From a social point of view the entire sub-system shown is part of the knowledge process of the society and may be understood in terms of knowledge science.

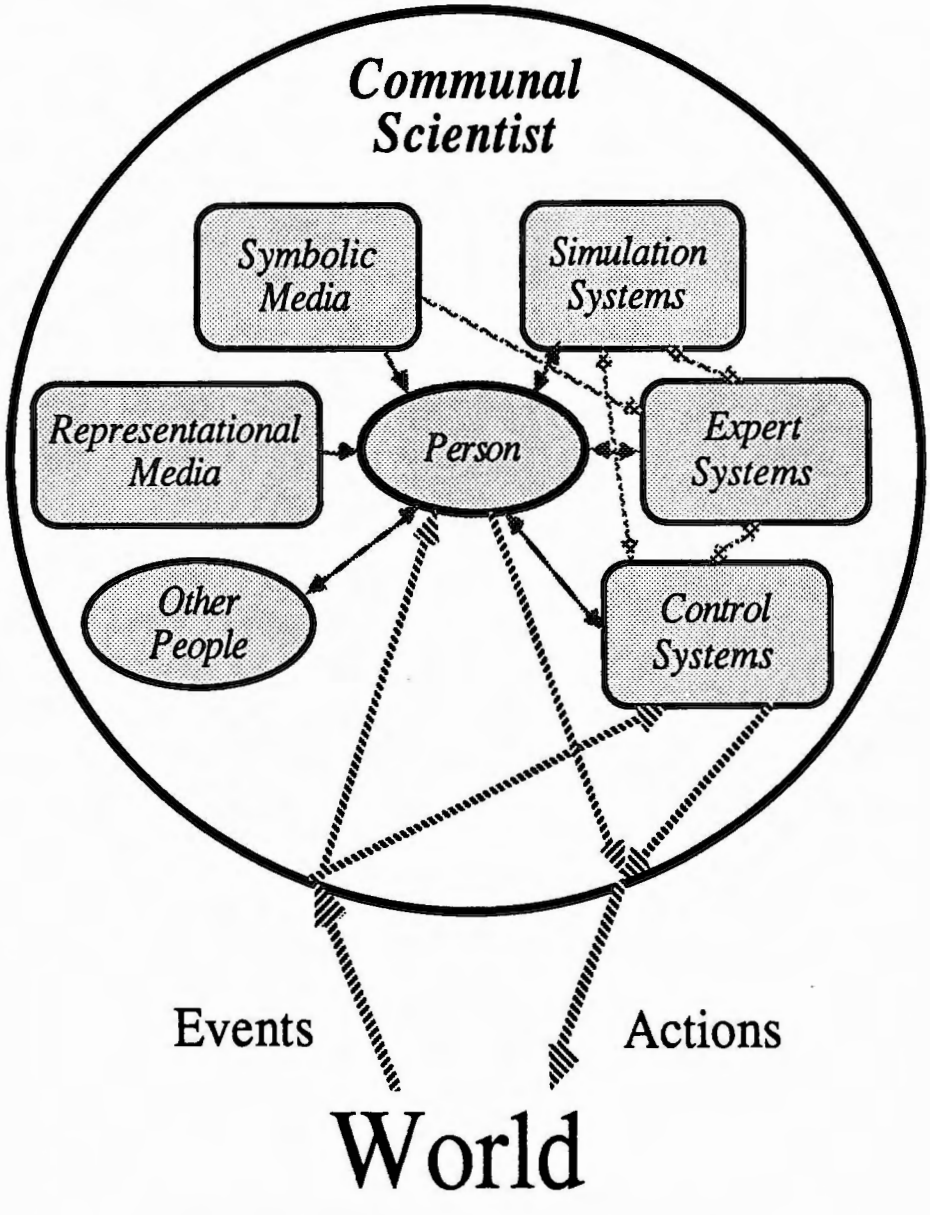


**Fig.31 The prosthetic brain**

## 6 A Participant Construct System Design

The preceding sections of this report have laid the ground work for the design of a *Participant Construct System* as outlined in Section 2.

Section 3 provides a basic cognitive model of people acting together in groups as anticipatory systems, *communal scientists*. It analyzes the cognitive structure as a hierarchy of distinctions which in psychological terms are the *personal constructs* of members of the group. It analyzes the logic underlying these systems of distinctions and the dynamics of their change through knowledge acquisition, including phenomena of lock-out/break-in, in the operation of group knowledge processes. Section 3 also analyzes the role of language in these processes and models the cultural support for communication of knowledge through a variety of mechanisms at different levels in the hierarchy.

The abstract models of Section 3 are given an operational interpretation in Section 4 in terms of Kelly's *repertory grid* techniques for eliciting construct systems. Previous interactive, computer-based systems for repertory grid elicitation and analysis, such as PLANET and ETS, are described in some detail and exemplified as a basis for the PCS design. In particular, the feedback processes used by PEGASUS and the interchange of constructs through exchange grids are important for a participant construct system design.

The abstract models of Section 3 are given a technological interpretation in Section 5 in terms of the role of representational and symbolic *media* in the knowledge processes of the communal scientist. Computer-based expert systems and knowledge elicitation systems are shown to be logical extensions of existing media, allowing two-way interaction where the previous media allow only one-way communication. Participant construct systems are presented as a further extension of such systems to support group knowledge processes. All these techniques are shown to play an important role in the generation of the *knowledge construct*, or world 3, that forms the infrastructure of human society. From an individual point of view this infrastructure appears as a form of *prosthetic brain*.

This section gives the design considerations behind the development of a participant construct system, PCS, based on a network of Macintosh computers. This system is being implemented as a result of this study in order to provide means of testing the feasibility, human-computer interaction, and applicability of participant systems in general, and those based on personal construct psychology in particular.

## 6.1 Objectives for a Participant Construct System

The primary objective has been to develop a participant system in the *strong* sense of Section 2.3, one in which the individual task is perceived as part of a mutual task. However, this does not preclude making the individual activities in themselves attractive and interesting. It is important to motivate users of any system by giving them useful results from their activities on as wide a front as possible. Different people will come to PCS with differing motivations and both the individual and group goals should be satisfied if possible.

With these considerations in mind, and based on past experience with the PLANET system, the PEGASUS individual grid elicitation procedure was taken as an initial model for PCS. Interaction with PEGASUS, with feedback of construct and element matches, is known to be a stimulating and enlightening experience. Then to ensure that the group interaction through PCS is seen as important in its own right, the features have been included to:

1) Select additional elements from those entered by other participants;
2) Compare one's own constructs with those of other participants;
3) Exchange complete grids with other participants and evaluate mutual agreement and understanding.

Such *exchange grid* procedures are known to aid individuals in coming to understand their agreements and disagreements with the way others perceive the world, and to help them to understand and use the constructs of others (Section 4.6, Shaw 1980a). They give a basis for group problem solving and hence PCS may be presented to interested users as a participant system around which group problem solving procedures may be built. In terms of the communal scientist model of Section 3.17, the exchange grid procedures in PCS should enable participants to explore their mutual perceptions of the same *world*, and hence better define both the world and their relations to it.

In choosing a technology for the implementation of PCS the importance of a simple and attractive user inteface has been paramount. PEGASUS was designed as a structured interview for users with little or no knowledge of problem solving techniques. The program largely controls the interaction and limits the user's choices to a few significant decsions. Greater flexible was both desirable in PCS and also intrinsically required by the overlay of group interaction on the basic construct elicitation procedures.

## 6.2 Choice of Computing System

The significance of effective human-computer interaction in the design of a participant system was emphasized in Section 2.4. Figure 3 in particular shows the way in which the human-computer interface mediates between the group and the computational processes. A poor interface can completely negate the value of the most advanced participant system. This has been a major consideration in the PCS design and the Apple Macintosh was chosen as a user terminal to PCS because:

1) The windowing facilities make it possible to present multiple channels of information in a modular and comprehensible fashion;
2) The graphic data presentation makes it possible to present grid data structures in an attractive and comprehensible format, replacing the display of numeric ratings with one based on spatial relations;
3) Much of the interaction with PCS can consist of spatial manipulation using the mouse to click and drag objects on the screen, rather than typing text or commands.
4) The proper use of the toolbox routines leads to a uniform interface that is consistent with other Macintosh programs that users already know.
5) The Macintosh has a reputation for being simple to understand and easy to use without training or reading manuals, reducing user anxiety and encouraging expectations of being able to operate the system.

The use of the Macintosh user interface, however, requires a complete reconceptualization of the PEGASUS flow of control shown in Figure 20. The Macintosh interface encourages an object-oriented programming paradigm in which the user has access to a number of discrete, manipulable objects, most of which are potentially accessible at any time. That is, there is very little imposed flow of control. This gives the system tremendous flexibility, allowing much freedom in use, and enabling the users to impose their own mode of working upon the system rather than having to conform to some preset sequence.

However, flexibility and freedom are not in themselves necessarily advantageous in human-computer interaction. Users may find the decision-making necessary to drive the system too great a burden, or they may never discover how to use the system effectively because it gives little indication of reasonable modes of use. Thus the Macintosh interface in its own right is no panacea for effective human-computer interaction. It needs careful system design based on an understanding of its underlying concepts, functionality and the psychology of interaction.

### 6.3 Design Rules for the PCS User Interface

The considerations of the previous section leads to the following design rules for the PCS user interface on the Macintosh computer:

a) Follow the Macintosh standards (defined by the toolbox and its use by programs such as the Finder, MacWrite and MacDraw) as closely as possible so that Macintosh users find PCS natural in use;

b) Make each object defined by a window a natural concept unit of the grid elicitation and analysis process so that its purpose and functionality are obvious;

c) Design each object to be self-describing so that minimal explanation and use of the manual are necessary.

d) Use a graphic representation of data structures and results of analysis.

e) Base user data entry on object manipulation using the mouse wherever possible.

f) Make the system tolerant of user actions giving ease of system exploration through the capability to reverse actions and recover from errors.

g) Within these constraints offer the user the maximum freedom of action possible.

These rules are largely ones of Macintosh programming style that any program should follow. There are, however, many commercial programs that deviate markedly from this style, often because they have been transfered from other computers. Worse, there are a number of programs also that apparently conform to the style but fail to follow it in some important features. These latter programs undermine the user's confidence in the system and his capability to understand it and it is very important that such problems be avoided in PCS.

It is reasonable to suppose that many of these design guidelines may be followed easily by writing PCS in a high-level programming language that is itself well-structured and gives natural access to the toolbox. However, when this study commenced there were very few high-level programming languages available for the Macintosh. In particular, Pascal was available only as a slow and limited intepreter on the Macintosh or as a cross-compiler on the Lisa. The choice was either to use C, to develop the system on a Lisa, or to use Neon, an object-oriented implementation of Forth. ARC were using Neon for CANTATA, a participant system for communications and selected it for the initial implementation of PCS.

## 6.4 The PCS Database

The key document in implementation is the User Manual appended to this report. It defines the menus and screens, their layouts, functionality and transitions between them. There are two major parts to the PCS system: the PEGASUS-style grid elicitation with amendments to conform with the Macintosh interface and the existence of multiple participants; and the exchange grids analysis with amendments to take into account a common database for the multiple participants.

The initial user interface is shown in the screen in Section 4.2 of the Appendix. PCS itself is designed to be a normal Macintosh application that has its own icon and can be launched by double-clicking. The PCS databases for different applications are files which can also launch PCS when double-clicked. Hence PCS startup is similar to that of most Macintosh programs.

The PCS database structure is key to its operation and requires analysis from a number of different perspectives. Each database corresponds to a topic, such as *Management Effectiveness,* under consideration by the participants. The database contains a number of repertory grids related to this topic, each with the mathematical structure described in Section 4 and illustrated in Figure 21. From a user perspective these separate grids all form one data structure as shown in Section 6 of the Appendix, that is the grids are linked by the elements and constructs they have in common. However, in the implementation it is more convenient to keep the grid as separate files and store the linkage information separately, that is to index the common elements, constructs and exchanged grids.

From a user perspective also the entire data structure is local to his machine and accessible to him at all times. However, in the implementation, the system architecture of Figure 1 will be used with a common database being accessed by all users. Note that there is no direct user-to-user communication necessary on the network for the operation of PCS. All users communicate with the same database and it is this which gives their apparent interconnection.

The interlock problem is simplified by having the grids originated by each user in separate files 'owned' by that user. The PCS design is such that participants write only into their own files and need read-access only to other participant's files. A simple interlock to force a wait if a file is open for write by another user will take care of interlock on reads, and vice versa on writes.

The appropriate file discipline is that only complete writes adding a new element or construct vector should be made to grid files. This should be done by creating a new copy of the file and then, with a unitary action, deleting the old file and renaming the new. This minimizes wait states caused by writes. Similarly, read wait states should be minimized by always reading up a complete grid in one action and then releasing the file.

PCS is designed to allow these simple file disciplines to be effective without causing prolonged system delays. The only screen where multiple file reads may lead to significant delays is the Elements Window described in Section 4.5.2 of the Appendix. If the delays in accessing this screen cause significant problems in the application trials then it may be necessary to set up an elements file as a separate entity to which also participants have write access using record interlock. However, this is unnecessary for the initial implementation.

The Participants Window shown in Section 4.4.1 of the Appendix should be part of the total participant system implementation allowing access to all active PSs which the user is entitled to join. It requires a common discipline between CANTATA, PCS, and other PSs, wherby the status of each participant is posted to a common database. The simplest implementation would be for each Macintosh on the system to be allocated a record in a single common file in which it records its status when it logs into, or out of, a participant system.

The Corvus network for the Macintosh used at the ARC supports database systems such as Omnis 3 which provide record interlocking mechanisms so that there are no basic problems in the file design described above.

### 6.5 PCS Grid Elicitation

The PEGASUS flow of control in Figure 20 is replaced on the Macintosh by a set of screens that correspond to the functions in the flow-chart, for example to adding/deleting elements or evaluating matches. This conforms with the Macintosh interface philosophy that the user can activate any one of a number of menus or windows independently of one another. The standard implementation for this at toolbox level allows a main event loop to be set up such that user activity with mouse or keyboard causes a branch to procedures appropriate to the menu or window in which that activity has taken place. This gives modularity at both the user and the implementation level.

The modularity must not be overdone, however, and it is important to group functions together logically in the minimum number of conceptually independent screens. In particular, in PCS the automatic control of the activity that takes place in PEGASUS to draw attention to element or construct matches is missing and it is important that these be shown naturally together with appropriate choices of action. It is also important on the Macintosh that the numeric ratings used in PEGASUS be replaced by a spatial representation of grid data that is readily visualized (that is the standard grid representation of Section 4.2 be replaced by the graphic one of Section 2.8).

The two screens in Section 5.5 of the Appendix show these features of the Macintosh implementation of grid elicitation. In the first figure elements are being assigned ratings not by numeric data entry but instead by clicking and dragging on the element name to place it at a point on the scale. The results are the same but the user interface shown conforms to the expectations of a Macintosh user. It has the general advantage of making the rating procedure very apparent to a user without the confusion of numbers and the translation of these to positions on a scale. In the second figure the highest element and construct matches are shown to the user on 'thermometer' indicators. High values are very apparent to the user and may suggest that action be taken to reduce them by adding elements or constructs, but the choice of action is under user control.

This control shows up well in the screen in Section 4.5.3 of the Appendix which shows the participant his constructs, the highest match between them, and gives him the choice of various actions: adding a construct, deleting one; editing the ratings on a construct; eliciting another construct choosing his own triad; or having the program generate a triad at random; or breaking the construct match by adding another element. Note that the user may decide to do none of these actions but may instead move to another window or menu.

There are occasions where keyboard action is necessary, such as adding construct labels as in Section 5.4 of the Appendix. For these requirements the normal Macintosh text editing features are activated allowing text entry through the keyboard with cut and paste through the mouse. In PCS text entry is confined to element and construct labels during elicitation and element labels can often be selected as copies of those being used by others as shown in Section 4.5.2 of the Appendix.

The exchange grid procedures follow naturally from the elicitation procedures and involve no new features in the interface. In particular, since the skeleton grid pre-exists, no construct or element labels have to be entered. However, filling in a complete grid can be a tedious operation and its important that the click and drag procedures for moving elements to rating scales operate simply and naturally. For example the circle marking a location on the rating scale nearest to an element being dragged should darken as soon as the element is near to it. Releasing the mouse once a circle has darkened should cause the element to 'jump' to that rating point.

The main problems in implementation, on the basis of experience in other Macintosh developments, will be in the interfaces to the tool box. These are not well-defined in the Apple documentation, *Inside Macintosh*, and are at a very low level. Fortunately the past few months have seen the release of improved documentation from many sources and a number of high-level languages compilers that run directly on the Macintosh and provide well-documented libraries of interfaces to the tool-box. Apple has also released this month upgrades to the toolbox that remove bugs, increase speed and improve functionality. These developments indicate that the logic behind the original decision to use the Macintosh remains valid.

It is less clear that the implementation of PCS in Neon is appropriate. The ARC experience to date has been that this language itself requires further development and problems with it are impeding the PCS implementation. The use of more recently available standard languages such as TML Pascal should be investigated, with a view to transfering to Apple's Pascal when it becomes available sometime in 1986. It would be appropriate to complete a trial version of PCS in Neon if possible so that application studies may commence, but the longer term support and extension of PCS may not be possible in this language.

## 7 Conclusions

This report has described a design study for the development of a *participant construct system.* The objectives of the study have been to: develop and refine the concept of a participant system; define one based on *personal construct psychology*; design such a participant construct system; and supervize its implementation and application.

A *participant system* is defined in this report as a computer-based communication system for multiple users that is essential to the performance of their mutual task, rather than merely incidental to their use of computer network. Personal construct psychology is presented in this report as a theory of *cognitive science* that has deep systemic foundations, models the person as an anticipatory system, and has been operationalized through computer programs that have proved very poweful in expert system development.

In order to provide foundations for the design of a participant construct system, a survey has been made of the literature on cognitive psychology, personal construct psychology, repertory grid techniques, and their computer elicitation, analysis and applications. Sections 3, 4 and 5 are based on this survey, as is the extensive bibliography of Section 8.

