Agent-Based Method for Building a Cooperative Knowledge-Based System

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Abstract

We aim at building a cooperative knowledge-based system (KBS), representing the knowledge of several cooperating experts and intended to help such experts for palliating any absent colleague. Our knowledge acquisition method is based on a collective elicitation protocol and guided by a model of cognitive agent. We show how to analyse the expertise documents obtained after such collective elicitation sessions and how to exploit our agent model in order to derive the specifications of a cooperative system intended to play the role of each of the experts according to the need. We illustrate our method through an application of traffic accident analysis.

1 Introduction

1.1 The problem

In some workplaces, several experts of different competence domains cooperate for a collective problem solving. Sometimes, an expert may be obliged to solve the problem by himself, and request help from his colleagues only on some precise points, or even solve the whole problem by himself if his colleagues are absent. In such cases, the building of a cooperative system aimed at helping one expert or a group of experts by playing the role of their absent colleagues seems interesting. Such a cooperative system should be able to adapt to the competence domain of the end-users. For example, at INRETS [1], psychologists, vehicle engineers and road infrastructure engineers cooperate to analyse traffic accidents. According to the case, each expert works alone or with some of his colleagues. We are presently working on the design of an expert system in road safety that would help the experts of INRETS stemming from any discipline [1]. So, we are interested in the problems raised by the building of such a cooperative system, and in particular, its influence on knowledge acquisition.

1.2 Cooperative systems

In [16], Worden et al define a co-operative expert system as working as an assistant to its end-user: for example, it should be able to accept the advice of the user, avoid repeating the same mistakes, try to understand the reasons underlying the users' interventions and know the limitations of its own

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knowledge. For Worden & al, the co-operative system and the end-user can be considered as "two agents, with incomplete and overlapping knowledge", that must "co-operate effectively on a task as a team to make the best use of their knowledge". We will adopt the following definition of a cooperative system: such a system must be able to cooperate with its ends-users and help them for their task, for example through a problem solving performed in co-operation with the end-user or through a capability of adaptation to the characteristics of the end-user. The cooperativeness may concern not only the problem solving capabilities but also the explanation capabilities. In [6], among the characteristics of cooperative environments, the authors notice that the system needs models of the task, of the interaction process, of the external world able to influence the task execution, of the user in order to adapt the interaction to the user.

The building of such a system involves collaborative knowledge acquisition and collaborative design. For example, knowledge acquisition from the group of experts may be needed so as to emphasize the points where the system could play the role of an absent expert: a collective elicitation protocol seems useful in this purpose.

The group "final cooperative KBS - users" can be considered as an heterogeneous multi-agent system made of one artificial agent and several human agents, performing altogether cooperative problem solving. The cooperative KBS itself can be made of multiple agents and the human agents can interact among themselves or with the artificial agents included in the KBS. The interaction among the users or with the KBS will be influenced by the workplace to which the users belong.

1.3 Outline of the paper

In this paper, we try to answer the problem evoked above: *"how to build a cooperative system that may help an expert or a group of experts by playing the role of the other experts when they are absent ?"*. In a previous work [9], we had proposed a model of cognitive agent for guiding knowledge acquisition from multiple experts. Our approach consists of extending this previous work in order to guide the design of a cooperative system, specially if it is based on a multi-agent architecture. After proposing a collective elicitation protocol, we will indicate how to analyse such collective elicitation sessions and to exploit the agent model in order to derive the specifications of a cooperative system intended to play the role of each of the actors according to the need. Throughout the paper, we rely on an application of traffic accident analysis.

Figure 1 summarizes this model of cognitive agent.

2 Agent-based Knowledge Acquisition

2.1 Our model of cognitive agent

Our model of agent, detailed in [9], is intended to model both experts and users involved in the KBS design. Moreover, it can serve not only to model the present situation but also to specify the intended behavior of the group constituted by the final KBS and the end-users, and how several such agents will cooperate for problem solving.

This model of agent includes *individual aspects* (concerning the agent himself independently of the organization in which he is inserted and independently of the other agents) and *social aspects* related to the agent's insertion in an organization and to his interactions with the other agents. The individual aspects include *general features* not linked to the particular problem to be solved (competence domain, high-level goals, expertise model, resources) and *problem-specific features* that depend on the phase of the considered problem solving (state, intentions...).

