COGNITIVE MODELS OF HUMAN-COMPUTER INTERACTION IN DISTRIBUTED SYSTEMS

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This paper presents systemic principles and cognitive science foundations for Participant Systems as distributed networks of computers and people operating together to pursue common goals. The mathematical foundations for these systems are analyzed as those of anticipatory systems using inductive inference to better predict and control their world. The role of computers in such systems is seen as a logical extension of the use of previous media to support human knowledge processes. The multi-level human factors problems of participant systems are analyzed within this framework.

INTRODUCTION

We are now in the fifth generation computing era with its emphasis on complex, knowledge-based systems involving close human-computer interaction [8]. Multi-task, multi-user, multi-modal systems go beyond human factors knowledge based on the textual display and keyboard technology of yesterday. If we continue to rely on empirical knowledge based on studies of the past we shall never be equipped to deal with the systems of the present let alone those of the future. This is the dilemma of current human-computer interaction research that can be resolved only through the development of foundational models of human-computer interaction that can be projected to novel situations.

Such models are feasible given the advances in neurology, psychology, linguistics, cognitive science and system science during the past twenty years. Previous papers have given a number of perspectives on human-computer interaction which portray the state of the art and why it is expected it to change [12], and have analysed what trends are leading to that change [13]. This paper analyzes some aspects of human-computer interaction in participant systems, describing the underlying systemic principles and how these lead to cognitive models.

PARTICIPANT SYSTEMS

Fig.1 shows a typical configuration for a participant system implemented as a network of personal computers. The group, who have come together to participate in the system, each access it through a personal computer acting as a terminal to a network. The database provides storage for data that may be shared among the participants. They may communicate with the database, or one another, through the network. Note the emphasis on a group. It is the essence of a PS that its users have some joint purpose, giving them coherence as a group.

Cantata [3,4] is a PS for conferencing that sends text messages from one user to all others on the network, displaying them in windows specific to the sender. No user interaction protocols are implemented within Cantata itself. Communication can exist at task and meta-task levels, but since both map on to text messages, no explicit mechanism for meta-task communication has been created. Chang notes that there are no explicit rules for communication, since everyone can address everone else at the same time for as long as each likes with no specific topicality. Turn-taking, topic switching, decision-making, must be dealt with through structures that the participants evolve.

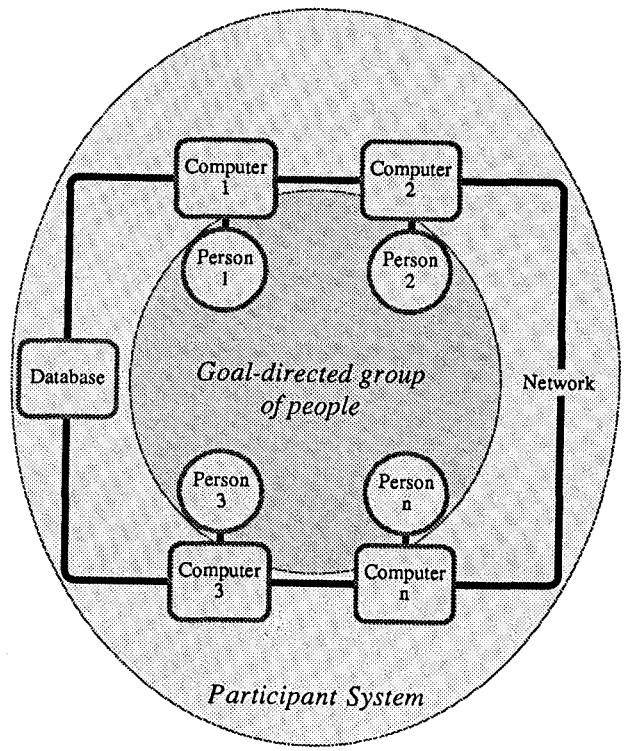

Fig.1 Typical participant system implementation

Chang remarks that this lack of enforced interaction protocol gives Cantata users great flexibility and freedom, but also creates the problem of coping with a novel communication situation and developing protocols to operate effectively. On the one hand users are able to receive messages as they are constructed, and can respond to one or more before the sender(s) complete them. This is therefore a medium that has no analog in the normal world of personal interaction: you can interrupt without interrupting, and listen to three people at the same time in Cantata. On the other hand, the absence of structure in the communications among participants causes some confusion. Chang has found that it is difficult to get away from the cultural expectation that only one person in a conversation has the floor, that there are leadership or consensus methods for changing or maintaining topics, that feedback is expected as one speaks.