Section 2 provided an overview of the main concepts presented in this report. It defined a participant system, analyzed its essential features and roles, and discusses some of the problems in participant system implementation and evaluation. Section 2 also provided the background to personal construct psychology and the use of repertory grids to elicit a person's construct system. It concluded with a proposal and rationale for a participant construct system supporting group problem solving by allowing multiple participants to exchange their constructs and evaluate mutual agreement and understanding.

Section 3 provided a basic cognitive model of people acting together in groups as anticipatory systems, *communal scientists.* It analyzed the cognitive structure as a hierarchy of distinctions which in psychological terms are the *personal constructs* of members of the group. It analyzed the logic underlying these systems of distinctions and the dynamics of their change through knowledge acquisition, including phenomena of lock-out/break-in, in the operation of group knowledge processes. Section 3 also analyzed the role of language in these processes and modeled the cultural support for communication of knowledge through a variety of mechanisms at different levels in the hierarchy.

The abstract models of Section 3 were given operational interpretations in Section 4 in terms of Kelly's *repertory grid* techniques for eliciting construct systems. Previous interactive, computer-based systems for repertory grid elicitation and analysis, such as PLANET and ETS, were described in some detail and exemplified as a basis for the PCS design. In particular, the feedback processes used by PEGASUS and the interchange of constructs through exchange grids are important for a participant construct system design.

The abstract models of Section 3 were given technological interpretations in Section 5 in terms of the role of representational and symbolic *media* in the knowledge processes of the communal scientist. Computer-based expert systems and knowledge elicitation systems were shown to be extensions of existing media, allowing two-way interaction where the previous media allow only one-way communication. Participant construct systems were presented as extensions of such systems to support group knowledge processes. All these techniques were shown to play an important role in the generation of the *knowledge construct*, or world 3, that forms the infrastructure of human society. From an individual point of view this infrastructure appears as a form of *prosthetic brain.*

Section 6 gave the design considerations behind the development of a participant construct system, PCS, based on a network of Macintosh computers. Particular attention was paid to the user interface and this is expressed as a set of design guidelines. The PCS User Manual is appended to this report, both as design documentation and in order to illustrate the intended use of PCS. This system is being implemented as a result of this study in order to provide means of testing the feasibility, human-computer interaction, and applicability of participant systems in general, and those based on personal construct psychology in particular.

This study has taken place in the context of major world-wide initiatives in the development of knowledge-based computing systems, the *fifth* and *sixth generation* computing research programs with objectives of:

- developing *knowledge-based* computing systems to aid the transition from information processing to knowledge processing;
- improving *human-computer* interaction to the effective use of computing systems by all people;
- involving *multi-disciplinary collaboration* between neurologists, psychologists, linguists, logicians and computer scientists.

This study is consistent with these objectives in combining four of the most significant uses of computing systems: facilitating communications between people; aiding human problem-solving; eliciting human expertise; and encoding human expertise to make it widely available. The *participant construct system* design developed in this report integrates major components of all four applications to provide a system for computer-aided problem-solving by a group of people participating through a network of personal computers.

The development of PCS, together with that of a second participant system, CANTATA, is a significant contribution to fifth and sixth generation computing system developments and places the ARC at the frontier of research on the human-computer interface and knowledge-based systems. The integration of these two systems into a participant system network supporting group conferencing and structured knowledge exchange should provide a problem-solving tool of interest to a wide range of professions and industries.

The next stage of this project should be the completion of the PCS implementation on the Macintosh computer, followed by studies of the effectiveness of human-computer interface and the utility of the system in applications. These further studies should result in an improved specification for the PCS leading to an applicable system that can be tested in a variety of applications. Integration of PCS with CANTATA to allow the conferencing facilities of CANTATA to supplement the structured knowledge elicitation of PCS should take place at this stage, and will be particularly important for geographically distributed users of the systems.

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# Appendix

## User Manual for Participant Construct System

**Notes on User Manual**

The PCS User Manual is a separate document intended to be used as background reading and reference by participants in PCS and, in particular, by those planning group problem solving activities around PCS.

However, the User Manual also constitutes the major design document for PCS since it shows all the screens involved, explains their functionality, and takes the user through sequences of interaction. This is precisely the information required by the programmer in implementing PCS.

Experience in developing previous interactive systems has shown the value of making the user manual the primary design document. This value becomes even greater with the Macintosh where screen layout and appearance is a major part of the system design.

Hence the PCS User Manual forms part of the design section of this report and should be regard as an extension of Section 6. Anyone implementing PCS or further enhancing it should be thoroughly familiar with the user manual and the functions of the screens shown.

*Note that the pagination of the User Manual has been left in its independent form to facilitate cross-reference to the actual manual.*

ARC-CPCS-PCS-MANUAL:FEB86

# Participant Construct System

## *User Manual*

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# 1. PCS INTRODUCTION

## 1.1 What is a Participant Construct System?

**PCS** consists of a set of computer programs for the elicitation and analysis of repertory grid data from several people.

**PCS** is based on the **Personal Construct Psychology** of George Kelly made operational through a participant system on an Apple Macintosh network.

**PCS** is a conversational tool for investigating the basis of yours and others thinking.

**PCS** may be used in a wide variety of applications ranging from group problem solving through prototyping expert systems to the development of instructional software.

**PCS** may be used in management systems, for the development of mutual understanding, problem analysis and system development.

**PCS** offers forms of conversational computer interactions for both casual and intensive users.

## 1.2 What can you do with PCS?

Here are some of the things you can do with **PCS**

- You can elicit a conventional repertory grid or a grid with on-going immediate feedback of similar constructs or elements.
- You can start to elicit a new grid or continue one previously started.
- You can explore your understanding of another participant on the same topic.
- You can explore your agreement with another participant on the same topic.
- Several people can elicit grids from different perspectives at the same time.
- You can match individual constructs with others of your own.
- You can have your constructs matched against those of another individual or group on the same topic.

## 1.3 What do you need to run PCS?

This manual describes **PCS** for a Macintosh network based on Appletalk communications.

To run **PCS** you need one Apple Macintosh for each user with at least 512K of memory and connected through an Appletalk network.

## 1.4 How do you use this manual?

For ease of use this manual is divided into fairly independent parts, some of which are introductory, some operational, and others technical.

**PCS INTRODUCTION,** which you are reading now, contains background information about PCS and its use on the Macintosh.

**PCS BACKGROUND READING** is an introduction to literature relating to repertory grids and the techniques used in **PCS.**

**PCS REPERTORY GRIDS** is an introduction to repertory grids and how they can be elicited and analysed using the programs in **PCS.**

**PCS GETTING STARTED** contains everything you need to begin using **PCS.**

**PCS RUNNING A SESSION** describes an actual elicitation by a manager exploring effectiveness in management using **PCS.**

**PCS DATA STRUCTURE OF THE PARTICIPANT GRID** shows how your grid contributes to the total grid of all the particpants in **PCS.**

**PCS EXCHANGE PROCEDURE** is a method for exploring your agreement with or your understanding of another particpant in **PCS.**

**PCS COMPARE PROCEDURE** enables you to compare your constructs with each other or with another participant in **PCS** to see if your views are similar to others or unique.

**PCS DIALOG** describes the structure of the **PCS** interactive dialog file and how it may be edited for different specialist applications or national languages.

## 2. PCS BACKGROUND READING

There is a wide range of published material on personal construct psychology, repertory grids and their applications. The list below covers books directly involving the **PCS** programs and also some key works that are relevant background.

**2.1 Think Again: Personal Decision Making and Problem Solving.** Shaw, M.L.G. & McKnight, C. (1981) Prentice Hall.

An elementary introduction to repertory grids and their applications in everday life.

**2.2 On Becoming A Personal Scientist: Interactive Computer Elicitation of Personal Models Of The World.** Shaw, M.L.G. (1980) Academic Press.

A detailed description of repertory grid elicitation and analysis programs and their applications, with many sample runs.

**2.3 Recent Advances in Personal Construct Technology.** Shaw, M.L.G. (1981) Academic Press.

Papers from a range of users of repertory grid techniques on computers covering both applications and new developments.

**2.4 Personal Construct Psychology and Education.** Pope, M.L. & Keen, T.R. (1981) Academic Press.

A work on educational applications using some of the programs in **PCS.**

**2.5 The Art of Computer Conversation.** Gaines, B.R. & Shaw, M.L.G. (1984) Prentice Hall.

Discusses the role of conversational systems in the development of human society, provides guidelines for effective interaction—a general background to PCS.

**2.6 A Manual for Repertory Grid Technique.** Fransella, F. & Bannister, D. (1977) Academic Press.

An introduction to repertory grid elicitation, analysis and applications in clinical psychology.

**2.7 The Psychology of Personal Constructs.** Kelly, G.A. (1955) Norton.

The two-volume work that first developed personal construct psychology and repertory grid techniques.

**2.8 The Construing Person.** Mancuso, J.C. & Adams-Webber, J.R. (1982) Praeger.

A thoughtful introduction to personal construct psychology, discussing Kelly's fundamental postulate and each of his corollaries in turn.

**2.9 Knowledge Elicitation for Expert Systems.** Kidd, A. (1986) Plenum.

A survey of techniques for knowledge engineering for expert systems including the use of repertory grids.

**2.10 A Constructivist Perspective on Assessing Personal Cognitive Structures.** Mancuso, J.C. & Shaw, M.L.G. (1986) Praeger.

A survey of techniques for computer elicitation and analysis of personal construct structures.

# 3. PCS REPERTORY GRIDS

## 3.1 What is a repertory grid?

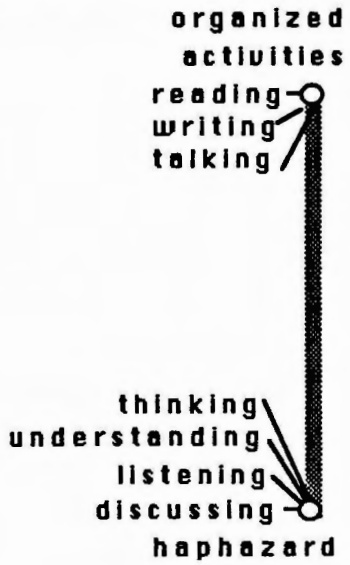
A **repertory grid** is a two-way classification of data in which events are interlaced with abstractions in such a way as to express part of a person's system of cross-references between his **personal observations** or experience of the world **(elements),** and his **personal classifications** or abstractions of that experience **(constructs).**

## 3.2 Purpose, elements and constructs

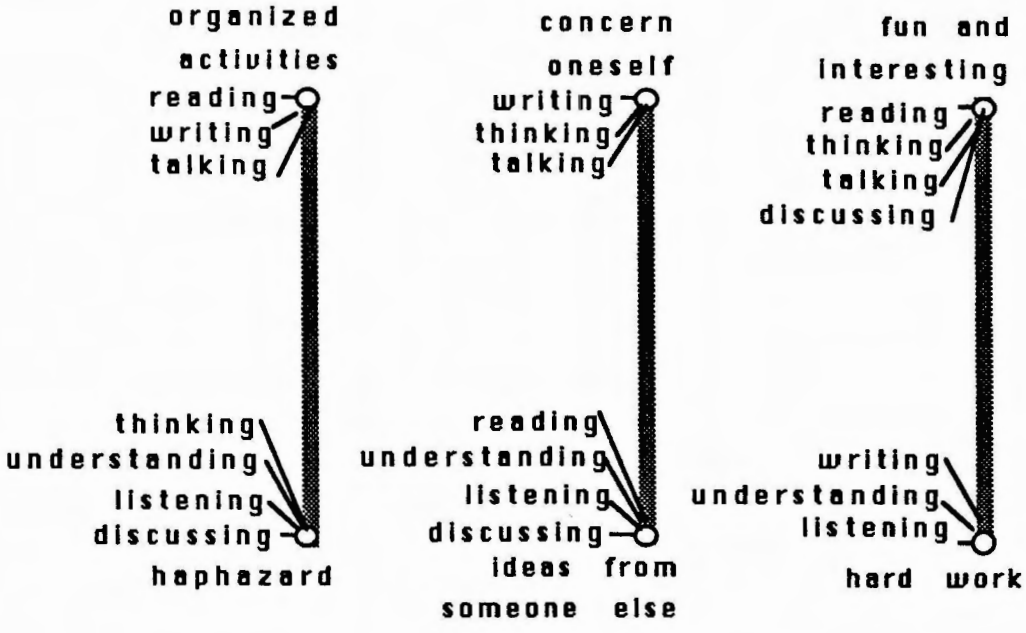
To set up a repertory grid, or **elicit** one from an individual, the **purpose** of doing it must be defined, such as "deciding what car to buy", or "how do I evaluate my staff?". Many more examples are given in the book **Think Again** by Shaw & McKnight.

A number of **elements** can then be elicited which are relevant to this purpose. For example, they may be such things as physical objects, people, events or careers. The elements should be of the same type and level of complexity, and span the topic as fully as possible. It is usual to start with about six to twelve elements.

The **constructs** are the terms in which the elements are similar or different from each other. Each construct therefore has two poles, each of which has a meaning with respect to its opposite. The elements are presented in **triads** and a construct is elicited by saying in what way two are alike and why the other differs. For instance, thinking of the three activities of **reading, writing, thinking,** in what way are two alike and thereby different from the other one? We might first of all say that **reading** and **writing** are alike since they are **organized activities,** whereas **thinking** is **haphazard.** This is, then, the first construct with its two poles or opposite descriptions. This also shows the significance of the term **personal** in personal construct since it would not obviously be a publicly held description of these activities. Now all the elements in the set must be rated on this dimension as either being **organized** or being **haphazard.**



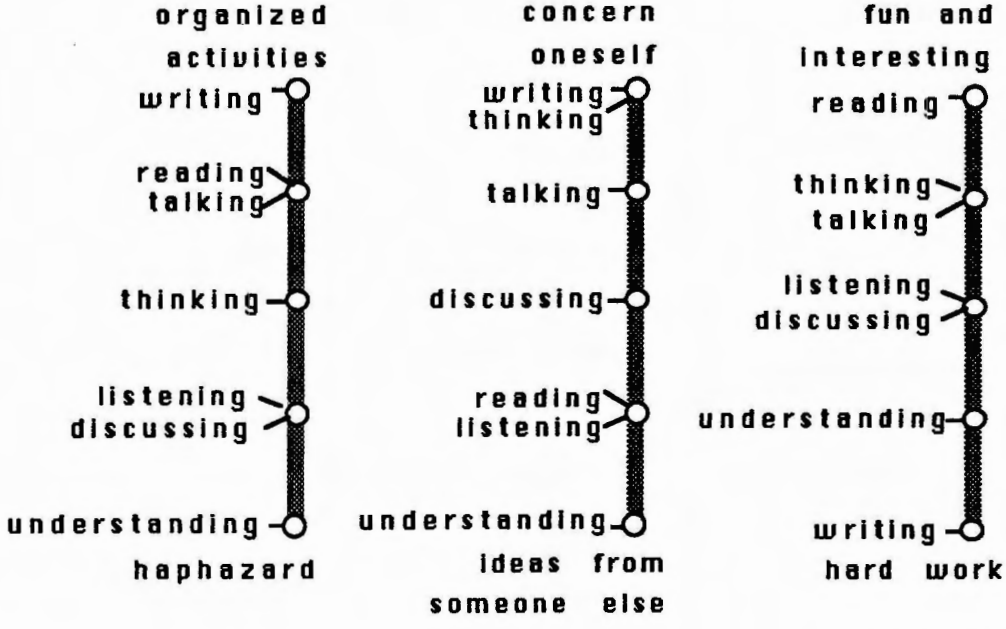
Then the second and subsequent constructs are elicited in exactly the same way using different triads each time.




The three construct shown here illustrate that constructs can be factual, imaginary, emotional, or whatever is important to the person generating the grid.

### 3.3 Rating scales

In **PCS** a scale allowing more distinctions may be used as required. If a 5 scale is used then the above example might become:



Thus, in this case, the first construct means that **writing** is considered the most **organized activity, thinking** is both **organized** and **haphazard,** and **understanding** is the most **haphazard activity.** Note how the use of a multi-point scale with an odd number of values allows for a central rating which does not force the user to choose either pole.

### 3.4 Repertory grid elicitation

In the past the elicitation of repertory grids has been a task requiring a skilled psychologist who can draw out a person's constructs whilst not imposing his own ideas or personality. This has involved the development of a variety of techniques and methodologies for grid elicitation (Kelly 1955, Fransella & Bannister 1977). The coming of powerful, low-cost personal computers has made it possible to program some of the elicitation techniques used by people in a form where they can be applied automatically. The **PLANET** system is an integrated suite of programs which runs on the Apple II/III family of computers. It is a suite of programs that operates through a menu system: **PCS** incorporates some of the basic ideas behind **PLANET. PLANET** contains a program **PEGASUS** (see 2.2) which elicits a single grid from a person and feeds back comments and suggestions during the elicitation. **PCS** is a multi-user version of **PEGASUS** that allows several people to interact as participants in grid elicitation, sharing and comparing their knowledge.

### 3.5 Construct analysis

Repertory grids encode information about a person's way of looking at the world. This information can be used without further analysis for some purposes since it is an aid to remembering the basis for decisions and actions. Shaw & McKnight (see 2.1) give an elementary introduction to decision making applications of repertory grids in everyday life. The information in a grid can also be analysed in a variety of ways to bring out possible underlying structures, or **construct systems,** in a person's world view and its relationship to those of others.

One major reason for analysis is to extract possible structure in the personal meanings of an individual and reflect it back to him in the context of the task in hand, and the perspectives of other participants in the group. The words **possible** and **reflect** are significant since we are dealing with **personal** meaning and any analysis is subject to debate; it is the basis of a conversation rather than some form of absolute answer.

The **FOCUS** algorithm (see 2.2) used in PLANET is a distance-based hierarchical cluster analysis technique that sorts the constructs into a linear order such that constructs closest together in the space are also closest together in the order. It is used in **PCS** to indicate the closest matching construct or element either in a single grid or between grids of the participants. It is left to the user to construe his own personal meaning in the result and confirm this directly in terms of the original data.