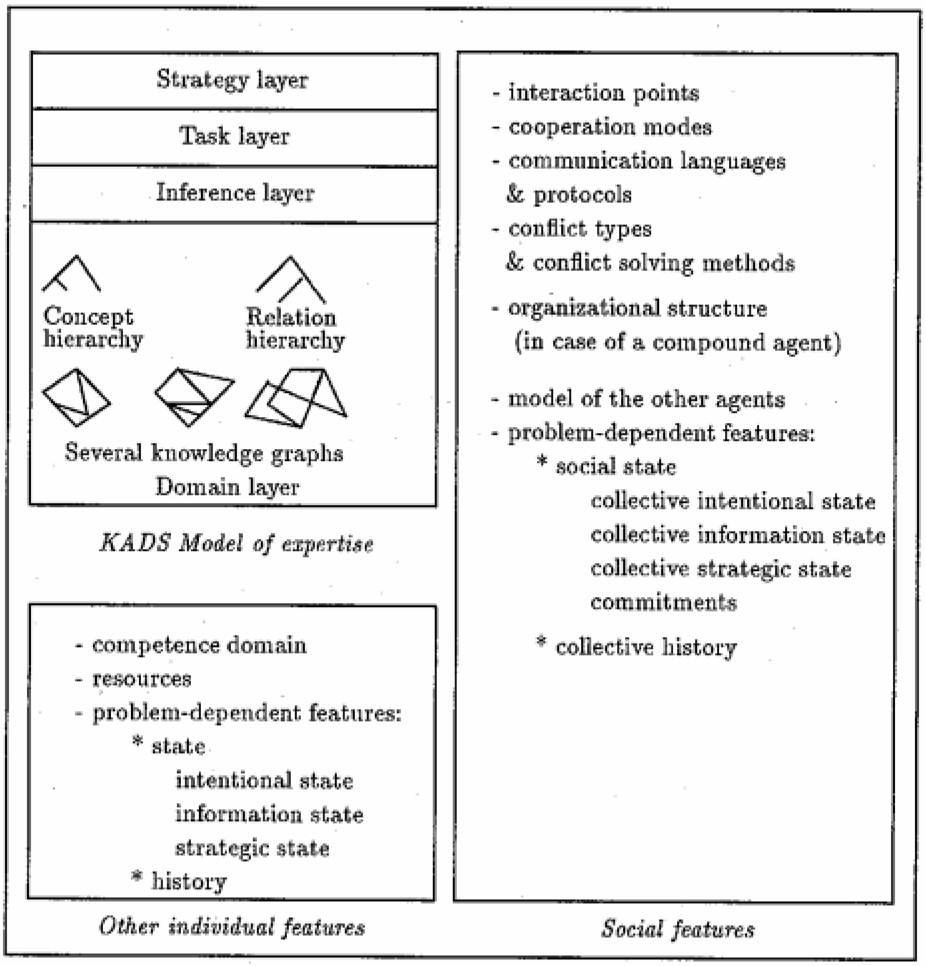

Figure 1: Our model of cognitive agent.

The social aspects include the cooperation modes, the communication languages, the interaction points and, in the case of a compound agent, its organizational structure.

We distinguish *simple agents* that are not made of other agents and *compound agents* (also called *organizations*) that are constituted by subagents gathered through an organizational structure, such subagents being themselves simple or compound. This notion of compound agent allows to model for example a group of cooperating experts or a group of collaborating users. The individual (resp. social) aspects of an agent exist, whether this agent is simple or compound.

2.2 Knowledge acquisition method guided by a model of agent

This section briefly presents our agent-based knowledge acquisition method (described thoroughly in [9]). Knowledge acquisition consists of knowledge elicitation and knowledge modeling. Once the previous model of agent is available, knowledge acquisition can be seen as the process of *identifying the adequate involved agents* and then *building the corresponding artificial agents* in the knowledge acquisition tool and *filling them progressively.*

The identification phase consists of identifying the different kinds of humans involved in knowledge acquisition phase and specially the experts and potential end-users in a given organization. Then the artificial agents that will represent them in the knowledge acquisition tool are progressively identified and built: according to the case, such artificial agents may correspond to one expert (resp. user), to a group of experts (resp. users) or to a combination of subparts of experts (resp. users).

The filling of the agents consists of eliciting and modeling knowledge from the adequate human agents (knowledge on the human organization, on the varied expertises, on the cooperation modes, etc.) in order to be able to fill the different individual and social features that must characterize the associated artificial agents.

The knowledge engineer can adopt a bottom-up approach (construction of the simple agents and then of the compound agents) or a top-down approach (construction of the compound agents and then of their subagents). The comparison of expertise models can lead to the "decomposition of a given expert" in several subagents ot to the "gathering of several experts" into a single artificial, compound agent.

Identification and filling of the agents are in fact interleaved as, throughout the knowledge acquisition process, the need to split an agent into several ones or to gather several agents into a compound one may appear.

2.3 Elicitation protocols

For the knowledge elicitation techniques, we suggest to use both individual techniques (interview of one expert; thinking aloud protocols of one expert solving a case) and collective techniques (collective solving of a case by several experts either from the same discipline of from different ones; individual resolution of a given case by several experts separately, followed by a meeting where they compare their respective solutions and discuss about them, etc.).

The individual sessions are helpful to determine the individual characteristics of each expert as well as some social aspects such as the way each expert explicitly describes his model of the other experts or his cooperation modes. The collective sessions usually help to refine the individual characteristics of each expert and to elicit his social aspects (the experts' interaction points, the way some experts can gather and reorganize their group during a given problem solving, their cooperation modes, the way they adapt their communication language to the interlocutor, etc.). The analysis of the individual (resp. collective) case studies give information on the problem-dependent, individual (resp. collective) characteristics of the experts.

2.4 modeling of multiple expertises

Figure 2 sums up our approach for modeling of expertise:

- It exploits the expertise documents obtained after retranscription of the elicitation sessions.
- It is guided by generic models (such as KADS generic models for modeling each individual expertise, and our agent model for taking into account multi-expertise).
- It relies on techniques of analysis of expertise documents (decomposition of the structure of the documents and annotation of elements of the documents with entities stemming from KADS models or from the agent model).

Our techniques for comparison of expertise models thanks to the comparison of the knowledge graphs appearing in the domain level of such expertise models was detailed in [10].