THREE LEVELS OF PROBLEMS IN HUMAN-COMPUTER INTERACTION WITH PSs

The implementation of Cantata-like systems is not difficult. This technological ease of implementation tends to obscure the very difficult problems of the psycho-social engineering of human-computer interaction in such participant systems. Three levels of problem may be distinguished.

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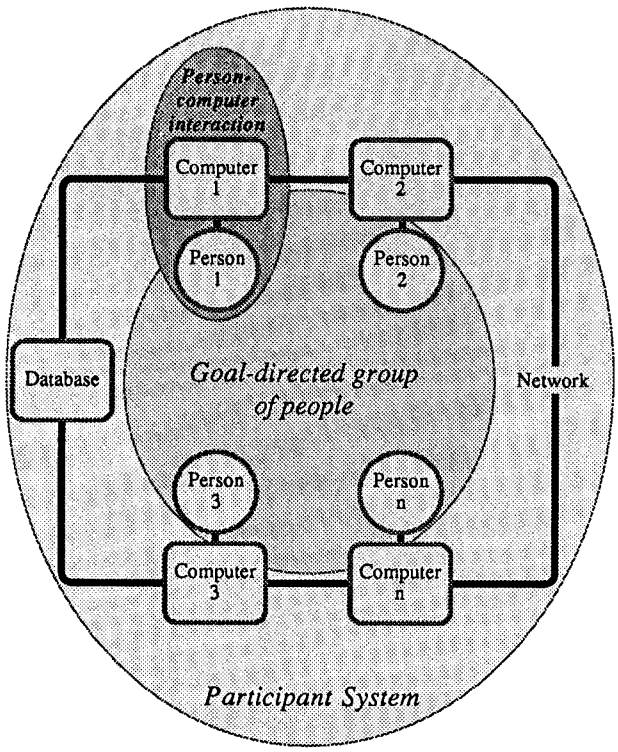


Fig.2 Person-computer interaction in a PS

Level 1: Person-Computer Interaction

Figure 2 shows the first level of analysis of human-computer interaction in a participant system. Person 1 is interacting with computer 1 and this may be analyzed in terms of the modalities involved, ergonomics, dialog engineering, etc. There is a wealth of literature and recommendations relating to this situation, largely derived from studies of individuals acting with programs running on workstations or terminals [6,9,13].

Level 2: Person-Person Virtual Circuits

Figure 3 shows the second level of analysis of human-computer interaction in a participant system. Person 1 is interacting with person 2 through the virtual circuit provided by the network. This mediated communication is a much less analyzed situation than that of direct person-computer interaction. There have been studies of communication mediated through a computer database [14,16,17,20,32], but very few of direct interaction through a computer network [19,21]. There is clearly an analogy to person-person discourse and the literature on this topic is relevant [1,15,22,26,33]. However, the discourse modalities are very restricted, lacking many important features of both verbal and non-verbal communication, and it is difficult to know how people will operate in such an impoverished environment.

Level 3: Multi-Person Virtual Circuits

Figure 4 shows the second level of analysis of human-computer interaction in a participant system. Persons 1 through n are interacting through the virtual circuits provided by the network. This is what Chang [3] reports as causing the most difficult problems in the operation of Cantata. This is not surprising given that the participants are being required to establish effective small-group communication in a highly impoverished environment. The problems of person-person interaction that have been noted in computer communications systems [19,21] are multiplied manifold in an n-person environment. The analogous problem for people is considered in the small group communication literature [2] but this is again of limited relevance to the computer-mediated participant system environment.