### 3.6 Analysis of constructs between participants

In **PCS** it is usually desirable to compare several constructs. **PCS** may be used to compare constructs within one's own grid, or to compare with any other construct on

the topic which has more or less the same set of element names. This is done by using the common elements on both constructs and computing the match, or level of similarity, based on the possible similarity and difference between the two. (This is dependent on the particular rating scale used which is always the same for each participant in the same participant grid.)

### 3.7 Analysis of agreement and understanding

Shaw (see 2.2) shows how **exchange grids** may be used for the measurement of understanding and agreement between either two people or one person on two occasions. In **PCS**, it is possible to exchange elements and constructs in either of these two modes. To explore **agreement** one person, A, must rate B's elements on B's constructs **as he, A, would have done**. If they **agree** on how these elements are rated then only high matches will appear when they are compared. A can then examine whichever construct matches he wishes, to explore agreement and disagreement with B.

To explore **understanding** A must rate B's elements on B's constructs **as he thinks B did**. Now if they agree it indicates that A can **understand** B's way of thinking, shown by the high construct matches. As before, A can examine whichever construct matches he wishes, to explore understanding and misunderstanding with B.

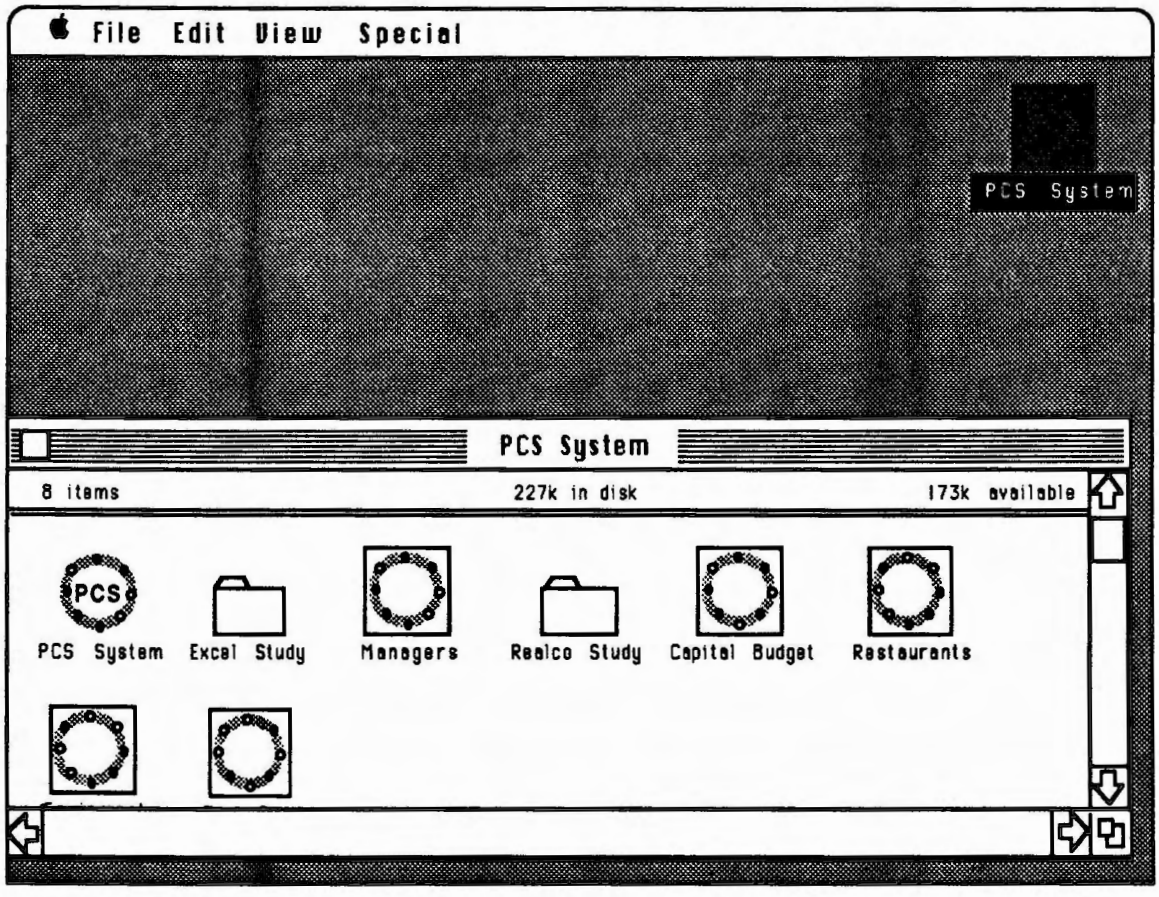
# 4. PCS GETTING STARTED

## 4.1 Computer configuration

PCS runs as an interactive participant system on a number of Apple Macintosh computers connected together through the Appletalk network.

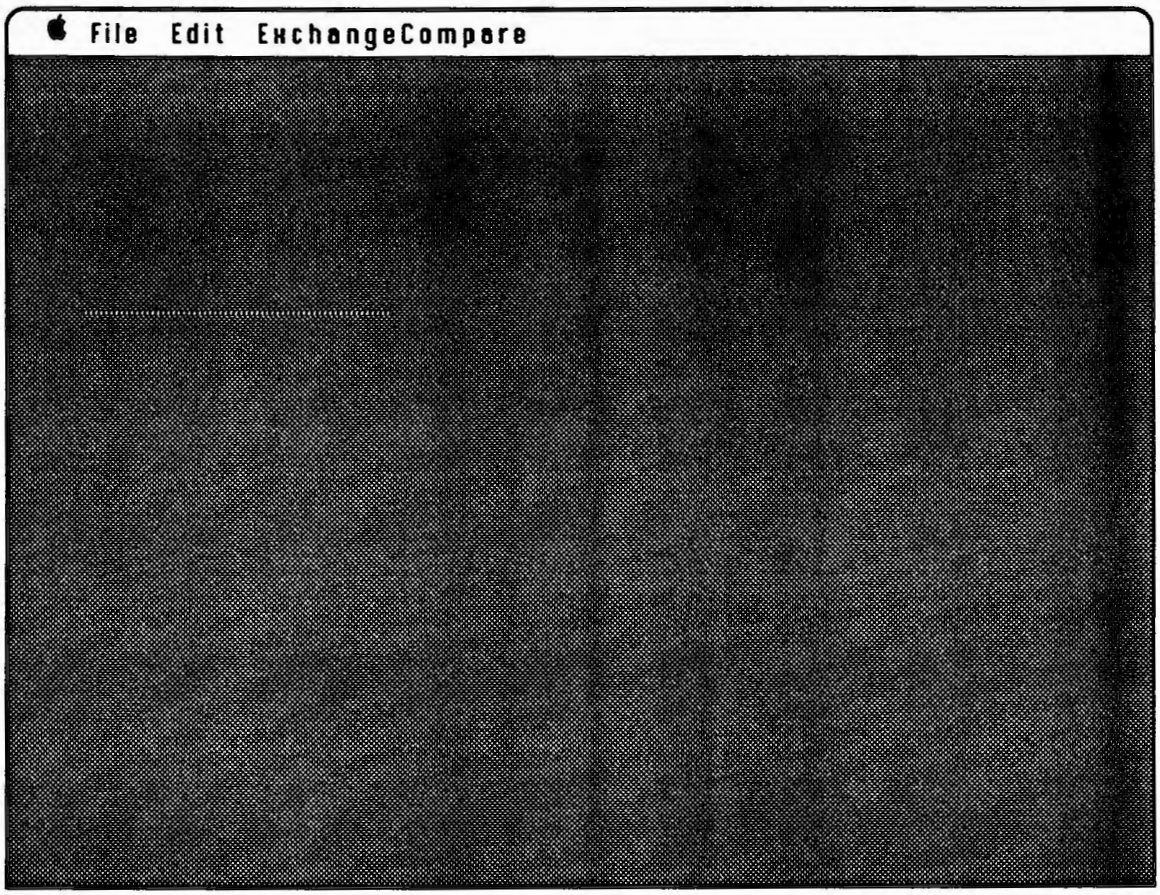
## 4.2 Starting up

1. Insert the **PCS** disk in the drive.
2. Switch on your Macintosh.
   Within a few seconds the **PCS** icon will appear on the screen and by clicking on it twice you are ready to start using the system.



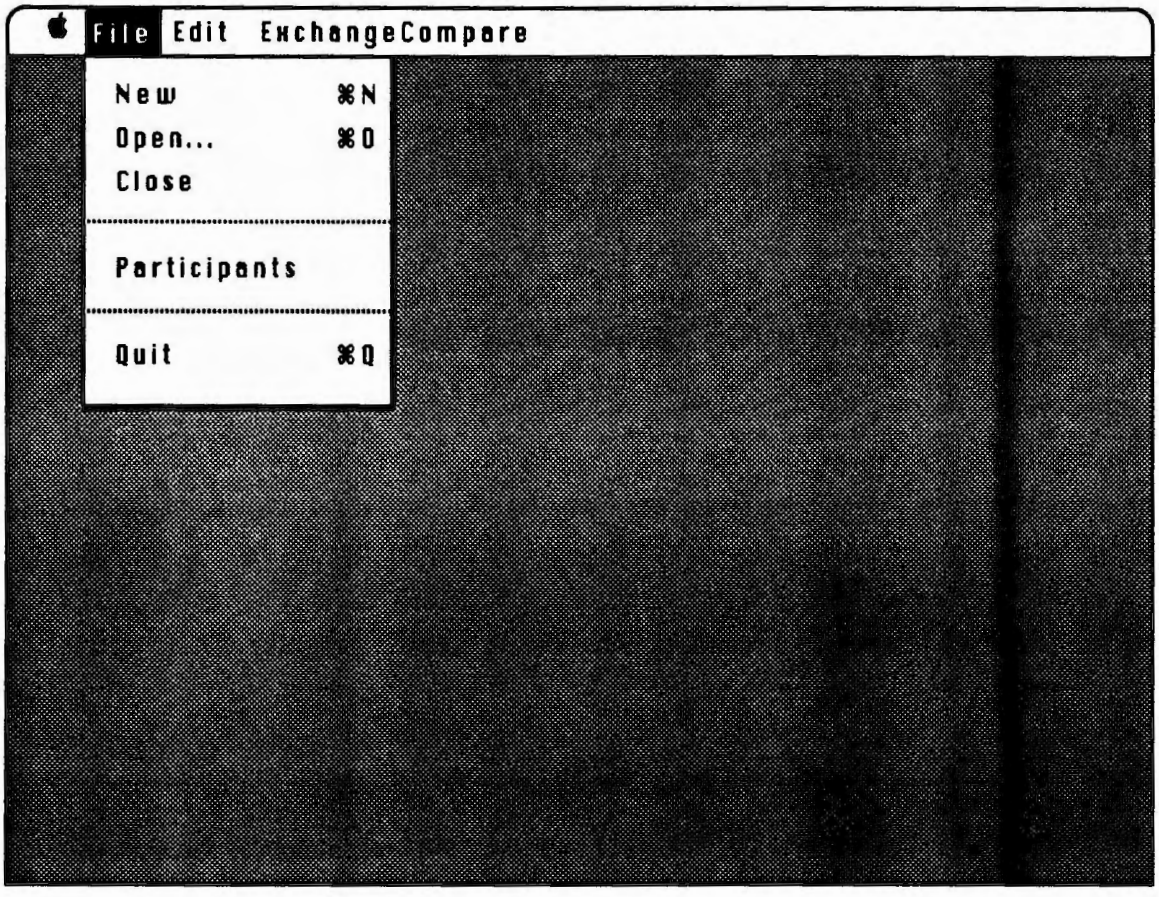
### 4.3 The PCS screen

The main screen contains a number of items in the menu bar offering options for editing or viewing data, and a working area for eliciting a grid or rating and comparing constructs.



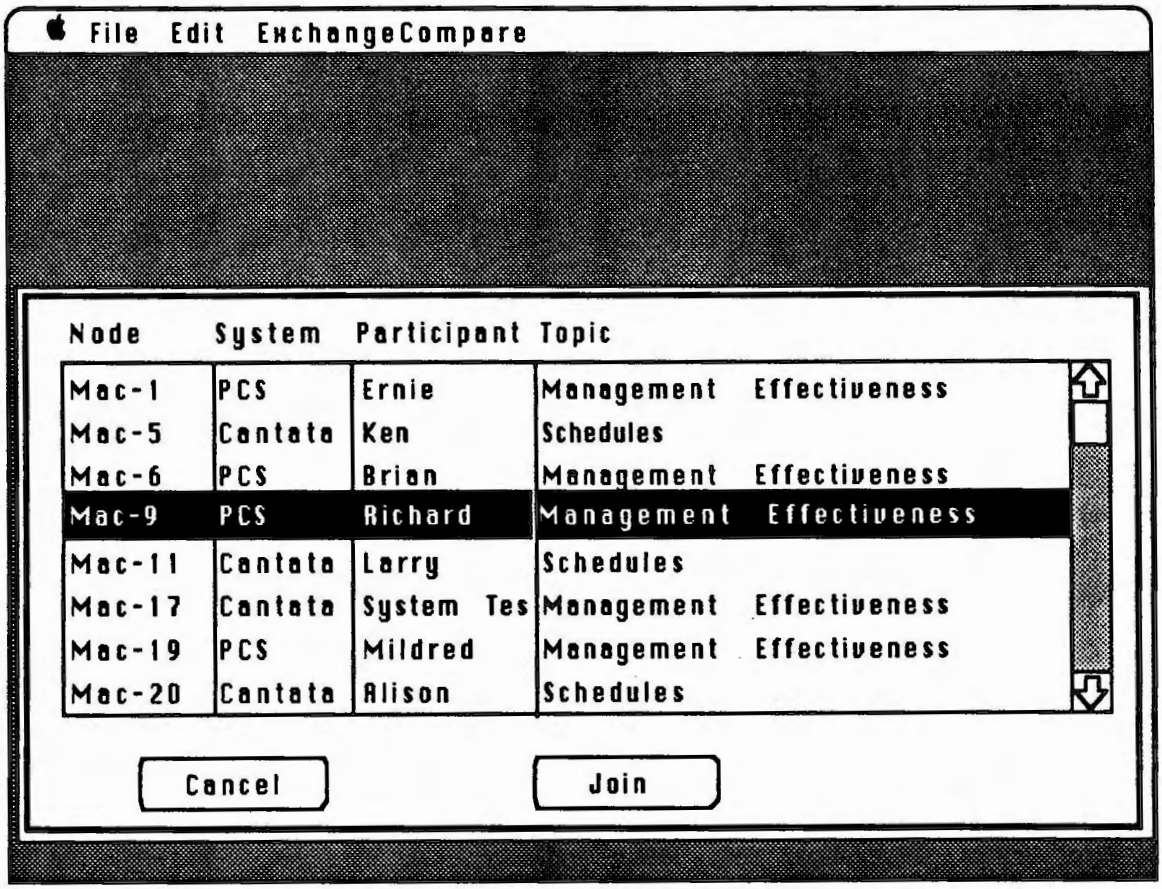
### 4.4 The File menu

Postion the pointer on the **File** menu title and press to bring down the **File** menu. This allows you to drag to select **Open, Close**, choose a **New** topic/community, see who else are **Participants** or **Quit**. If you want to see who is on the network and what they are doing then select **Participants**. If you want to start a new topic select the **New** option, then fill in the new values you want on the **Status** menu. If you wish to continue an elicitation already started, exchange construct ratings with another participant, or match your own or others' constructs then select **Open** and go to the appropriate menu for what you wish to do. If you select **Close** then your interaction with the current topic will be (temporarily) terminated. **Quit** returns you to the main system.



### 4.4.1 The Participants window

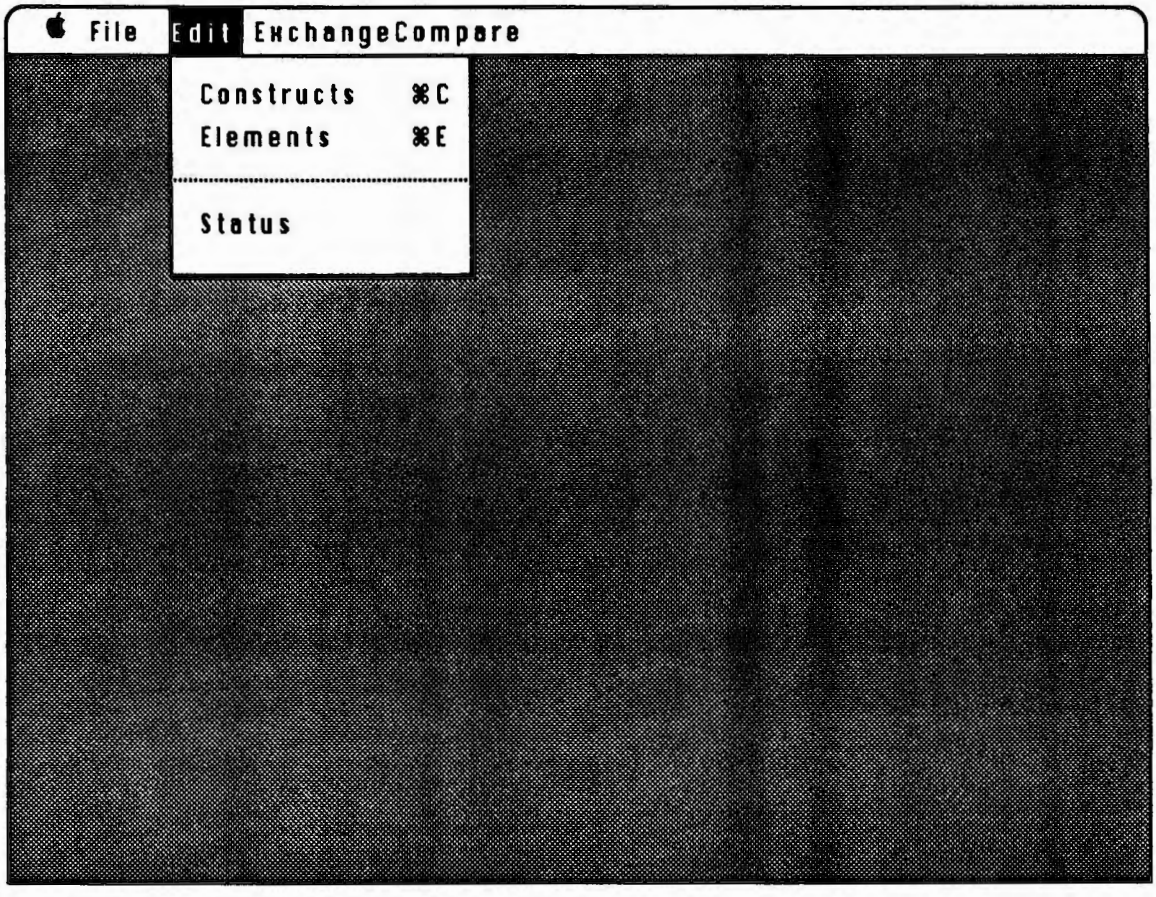
Release on **Participants** to bring up the **Participants** window. This shows each of the nodes logged in to the network, what system each is using, and the name and topic of the participant.