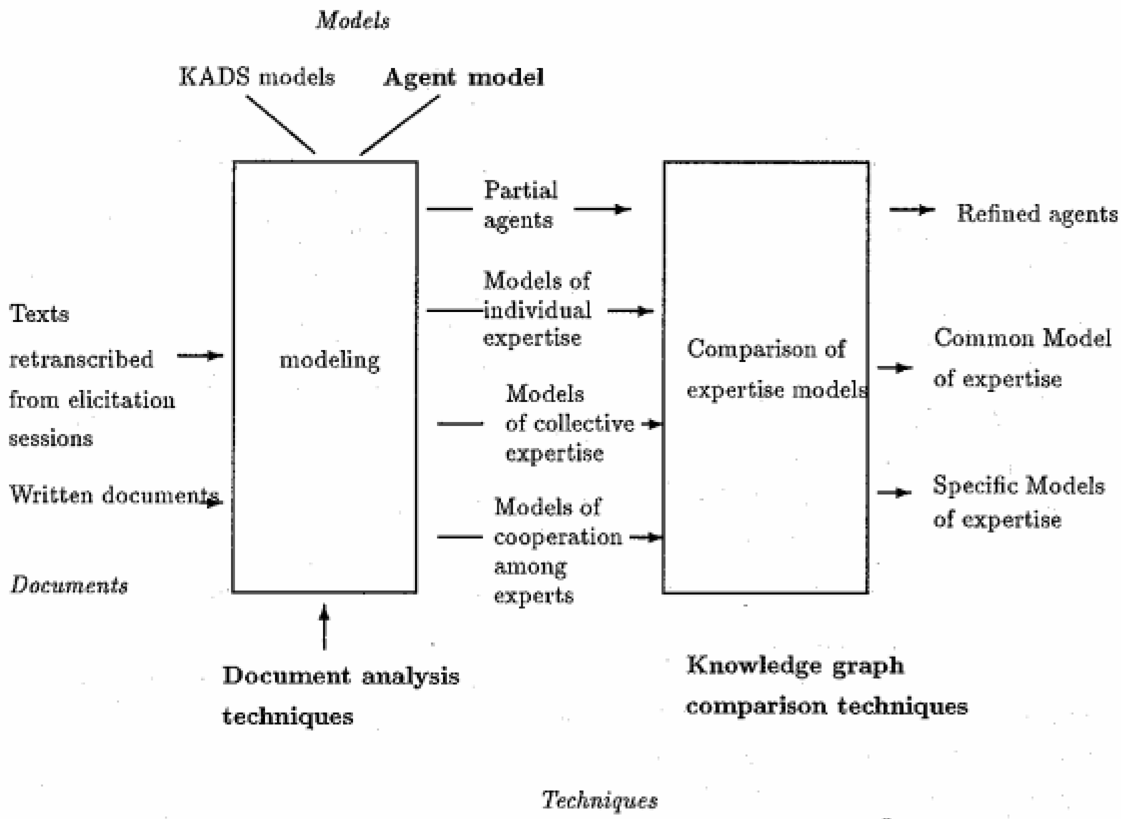

Figure 2: Our approach for modeling multiple expertises [2].

3 Analysis of a collective case study

After the elicitation sessions, the analysis of the collective case studies allows to determine several aspects. We will illustrate the possible results of the analysis through examples related to a case studied cooperatively by two experts - an infrastructure engineer and a psychologist.

Figure 3 shows the task decomposition obtained from the analysis of the collective resolution of the case by both experts.

- *Which tasks are exclusively performed by only one expert ?* For example, the approximative kinematics reconstitution and the analysis of the infrastructure check-list were carried out only by the infrastructure engineer, while the analysis of the quality of the interviews of the drivers and the assessment of the reliability of the drivers' declarations in the interviews were performed only by the psychologist.
- *Which tasks can be carried out by any of the experts ?* For most of the tasks appearing in figure 3 (analysis of the map, of the photos, of the vehicle check-list, of the PV, and determination of the accident factors), both experts brought a significant competence.

[2] The elicitation protocol and the method for modeling multiple expertises are the fruit of the collective work of the whole Acacia project.

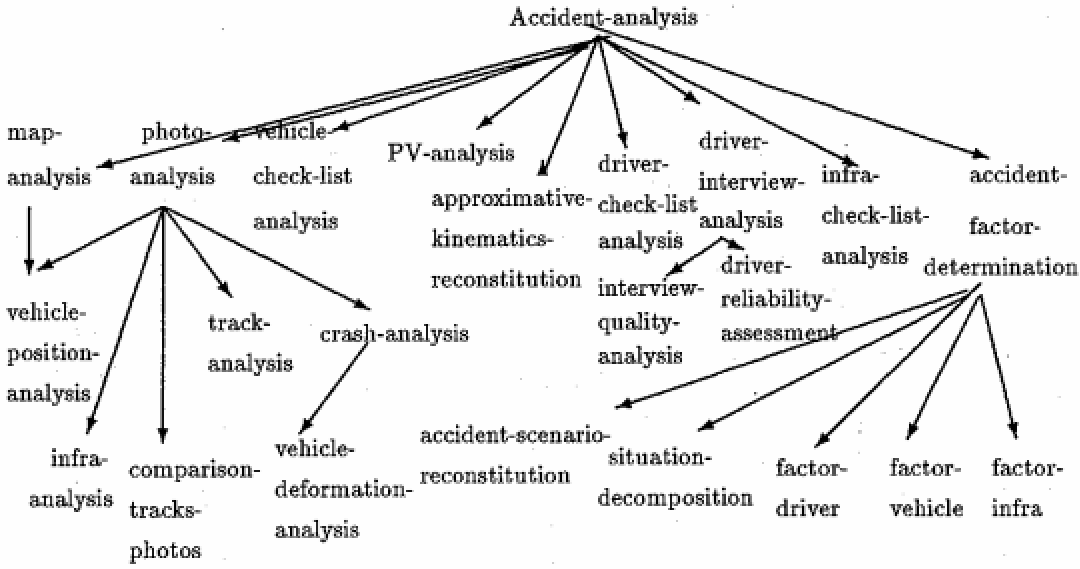

Figure 3: Hierarchy of the tasks of the agents Infrastructure-engineer and Psychologist.

- *Which tasks should have required the competence of an absent expert ?* For example, a precise kinematics reconstitution by the absent vehicle engineer was needed. The description of this missing task by both experts showed their vision upon the task of their absent colleague.

