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TOWARDS EXPLICIT CONSIDERATION OF TIME IN COGNITIVE ENGINEERING WORKBENCHES FOR "INTELLIGENT" ASSISTANCE SYSTEM DESIGN*

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ABSTRACT

The problematic issues of the knowledge and temporal strategies used by the human operator in the control rooms of complex industrial process are studied. This includes the different tools and the current knowledge engineering workbenches which ease the knowledge acquisition, structuralization and formalization for the ergonomist and the knowledge engineer. Especially emphasized will be certain temporal tools available in Artificial Intelligence which can contribute to the development of knowledge engineering workbench considering explicitly the time. Finally, a pluridisciplinary research approach is proposed.

RELEVANCE TO INDUSTRY

Field studies show that there exist many poorly adapted "intelligent" assistance systems in the controls rooms of complex industrial processes. One reason is that to be really efficient, these tools particularly have to consider the use of time in the different human tasks. The development of better knowledge engineering workbenches explicitly utilizing the time is crucial. This paper proposes such a contribution in this field.

KEYWORDS

Cognitive engineering workbench, time, process control, assistance system design, pluridisciplinarity

INTRODUCTION

As a consequence of technological development, the human operator of the industrial process control room is becoming less and less involved in manual control tasks, while at the same time, realizing ever more complex cognitive tasks to solve problems (Rasmussen, 1986; Moray 1986). In complex processes, the tendency has been to assist the operator by "assistance systems" (see for instance the works of Helander, 1988; Millot, 1988; Boy, 1988; 1990; Tendjaoui et al., 1991 ; Kolski et al., 1992, and so on). These new systems can be based -or not- on Artificial Intelligence approach, such as expert systems. To be really efficient, it is important that these tools consider how the operators use time in their different tasks. However, the acquisition, the structuralization and the formalization of knowledge and temporal strategies obviously pose a problem which has not been yet solved. The ergonomist and the knowledge engineer themselves have especially been lacking in this respect, although, at the present time, cognitive engineering workbenches are starting to appear. The main idea of the article is that, although, these workbenches are not really adapted to human tasks in the control room. Recent advances in temporal logics in Artificial Intelligence allow this approach to be possible.

The article consists of five main parts. After an initial description of assistance systems that can be found in control rooms of industrial processes, the problematic issues of knowledge and temporal strategies used by the human operator in such control rooms will be studied. The third part will discuss the different tools and the current knowledge engineering workbenches which ease the knowledge acquisition, structuralization and formalization for the ergonomist and the knowledge engineer, in spite of the lack of temporal aspects consideration. The fourth will emphasize certain temporal tools available in Artificial Intelligence which can contribute to the development of knowledge engineering workbench utilizing time explicitly. Finally, a multidisciplinary approach is proposed.

CLASSIFICATION OF ASSISTANCE TOOLS IN INDUSTRIAL CONTROL ROOMS

Presently, the human operator in industrial process control rooms can be assisted in problem solving tasks by systems which are generally based on Artificial Intelligence techniques.

These complementary tools can be classified according to their functionalities during the problem solving step, as defined by Rasmussen (1980), used by a human operator in case of an abnormal situation. This step can be split up into several sequential stages : In case of alarm or of abnormal event detection, the operator observes information in order to identify the process state. Therefore, he uses predictions, evaluations and alternatives to define a general strategy. Then, he defines tasks and chooses some adequate improvements in the process. He has therefore to define the action procedures, to act on the process, and finally to keep up with the effects of the corrective actions.

Figure 1, modified from Taborin (1989), classifies assistance tools for each of these stages. Note that the operator, facing familiar or preplanned situations, is not obliged to perform the complete process of problem solving.

Class 0 : This class has no assistance system and therefore operator is not assisted. In case of dysfunctioning, the system just raises the alarms.

Class 1 : This class consists of filtering alarms systems. In case of a defect, these systems present the most significant alarms of the ordinary state of the process. The sub-alarms are eliminated, because they are not the direct consequence of the defect. The integration of these systems furthers a preventive behavior and bases the observation and diagnosis stages on significant variables. Such systems are described by Andow (1980) and Lees (1983).

