Building of a Corporate Memory for Traffic-Accident Analysis

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■ This article presents an experiment of expertise capitalization in road traffic-accident analysis. We study the integration of models of expertise from different members of an organization into a coherent corporate expertise model. We present our elicitation protocol and the generic models and tools we exploited for knowledge modeling in this context of multiple experts. We compare the knowledge models obtained for seven experts in accidentology and their representation through conceptual graphs. Finally, we discuss the results of our experiment from a knowledge capitalization viewpoint.

There is an increasing industrial interest in the capitalization of knowledge (that is, both theoretical knowledge and practical know-how) of groups of people in an organization, such groups being possibly dispersed geographically. The coherent integration of this dispersed knowledge in a corporation is called *corporate memory* (Steels 1993). The memory of an enterprise includes not only a *technical memory* obtained by capitalization of its employees' know-how but also an *organizational memory* related to the past and present organizational structures of the enterprise (human resources, management, and so on) and *project memories* for capitalizing lessons and experience from given projects (Pomian 1996). Tourtier (1995) distinguishes *profession memory*, composed of the referential, documents, tools, and methods used in a given profession; *society memory*, related to organization, activities, products, and participants (for example, customers, suppliers, subcontractors); *individual memory,* characterized by status, competencies, know-how, and activities of a given member of the enterprise; and *project memory,* comprised of the project definition, activities, history, and results.

The construction of a corporate memory requires abilities to manage disparate know-how and heterogeneous viewpoints, make this knowledge accessible to the adequate members of the enterprise, and integrate and store this knowledge in paper-based or electronic documents or in knowledge bases or case bases that should be easily accessible, usable, and maintainable. The solutions offered by research (Macintosh 1994) to this problem crucial in industry (Morizet-Mahoudeaux 1994) can be related to the analysis and modeling of an enterprise (Fox 1993; Fox, Chionglo, and Fadel 1993); its evolution through time; the experience acquired from past projects; the integration of models of expertise from different groups in an organization into a coherent corporate-expertise model; the construction and integration of distributed, heterogeneous knowledge bases or knowledge-based systems, possibly stemming from multiple experts; the development of an intelligent documentary system (Ballay and Poitou 1996; Poitou 1995); the management of hypertext links between knowledge bases and documents (Martin and Alpay 1996); knowledge sharing between different groups; the exploitation of AI techniques such as case-based reasoning (Simon 1996; Simon and Grandbastien 1995; Kitano et al. 1992); the exploitation of multiagent systems (Oliveira and Shmeil 1995; Vandenberghe and de Azevedo 1995); the exploitation of the web (Huynh, Popkin, and Stecker 1994); and natural language document-analysis techniques (Trigano 1994).

As noted in Nonaka (1991) and Van Engers et al. (1995), the knowledge chain consists of seven links: (1) listing the existing knowledge, (2) determining the required knowledge, (3) developing new knowledge, (4) allocating new and existing knowledge, (5) applying knowledge, (6) maintaining knowledge, and (7) dis-

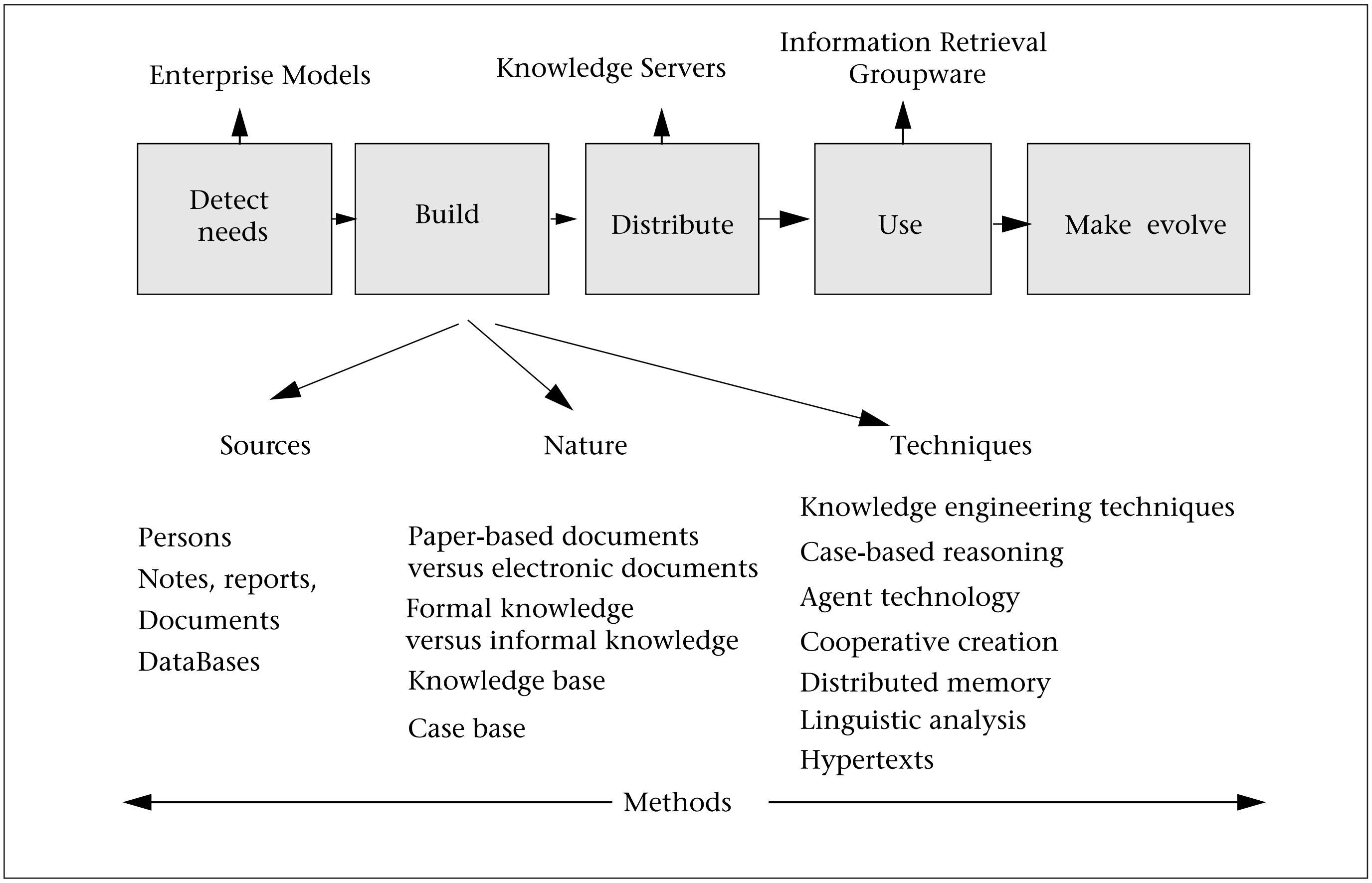

Figure 1. Corporate Memory Management.

posing of knowledge. Thus, we can consider the building of the corporate memory as relying on the steps outlined in figure 1.