  Moreover, the analysis of the case study gave indications on the interaction points of the vehicle engineer, even though he was missing: vehicle position analysis from photos, analysis of vehicle deformations from photos, analysis of the vehicle check-list, *precise kinematics reconstitution* (that, according to the infrastructure engineer, consisted of decomposition into sequences, calculation of distances, calculation of the vehicle speeds, vehicle trajectory simulation, verification of the compatibility with the tracks on the photos), determination of the accident factors linked to the vehicle..

- *How do the experts palliate the absence of their competent colleague ?* When the experts needed the speeds of the vehicles involved in the accident, without the precise kinematics reconstitution that the missing vehicle engineer could have carried out, the infrastructure engineer performed an approximative kinematics reconstitution while the psychologist rather assessed the reliability of the drivers' declarations upon their speeds,

- *How do the experts cooperate ?* Both experts took part in the organization of the collective task; the psychologist explicitly requested for explanations upon specific aspects of the competence of the infrastructure engineer (e.g. explanations on the infrastructure check-list). Each expert tried to strengthen the hypotheses emitted by the other expert. Other possible cooperation modes could be task sharing or result sharing.

- *How do the cooperation modes of the experts evolve ?* What are the criteria of such an evolution throughout a given problem solving or according to the partners ?

- *What kind of conflicts occurred and how were they solved ?*. Some divergences appeared upon the organization of the collective task: differences in the order both experts usually analysed the check-lists, discussion on the proposition of an expert to delay a given task in order to focus on more interesting hypotheses.

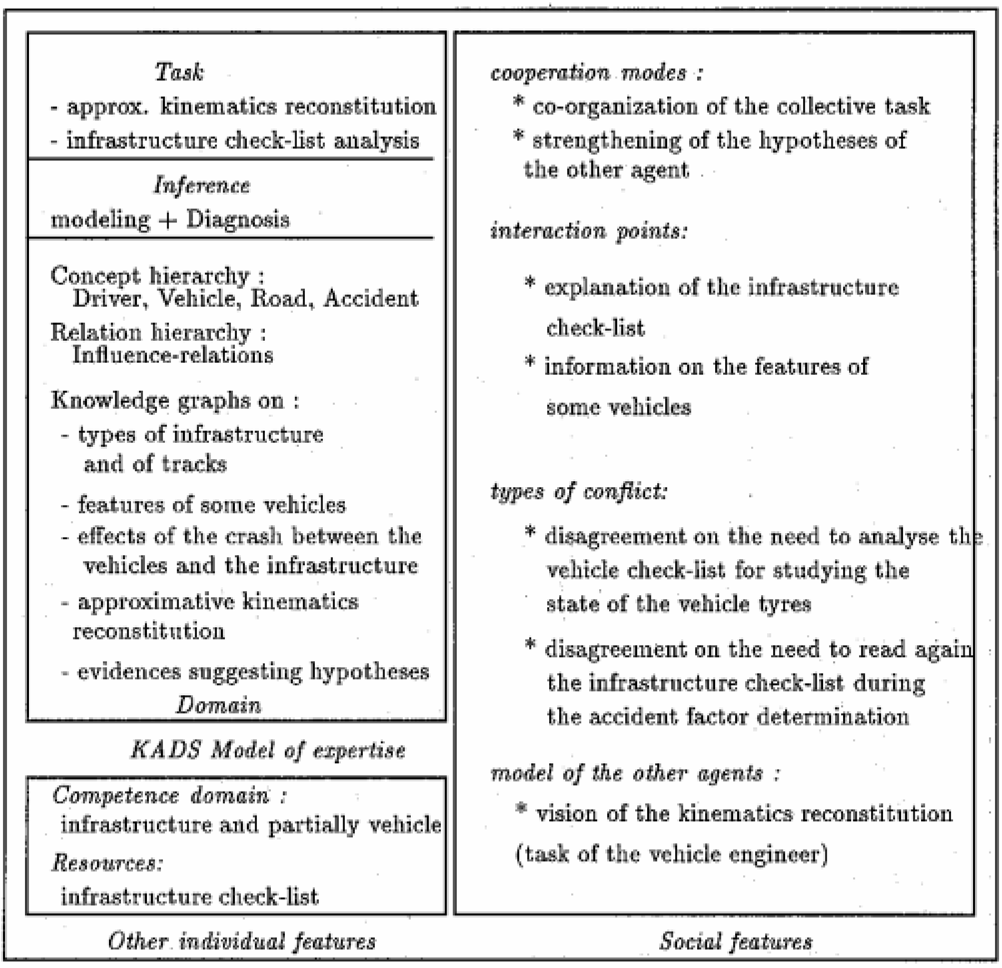

Figure 4: The agent Infrastructure-engineer.

Figures 4, 5, 6 present the agents respectively associated to the infrastructure engineer, to the psychologist and to the group of both agents.

4 Specifications of the cooperative KBS

The analysis of the collective case studies can help determine the specifications of the cooperative system, i.e. specify the structure, function and behavior of the cooperative system. Once completely determined, the artificial agents handled through the knowledge acquisition phase can serve as the basis of the artificial agents composing the final KBS, if it is based on a multi-agent architecture. For example, in the case of INRETS, we used the collective elicitation protocol described above, in order to elicit knowledge from two psychologists, three engineers in road infrastructure and two vehicle engineers. As the final system for traffic accident analysis must be able to play the role of any of the experts, it should be made of several agents corresponding to those identified during the agent-based knowledge acquisition phase (see figure 7).