Class 2 : The second class groups together systems that search and synthesize significant information, i.e. selecting that information which is most indicative of the process functioning state. The operator must consider this information not only during the supervision tasks, but also during the problem solving ones. Furthermore, when useful information is not available, the system must be able to supply information issued from upper levels, for instance variables in relation with chemical reactions. These principles have been studied by Goodstein (1981), Rouse et al. (1982) and Gambiez et al. (1991) for instance.

Class 3 : The third class groups the diagnosis aid systems able to locate defects and to define their causes, from the set of available information. Contrary to the class 1 systems, they do not provide any help concerning the fault detection. Generally, the reasoning period is too long to alert the operator quickly enough to the emergence of a problem and a diagnosis result. On the other hand, they provide him with interactive help for reasoning and evaluation of the situation, by presenting high level information on the process state. To this effect, they must satisfy a additional constraint, the capacity to justify their results. The HORSES system, developed by Boy (1986) fits this class. Its originality consists in a knowledge base constituted by three levels : the first one permits a fast situation recognition, the second one analyses this situation and makes a diagnosis, the third and last level - called metaknowledge - controls the other levels. The advantage of this decomposition is to allow an adaptation of reasoning to the situation.

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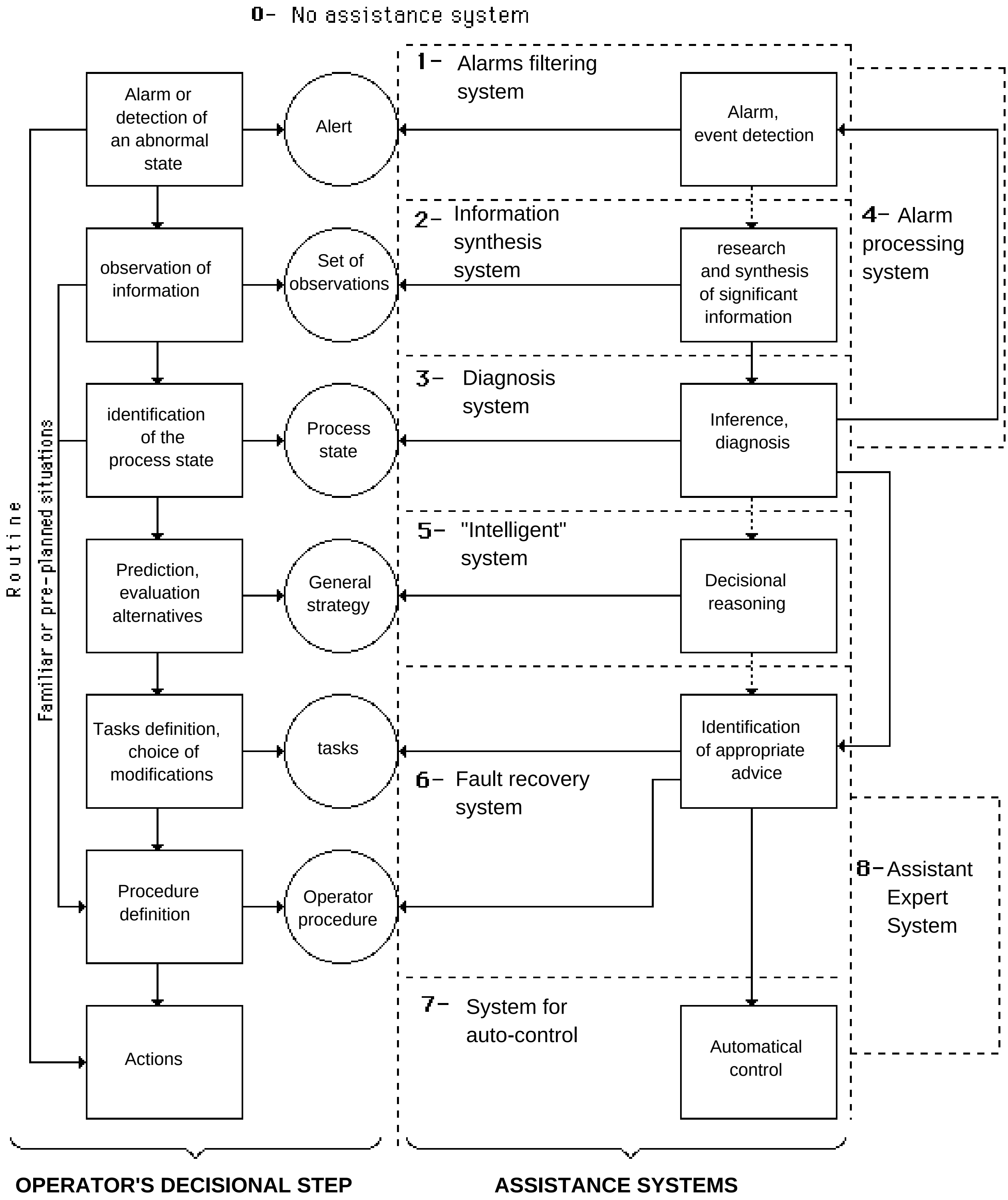