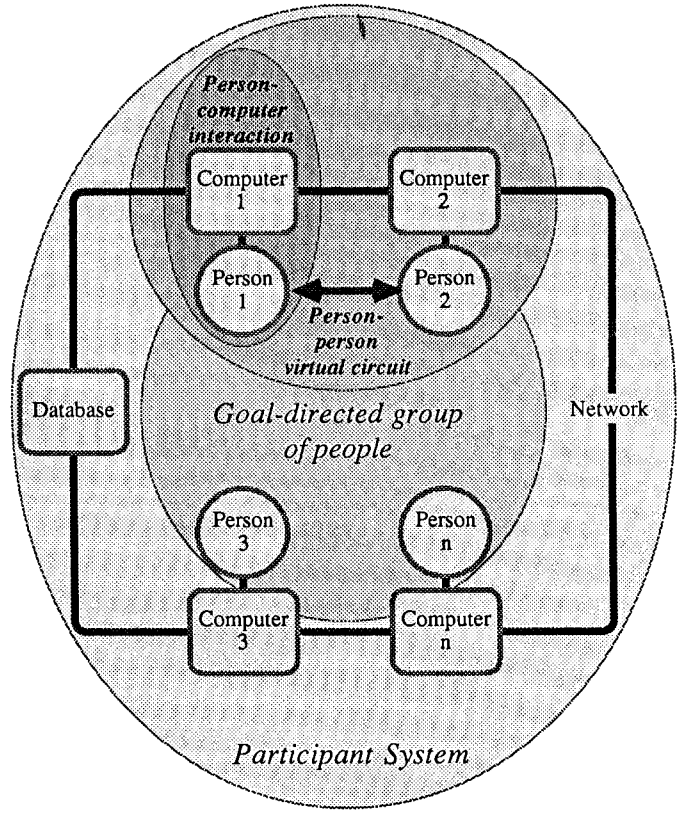


Fig.3 Person-person virtual circuit in a participant system

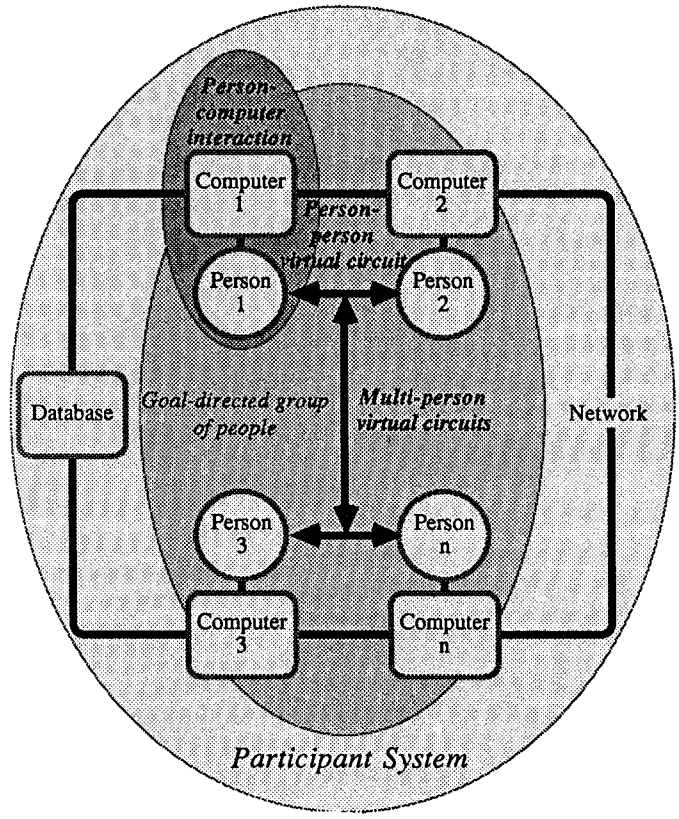


Fig.4 Multi-person virtual circuits in a participant system

SYSTEMIC & COGNITIVE SCIENCE FOUNDATIONS

An overall theory of human-computer interaction has been developed that is rich enough to encompass the three levels of problems encountered in participant systems. The theory commences with the notion that human society is an anticipatory system acquiring knowledge in order better to anticipate the future [30]. The mathematical foundations for this system have been developed as a hierarchical structure of distinctions supporting inductive inference to better predict and control the world [7,10]. Groups, people and roles within people are treated uniformly as cross-sections of this hierarchical structure as shown in Fig. 5 (which is a condensation of figures in a sister paper at this meeting [28]). The analysis of distinctions made in a modeling hierachy can be used as a practical technique for rationally reconstructing major domains of knowledge [11].