In particular, this analysis aims at helping to specify: (a) which agents must be included in the cooperative system; (b) the decomposition of the global task between the KBS artificial agents and the end-users according to their respective competence domains; (c) the distribution of subtasks; (d) interactions between the system and the end-users; (even though the artificial agents are inspired of the results of the analysis of the collective elicitation sessions, they are constrained by the differences of capabilities between human agents and computer agents); (e) the interaction points of the cooperative system; (f) the adaptation of the communication language used by the KBS according to the characteristics of the end-user; (g) the possible conflicts between the system and the end-user and the way such conflicts will be solved.

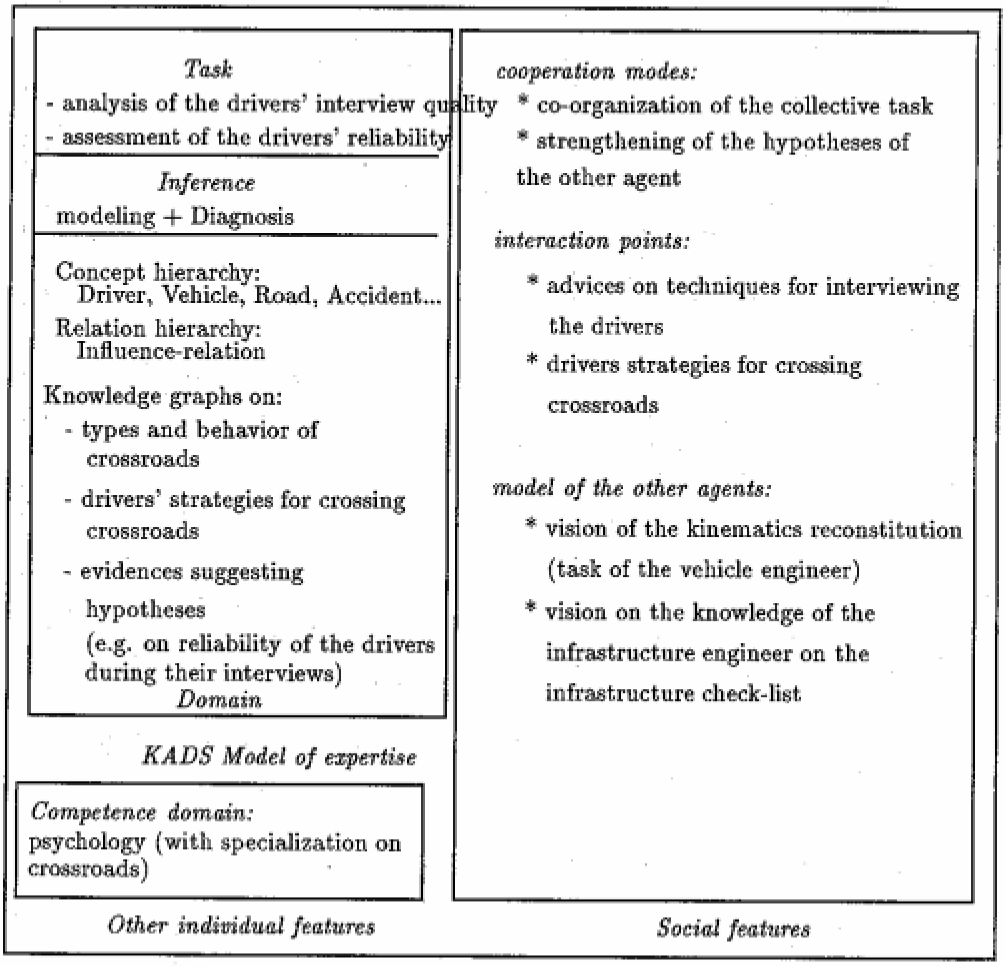

Figure 5: The agent Psychologist.

It is important to specify: (1) the characteristics of the cooperative system considered as a compound agent, (2) the characteristics of each potential end-user of the future KBS: the end-users can be considered either as simple agents (in the case of a single expert) or as compound agents (in the case of a group of experts using the KBS), (3) the characteristics of the compound agent constituted by the cooperative system and the end-users.

Our previous model of cognitive agent summarized in figure 1 seems to be helpful, as it indicates which individual and social features must be specified for each of such agents. Clearly, the results of the elicitation sessions directly reveal the characteristics of each potential end-user of the future system.

Moreover, we think that the features by which Worden & al [16] characterize a cooperative system, can serve as a guide for deriving the specifications of the compound agents "cooperative KBS" and "cooperative KBS + end-users".