Figure 1 : Classification of assistance systems (from Taborin, 1989)

Class 4 : This class groups the systems by alarms treatment. Their function consists in alerting the operator when a defect appears. They do not limit the selection to the most significant alarms - like in the class 1 -, but are able to make a first analysis of the situation in order to quickly present a set of information, especially concerning the state of the different sub-systems which are implicated in the perturbation. This first diagnosis is less complete than a diagnosis which could be provided by a class 3 system, but it helps the operator during his problem solving step, by presenting him a set of information to be considered. The interface design is very important, because the help provided by these systems covers a large part of the human problem solving step. Their main interest consists in limiting errors made during the situation evaluation. An example of such a system is described by Ancelin and Legaud (1986).

Class 5 : In this class, a system has to : (i) estimate the reactions of the process consequent to the actions, (ii) predict the future state of the process, (iii) formulate hypotheses, and finally (iv) make decisions. In other words, it has to reason like a human, adopting a knowledge-based behaviour. But such truly intelligent and extremely complex reasoning has not yet been modelled in spite of the very active research in this field. Artificial Intelligence contributions to the design of such systems particularly include : the deep reasoning, the planning, the reasoning by analogy, the temporal logic, and the qualitative physics. The system PREDEX (Tang and Schoelkopf, 1990) provides several functionalities of the tools from this class.

Class 6 : The systems of this class aid at a recovery. Unlike those of class 5, the knowledge of these systems corresponds to the one used by a well trained human operator, who adopts a procedural behaviour. These tools propose a diagnosis and suggest a procedure to correct the defect. So, they provide the operator with a great quantity of different information on several levels : significant information, diagnosis, corrective actions, etc. The problem is the choice and manner of presenting the information. These systems allow the operator to check, before acting on the process, if the defined procedure is the same that the one proposed by the assistance system. This condition limits the errors made during the evaluation of the situation, in particular (i) those related to the procedures, (ii) the errors due to the planning and correction. Several tools of this class, such as ESCORT (Paterson et al., 1985), PREDEX (Tang and Schoellkopf, 1990) or DIAPASON (Coudouneau et al., 1990), make deep and/or shallow diagnoses and propose advice so as to correct the situation.

Class 7 : In this class, the intelligent systems automatically control the process. These are class 6 systems which perform actions based on reasoning. One such system, ARTIFACT, is based on a relational model linking the different sub-systems of the process (Francis and Leith, 1985). It deduces "conditions/actions" rules from which a planning module analyses the best set of possible actions to reach the wanted state. Nevertheless, such a system does not take into account time in its reasoning process. Therefore, it can only be applied to processes whose inference duration is slow enough to be considered as static. ARTIFACT has only been applied on very simple processes. It is not yet possible to let to such a system completely control complex processes because it still must integrate the knowledge related to all the possible situations. Few systems exist in this class.

Class 8 : In this class, a system assists the operator when requested (Mandiau et al., 91). Using knowledge about (i) the tasks to be performed and (ii) data issued from the process, this system permanently generates action plans. These plans can either be used by the operator, or be applied directly by the system on the process at the operator request. These systems are called "Operator assistant systems" (Boy, 1988) or "Assistant Expert Systems". They use certain functions of class 6 systems, providing the operator with recovery assistance, and acting directly on predefined processes.