Detection of needs in corporate memory: This needs detection can be based on advisability analysis, allowing the determination of crucial knowledge to be kept in the corporate memory (Grundstein and Barthès 1996), or on the exploitation of enterprise models (Uschold et al. 1996; Fraser 1994). This phase can help to determine the potential users of the corporate memory and, perhaps, the possible modes of exploitation useful and adapted to their work environment.

Construction of the corporate memory: The adopted techniques depend on the sources from which the corporate memory can be built (specialists, paper-based or electronic documents such as reports or technical documentation, existing databases or case studies, dictionaries) and the nature of the needed corporate memory according to the intended users (paper-based documents versus electronic documents, a documentary system; formal knowledge versus informal knowledge; knowledge base versus case base). Both construction of the corporate memory contents and adequate organization of this corporate memory must be tackled. As emphasized during the Tenth Banff Knowledge Acquisition for Knowledge-Based Systems Workshop (KAW'96) track entitled "Corporate Memory and Enterprise Modeling," a corporate memory is of course different from a knowledge-based system: It might be a paper-based document making explicit a corporate members' knowledge that had never been elicited and modeled. It might also be implemented in a computational memory, such as an intelligent documentary system (Ballay and Poitou 1996; Poitou 1995); a knowledge base; a case-based system (Simon 1997, 1996; Simon and Grandbastien 1995); a combination of documents, knowledge bases, and case bases (Kühn and Abecker 1997); and a web-based system or a multiagent system.

Diffusion of adequate elements of the corporate memory: This distribution can be passive or active to specially selected members of the enterprise (Van Heijst, Van der Spek, and Kruizinga 1996): Either the user can research for the needed information, or knowledge distribution can be decided systematically and taken in charge by an adequate service of the enterprise. Individuals and organizations can take advantage of the remarkable possibilities of access to data, information, and knowledge provided by the internet. Knowledge diffusion can, for example, exploit the possible access to the internet or an intranet inside the enterprise. It can thus rely on a knowledge server on the web or on a publication on the web (Euzenat 1996).

Use of the corporate memory: In all cases (documentary system, knowledge base, case base, web-based system, and so on), we must notice the importance of information search by the authorized members of the enterprise, if possible adapted to the users' needs, their activities, and their work environment.

Maintenance and evolution of the corporate memory: Problems linked to the addition of new knowledge, removal of obsolete knowledge, and coherence underlying a cooperative extension of the corporate memory must be tackled.

Traffic-Accident Analysis

We have worked with the Institut National de Recherche sur les Transports et leur Sécurité (INRETS) Salon de Provence in a project that resulted in the building of a partial corporate memory of a team of specialists in road traffic-accident analysis (Alpay et al 1996). INRETS Salon de Provence comprises researchers (that is, experts) and investigators. The experts at INRETS stem from various disciplinary fields: psychologists specialists of the driver's behavior, engineers specialists of the vehicle, and engineers specialists of road infrastructure. After an accident, INRETS is immediately informed by Safety Service (in France, firemen). Two investigators from INRETS go to the scene of the accident. One of them carries on interviews with the persons involved in the accident, while the other investigator tries to keep track of the accident scene (shots, measurements, and so on). Then, the two investigators exchange their first ideas or hypotheses. They determine the missing data, which will require an additional collection, after which both investigators analyze the case together and write an account called a *synthesis*. Once finished, the accident file obtained with the Detailed Study of an Accident is put in the archives. Then, such dossiers are used by the INRETS researchers for thematic analyses, directed toward specific research topics (for example, driving behavior of old persons). The experts at INRETS are currently researchers working mainly on thematic analyses, but several of them had been investigators for several years. Thus, they were interested in an experiment of knowledge capitalization that would enable them to formalize their know-how (this formalization could, for example, result in the writing of a book), share this expertise within the whole institute, enhance the work of the new investigators or even of the researchers (in particular, by making explicit the competences of researchers from other disciplines), and improve communication and cooperation between the experts.

In addition to formalizing their tacit, implicit knowledge (Nonaka 1991), they were also interested in a computational tool that could have multiple purposes: (1) support traffic-accident analysis, in particular, help the new investigators by making available the experts' know-how, and (2) help the experts by making available the abilities of the other researchers from other disciplines.

From the viewpoint of the building of a corporate memory, this experiment helped us to focus on the following questions: how to analyze the evolution of a group through time, the experience acquired from past projects, and how to integrate models of expertise from different members of an organization into a coherent corporate expertise model. In this article, we present this experiment of expertise capitalization. First, we describe our method (our elicitation protocol and the generic models and tools we exploited for knowledge modeling). Then, we describe and compare the knowledge models obtained for seven experts in accidentology and their representation through conceptual graphs. Finally, we discuss the results of our experiment from a knowledge capitalization viewpoint.

Method of Knowledge Acquisition from Multiple Experts

We conducted an investigation with 18 French or foreign enterprises or research laboratories that had faced the problem of knowledge acquisition from multiple experts (Amergé et al. 1994). This questionnaire was developed and distributed by our colleagues at the French research group, Multi-Exp. We took stock of the expertise-elicitation techniques and knowledge engineering methods used and their advantages and drawbacks for multiexpertise, the type of expertise conflicts and the methods used for solving them, the other kinds of multiexpertise-related problem encountered, and the architecture used for implementation.

Relying on the analysis of previous work, we developed our own method for acquiring knowledge from multiple experts. This method is inspired by the principles of the COMMONKADS method (Breuker and Van de Velde 1994) and relies on several generic models, among which is a model of a cognitive agent inspired by distributed AI. Our method is based on the following steps: (1) document collection and knowledge elicitation, (2) knowledge analysis and modeling, (3) validation of the knowledge models obtained, and (4) building of the corporate memory. The validated knowledge can be represented in a formalism such as conceptual graphs (Sowa 1984) and compared as a result of (informal or formal) techniques of expertise-model comparison.

Knowledge Elicitation Protocol

We performed our observations on seven experts: two specialists of the driver's behavior, two vehicle engineers, and three infrastructure engineers. We needed an elicitation protocol that would enable us to build a coherent corporate memory from the integration of the expertise models of the different experts. Our objectives were to determine the individual expertise of each expert and the influence of other experts on an individual resolution; identify the points leading to discussions between the experts; and determine the help expected from the future computational corporate memory, according to the expertise domain. Thus, we had to be able to compare (1) individual resolutions of the different experts, (2) an individual resolution and a collective resolution, and (3) a resolution of a homogeneous group of experts and a heterogeneous one (homogeneity with respect to to the expertise domain).

Our Protocol Taking into account our objectives, we developed an elicitation protocol composed of a collection of documents from INRETS, nondirective interviews, individual resolutions of an accident case, and collective resolutions of an accident case.