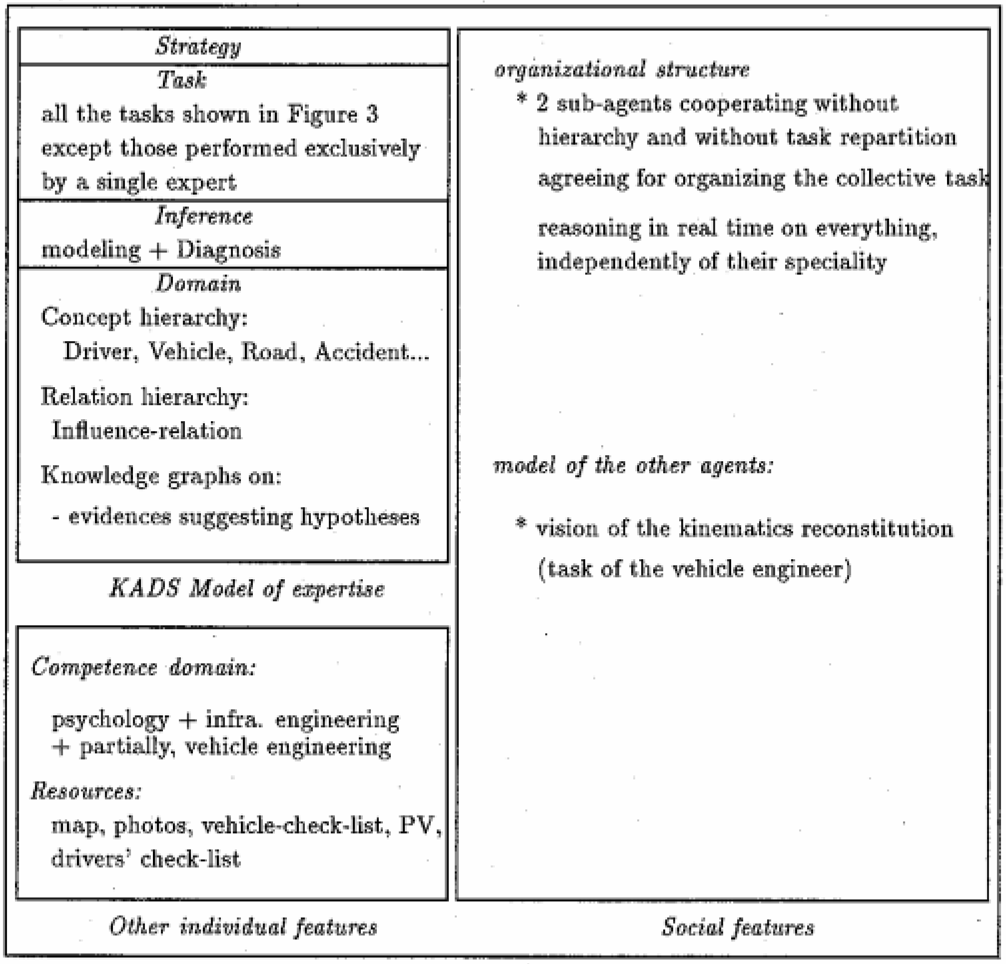

Figure 6: The compound agent Infrastructure-engineer + Psychologist.

4.1 Task division

One of the most important features of a cooperative system is the labour division between such a system and the user. It has an influence not only on the social characteristics of the cooperative KBS but also on some of its individual features:

- *competence domain*: the official competence domain of the cooperative system must be explicitly specified, as well as the competence domains of the possible end-users: the cooperative system will rely on what it supposes upon the competences of its end-users. Such competence domains must be compatible with the list of the tasks each of the agents can perform.

  According to [16], "the most important meta-knowledge required by an effective assistant is a knowledge of the structure and extent of his own knowledge". It implies the explicitation of the different agents (cf figure 7) and of which agents are able to realize a given task (cf figure 3).

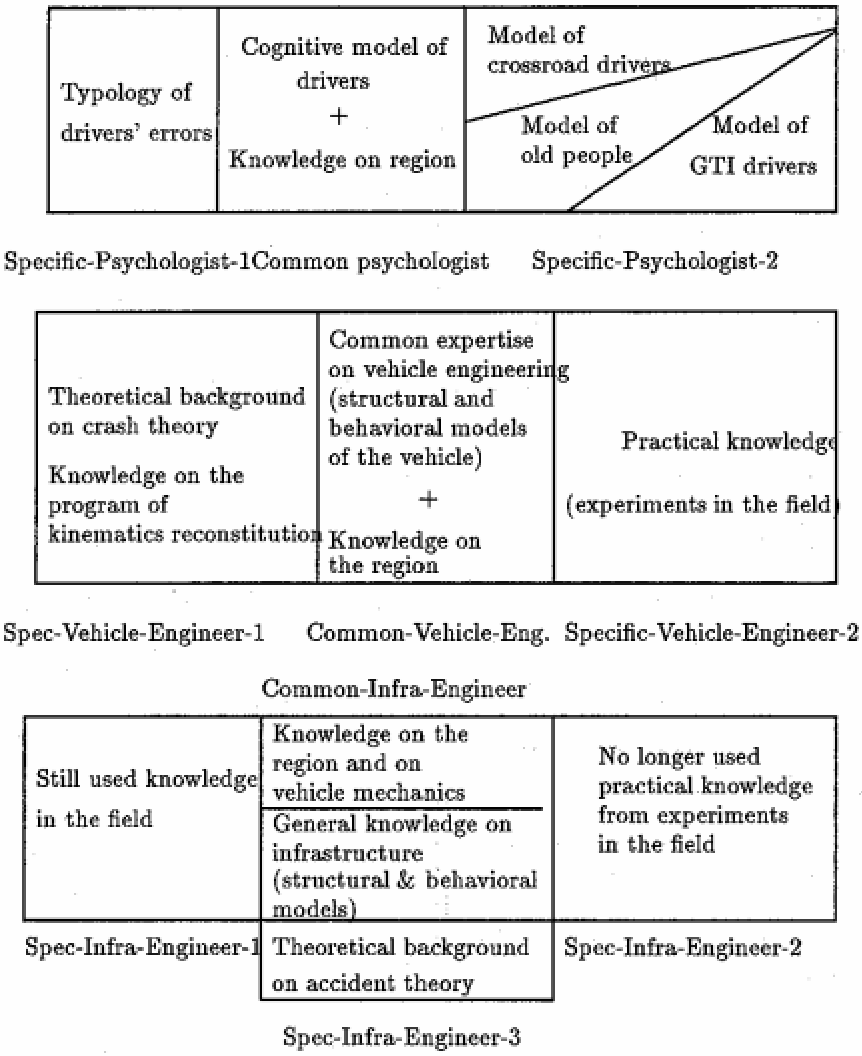

Figure 7: The agents involved in traffic accident analysis.