The implementation of each of these systems leads to problems related to (i) the dynamics and the complexity of the process to control and (ii) the objectives of the computing assistance. Indeed, these systems exploit heterogeneous and complex knowledge geographically distributed in the installations. Furthermore, these systems require functions dependent on the operator problem solving state. Field studies of control rooms show the existence of many poorly adapted "intelligent" assistance systems. One reason for their efficiency is that these tools do not consider how operators used time in their different tasks.

TEMPORAL KNOWLEDGE AND STRATEGIES OF THE HUMAN OPERATOR IN A CONTROL ROOM

Temporal problems have been studied for many years in psychology (see the works of Piaget, 1946 and Fraisse, 1957 quoted by Decortis, 1988). The temporal dimension of human operator activities in complex industrial process control rooms, have been researched in work psychology for only about ten years. But a better understanding of the intervention of the time in the human operator's reasoning and knowledge and the specification of future assistance tools have already been identified (see De Keyser et al., 1987; Dorner, 1988; Decortis, 1988; Grosjean and Javaux, 1991 or De Keyser, 1990; 1991).

For example, in a continuous steel casting control room (De Keyser et al., 1987) direct actions given to the operator are weak, but, on the other hand, the control room can change into a "dispatch" room. In addition to the supervision of process and actions in the form of orders which modulates the actions of other workers, the operator manages and co-ordinates all the activities surrounding the casting machine. Because of information exchanges with the staff, he detects or collects the technical failures, works out a pre-diagnosis and appeals to the department concerned, in addition to other administrative tasks. The operator must therefore be in interaction with many other workers. According to field studies, operators communicate verbally : dated or undated facts, numerical data, tendencies, estimations related to a chronology of actions, qualitative valuations, judgments, references to the past, reactions to certain operator's decisions. These different types of verbal communications are used for support of information and to make the estimation, the judgment and the diagnosis easier in some situations. They are used as a collective memory which can be refreshed by the operator and from which information can be drawn. They include different notions of time.

Many other studies show the cognitive wealth of the human operator's work. For example, in his study about the temporal dimension of operators cognitive activity in a start up of a thermal power station, Decortis (1988) emphasizes the temporal aspects of operator, such as : (1) estimation of process state durations according to the content of events, temporal limits and variation speeds, (2) temporally reasoning on interdependent process elements, (3) estimation on the duration of the action and annex events, and on intervention time, (4) optimal management of simultaneous actions, (5) synchronization of collective actions of different intervening parties, (6) reduction of time for events in order to make up delays, (6) watching the evolution of events before intervening at the right time, (7) adaptation and development of chronological, sequential and simultaneous strategies, according to the situation of the process running.

With regard to such temporal aspects, De Keyser (1990) discussed the difficulties that the operator faces when evaluating, integrating, coordinating or planning the machine system, and the errors which can be associated with these situations.

Thus, the importance of the real needs concerning the human operator's assistance in control rooms is shown. In the development process of assistance tools in complex systems, computerized tools, particularly for acquiring and formalizing the knowledge are used. But these tools are yet not really adapted to the temporal problems of assistance. The following paragraph deals with one such study.

REVIEW OF THE METHODOLOGIES AND TOOLS FOR KNOWLEDGE ACQUISITION IN RELATION TO THE DEVELOPMENT OF ASSISTANCE TOOLS

Whatever the application, current approaches to knowledge acquisition can be based on a large variety of methods, techniques and tools, most of them imported from other sciences (psychology, linguistics, epistemology, software engineering, artificial intelligence...) and adapted for computerization.

The principle of a knowledge engineering workbench consists of a wide range of tools whose purpose is to support the knowledge engineer, in cooperation with an expert, in core knowledge engineering activities. Figure 2 shows a general architecture of the different functions of such a workbench. With an elicitation toolkit box, the expert's knowledge can be acquired in relation to a pre-existing model, which is including in a library of generic models, characterized at structural, functional and conceptual levels. Finally, a translator module uses a transcription of the high level model into lower level form (objects, rules...) directly executable via an inference engine integrated in the assistance system.

Many elicitation tools, which are specific to one or several acquisition techniques, currently exist. For example : ETS (Boose, 1985) based on repertory grids techniques, MACAO (Aussenac, 1989) based on protocol analysis, ROGET (Bennet, 1985) and MORE (Kahn, 1985) based on interviewing techniques. Other such tools specific for a given task are described by Boose (1989). However, none of them explicitly represents the notion of time.