A collection of documents from INRETS: We collected numerous documents (reports, articles, notes, and so on) from INRETS, where the official or theoretical expertise in accidentology is described. This knowledge of the official expertise allows us to better comprehend the expertise as the experts practice it effectively. Such documents are part of the history of INRETS, and their analysis could help to understand the evolution of INRETS through time and its past projects.

Nondirective interviews: Each expert had an individual interview where he described his work: his functions in the enterprise, the way he realizes them, and so on. The interviews were recorded on tape and video. In the interviews, the experts talked about the history of INRETS Salon de Provence and about their tasks globally, whereas in the case studies, they supported such tasks with actual data.

Individual resolutions of an accident case: The experts had to solve several case studies while they were recorded on tape and video. The proposed cases were cases of actual accidents that happened recently and had been processed by the new investigators but were new for the experts. The task of the experts consisted of understanding how the accident had progressed. The experts had an accident dossier comprising plans, photos, information to identify the accident, information on the involved drivers and vehicles, and information on the road infrastructure (that is, accident physical environment). Usually, in an accident dossier, there is also a synthesis written by one of the investigators, which consists of a summary; an account of the accident circumstances; and a list of accident factors, subdivided into three types: (1) driver, (2) infrastructure, and (3) vehicle. In the dossiers given to the experts, we deliberately removed this synthesis because the task required from the experts was to elaborate the accident synthesis. Each expert processed three different case studies, and all the experts processed the same cases.

Collective resolutions of an accident case: The experts were set in a situation of interaction: Either two experts of the same specialty processed an accident case together, or the case was processed by two or three experts from different specialties. The experts processed the cases in two interaction conditions: situation A, *free cooperative resolution,* where the experts could freely organize their processing of the dossier, and situation B, *cooperative resolution in two phases,* where the experts processed the case individually, then exchanged their viewpoints. Whatever the interaction condition, the experts had to perform an oral synthesis of the accident and write a list of factors explaining the accident. Table 1 sums up the situations and conditions of interaction between the experts during the collective case studies. The elicitation sessions were recorded on tape and video and fully retranscribed.

Remarks It was not possible to observe the experts during actual data collection at the scene of the accident. The task proposed to the experts during the case studies corresponds to the Detailed Study of an Accident, where the analysis of the dossier is aimed at understanding the sequencing of the accident. Five of the seven experts had carried out this activity for several years a few years ago. Currently, they

Combination of Experts	Type of Accident in Situation A	Type of Accident in Situation B
3 homogeneous duos	Accident of old persons Crash at the back	Crash at the back of several vehicles in line
3 heterogeneous duos	Vehicle alone crashing into tree Crossroad accident	
2 heterogeneous trios		Lane change by one of the two vehicles Bike accident

Table 1. Collective Case Studies.

concentrate on the thematic analysis of dossiers constituted by new investigators. Contrary to the interaction situations in the protocol, the experts usually don't analyze a dossier together.

Collected Documents Thanks to the elicitation sessions conducted according to the previously described protocol, we collected the following expertise documents: audio and video transcriptions, notes of the experts and notes of the knowledge engineers on the experts activities, dossiers of the accident cases that were processed, and manuals used during the interviews, that is, documents directly related to the interviews, and reports, articles, books, lexicon specially built by an expert, and an INRETS manual on data collection, that is, documents not directly related to the interviews.

Knowledge Analysis and Modeling

The analysis of the expertise documents enabled the elaboration of three main types of knowledge model: (1) task (Duursma, Olsson, and Sundin 1993), (2) expertise (Breuker and Van de Velde 1994), and (3) agent (Dieng, Corby, and Labidi 1994).

We preprocessed some expertise documents with the statistics-based analyzer of natural language texts, ALCESTE (see Lapalut [1996] for more details).

We elaborated several task models from the different expertise documents (figure 2): a theoretical-generic model, a model by expert, and a model by type of expert.

The theoretical-generic model stems from COMMONKADS (Breuker and Van de Velde 1994), which provides a modeling library that contains generic expertise models for problems such as design, diagnosis, and planning. The models can be instantiated for a particular application. The "modeling" task offered by the COMMONKADS library can help to model the process that consists, for the expert, of reconstituting the accident sequence. Research of elements explaining the malfunctioning of the system driver-vehicle-infrastructure (DVI) can be seen as a diagnosis task.

After we established the expertise model of accidentology, we elaborated the agent model (cf. figure 3), which integrates components appearing in the task model and the expertise model.

We view the realization of a corporate memory in an organization as a cooperative activity between experts, knowledge engineers, developers, and potential end users of this memory. We proposed a model of cognitive agents (Labidi 1995, 1996; Dieng, Corby, and Labidi 1994) to help the knowledge engineer to model the organization (that is, human, material, and software environment in which the corporate memory will be integrated) and the interaction-cooperation between the experts in a situation of problem solving. Our agent model indicates individual characteristics and social characteristics. We also distinguish static characteristics and dynamic characteristics. All such characteristics must be instantiated by the knowledge engineer for the application during the knowledge-acquisition process. The agent's expertise model is described using the COMMONKADS framework. Figure 4 illustrates the method for exploiting the agent model during analysis of the expertise documents.

For the analysis of the expertise documents, we used the previously described generic models; the types of knowledge obtained depended on the nature of the analyzed documents.

From the reports, articles, and interviews of an expert, we can obtain (1) the explicit view of this expert on the characteristics of the other experts; (2) his thematic specificities; (3) his model of the collection and analysis of road traffic accidents; and (4) his expertise model. This expertise model includes, at the domain level, (1) his terminology (that is, personal

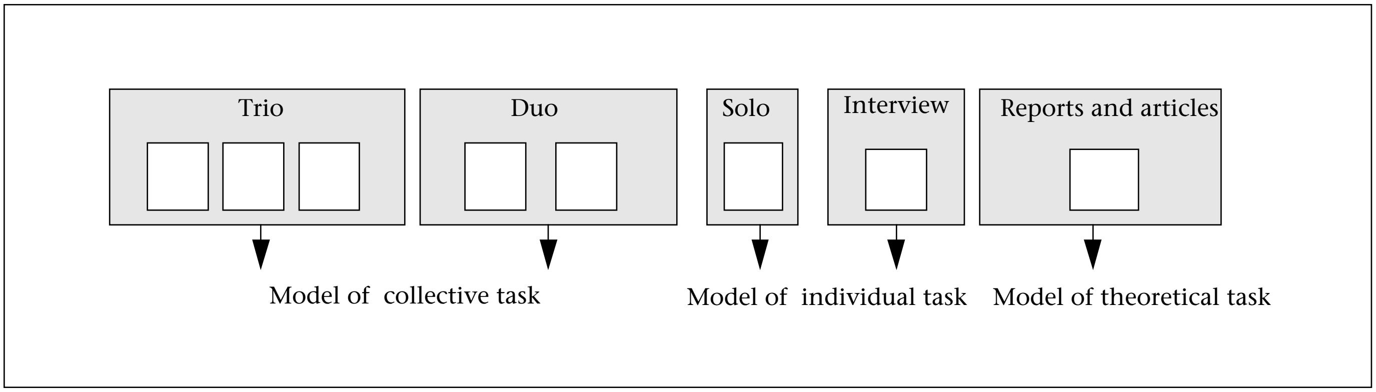

Figure 2. Models of Tasks Established.