If you want to join an existing topic in PCS then you can select one from the topics in progress, otherwise select from the closed files available on the start-up screen (see Section 4.2).

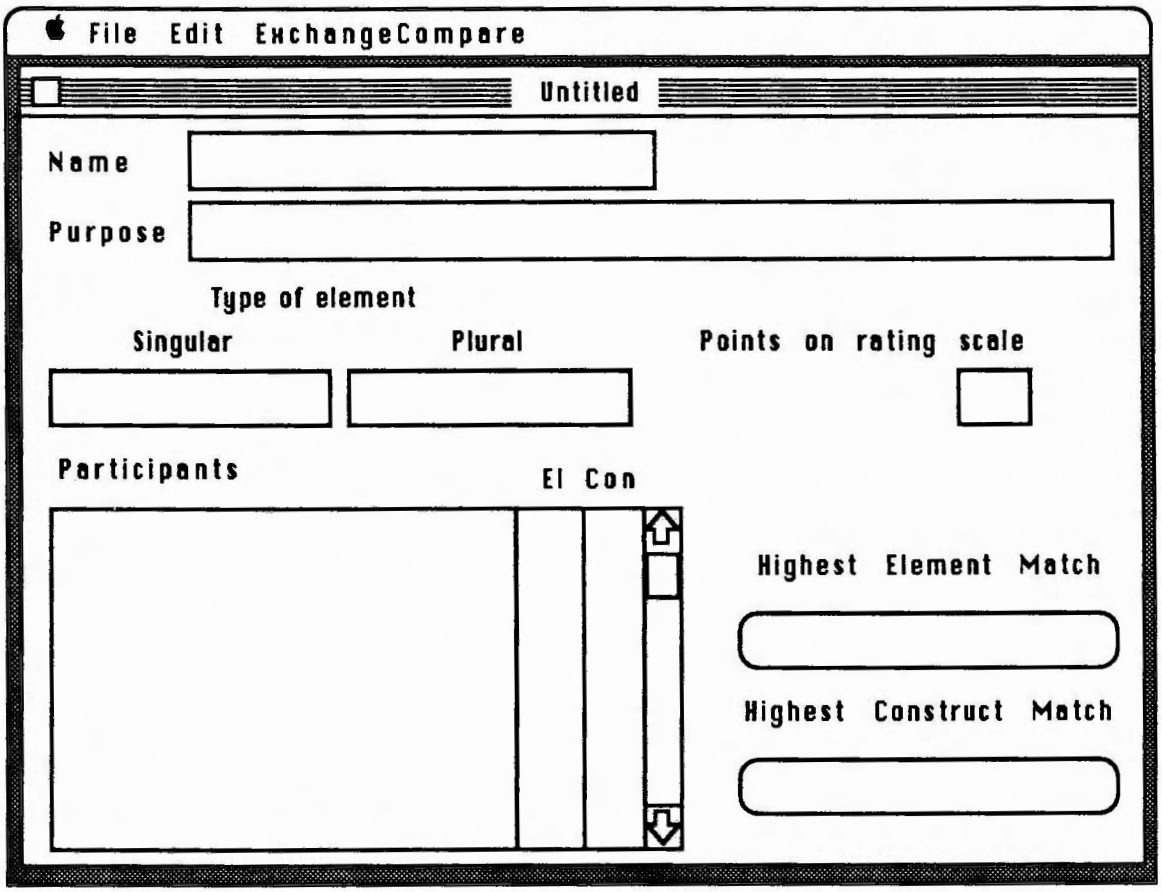
### 4.5 The Edit menu

Position the pointer on the **Edit** menu title and press to bring down the **Edit** menu. This allows you to drag to select **Constructs, Elements** or **Status.**



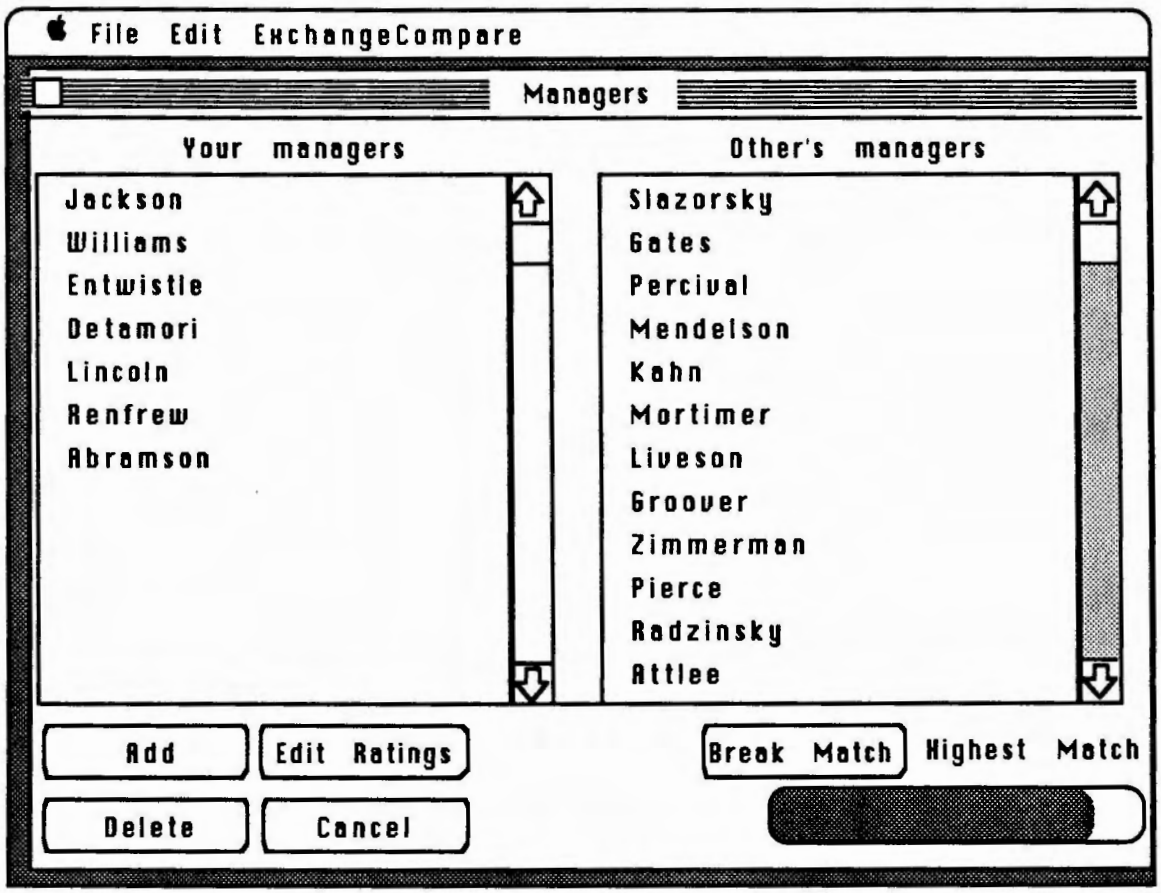
### 4.5.1 The Status window

Release on **Status** to bring up the **Status** window. This shows the name of the user, the purpose of the elicitation, the singular and plural forms of the type of elements and the rating scale. Any of these can be changed if this is a new file, but if you are matching constructs or exchanging data some options will be disabled (coloured grey). During the elicitation procedure it also shows the names of other participants on the same topic, the number of the user's and other participants elements and constructs and the status of the user's highest element and construct matches.



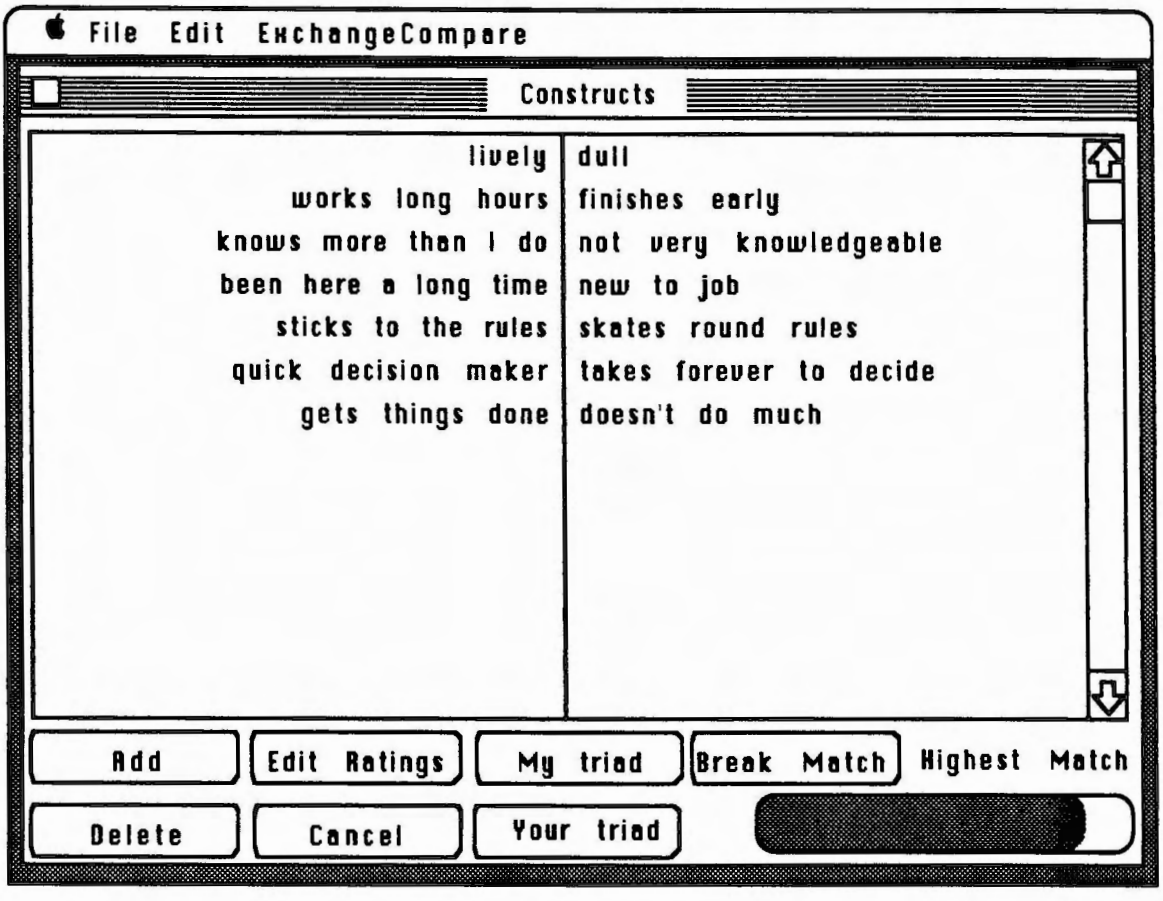
### 4.5.2 The Elements window

Release on **Elements** to bring up the **Elements** window. The left box shows you your element list which you can edit, add a new element if you think of one you would like to include, delete an element that you find no longer appropriate but only if you chose to add it yourself, rather than it coming from the group, or edit your element ratings. The box on the right shows other participants' elements which you can view or move to your own list. The window also shows the status of your highest element match which you can choose to split by clicking on the **Break Match** box to add a construct.



### 4.5.3 The Constructs window

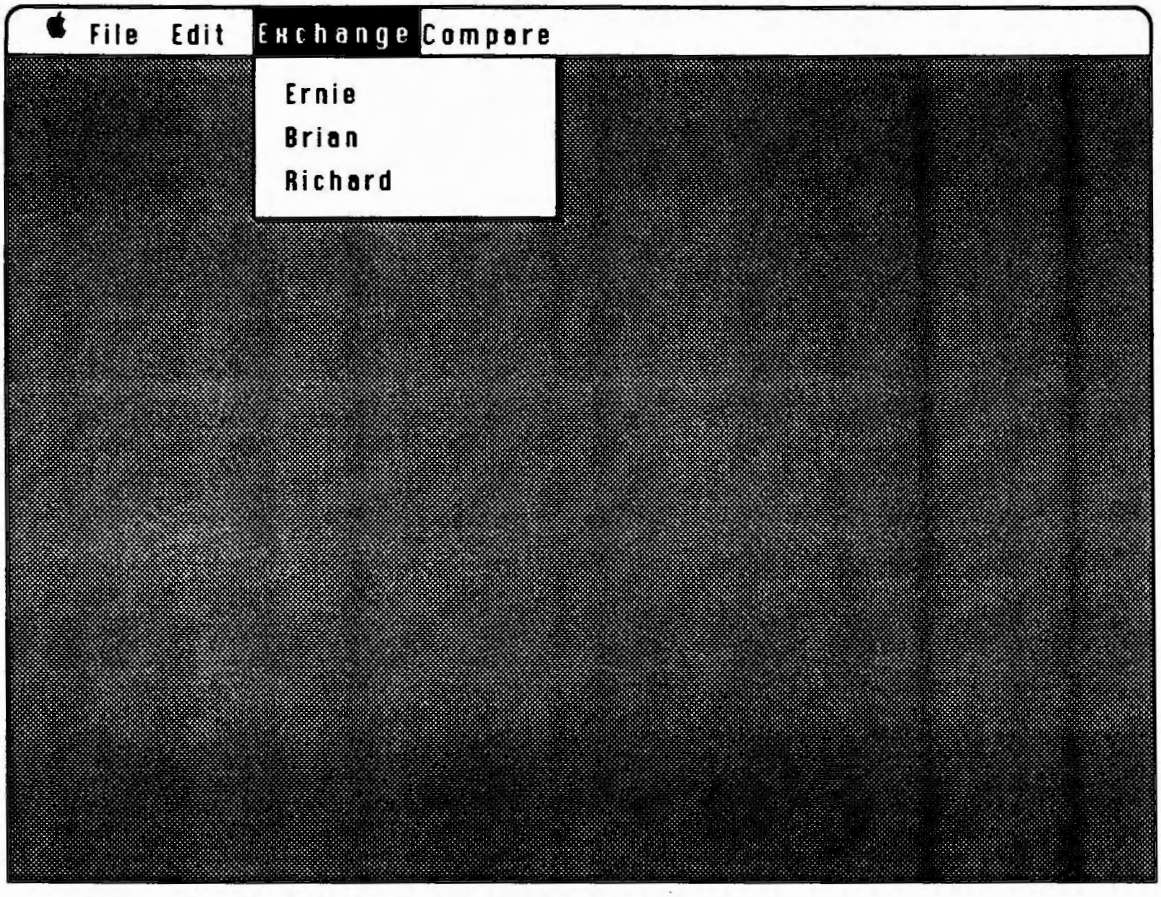
Release on **Constructs** to bring up the **Constructs** window. This shows you your construct list which you can edit, add a new construct if you think of one you would just like to include, delete a construct that you find no longer appropriate, elicit a new construct from a triad or edit your construct ratings. It also shows the status of your highest construct match which you can choose to split by clicking on the **Break Match** box to add an element.



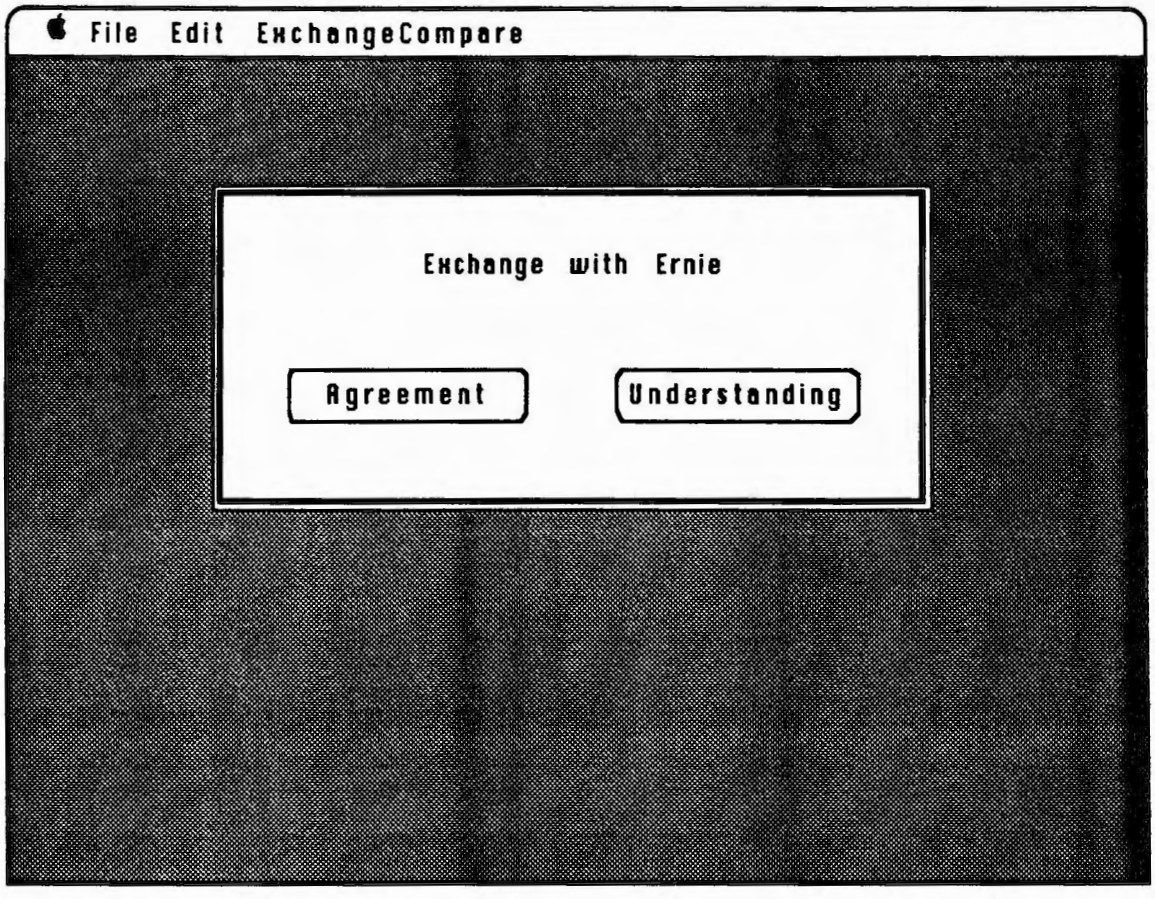

When you have finished with the window you are using, click on the close box in the top left corner to return to the main screen. Usually the Status window is displayed unless specifically turned off.