Current research is trying to combine knowledge acquisition techniques in a toolbox form, e.g. AQUINAS, a knowledge acquisition workbench including repertory grid, interviewing and scaling techniques (Boose, 1989). The Esprit project ACKnowledge is studying the integration of machine learning and the techniques and tools for knowledge acquisition, to result in a coherent computing environment called KEW (Knowledge Engineering Workbench). The workbench associates techniques for knowledge collection (card sorting, repertory and scaling grids) and machine learning techniques (e.g. generalization). The selection of these techniques depends on the type of knowledge and the way the knowledge is represented. At some point in the process, the elements of knowledge are included and the quality of the knowledge base is evaluated in order to establish what should be complemented, refined or made coherent (Julien, 1991). In comparison with the various temporal strategies brought into operation by a human operator in a control room of complex systems, these workbenches seem to be insufficient in spite of the variety of techniques that they offer to the designers.

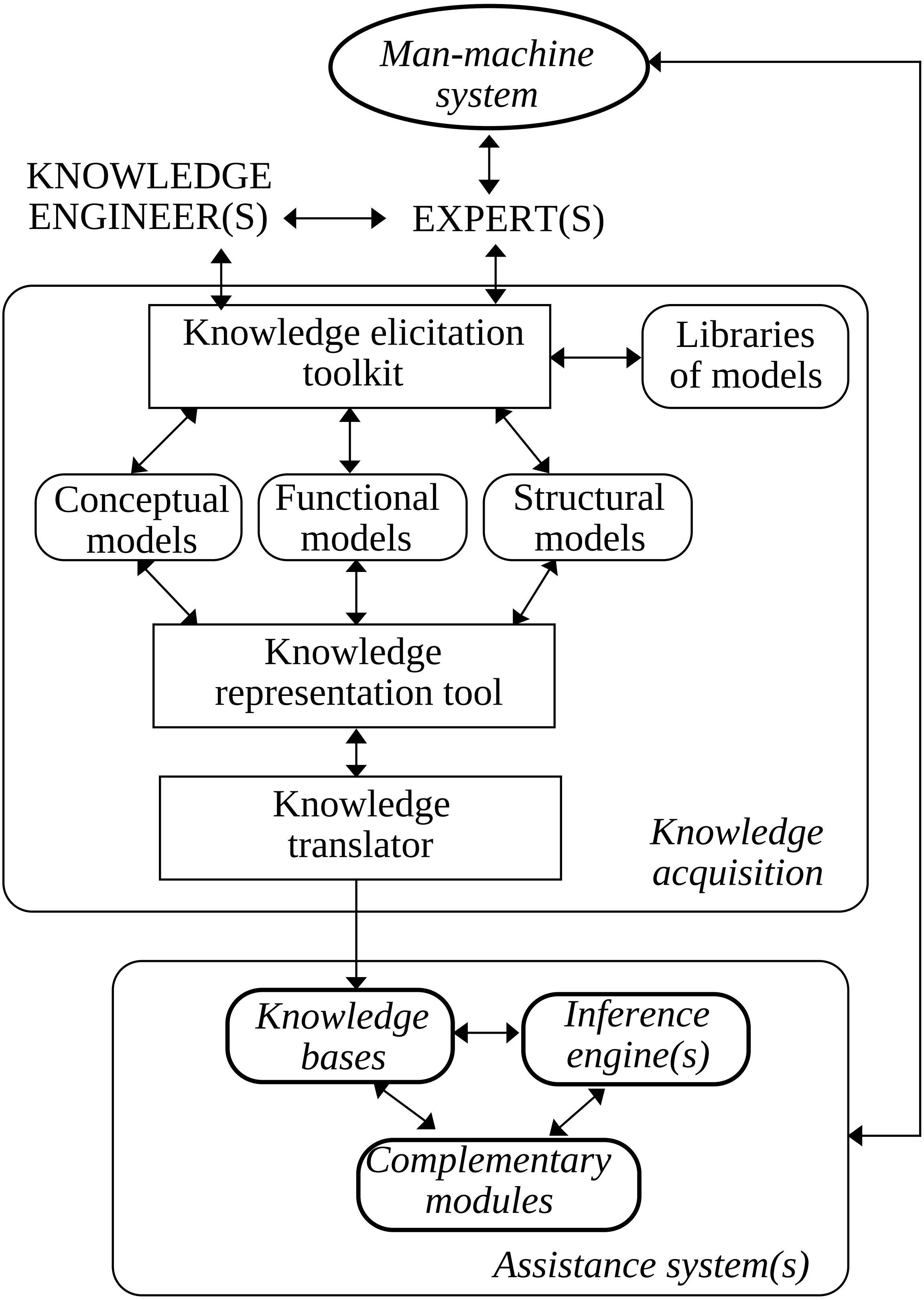

Figure 2 : Global principle of current computerized tools for knowledge acquisition

The first knowledge acquisition methods, associated with the life cycle of a knowledge-based system, were often based on the rapid prototyping. A prototype was first of all developed and then refined until the final knowledge-based system was obtained. This incremental approach has lead the development of many knowledge-based system methodologies (Hayes-Roth et al., 1983, Nassiet, 1987, Benkirane et al., 1991). This process, also called structured acquisition of knowledge (Johnson, 1988) enables the collection of the knowledge and the development of field models. Extension of other scientific methods have resulted in the development of very formalized and powerful methodologies, such as KADS and KOD which are briefly described below. Such methodologies seem to be particularly attractive to the present research.

The KADS methodology, originating from epistemology, guides the knowledge based system development from the organization of the domain to the development of the whole system. Based essentially on the construction of several models, it breaks the domain organization into stages where the problem is decomposed into component parts and the analysis of knowledge is separated from its machine implementation. KADS has three modelling levels : (1) a language to describe the conceptual model, constituting an intermediate representation between the expert's data and the design/implementation of the knowledge based system ; (2) a design module describing the representation of the conceptual