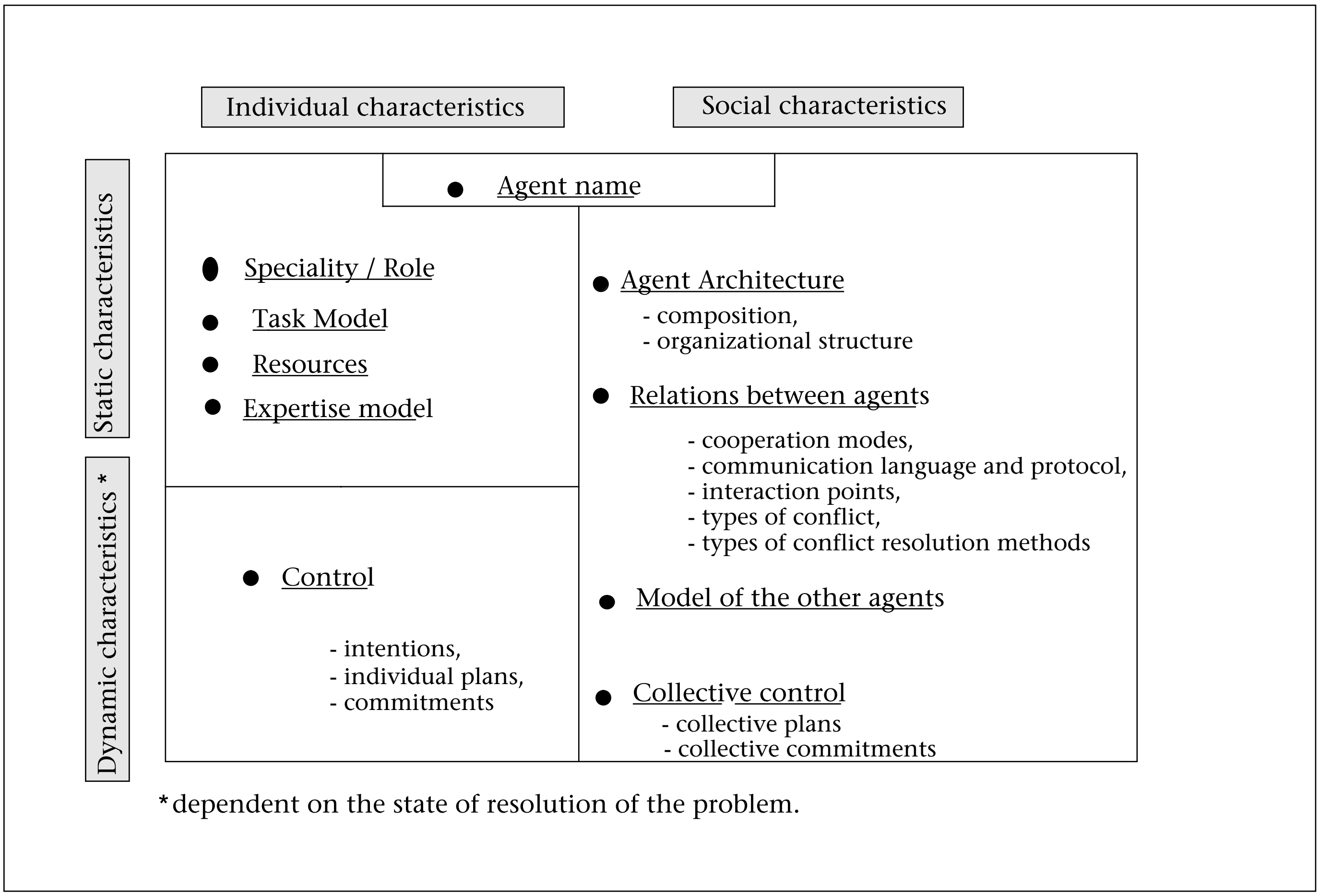

Figure 3. Our Model of a Cognitive Agent.

ontology), comprising definitions of some terms and examples, (2) typologies of domain concepts, (3) domain models, and (4) expertise rules indicating which hypotheses are generated by this expert and which clues are extracted from the accident dossier; at the inference level, the inference structure modeling this expert's reasoning; and at the task level, the control information added to this inference structure.

From the analysis of an expert's individual case, we can deduce his view of the characteristics of some other absent experts; (2) the exploitation of his thematic specificities; (3) his model of the task of traffic-accident analysis in situation; and (4) his model of expertise. With the model of expertise, we can also deduce at the domain level, the domain mod-

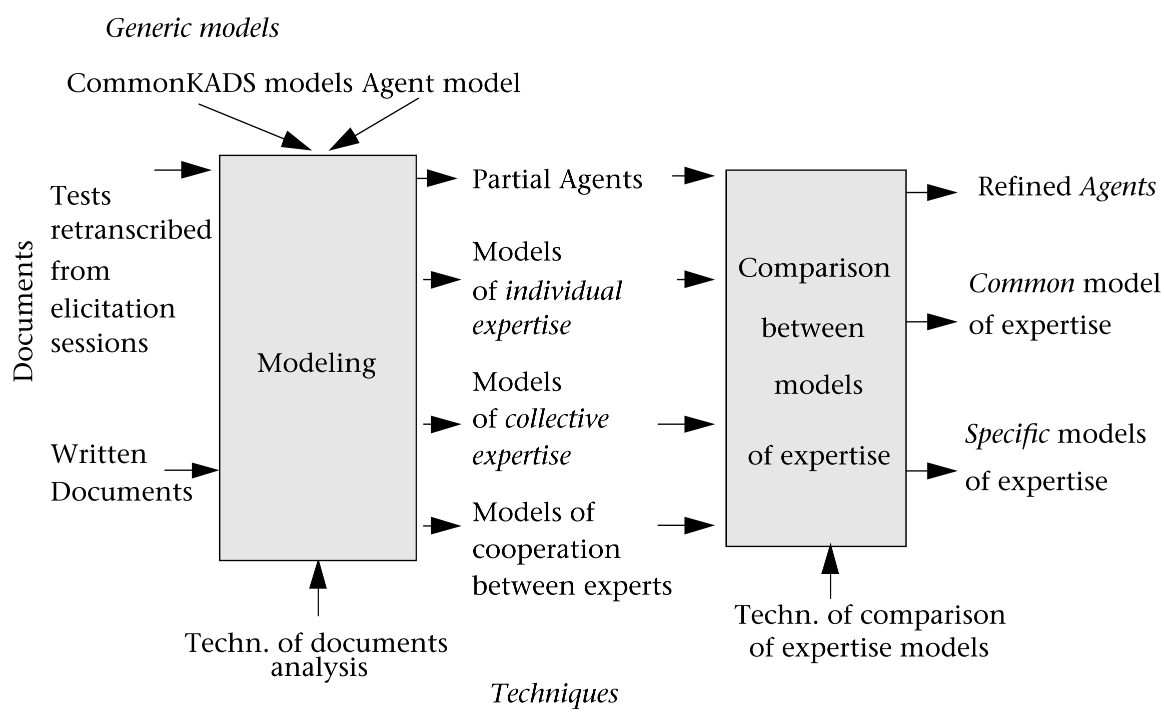

Figure 4. Method of Analysis of the Expertise Documents.

els used and expertise rules on the generation of hypotheses from clues; at the inference level, the inference structure modeling this expert's reasoning; and at the task level, the control information added to this inference structure.