### 4.6 The Exchange menu

Position the pointer on the **Exchange** menu title and press to bring down the **Exchange** menu. This allows you to drag to select the person on your topic with whom you wish to exchange constructs.



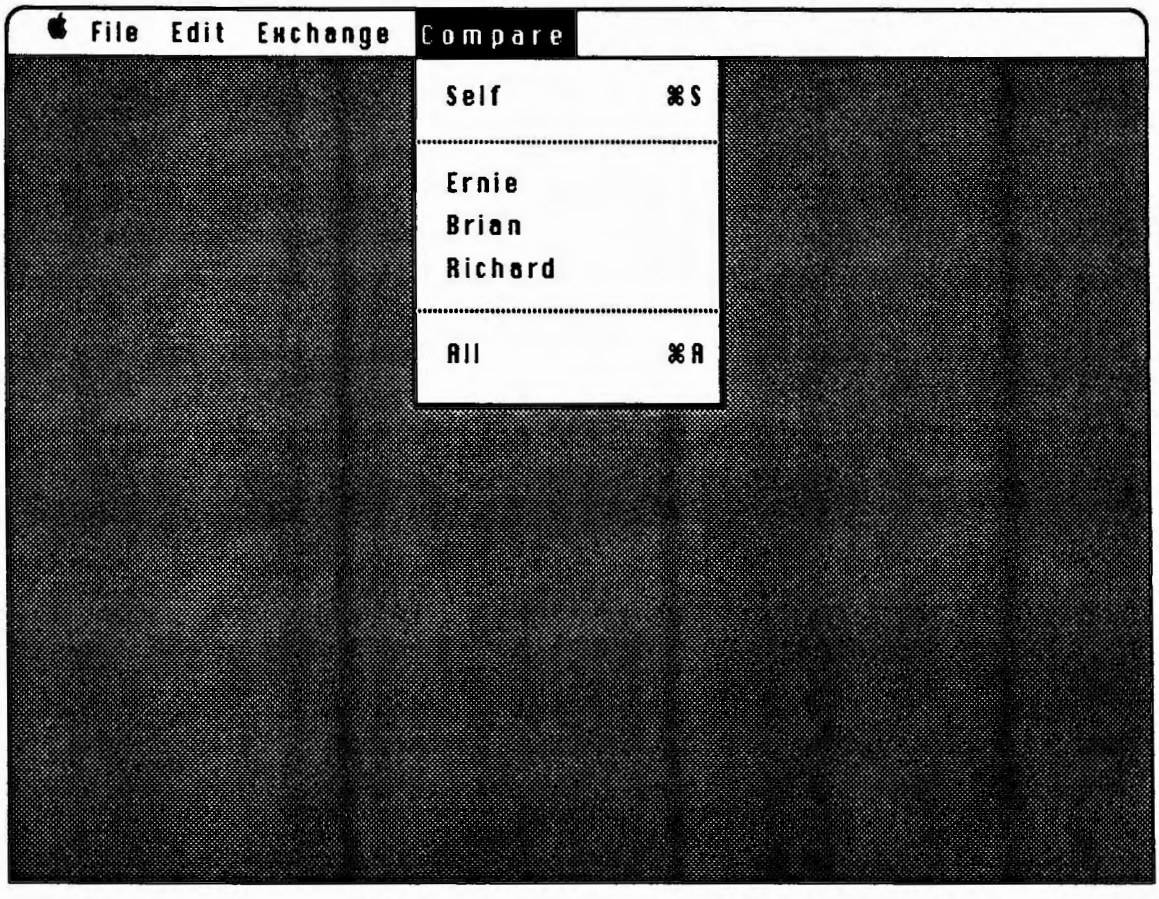
Then you can select either **Agreement** or **Understanding** (See Section 7).



### 4.7 The Compare menu

Position the pointer on the **Compare** menu title and press to bring down the **Compare** menu. This allows you to drag to select **Self** to compare your own constructs with each other, select the person on your topic with whom you wish to compare constructs, or you can choose to compare with **All** of these.

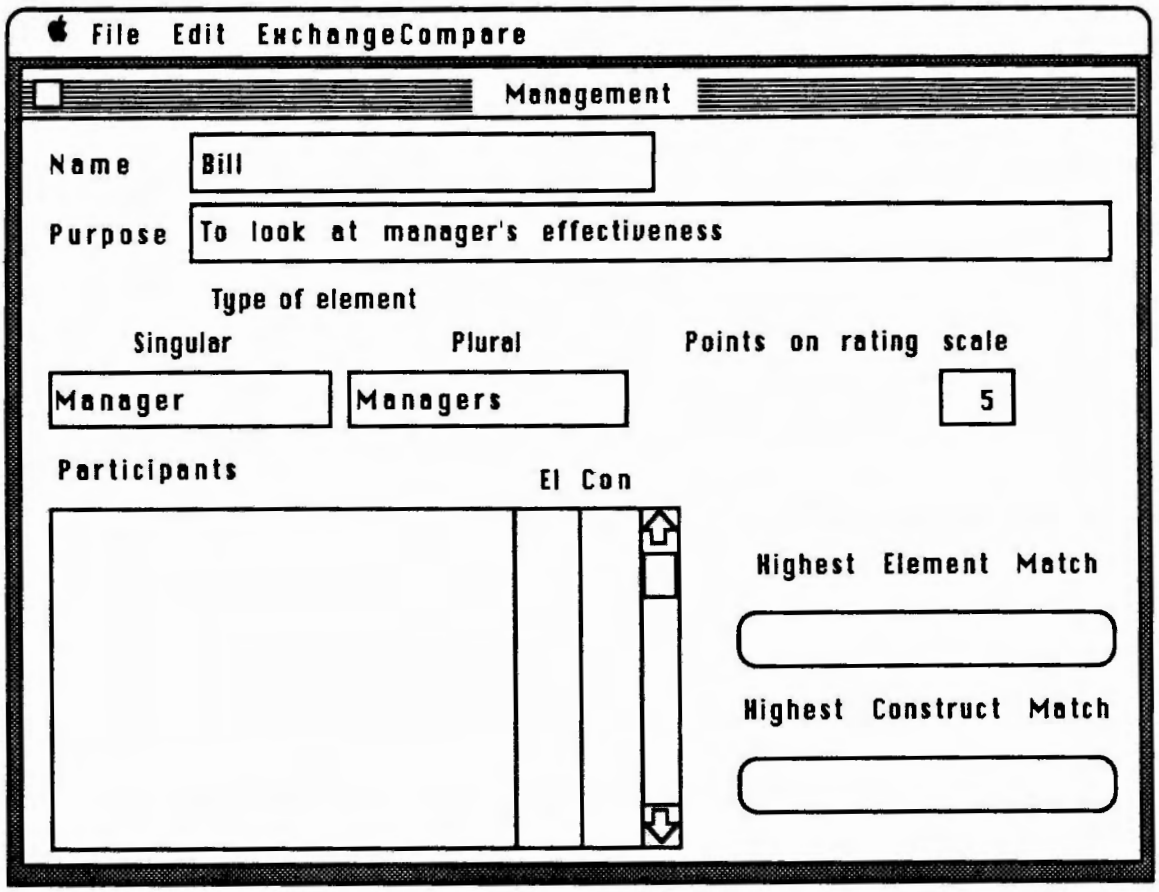
Obviously, you cannot compare constructs if all or most of the elements are different since there is no basis for the comparison. If, however, only one or two are different, comparison is made on the basis of the ones held in common.



# 5. PCS RUNNING A SESSION

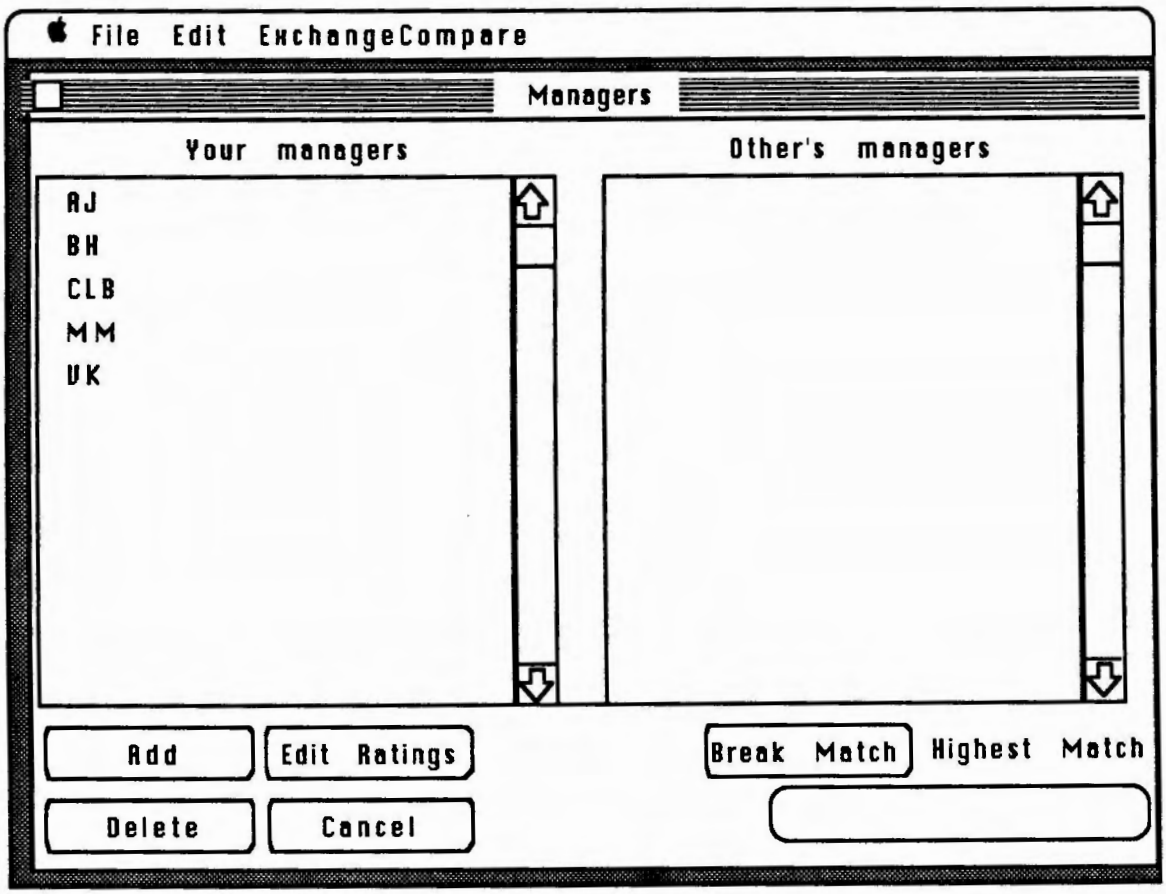
## 5.1 Set up the Status

When starting a new topic the status window must first be checked and changed if necessary. Usually a new topic will have a specific purpose which should be entered in the appropriate box, and kept in mind as the interaction proceeds. The bottom half of the window will change automatically as elements and constructs are added. In this example Bill is construing **managers** to see which of the ones he knows are **effective** and why.



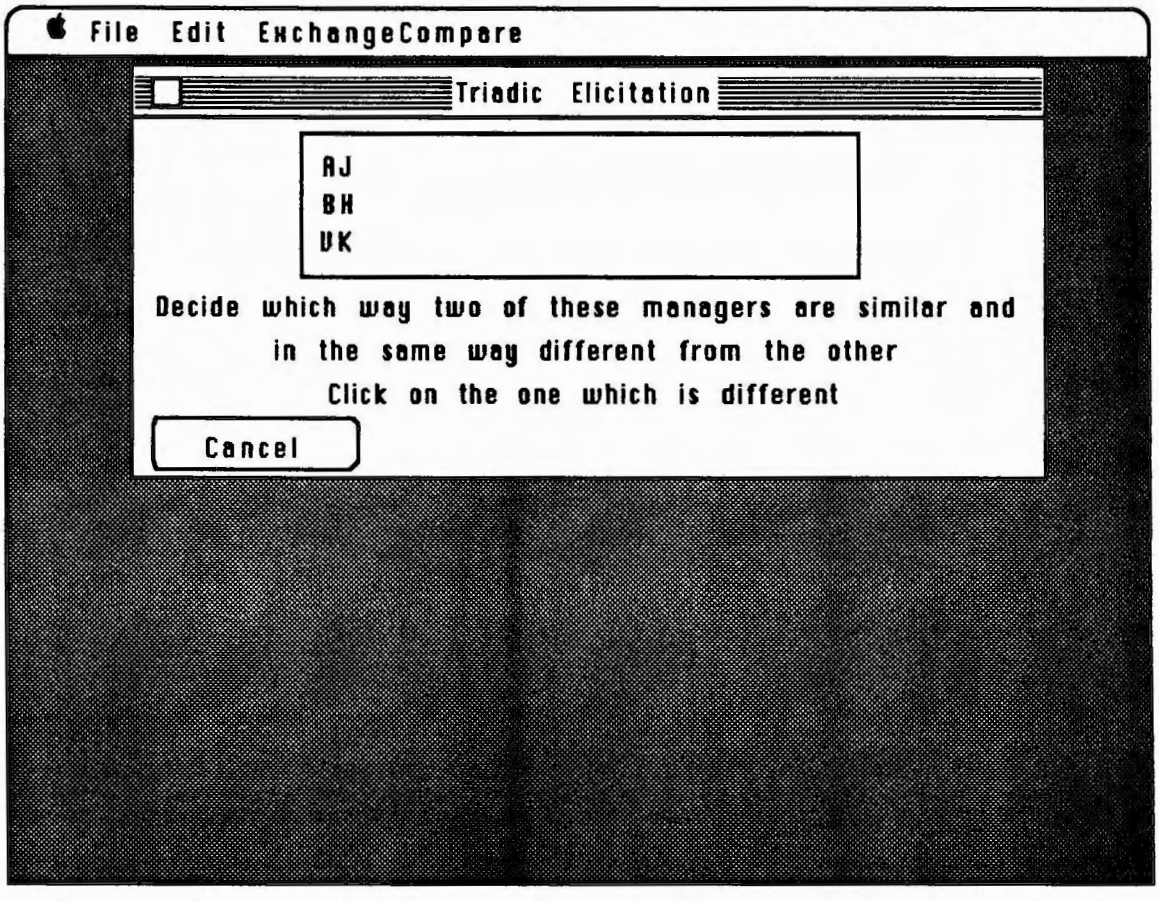
## 5.2 Initial Elements

The next thing for Bill to do is to think of some managers and add these as elements. He does this by going to the **Elements** window in the **Edit** pull-down menu, then typing in the names of the managers he would like to think about one on each line. There is always an empty line after the list of elements for you to add another any time you want. Bill knows that about six is the best number to start with, and that less than three will make triadic elicitation impossible. He adds five. If a typing error is made he can just go back and correct it.



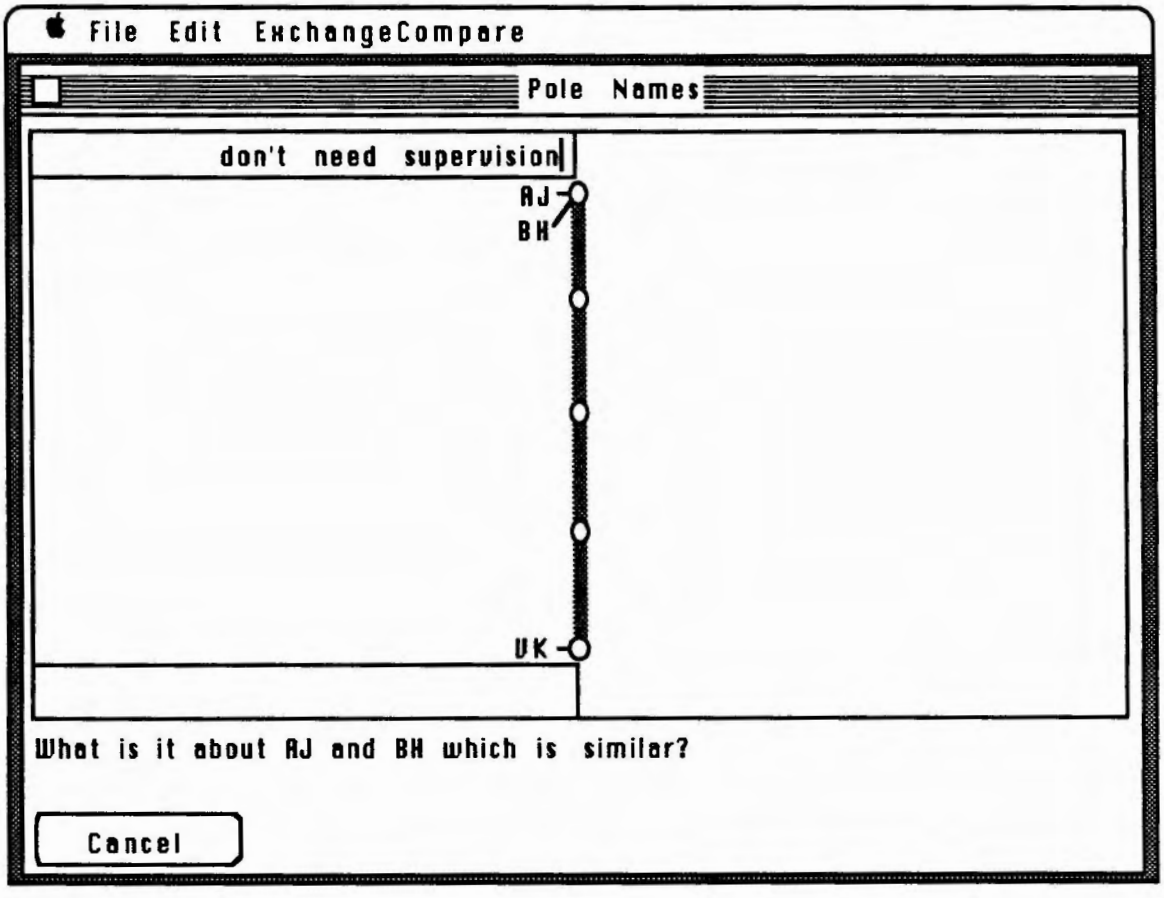
### 5.3 Triadic Elicitation

As Bill is just starting his grid, he decides to elicit a construct from a triad, so he goes to the **Constructs** window in the **Edit** pull-down menu, and chooses triadic elicitation from a random triad. Sometimes part way through the elicitation the user may wish to choose his own triad, otherwise the system will choose one at random. Bill sees the three elements in the triad, and decides that VK is the one which is different from AJ and BH.