model to the external needs using an appropriate framework, and (3) a module of modalities to specify the co-operation and the communication between the knowledge based system and the user. The success of KADS has been represented by the marketing of a tool called OPEN KADS. The workbench has proved itself in large applications such as the SACHEM (Système d'Aide à la Conduite des Hauts fourneaux En Marche) project developed for SOLLAC. This project developed an intelligent system based on expert knowledge to supervise metallurgy blast furnaces. The KADS methodology does not explicitly mention temporal management, although it should be possible to take into account temporal constraints of a process, as is presently being done by the designers of KADS.

The KOD methodology (Knowledge Oriented Design) concerns the acquisition of an expert's knowledges (but only by interviewing techniques), their modelling based on the retranscription of the verbalizations, and finally a specification of the knowledge base according to a multiple step analysis of the verbal data. Also based on a knowledge modelling, the KOD methodology offers a cognitive model which is used as an intermediary between the natural language of the expert (practical model) and the computer language in which the knowledge based system will be implemented (computing model). On the cognitive level, the expert uses "taxonomies", "actinomies" and schemes of interpretation and reasoning (Vogel, 1988). From this data acquired from the verbalizations of the expert, the practical mode allows to obtain a specification of the expertise, which states precisely the field and the phases of setting up the expertise. The practical model is leading the collect of data in order to make the future knowledge structuralization easier. Then, the collected data is reduced in order to recognize the manipulated units in the expert's speech (cognitive model). KOD is now called K-Station which is available on the market. The time notion is not explicitly considered in the K-Station. However, this notion is explicitly mentioned by Vogel when he deals with the "actinomy" by decomposing it in elementary sequences, which are combined in order to produce complex sequences. Vogel suggests that Allen's model (see the next paragraph) enables to calculate the temporal relations between the events.

Despite promises of explicitly taking time into account, most assistance systems for human operators in the control rooms of industrial complex systems have not done so. Even if knowledge acquisition utilizes resources from different fields, the temporal tools of artificial intelligence are not utilized. Nevertheless, in the following paragraph, different temporal tools can be used to deal with problems related to dynamic complex processes.