The analysis of the collective case studies gives indications on the task division within a group of experts, or even, for a given expert, the task division between his different capabilities modeled through different subagents: for example, in figure 7, the second psychologist is represented by subagents having respectively a model of drivers in crossroads, a model of the driving behavior of old people, and a cognitive model of drivers of GTI vehicles. Moreover, the choice of the subagents of the cooperative system and of their respective tasks can be inspired from such an analysis. Last, concerning the group "cooperative system + end-users", several task divisions are possible according to the degree of cooperativeness. Worden & al distinguish the following possibilities: (1) user does task, (2) user does task, assistant critiques, (3) assistant does task, user vets results, (4) assistant does task.

- *resources*: for determination of the task division between the KBS and the user, the resources needed for a given task must be taken into account. For example, in traffic accident, some tasks require data extracted from a map or from photos or even from the interviews of the drivers, which are resources that can hardly be exploited directly by the computer. So the tasks of analysis of the map, of the photos or of the drivers' interviews cannot be entirely performed by the cooperative KBS: clearly, either they will be entirely carried out by the end-users, or the KBS will only guide the user by asking him adequate questions or by giving advices upon the information to extract from such resources. On the contrary, the formats adopted in the check-lists related to the driver, the vehicle or the infrastructure were aimed at a coding on a computer. So, as such resources can be used by the KBS that can automatically process them, the tasks of analysis of such check-lists can be taken in charge by the KBS. By the same way, the vehicle engineer uses a program of kinematics reconstitution: according to data extracted from the vehicle and infrastructure check-lists, and from the drivers' interviews, he enters various parameters in the program and runs the program in order to reconstitute the speeds and trajectories of the vehicles, so that they can be compatible with the tracks found on the road and with the photos of the vehicles after the crash. So this program of kinematics reconstitution is a possible resource for the cooperative KBS but a completely automatic use of this program, with for example, automatic generation of the parameters entered in it, seems impossible. So, the task of precise kinematics reconstitution should probably be performed cooperatively by the KBS and the user altogether.

4.2 Specification of the social features

Let us study how to determine each of the social features of the cooperative system, and of the compound agent "cooperative system + end-users".

- *organizational structure*: the cooperative system can be made of some of the (simple or compound) subagents, determined after the agent-based knowledge acquisition phase. For example, each of the subagents identified in traffic analysis (cf figure 7) can be explicitly represented in the cooperative system, with the possibility of gathering some subagents with an adequate organizational structure, according to the context. These organizational structures related to the cooperative system subagents can be either inspired of the organizational structures adopted by the human experts or based on the characteristics of the multi-agent shell to be used for the KBS implementation. Examples of organizational structures inspired from human organizations are: hierarchical organization with one of the subagents playing the role of a supervisor, horizontal organization with equality among the subagents, etc. Examples of organizational structures stemming from systems implemented in distributed artificial intelligence are the contract net of Smith [14], the production lattice of Gasser [12, 13], the partial global planning of Durfee & al [11], the commitment-based organizations of Bond [2, 3].

  For the group "cooperative system + end-users", the organizational structure must also be indicated: it can be a hierarchical organization (the supervisor being either one of the users, or one of the artificial subagents of the cooperative system); it can be more balanced between the system and the users. The choice depends on the recognized competence domains of the different agents: the most competent agent on a topics should be allowed to supervise the cooperative work and use authority for solving conflicts.

- *interaction points*: a part of the specification of the cooperative system consists of determining the interaction points of the cooperative system: therefore, the developer must choose the possible requests of the user to the system (in particular, the tasks the user is allowed to ask the system to solve or the explanations he is allowed to ask) as well as the possible requests of the system to the user (mainly, information or tasks to solve). In all cases, the contexts where some requests are allowed must be specified. How a request of the user on an interaction point of the cooperative system will be forwarded to the adequate subagents of the cooperative system must also be specified: it must be compatible with the organizational structure of the cooperative system seen as a compound agent. The analysis of the collective case studies must help make explicit the information on the possible organizational structures of the compound agents that may appear during the problem solving, on the way such organizational structures can evolve, on the contexts where a given compound agent will change his organizational structure.

- *cooperation modes*: the agent's mode of cooperation may depend or not on the problem to be solved. The analysis of the collective case studies can indicate whether the types of cooperation presented in [7] (accidental cooperation, unilaterally intended cooperation, mutual cooperation) or in [15] (negative cooperation - i.e. the agents avoid to do the same task simultaneously - and positive cooperation - i.e. the agents need one another to perform a task) are relevant for the application and appear among the human agents. In which case, such cooperation modes will appear at least in the agents constituted by the end-users. The knowledge engineer may decide whether such cooperation modes can characterize the cooperation between the cooperative KBS and the user. By the same way, according to the multi-agent shell available for the implementation, the knowledge engineer must choose the level of social complexity for the subagents of the cooperative system [5]: perception capabilities, communication capabilities, contract capabilities, delegation capabilities or joining capabilities.

  The knowledge engineer must also specify whether the agents inside the cooperative system will be able to change their cooperation modes according to the context of the problem solving or according to the end-users. The conditions of evolution of the cooperation modes between the cooperative system and the end-users must also be specified.

- *model of the other agents*: as noticed in [16], "effective co-operation depends on knowledge about the structure and extent of our knowledge and of our partner's knowledge." Therefore, making explicit the model an agent has upon the other agents is important. As the "model of the other agents" appears as a characteristics of our model of agent (cf figure 1), it allows to determine what must be explicitly stored in the cooperative system as a model of the end-users, and what must be the model the end-users have upon the cooperative system.