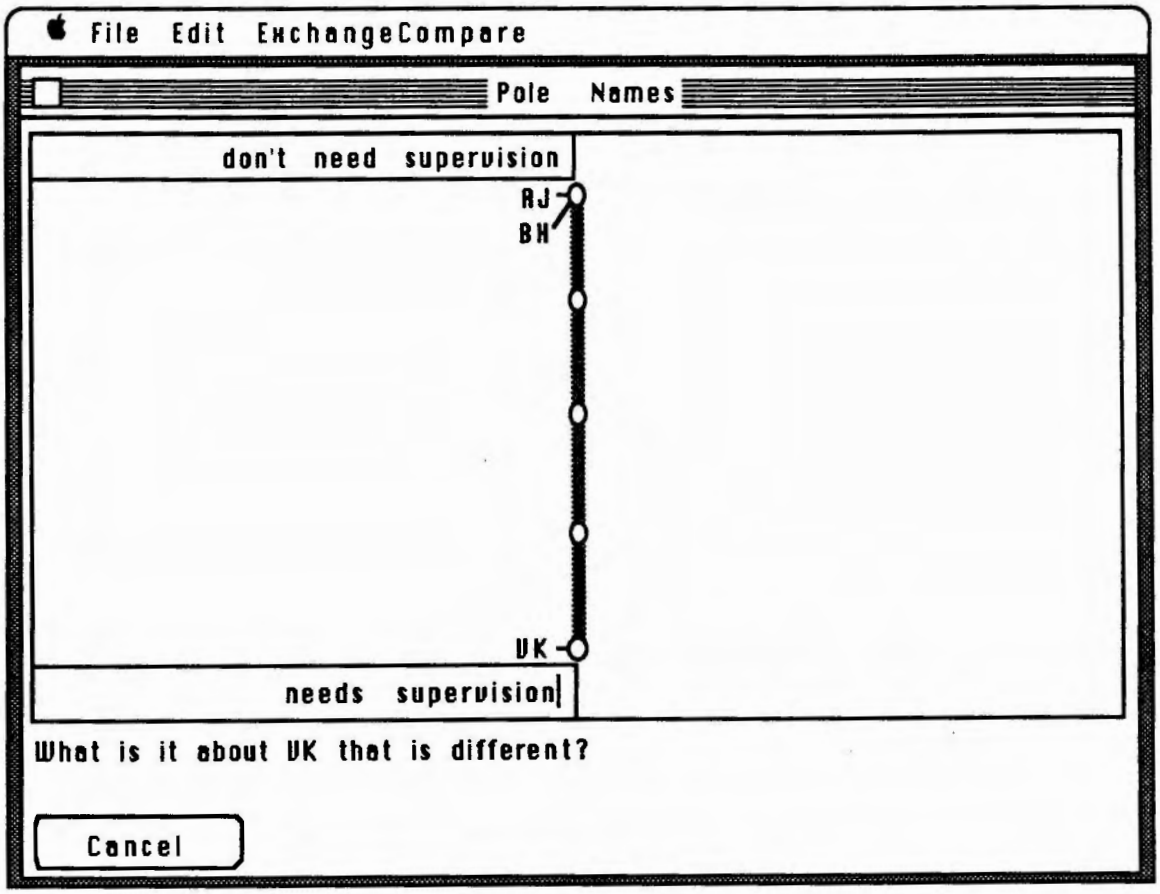


### 5.4 Naming the Construct

Now Bill has to decide why he thinks AJ and BH are alike and different from VK. He types in the description of the pair, **don't need supervision**, on one pole of the construct.

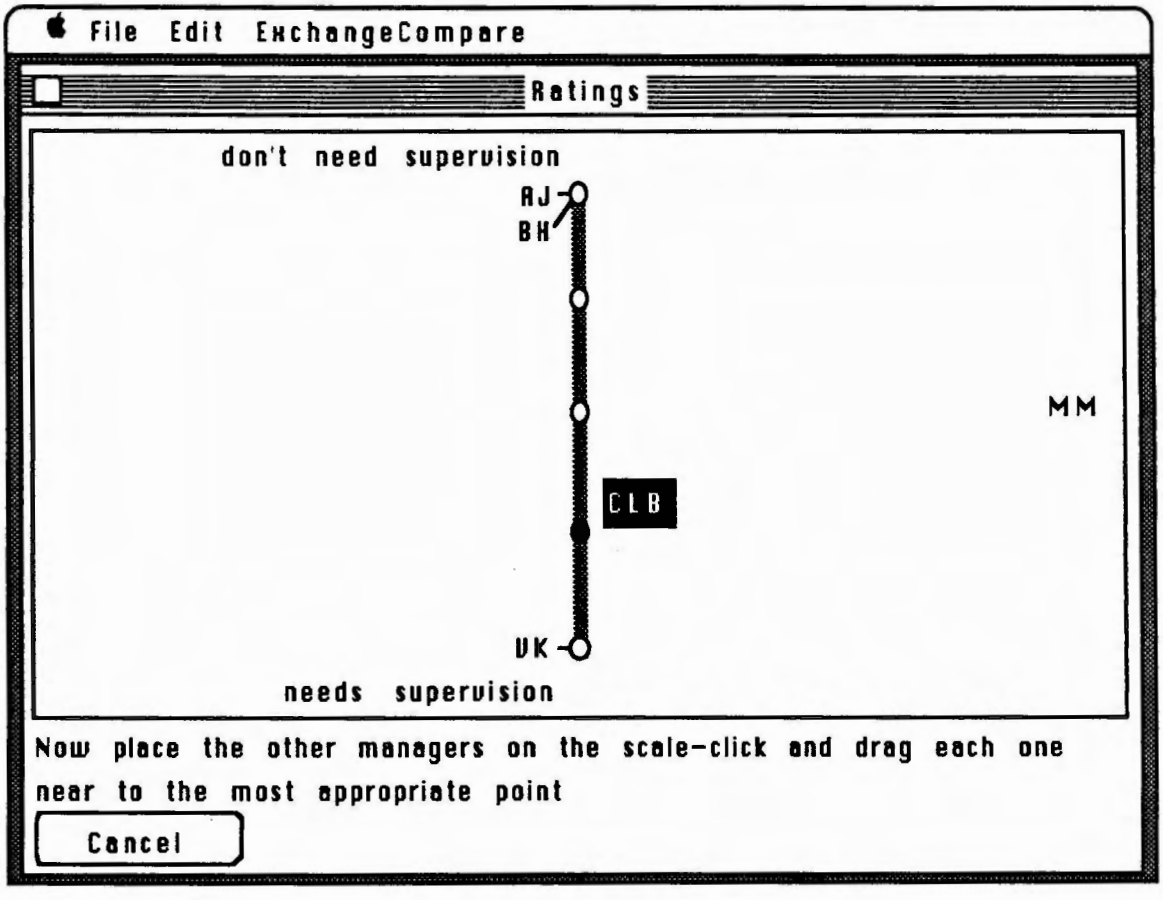


Then he names the other end of the construct. That is, the way in which VK is different is that he **needs supervision.**

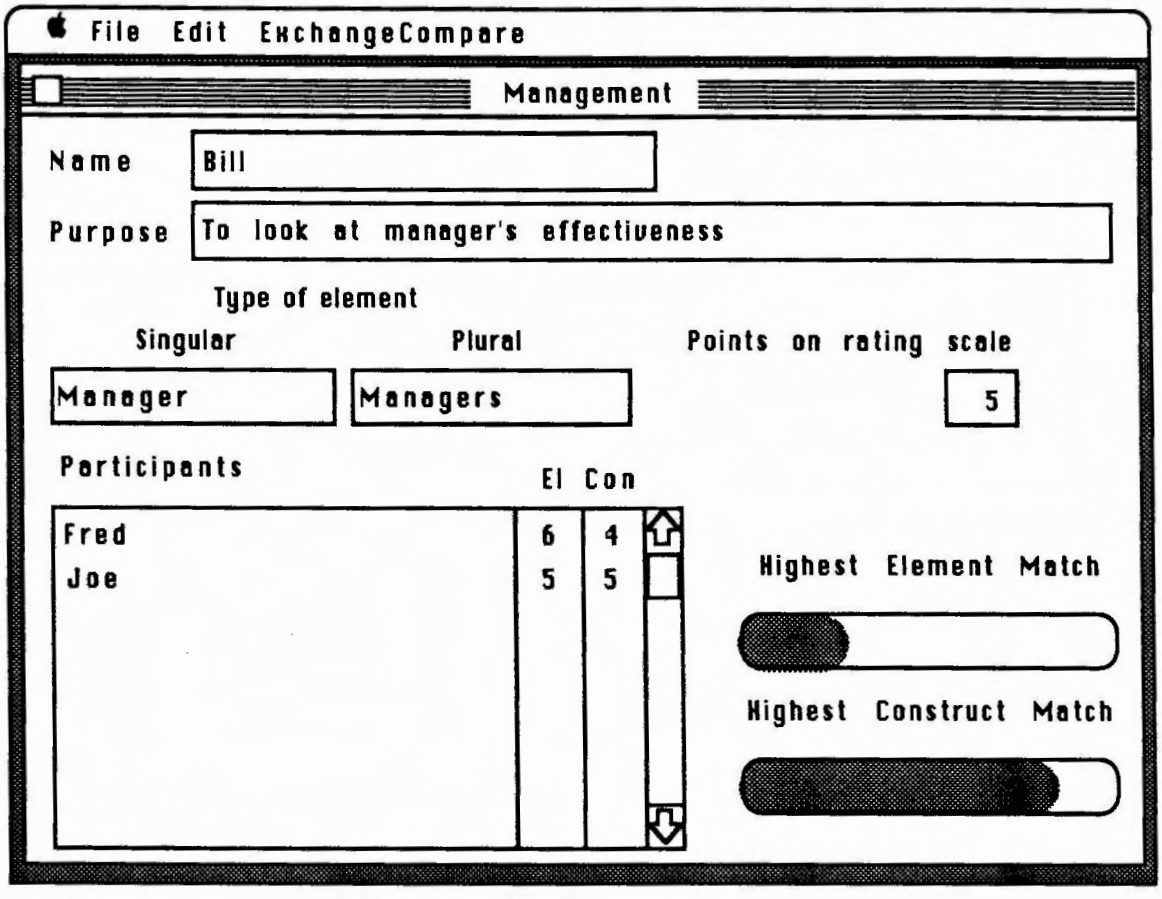


## 5.5 Ratings

This defines Bill's scale from **don't need supervision**, to **needs supervision**. He now has to rate all his other elements on this scale too. If he finds that his original triad AJ, BH and VK need to be moved to accommodate the others he can do that. In this case he puts CLB partly up the scale, and MM partly down the scale, because MM doesn't need much supervision and CLB needs a bit more but not as much as VK.

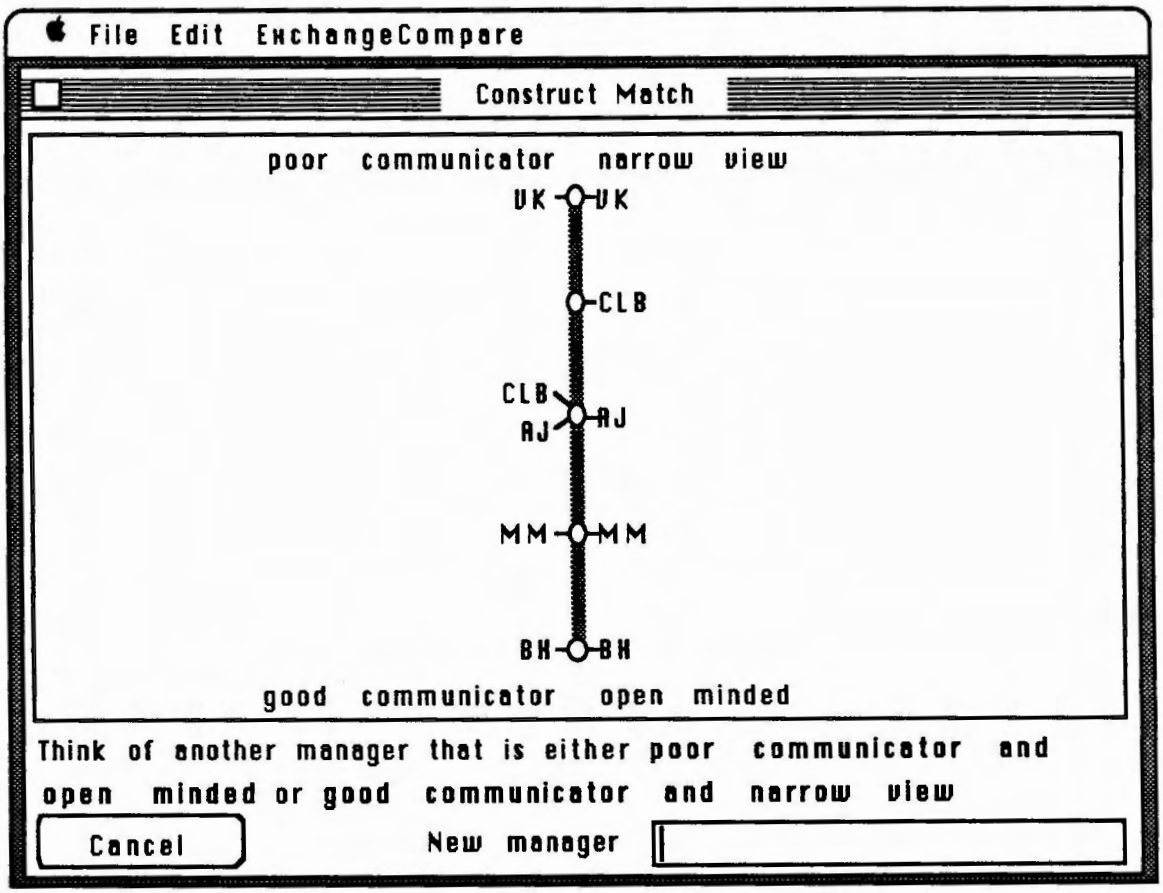


Now Bill has got his first construct. He now continues adding several more constructs from triads before he decides to look at who else is on the system. He brings up the **Status** window from the **Edit** menu, and sees that Fred has six elements, and Joe has five. He can also see that he has a high construct match, and decides to split it. Perhaps he can use one of Fred or Joe's elements for that.



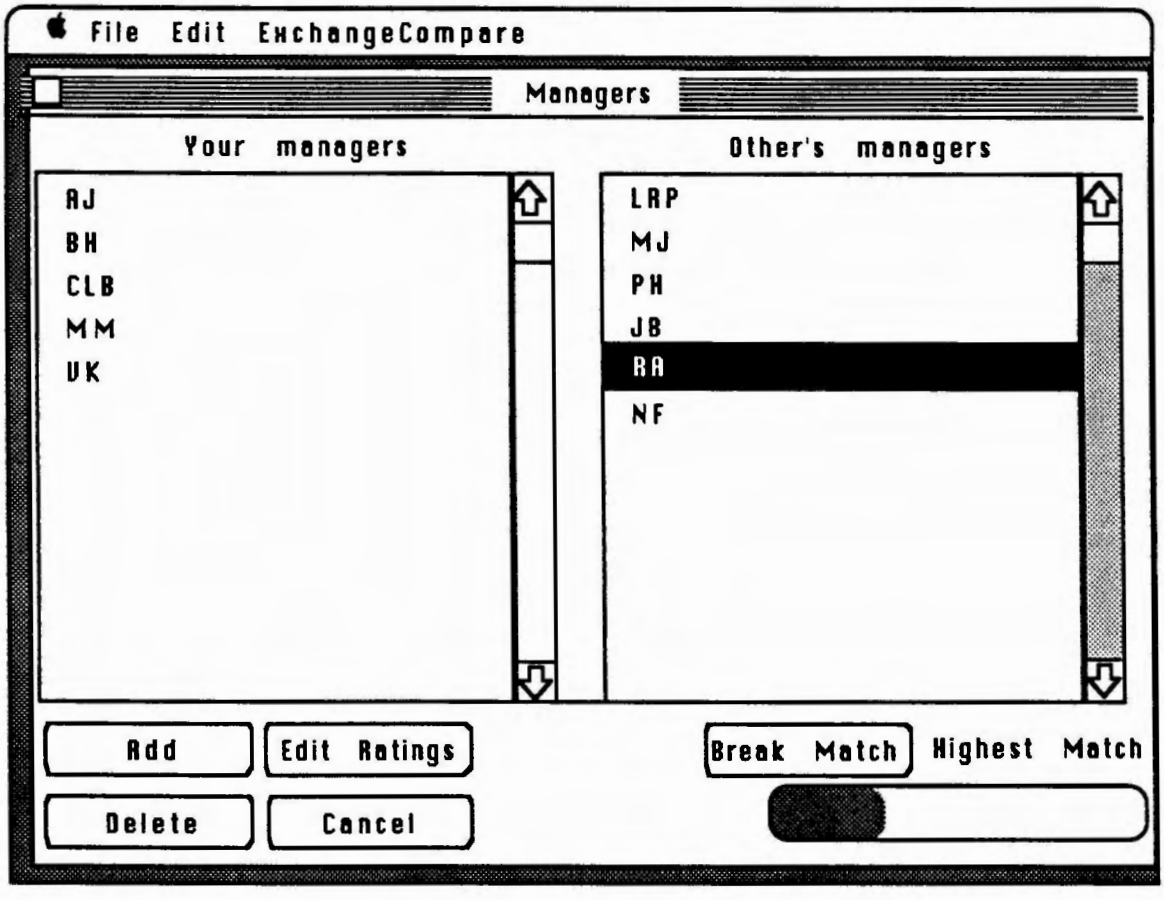
### 5.6 Matched Constructs

Bill brings up the **Constructs** window from the **Edit** menu and clicks on the **Highest Match** box. This takes him to a new screen showing which constructs are matched.