THE POTENTIAL CONTRIBUTION OF TEMPORAL TOOLS IN RELATION TO KNOWLEDGE ACQUISITION AND MODELLING

In artificial intelligence, logical formalisms and tools for the explicit management of time can be used to solve problems (Bestougeff and Ligozat, 1989). But, for any application, the most primitive adequate temporal entities should be chosen. Systems based on "points" are used the most, because they are easy to model. In fact, a representation based on punctual entities does not naturally represent the notion of duration. The need for extensive entities has led to different definitions of interval : sub-sets of points or pairs of points for instance (Libert et al., 1990). Similarly, the relationship between these entities is important. To representat time, the notion of precedence is fundemental. This relationship can be expressed as : "has begun strictly after/before", "has started simultaneously at", "just before/after", and so on. When there are temporal intervals, the insertion between two time intervals is natural. Finally, the properties of the relationship between the temporal entities must be satisfied. Discrete modelling can be used, for others applications, a continuous point of view is necessary.

In artificial intelligence, the basic time models are those of Allen (1984) and McDermott (1982). These models have been at the origin of many studies, extensions and realizations leading to deduction systems. For example, based on the temporal model of Allen, the NEMO inference engine is used for the development of real-time knowledge-based systems (Tang, 1990 ; Gambiez et al., 1991).

According to Allen (1984), time is an abstract notion which only exists with regard to the evolution of the universe, and is perceptible only due to environment changes. The practical representation of time is therefore linked to the evolution of the environment, i.e. to the concepts of event, state, situation, succession of states and so on. This model is essentially based on time intervals. A set of thirteen basic binary relations describes all the possible ways two intervals can be related to each other. Three entities are then taken into consideration : the properties about intervals, the events and the processes during an interval.

According to McDermott (1982), the time can be considered in a continuous manner and basic entities of the model are a set S of states a set T of instants. This model represents the world state as a photograph of the world at a fixed time, and defines temporal points as elementary entities for the representation of time. Some facts are identified with subsets of the set of states. In this model, an event can have a duration, corresponding with a succession of states in which the event happens only once in time, and is missing in states near this succession. McDermott also introduced notions manipulating basic entities.

In spite of their limits, the McDermott and Allen's models have introduced a basic formalism, which is used as a reference for different models for an efficient management of the temporal relations (Ghallab and Alaoui, 1989; Ermine and Cauhapé, 1990).

Each of the temporal approaches contribute to time modelling in knowledge engineering workbenches and are used by the designers in developing assistance tools for operators in complex systems. Meanwhile, two crucial problems appear : (i) the specialists in temporal logics are not conscious of the real assistance needed in control rooms, while (ii) human factors specialists are not really knowledgeable concerning the study and development of knowledge engineering workbenches for assistance systems design in complex processes. Thus, the integration of these temporal aspects requires a close collaboration between work psychologists, ergonomists, knowledge engineers, automatists and computer scientists.

CONCLUSION : NECESSITY OF A MULTIDISCIPLINARY APPROACH FOR THE EXPLICIT CONSIDERATION OF TIME IN COGNITIVE ENGINEERING WORKBENCHES

Because of automation of complex industrial processes, human operators in control rooms require assistance systems considering explicitly time. The development of such assistance systems requires the use of improved tools, to acquire, structuralize and formalize expert knowledges and strategies. These tools are presently being studied, developed or validated in industrial and university research laboratories.

However, to obtain the most efficient tools for incorporating temporal needs of the human operator, a multidisciplinary approach between work psychologists, ergonomists, knowledge engineers, automatists and computer scientists is necessary. Each of these has complementary knowledges concerning : (1) the real needs of the human operators in control rooms, (2) the tasks to be performed, (3) the characteristics of the man at work, (4) different technical, ergonomical and methodological aspects related with knowledge acquisition, structuralization and formalization, (5) techniques, tools and methods issued from artificial intelligence, and so on.

The figure 3 proposes a multidisciplinary approach in this field. With Work Psychology, Sociology and Ergonomics experts, it is possible to take a census of temporal needs and strategies in control rooms of complex processes. A collaboration with Cognitive Engineering experts can lead to a census of the current knowledge acquisition tools and their characteristics and functionnalities. With Artificial Intelligence experts, it is possible to take the census of temporal logics tools. With all three, it is then possible to study the adequacy of identified models, methods and techniques. This analysis must lead to (1) a better specification of cognitive engineering workbenches usable for the development of knowledge bases integrated in assistance system(s), and also (2) a better specification of specialized workbenches (for instance real-time expert system shells) for the development of inference engine(s) integrated in assistance system(s).