From the analysis of a case processed collectively by this expert and another expert (Dieng 1995b), we obtained knowledge on (1) his view of the characteristics of some other experts, an explicit call to the other present expert, or an explicit need of the capabilities of an absent expert; (2) the exploitation of his thematic specificities; (3) his model of the task of analysis of an actual accident, processed in situation (we noticed the parts where all the experts showed their competence and the parts revealing the exclusive competence of one of them); and (4) his model of expertise. It was sometimes difficult to dissociate the experts and distinguish the individual expertise of each of them and the collective expertise emerging from their gathering.

In all cases, the knowledge modeled can be structured in a model of agent associated to this expert. Thus, the following instantiated agent models can appear (figure 5): (1) an agent corresponding to the knowledge modeled from the articles, reports, and interviews (that is, rationalized knowledge); (2) an individual agent corresponding to the work of the expert alone, in situation; (3) a specific agent corresponding to the aspects specific to this expert when he was solving a case with another expert; and (4) an agent common to this expert and to another expert and corresponding to their collective expertise during their collective case studies. We modeled the agents' individual aspects such as task model or expertise model and their social aspects (for example, viewpoint on the other agents, interaction with the other agents).

Informal Validation

We carried out two types of informal validation of the models built: (1) with the other knowledge engineers and (2) with the experts themselves. The knowledge engineer presented the models to the expert and gave him/her explanations if needed. If the expert did not agree with such models, he was required to give explanations. These comments and remarks were then studied, and if needed, the models were modified. The validation could be verbal (that is, a model was submitted to the expert and we discussed verbally about its validity) or written (that is, the graphic representation of a model was submitted to the

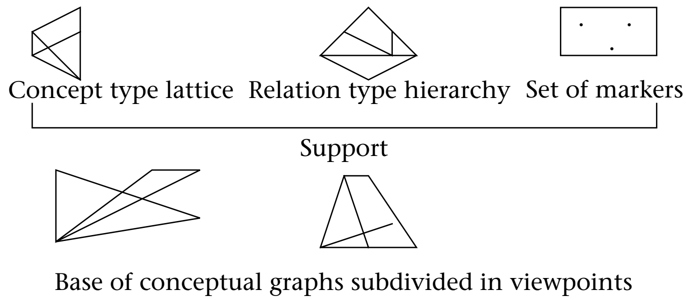

Figure 5. Viewpoints in the Base of Conceptual Graphs Associated to a Psychologist.

expert, and he wrote alone his comments about this model).

Expertise Conflict Management

When the expertise capitalization in an enterprise involves several experts for the knowledge-acquisition phase, the knowledge engineers must detect and solve several kinds of conflict: (1) differences of terminology, (2) incompatibility between terminologies, (3) differences between compatible reasonings (that is, the experts use different problem-solving methods but obtain noncontradictory results), and (4) incompatibility of reasonings (that is, the different problem-solving methods used by the experts lead to contradictory results). In knowledge-acquisition methods, expertise conflict management is taken into account by studying terminology conflicts (Gaines and Shaw 1989), managing several viewpoints (Easterbrook 1991), and detecting conflict in the framework of KADS-I methodology (Dieng 1995a) or a library of concurrent design conflict models in the framework of COMMONKADS (Matta 1996).

The knowledge engineer can analyze the expertise documents to build a common model corresponding to the kernel of knowledge common to all experts and perhaps models common only to subgroups of experts and specific models corresponding to knowledge specific to an expert and not shared by other experts. Two approaches are possible: First, either the knowledge engineer tries to build such models directly from the expertise documents, or second, he separately builds each model of expertise corresponding to each expert and then tries to compare the obtained models of expertise to find their common parts and their specific parts. In our case, eight knowledge engineers were involved in the construction of the expertise models: Each of us was responsible for modeling (a specific aspect) of one expert.

We represent each expert by an artificial agent (Labidi 1995, 1996; Dieng, Corby, and Labidi 1994) whose expertise model is described in COMMONKADS. Moreover, we represent the concepts and relations of the domain layer by conceptual graphs (Sowa 1984). As shown in figure 6, an agent has (1) a *support* indicating the conceptual vocabulary (a support is composed of a concept type lattice, a relation-type hierarchy, a set of markers, and a conformity relation) and (2) a *base of canonical conceptual graphs*, built on this support and representing the view of this agent on the world as well as his expertise. This base of canonical conceptual graphs is subdivided into several different viewpoints (figure 5). Therefore, the detection of conflicts between several expertises is based on the comparison of the domain levels of the expertise models of the agents associated with the experts, such domain levels being represented through conceptual graphs.

Searching the common support associated with several experts of the same domain can be seen as a part of the search of a common, shared, or accepted ontology among the experts (Garcia 1996). One can work either at the knowledge level (Newell 1982), without choosing a representation formalism, or at the symbol level, once having chosen a representation formalism. Our choice of the framework of the conceptual graph formalism allows us to propose algorithms based on the notions underlying conceptual graphs. In Dieng (1997, 1996), we proposed a procedure for comparing the expertise models of two experts based on