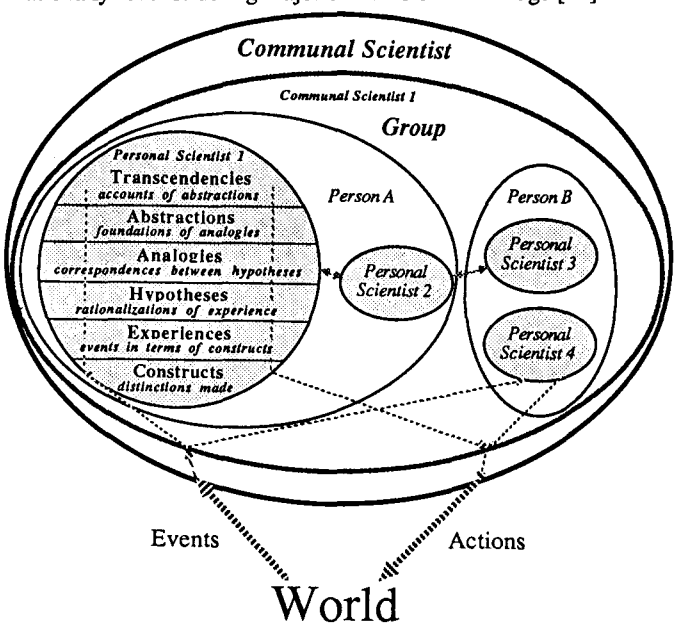


Fig.5 Epistemological hierarchies, roles, people and groups in a communal scientist anticipating the world

The role of computers in these social knowledge processes can be analyzed as a logical extension of the use of previous media to support human knowledge processes [30]. The theory has found direct application in the development of expert systems in providing a variety of mechanisms for the transfer of expertise [31]. Figure 6 shows a *conversational suppport system* combining knowledge elicitation and expert systems technology to support the knowledge processes of a community. A PS with some of these features is described in a sister paper [29]. The overall theory provides a socially-embedded cognitive science framework for participant systems with strong systemic foundations that provides a basis for analysis of the human-computer interaction problems discussed above.

The theory of the communal scientist is fully recursive in that we as analysts are part of the knowledge process and use a hierarchy of distinctions to model human-computer interaction in participant systems. Three basic systemic distinctions underly the notions of abstraction, agency and actuality and can be analyzed in terms of Popper's [27] 3 worlds theory. Figure 7 shows the existential hypotheses underlying Popper's 3 worlds as very general distinctions made about distinctions:

- World 1 arises from the hypothesis that there exist necessary distinctions. Truth in this world relates to correspondence between distinctions and the properties of physical objects. The conceptual framework may be termed one of *actuality*.

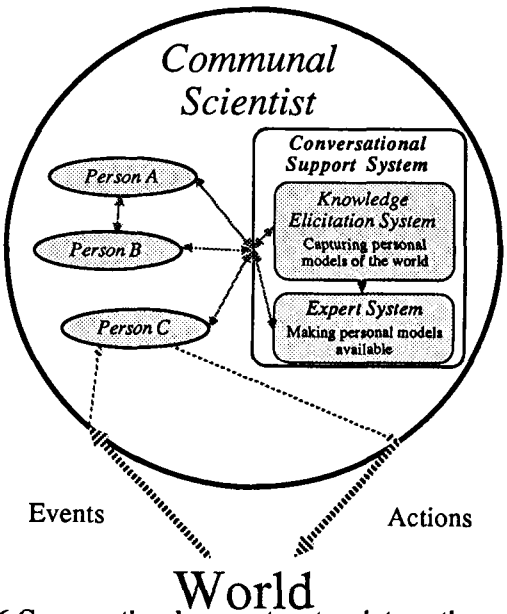


Fig.6 Conversational support system integrating group knowledge processes in a communal scientist

- World 2 arises from the hypothesis that there exist distinction makers. Truth in this world relates to the ongoing consistency of subjective choices of distinctions to make and hence is performative in nature. The conceptual framework may be termed one of *agency*.
- World 3 arises from the hypothesis that there exist distinctions independent of their source in actuality or agency. Truth in this world relates to the internal coherence of the systems of distinctions made. The conceptual framework may be termed one of *abstraction*.