- *communication languages and protocols*: the knowledge engineer must specify the communication languages and protocols of the group "cooperative system + end-users" and the contexts in which one a given protocol will be used rather than another. In fact, the end-user may dynamically change the communication protocol according to the context.

- *types of conflicts and of conflict solving methods*: the choice of the interaction protocol between the cooperative system and the users influences the kinds of conflict solving methods that may occur. If, during the case studies, a type of conflict was solved by authority within a group of experts, the same strategy may be adopted for solving conflicts among the subagents of the cooperative system, but not necessarily between the cooperative KBS and the users: an expert would hardly accept an authority decision from the KBS; he would rather expect the system to provide explanations, but he would like to keep the final decision. So the knowledge engineer must specify an explanation capability of the KBS for such conflict types. For the types of conflicts that were solved by the experts thanks to explanations, an explanation capability of the KBS can also be specified but the capability of the KBS to understand explanations from the users seems to us more utopian.

4.3 Specification of operations on the agents

In [9], we had presented several operators on the agents: creation of a new agent, sending a message to one or several agents, aggregation of several agents, decomposition of a task among several agents, modification of a compound agent, destruction of an agent, dissociation of a compound agent.

The knowledge engineer had to acquire information on the contexts where such operators could be used and he could then exploit them for the design of the final KBS if it was based on a multi-agent architecture. So, for the design of a cooperative KBS, the knowledge engineer must specify knowledge on the way the different operators can be applied on the artificial subagents of the KBS (specially if the structure of the cooperative system can be dynamic and can evolve throughout the problem solving).

For example, when during a collective case study, several experts decide to gather for solving a common goal, it can reveal a possible context of creation of a compound agent. If a group of experts decide to reorganize (e.g. a new expert may join them, or an expert may leave the group, or the group may change its organizational structure...), it may correspond to a context of modification of an agent. When a group of experts decide to break up their association, it reveals a possible context of dissociation of an artificial subagent of the KBS, aimed at representing this group of experts.

4.4 Protocol of use of the cooperative system

In the protocol of use of the cooperative system, the knowledge engineer must specify: (a) which tasks will be performed entirely by the user, (b) which ones will be performed cooperatively by the KBS and the user, (c) which ones will be performed entirely by the system.
As we saw earlier, this task division depends on the official competence domains of all the involved (human or artificial) agents, and on the resources needed for achieving the tasks. We also showed its strong influence on the possible organizational structures, cooperation modes and conflict solving methods of the agents. The users can interact with the cooperative system either via the agents or via the tasks.

Agent-based protocol

When the experts use the cooperative system, they will identify themselves as a set of agents chosen among the artificial agents included in the system. It will mean that the part of the work performed by such artificial agents would be performed by the human experts, while the remaining tasks would be performed by the other artificial agents needed for solving the problem.

For example, the psychologist and the infrastructure engineer of the previous example, would choose to work with an artificial agent "Vehicle-engineer" (that would be composed of all the subagents specialists in vehicle engineering appearing in Figure 7). This artificial agent would take the relay of the human experts for all its official interaction points, such as the task of precise kinematics reconstitution. On the contrary, if the psychologist works alone, he may choose to work with two artificial agents "Infrastructure-engineer" and "Vehicle-engineer" that will take the relay on their interaction points.

Task-based protocol

When the experts use the cooperative system, they will choose the tasks they will realize alone, the tasks they will ask the cooperative system to solve by itself, and the tasks for which they prefer to co-operate with the KBS. In case of need, the adequate artificial agents, able to realize the tasks, will be created by the KBS. But, in this case, the experts do not need to know the agent-based structure of the cooperative system.

In the previous example, the psychologist and the infrastructure engineer would ask a cooperative resolution of the tasks *crash-analysis*, and *precise-kinematics-reconstitution*, and would decide to perform by themselves the tasks *PV-analysis* and *driver-interview-analysis* and to let the KBS work alone on the task *vehicle-check-list-analysis.*

5 Conclusions

This paper proposed a method for specifying a cooperative system thanks to the analysis of collective elicitation sessions and to the exploitation of our model of agent. We illustrated the proposed ideas through an example in traffic accident analysis.

Related Work

The description by Worden & al of the characteristics of a cooperative system [16] was often evoked in this paper, as we were often guided by such characteristics.

The work performed on KADS-I model of cooperation [8] emphasizes the importance of the analysis of cooperation between the future KBS and the user. The cooperation model helps to specify (1) the task distribution among the agents, (2) the dependencies among the tasks, and, in particular, the ingredients transferred from one task to another, (3) the control.

In [17], the authors describe several successive tools for helping developers to build customized applications in a workplace: such tools exploit contextual information on the tasks thanks to models of the workplaces and work processes involved in the tasks.

In [6], the authors study a user centered design of a KBS in order to obtain a cooperative environment where intelligent agents will interact among themselves and with the external world. They present a task model and show how a formal analysis based on this task model, allows to build the conceptual models of cooperative agents and to structure the interaction between the KBS and the user.

In [5, 4], the author proposes a model of cooperation for building cooperative agents, with several possible levels of social complexity. Two viewpoints on the notion of cooperation are distinguished: the viewpoint of an external observer and the viewpoint of an agent.

Further Work

The method proposed in this paper is rather informal, but our further research will try to formalize several aspects of our work, in particular our model of agent. As a possible further work, we will also study whether we could express a formal specification of our cooperative system in the formal language DESIRE [6] that seems useful for specifying a cooperative environment.

If we choose an implementation framework (e.g. a tool such as MAGES IV [4]), we can exploit the implementation constraints on the artificial agents in order to guide more systematically the design of a cooperative system aimed at being implemented in such a tool. After making our method more systematic, we will actually implement the cooperative system for help to traffic accident analysis.

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