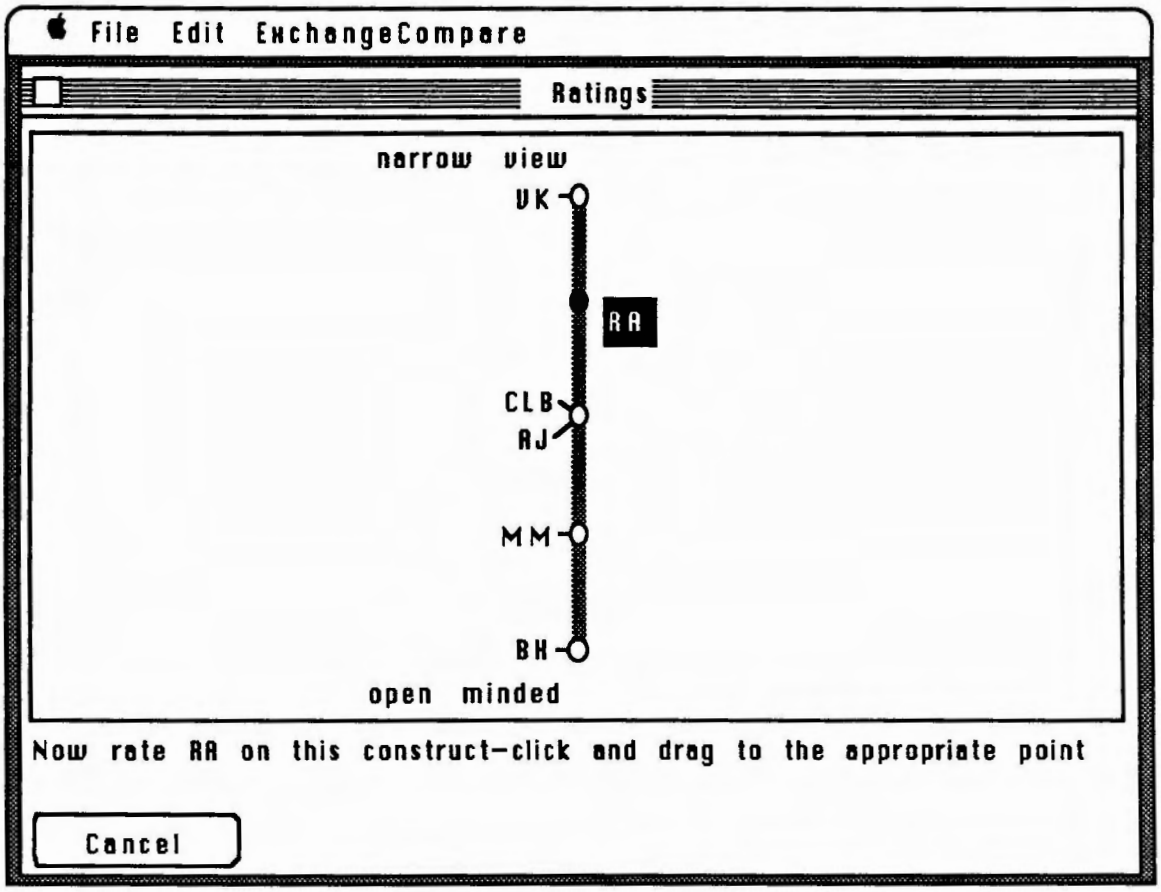


### 5.7 Adding an Element

Bill decides to add an element so he brings up the **Elements** window from the **Edit** menu. Now he can see the elements put in by Fred and Joe, and either click on one of those to add it to his list, or just type in a new one of his own. If he wants to go back and look at the matched constructs again, he would have to go back to the **Constructs** window, and click on the **Highest Match** box. He chooses to add **RA** from Fred and Joe's list.



Now he will have to rate **RA** on each of his constructs in turn. The screen shows his constructs one at a time and he must place **RA** where he thinks he fits on the scale.




Note that he may still choose not to rate **RA** on opposite ends of the two matched constructs, but if he does not then the constructs will still be highly matched.

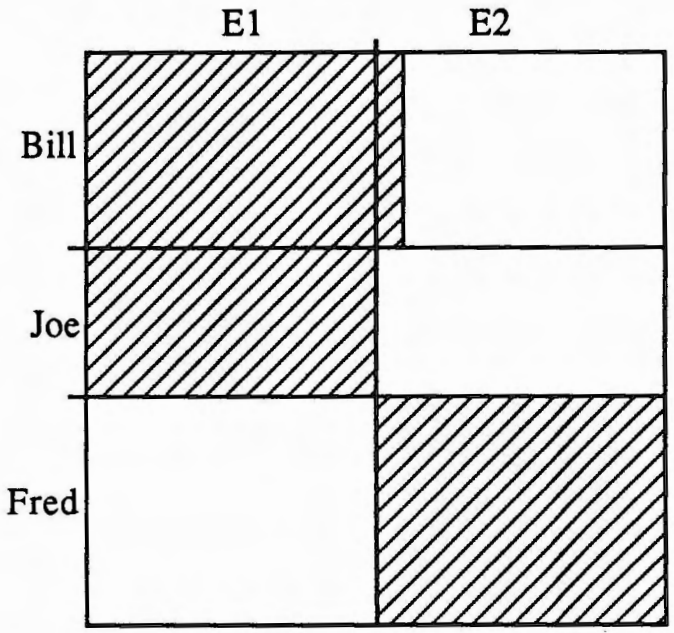
If he does not complete the ratings for a new element on each construct (or each element on a new construct) he will be unable to close the window without losing the new element (or construct).

## 5.8 Continuing the Interaction

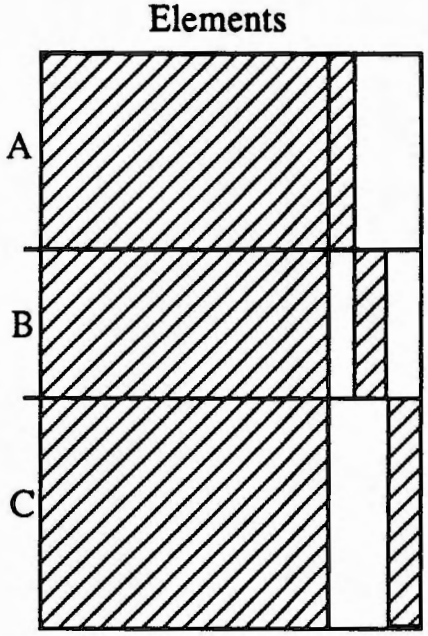
Bill continues to elicit his grid with the options available as described in Section 4. At any time he can review his purpose on the **Status** window to make it more closely reflect his choice of elements and constructs. He can add or delete elements or constructs, use triads or just type in names and ratings. When he chooses to finish he can **Close** the file from the **File** menu, and it will be stored as part of the total interaction on the Participant Grid under the topic file name.

# 6. PCS DATA STRUCTURE OF THE PARTICIPANT GRID

The grids elicited from each participant contribute to one data storage grid. At the first stage of grid elicitation this has rows of constructs and columns of elements with blocks of ratings for each participant, and sparse areas where no overlap occurs.

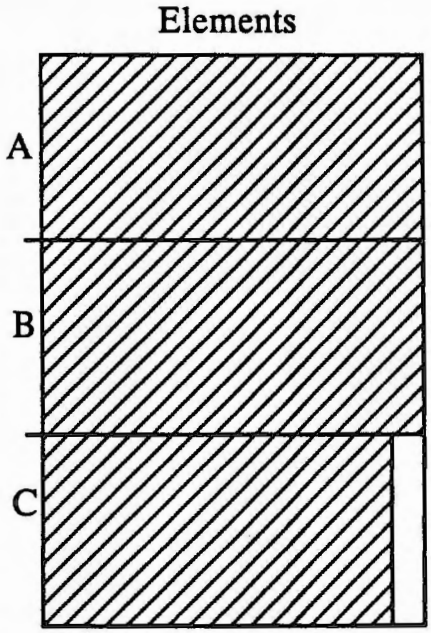



This shows that Bill has elicited his grid using element set E1 and an odd one or two from set E2. Joe has used the same initial set as Bill, that is, set E1, and elicited his own constructs. Fred has used element set E2 to elicit his own set of constructs as shown. Sometimes the group would choose to have the same element set initially, and add one or two individual ones of their own.




As other parts of the interaction take place, such as rating elements on another's constructs, new rows are added to this data structure.

When doing an **Exchange** new constructs will be added (see Section 9).



# 7. PCS EXCHANGE PROCEDURE

There are two forms of construct **Exchange** -- rating the chosen participant's elements on his or her constructs as:

(1) you would have done;
(2) you think he or she did.

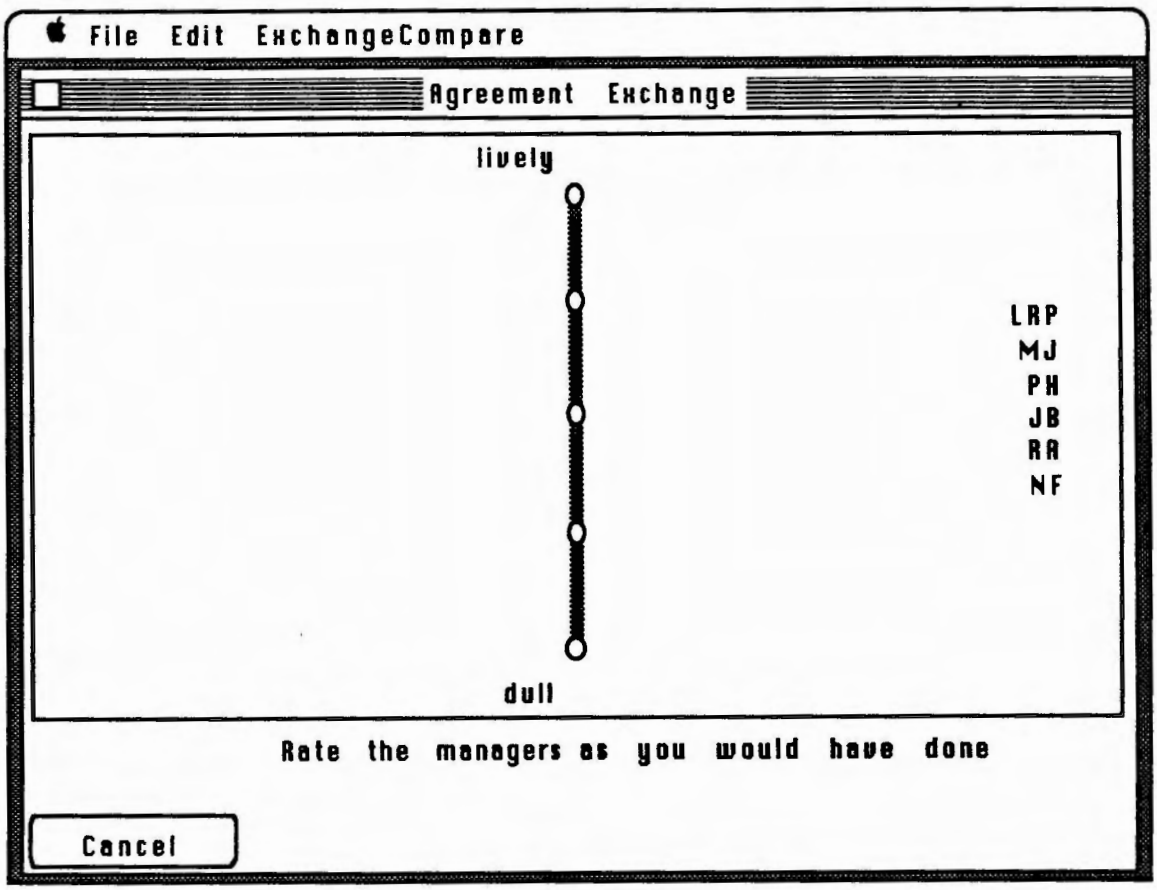
These two procedures enable you to compare:

(1) your agreement with the other participant;
(2) your understanding of the other participant.

You can select either of these forms, or do both one after the other. Whichever you select, you will follow the same procedure, but with a different rubric.

## 7.1 The Agreement Exchange

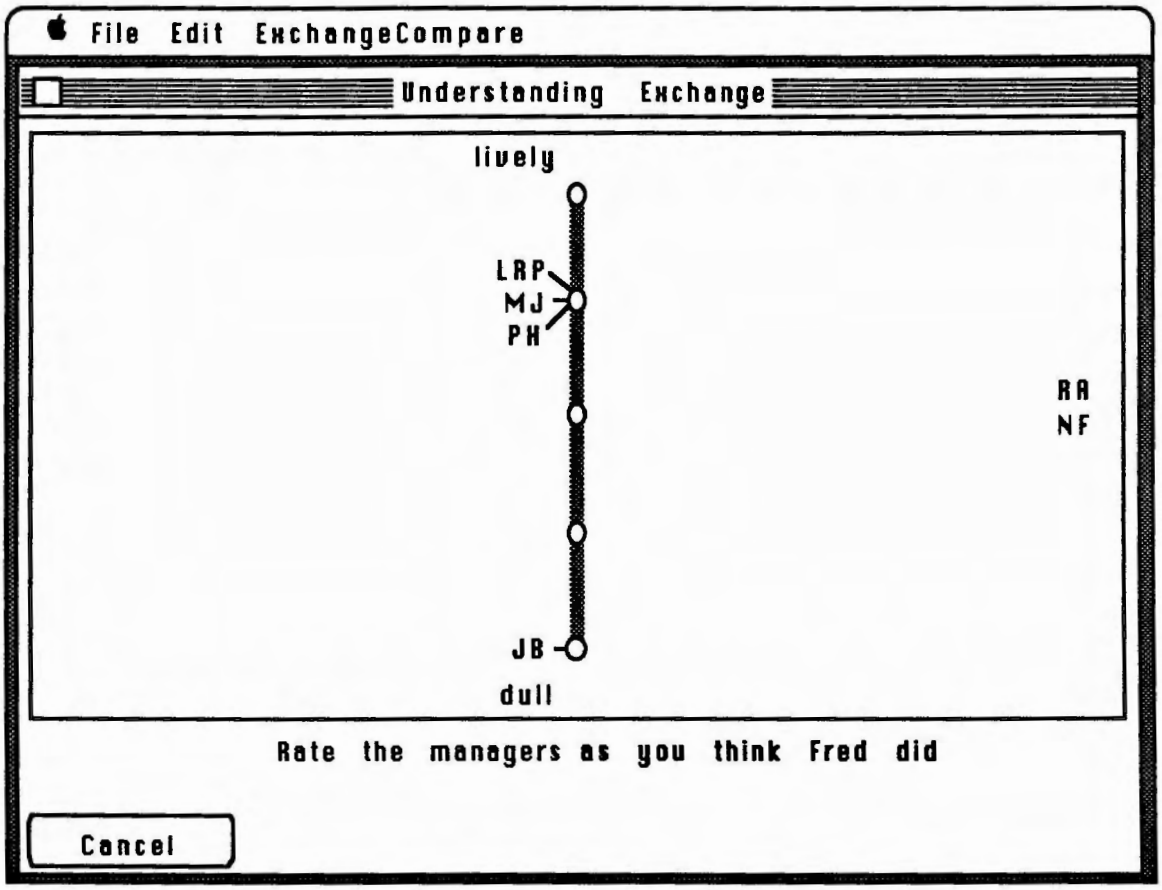
Drag to the name of the person with whom you wish to **Exchange** on the **Exchange** menu and release. Click on the **Agreement** box for this type of **Exchange**. The first construct of the person you selected will appear, and you must rate his or her elements on this construct **as you would have done** if they were your elements and your construct. Bill chose to **Exchange** with Fred; his first screen was:



He placed these elements on this construct as if it were one of his own constructs, the continued with the next construct until he had done this for all of Fred's constructs.