These basic distinctions give rise to the notions of abstraction and instantiation as relations between world 3 and worlds 1 and 2 as shown, and also to that of *analogy* between worlds 1 and 2 when we attribute to agency to the causal dynamics of physical objects or necessity to the social conventions of human activity.

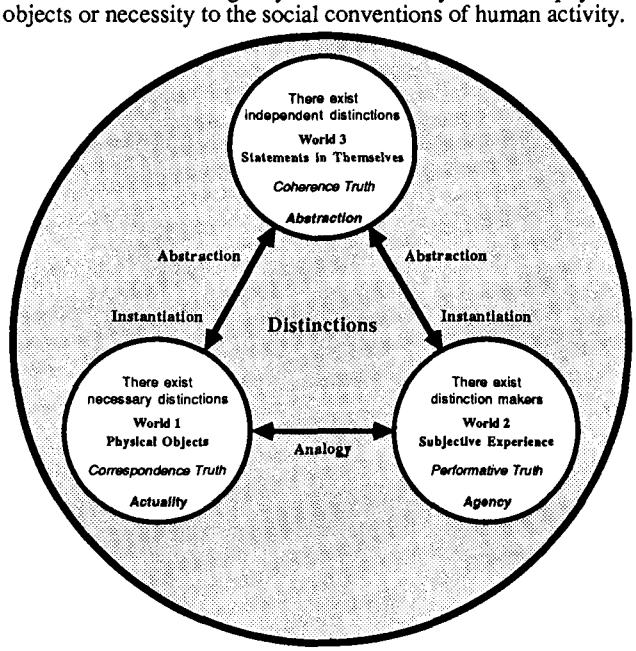


Fig.7 Actuality, agency and abstraction as basic distinctions among distinctions

Analogy and Abstraction

Abstraction and analogy are significant reasoning techniques in human modeling of experience and have important roles to play in the study of human-computer interaction [13]. Figure 8 illustrates the derived systems possible when abstraction/analogy are applied to the person-computer system. As Lakoff and Johnson [23] have noted the linguistic metaphors resulting from these analogies and abstractions can become so much a part of our thinking and vocabulary that we are no longer aware of their metaphorical nature. Computing terminology abounds with words that were specific to human knowledge processes but are now used for equipment.

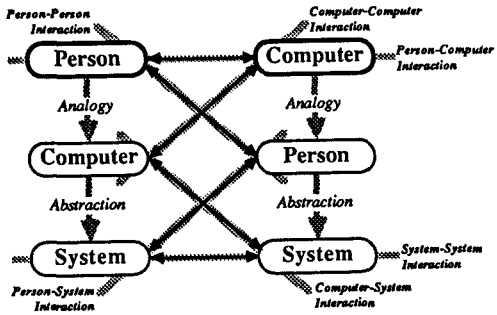
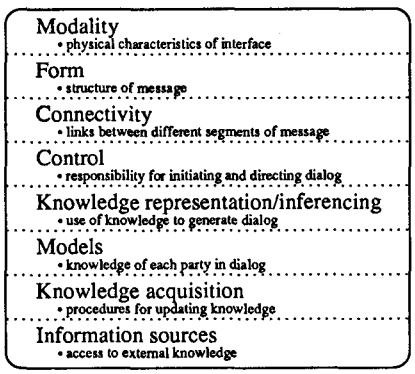


Fig.8 Abstraction and analogy in the analysis of person-computer interaction

An Intelligent Dialog System Evaluation Schema

Edwards and Mason [5] have developed an evaluation schema for intelligent interactive systems and applied it to a range of advanced multi-modal systems [25]. They analyze the dialog along eight aspects and four dimensions as shown in Fig. 7.



Aspects of Dialog

Observer \ System	Structure	Behavior
Logical	Elegance *Efficient design*	Functionality *Total capability*
Psychological	Understandability *Comprehensible design*	Suitability *Usable capability*

Dimensions within Aspects

Fig.9 Edwards and Mason's evaluation schema

A systemic analysis of the evaluation schema in terms of the basic distinctions defined above is shown in Fig.10. It shows that there are two symmetric structures involved, one for the messages as carriers of dialog, and the other for knowledge as the basis of dialog. A similar analysis can be given of intentionality as the function of dialog.