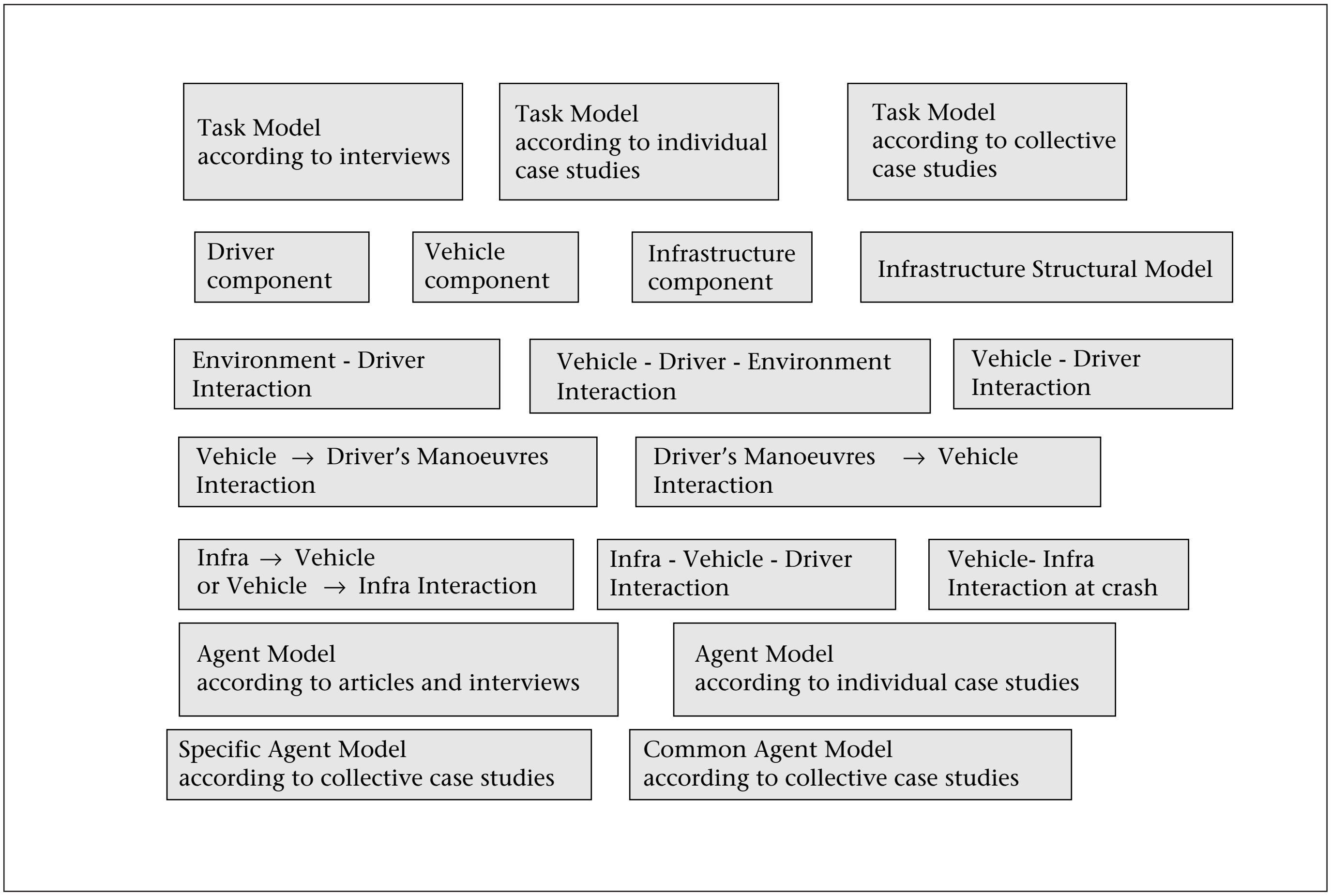

Figure 6. Domain Layer of the Expertise Model, Represented through Conceptual Graphs.

the following steps: (1) comparison and integration of both supports to build a common support, (2) comparison of the two bases of conceptual graphs, and (3) construction of the base of integrated conceptual graphs according to the chosen integration strategy.

Models of Knowledge of the Experts

The knowledge models obtained for each expert comprised his terminology, his task model, his expertise model (with, in particular, the domain models used by this expert and his expertise rules), his agent model, and his links with the other experts. We applied our research on a model of a cognitive agent to the design of the agents corresponding to the experts at INRETS. The construction of expertise models associated with these agents relied on COMMONKADS methodology and exploited the generic models for the tasks of modeling and diagnosis offered in the COMMONKADS library (Breuker and Van de Velde 1994). For each expert, sessions of individual or collective validation allowed us to correct, deepen, and refine the obtained models.

Knowledge Models Obtained

Figures 7 to 14 give examples of the knowledge models of the different experts.

Implementation through Conceptual Graphs

We used the conceptual graph knowledge-acquisition tool (CGKAT), a tool developed by the ACACIA Project (Martin 1995) to build the hierarchies of concept types and relation types for the different experts as well as conceptual graphs describing the reasoning strategies of the different experts (Alpay 1996). We exploited the predefined ontology offered by CGKAT as well as its ability to visualize conceptual graphs. CGKAT also enables us to associate a base of conceptual graphs to the structured documents constituted by the expertise documents (Martin and Alpay 1996). Figure 15 shows an example of a conceptual graph base subdivided into several viewpoints. The

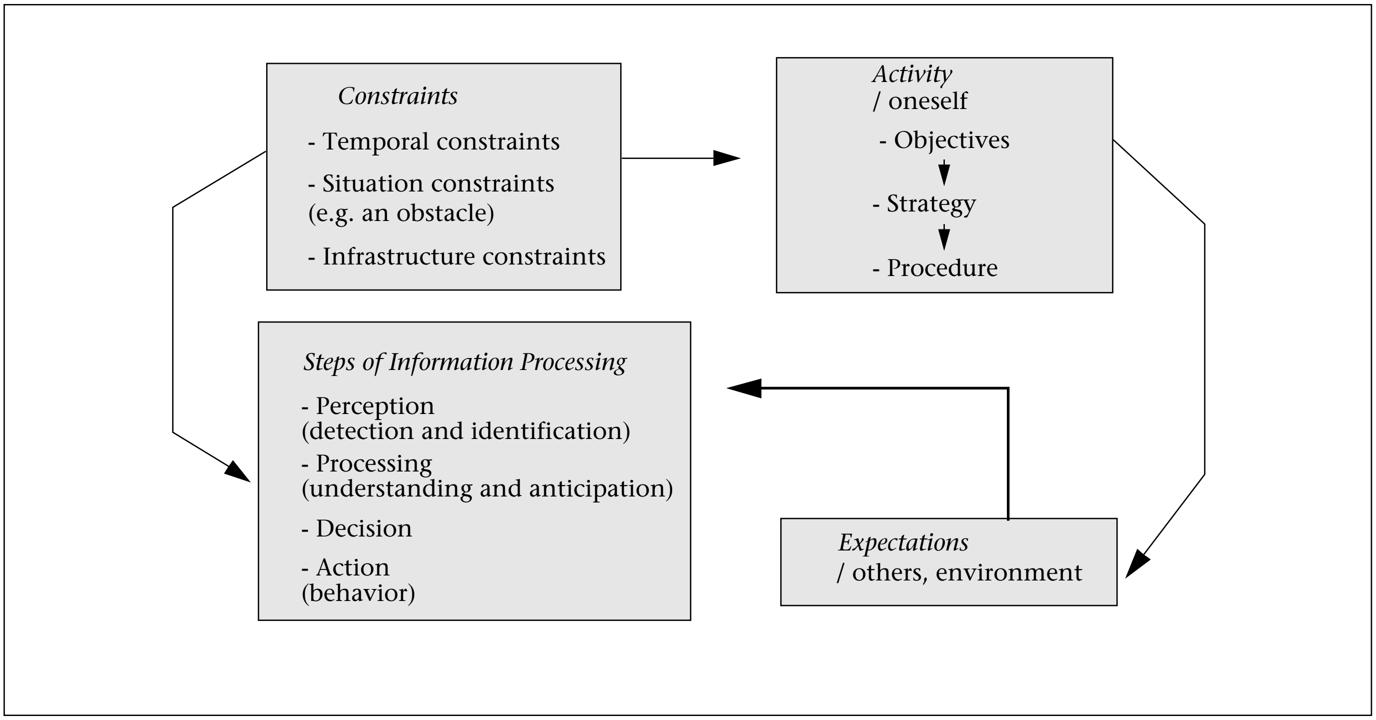

Figure 7. Model of Driver's Behavior, According to a Psychologist.