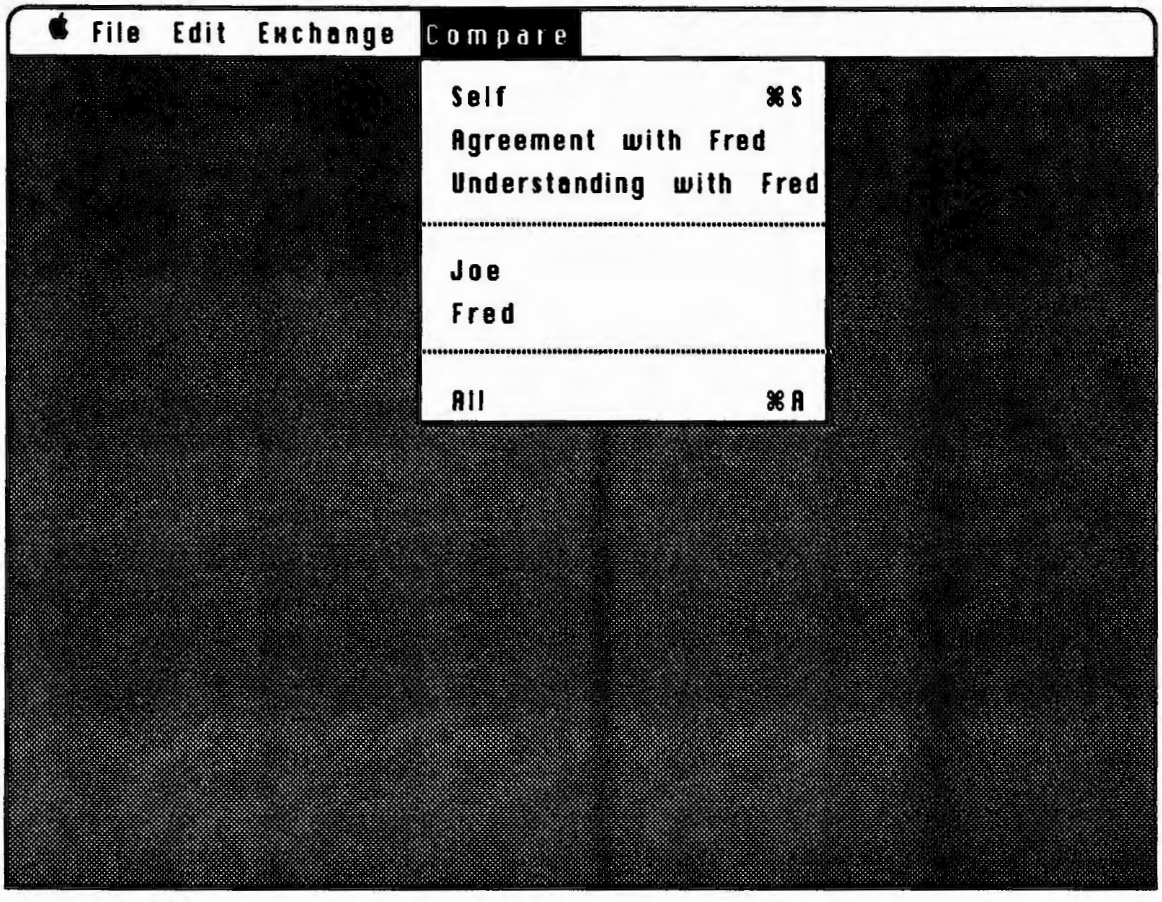
### 7.2 The Understanding Exchange

To repeat this process for **Understanding** Fred's constructs, Bill had to go back to the **Exchange** menu title, drag to **Fred** as before, then select **Understanding** by clicking on that box. This time he had to rate Fred's elements on Fred's constructs **as he thought Fred had rated them.** The screens looked the same for each construct, just the positioning of the elements was different.

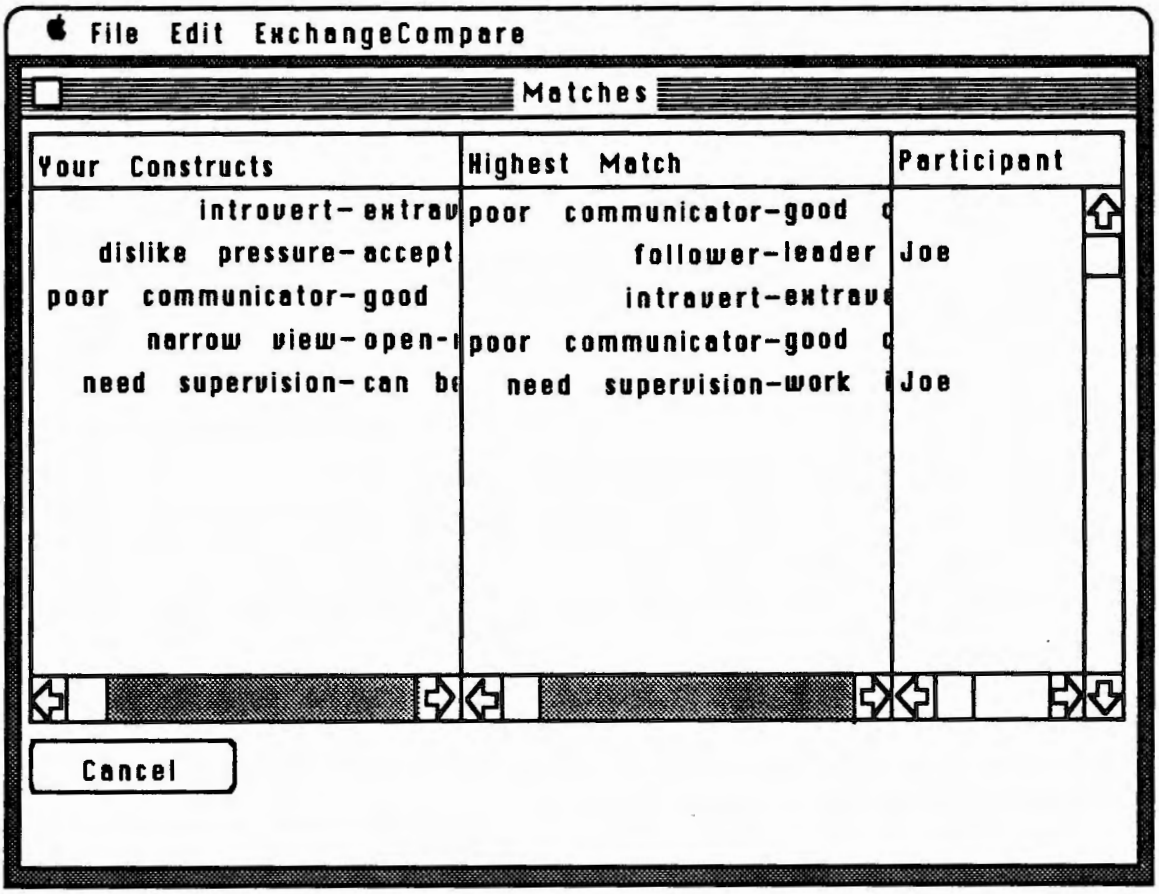


# 8. PCS COMPARE PROCEDURE

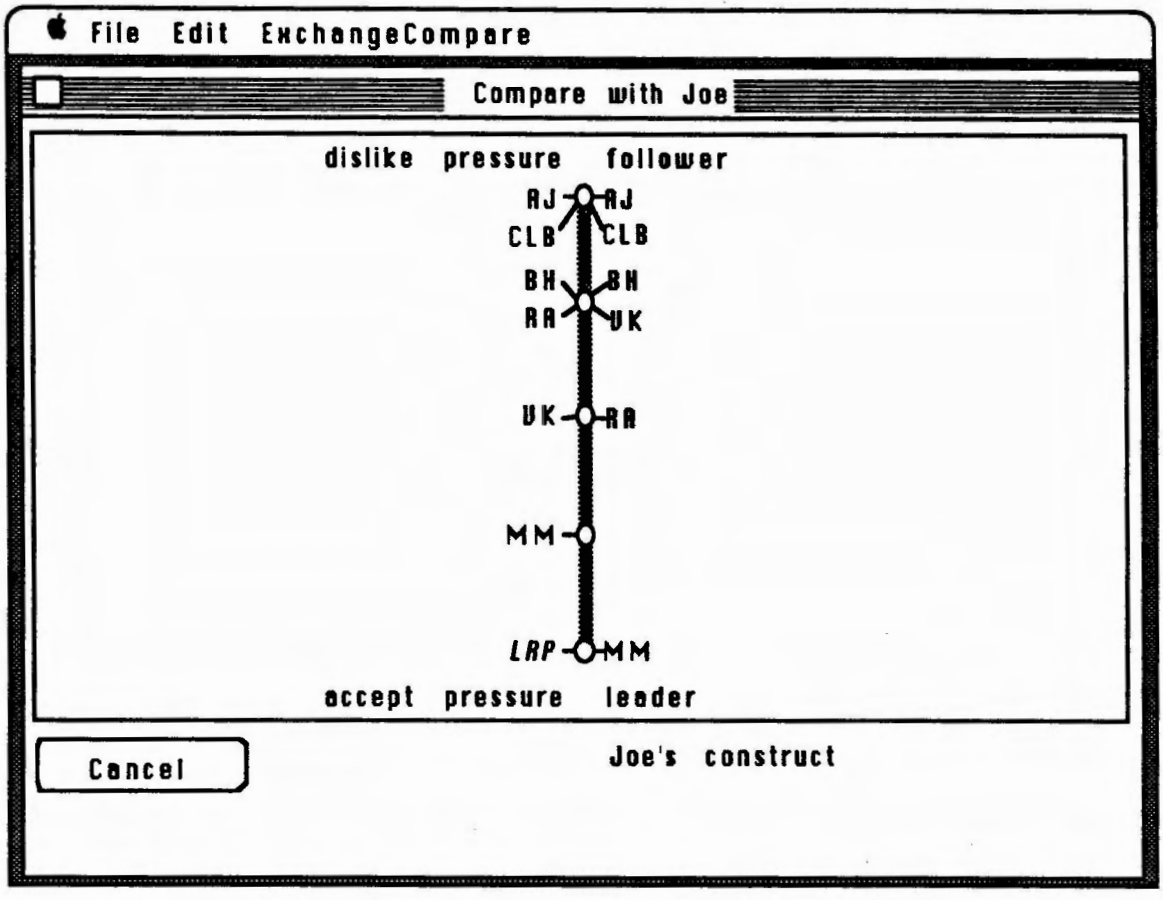
Bill wanted to see how all his constructs would **Compare** with those of everyone else.




First of all he chooses to **Compare** with **All**, then later he will want to look at his **Agreement** and **Understanding** with Fred. Notice that he cannot **Compare** his own constructs with Fred's constructs here, since they each started with a different set of elements.




First he wants to see the highest match with Joe so he clicks on line 2.



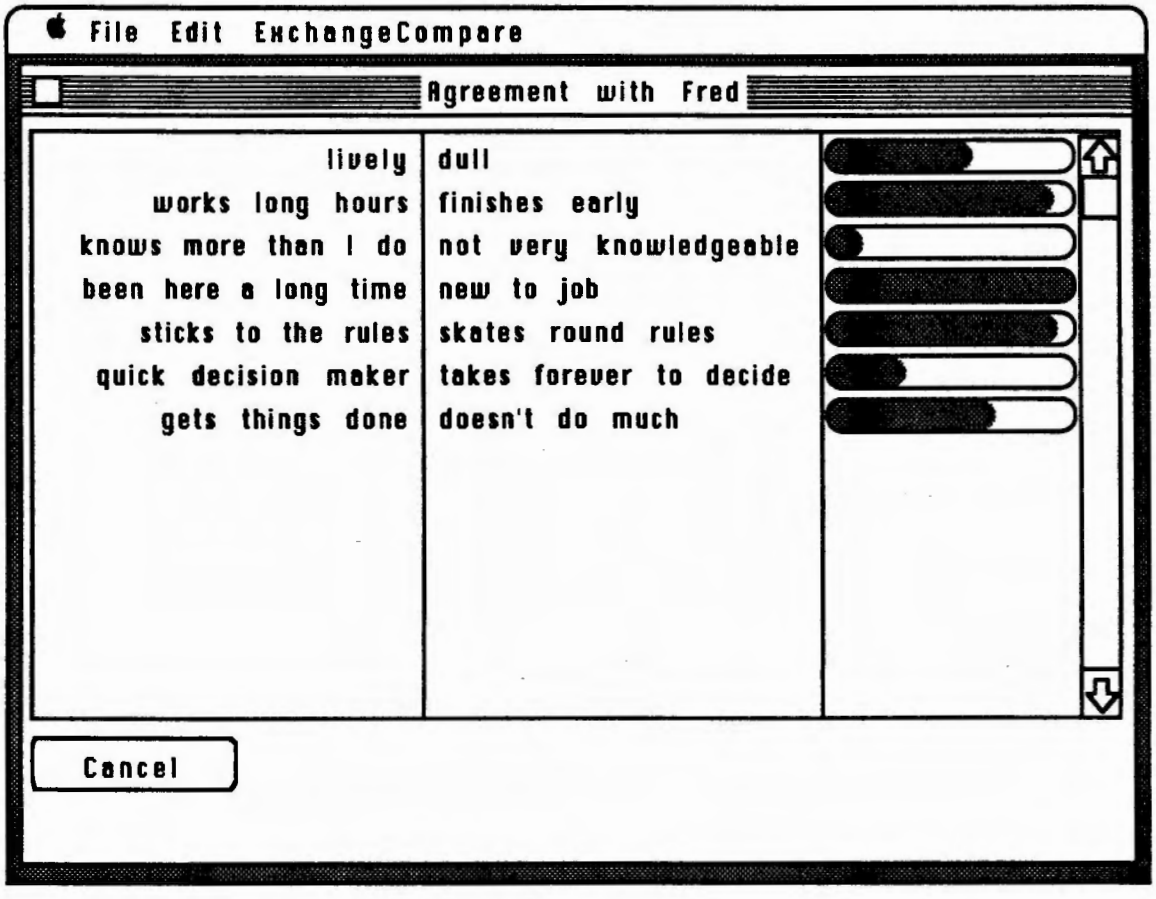

This allows him to see how closely he has agreed with Joe in rating his elements on this construct. Notice here that Joe has less elements than Bill, and the comparison is made only with the common elements, although all of Bill's elements are shown. He can continue to **Compare** any of his constructs he chooses with any others, scrolling as necessary to see the whole list.

In this case he can see that when he is saying that a manager dislikes pressure he is also saying that the manager is a follower, and when he is saying that a manager accepts pressure he is saying that the manager is a leader. He could have looked at this match during the elicitation if it was the highest at the time, but under **Compare** he can look at any matches he is interested in.

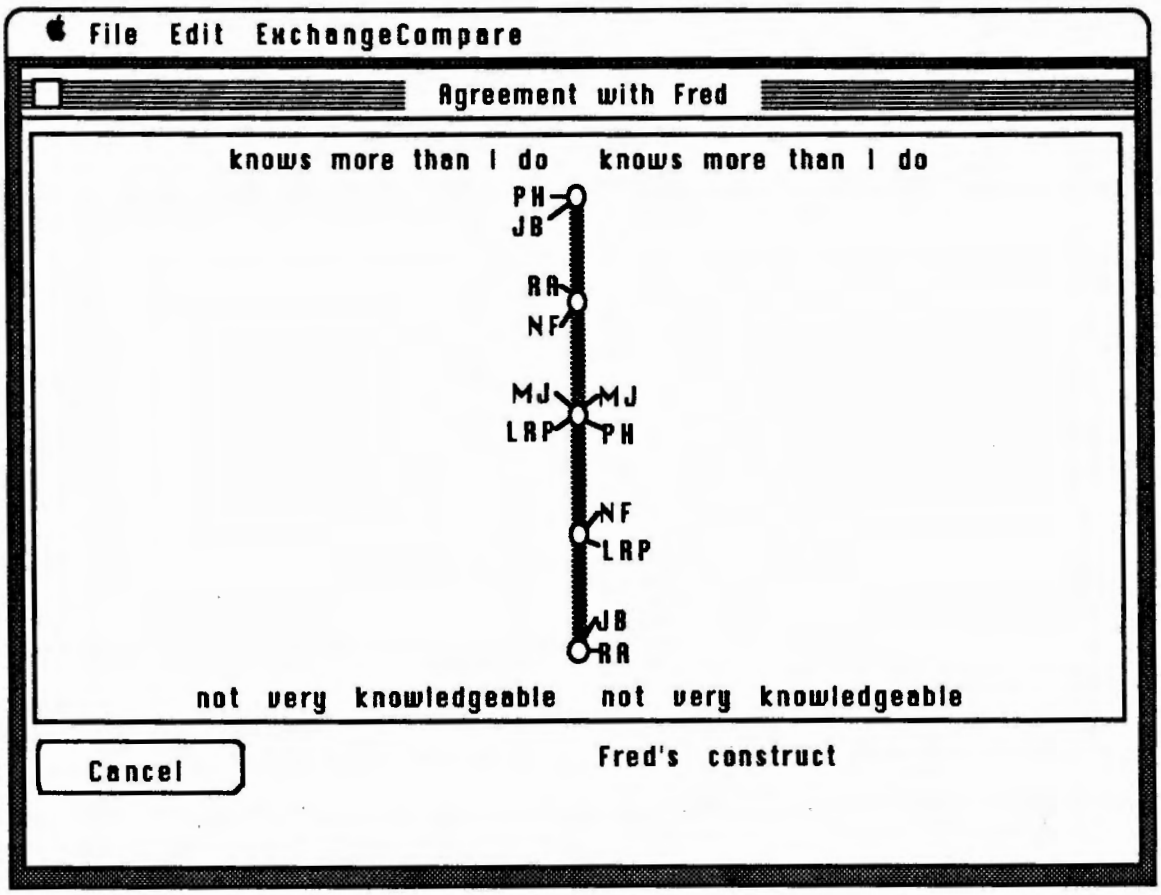
Here he can see why this very high match occurred: **AJ** and **CLB** are rated at the same end on both constructs, that is, they are both on **dislike pressure and follower; BH** is a little way down on both, that is, he does not dislike pressure or is a follower quite as much as **AJ** and **CLB**, but still towards that end; **VK, RA** and **MM** are only a distance of one position away on each construct; so they are quite similar overall.

### 8.1 Comparing Agreement

Bill then went back to the **Compare** menu to look at how closely he and Fred **Agree**. To do this he selects **Agreement with Fred** which will automatically **Compare** with Fred's constructs.




Bill can see that he disagrees most with Fred on the construct **knows more than I do -- not very knowledgeable**, so he clicks on that line to see why not.




Here he can see that he and Fred disagree because they have different specialisms, and Fred has chosen to construe managers in his own field which is highly technical, whereas Bill is in a more general management field and their technical knowledge is irrelevant to his job. It is obvious why he and Fred disagree once he realizes what has happened; Bill would be in the wrong job if it were not the case.

### 8.2 Comparing Understanding

To repeat this procedure for **Understanding** Fred's constructs, Bill had to go back to the **Compare** menu title and drag to **Understanding with Fred** to **Compare** with Fred's constructs. Again, he can examine whichever constructs he is most interested in, either low or high matches, or all of them if he chooses.

## 9. PCS DIALOG

Experienced Macintosh system developers may wish to customize PCS. Each part of the dialog in PCS is a normal Macintosh **resource**. The dialog may be changed to another language and/or edited for special applications by using one of the Apple Resource Editors.