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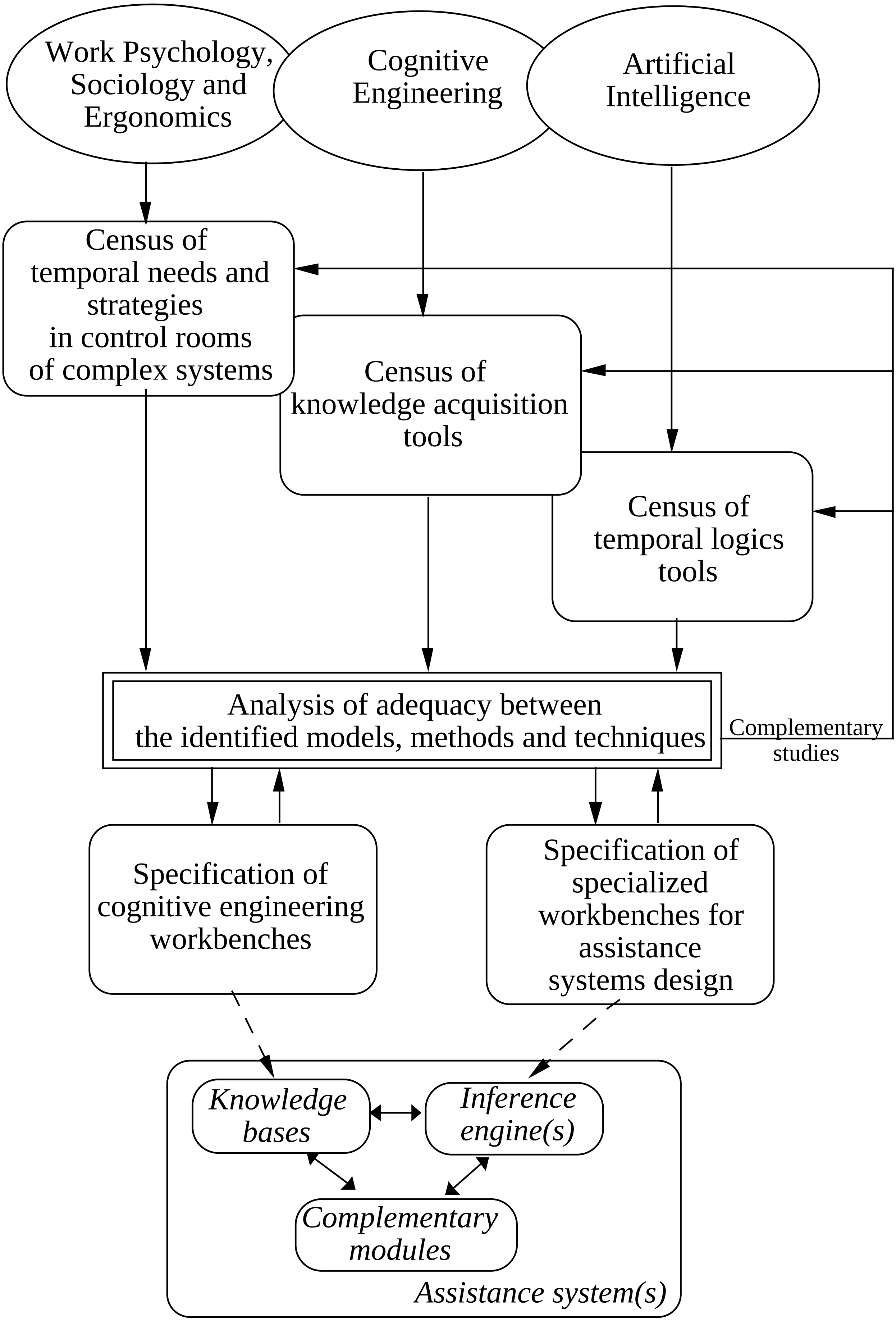

Figure 3 : Proposition of a multidisciplinary way of research

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