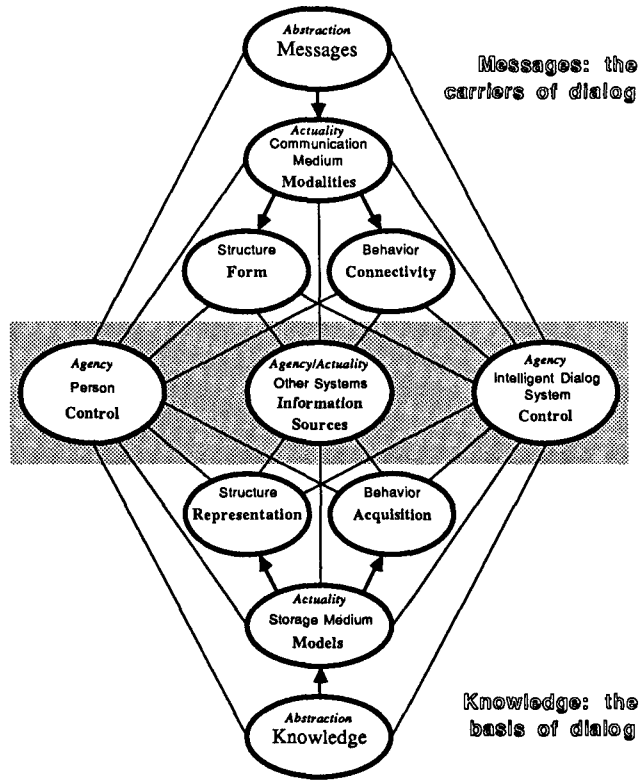


Fig.10 A systemic analysis of the evaluation schema

Analyzing Control Structures in Dialog

One of the most difficult features to implement in a participant system is the natural expression of the control structures that determine the type of interchange taking place. Penman [26] has analyzed control structures in person-person communication in terms of two basic dimensions: *power* and *involvement*. Figure 11 shows her classification of speech acts in these terms.

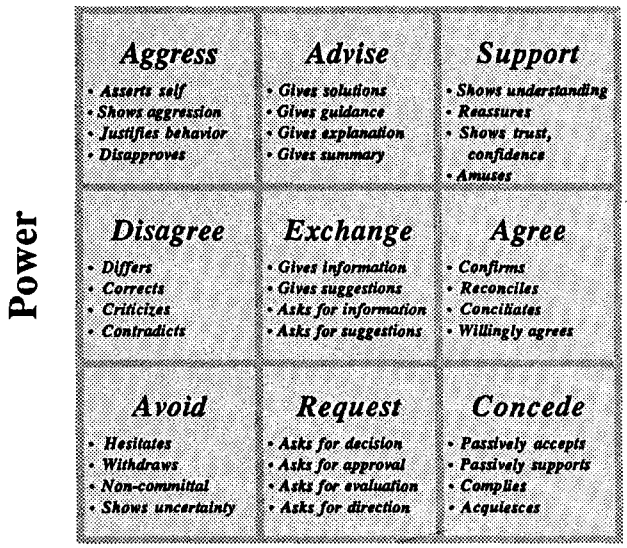


Fig.11 Penman's analyis of the structure of dialog

CONCLUSIONS

This brief sketch of theoretical foundations for the analysis of human-computer interaction in participant systems emphasizes rather than removes the problems that Chang [2] has noted in the design of Cantata-like systems. The implementation of Cantata omits the knowledge-based component of Fig.10 and the keyboard/screen modalities used provide only impoverished cues for the control information of Fig.11 which is normally carried not only by affective words but also by vocal inflection and body language [22]. The participant construct system design [29] provides a knowledge-based component, and the addition of a speech and video channels to Cantata would provide access to the control information. The *talking heads* system for the Macintosh connected to CompuServe is an attempt to provide some features to a video channel [24].

The problems outlined in this paper are major ones but the analysis provided forms the basis for understanding and generating creative solutions. Participant systems are technically feasible and will come into increasing use. The solutions generated to the human-computer interaction problems involved will form the basis of new generations of knowledge support technology of which we can only catch a glimpse as present.

ACKNOWLEDGEMENTS

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