Specialty: psychology, with particular studies on support to driving, on drivers's errors or on crossroads, on GTI drivers, on old persons

Resources: plan, maps, check-lists, tracks, drivers' interviews, sometimes photographs

Some individual characteristics

Task
Collection and Accident analysis

Inference
Modeling + Diagnosis

Domain

Ontology

Domain models:

- DVI Model
  - Driver's Cognitive Model: Information processing by the driver, Driver's errors
    - Old Driver, Crossroad Driver, GTI Driver, Driver having right of way
  - Infrastructure Model: Crossroad model
  - Vehicle Model: GTI model
- Accident Model
- Phase model

Rules of generation of hypotheses on faults, factors or accident sequencing from clues

Expertise model

Figure 8. Agent Representing the Two Psychologists.

Specialty: vehicle engineering
Resources: plan, maps, check-lists, tracks, photos, drivers' interviews
software AN AC-2D and AN AC-3D

Some individual characteristics

Task
Kinematics Reconstitution

Inference
Modeling

Domain

Ontology

Domain models:

DVI model

Vehicle model: Model of mechanical faults, Model of kinematics sequences

Model of tracks

Accident model: accident types, accident scenarios

Rules of cutting into kinematics sequences and of hypothesis generation

Expertise model

Figure 9. Agent Representing the Two Vehicle Engineers.

Specialty: infrastructure engineering & partially vehicle engineering

Resources: plan, maps, check-lists, tracks, drivers' interviews,
camera, measurement roulette wheel, inking pad, vehicle on scale on a sheet of paper

Some individual characteristics

Task
Collection & Accident analysis

Inference
Modeling + Diagnosis

Domain

Ontology

Domain models

Accident model: Accident categories, Accident typology, Accident scenario model,
Phase model, Manoeuvre origin of the accident

Functional model

DVI model

Infrastructure model: Road typology, Section typology, Pavement model, Infra design,
Model of tracks

Model of involved modes: Driver model, Road-user, Driver's profile,

Vehicle model: Kinematics model

Rules of generation of hypotheses on accident type according to infra type or vehicle type,
rules on Vehicle, Human, Environment and Interaction Human-Environment
rules associated to models of infra and to models of vehicle

KADS expertise model

Figure 10. Agent Representing the Three Infrastructure Engineers.

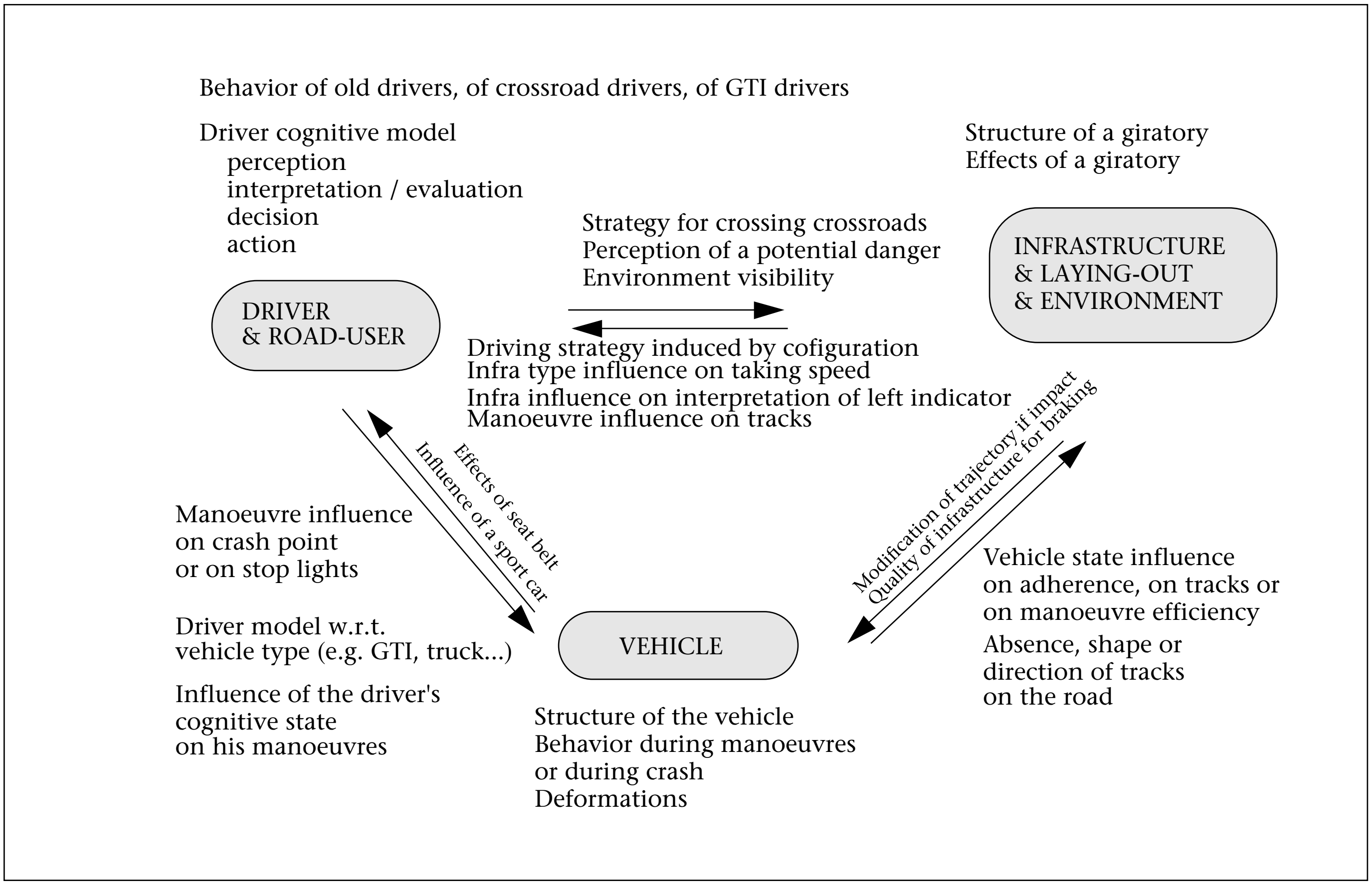

Figure 11. Model of the Driver-Vehicle-Infrastructure System.

detailed base of conceptual graphs associated with the different experts can be found in Dieng (1997).

Comparison of the Experts' Knowledge Models

The structures of the expertise and agent models (figures 8, 9, and 10) help to identify the natural criteria of comparison between the knowledge models of different experts.

Expertise Model **Terminology:** There were different viewpoints on the concepts of scenario and factor.

Inference and task: The vehicle engineers (cf. figure 9), rather, carry out modeling because their main task, kinematics reconstitution, can be modeled as a modeling task (figure 13). The psychologists (cf. figure 8) and the infrastructure engineers (cf. figure 10) perform not only modeling when they reconstitute the accident progression but also diagnosis when they search factors explaining the processed accident.

Domain models: Some domain models are used by all the experts and seem to characterize accidentology independent of any disciplinary aspect: (1) the DVI model (cf. figure 11) (all the experts noticed the importance of the interactions between the components of this model) and (2) the model of decomposition of the accident into the phases of driving, accident, urgence, and crash situations. Some experts personalize this second model by introducing an approach situation and a preaccident situation.

Some models seem specific to a discipline: Only the vehicle engineers made explicit a model of vehicle mechanical defaults and a model of kinematic sequences, the models of tracks are exploited by the infrastructure engineers and the vehicle engineers, and the cognitive models of the driver are typical to the psychologists and most of the infrastructure engineers (cf. influence of the infrastructure on the road user's behavior). Within a given discipline, we can also take into account the specific models acquired by an expert thanks to his thematic research; for example, one psychologist has a model of drivers' malfunctionings and a model of help for driving, but the other psychologist has a model of the crossroad driver and the GTI (Grand Tourisme á Injection) vehicle driver. The detailed models

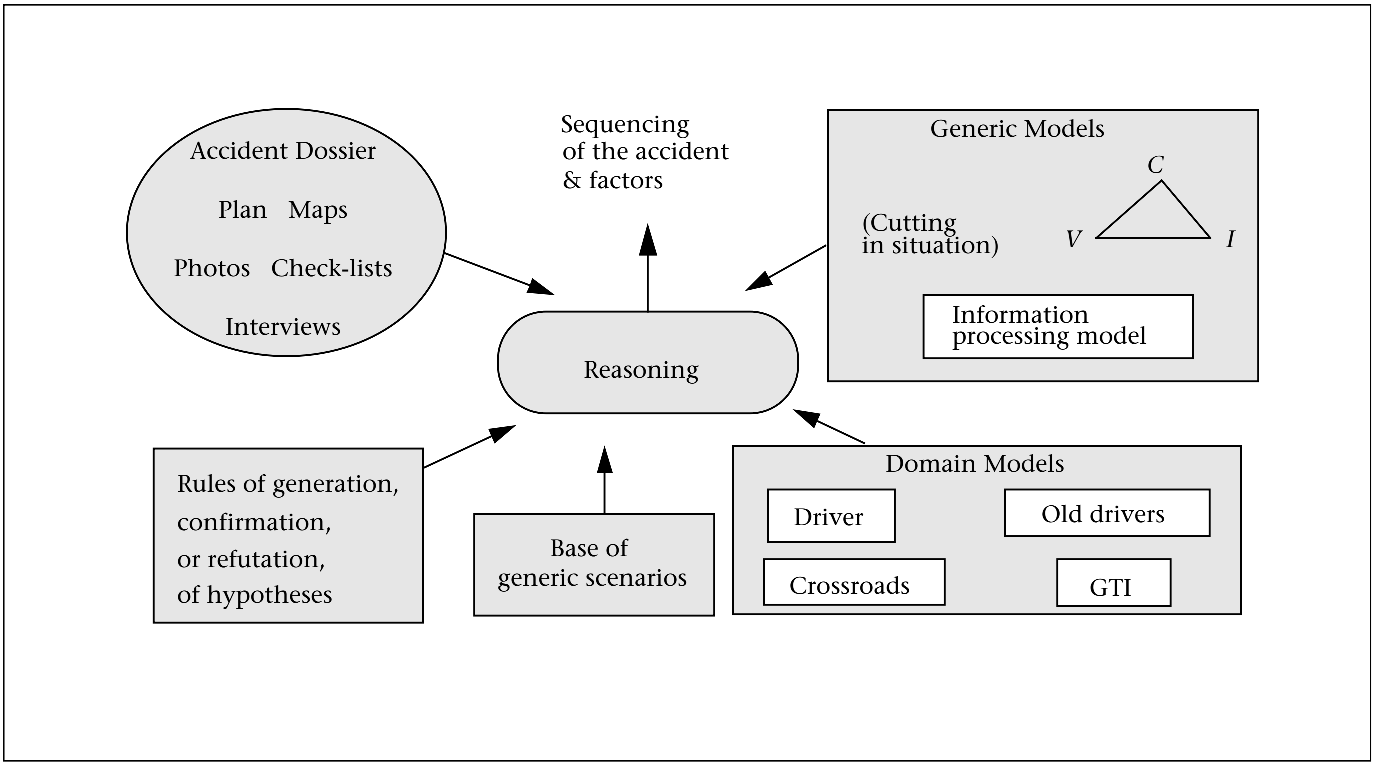

Figure 12. Reasoning of a Given Psychologist.

of infrastructure are specific to the infrastructure engineers (as an exception, a psychologist has an expertise because of his thematic analyses on the drivers in crossroads; this expertise appears through his deep model of crossroads). We can also distinguish the explicit use and the implicit use of a model by an expert.

Task Model For an expert, we can notice differences between the model of the rationalized task obtained from his articles and interviews, the task model obtained from his individual case studies (moreover, we could have studied the evolution of this task model as the expertise-elicitation sessions advanced because of the influence of the collective case studies), and the task model obtained from the collective case studies. According to the discipline, some subtasks were emphasized: kinematics reconstitution by the vehicle engineers, drivers' interview by the psychologists, and analysis of the tracks on the pavement by the infrastructure engineers.

Agent Model **Resources:** Plans, maps, checklists, and driver interviews are used by all the experts. The exploitation of photos depends on the discipline. Only the vehicle engineers use the ANAC software. The infrastructure engineers use specific resources such as an inking pad.

Interaction points: The input interaction points of the agents (that is, the requests the corresponding experts can receive) depend on the discipline: The elicitation techniques during the interviews with the drivers and the analysis of the drivers' reliability degree are typical of the psychologists; the task of kinematics reconstitution, the analysis of the vehicle mechanical defaults and the tracks on the road are characteristic of the vehicle engineers; the design of the infrastructure, the characteristics of the roadway, and the analysis of the tracks are logically the concern of the infrastructure engineers.

Models of the other agents: Psychologists as infrastructure engineers described their view of the task of kinematic reconstitution specific to their vehicle engineer colleagues. The analysis of the case study common to a psychologist and that common to an infrastructure engineer revealed their respective implicit view on each other as well as their view on the task of kinematic reconstitution that was the concern of the discipline absent from this collective case study. Likewise, some experts made explicit their view of the terminology of other experts (in particular, on the notions of scenario and factor).

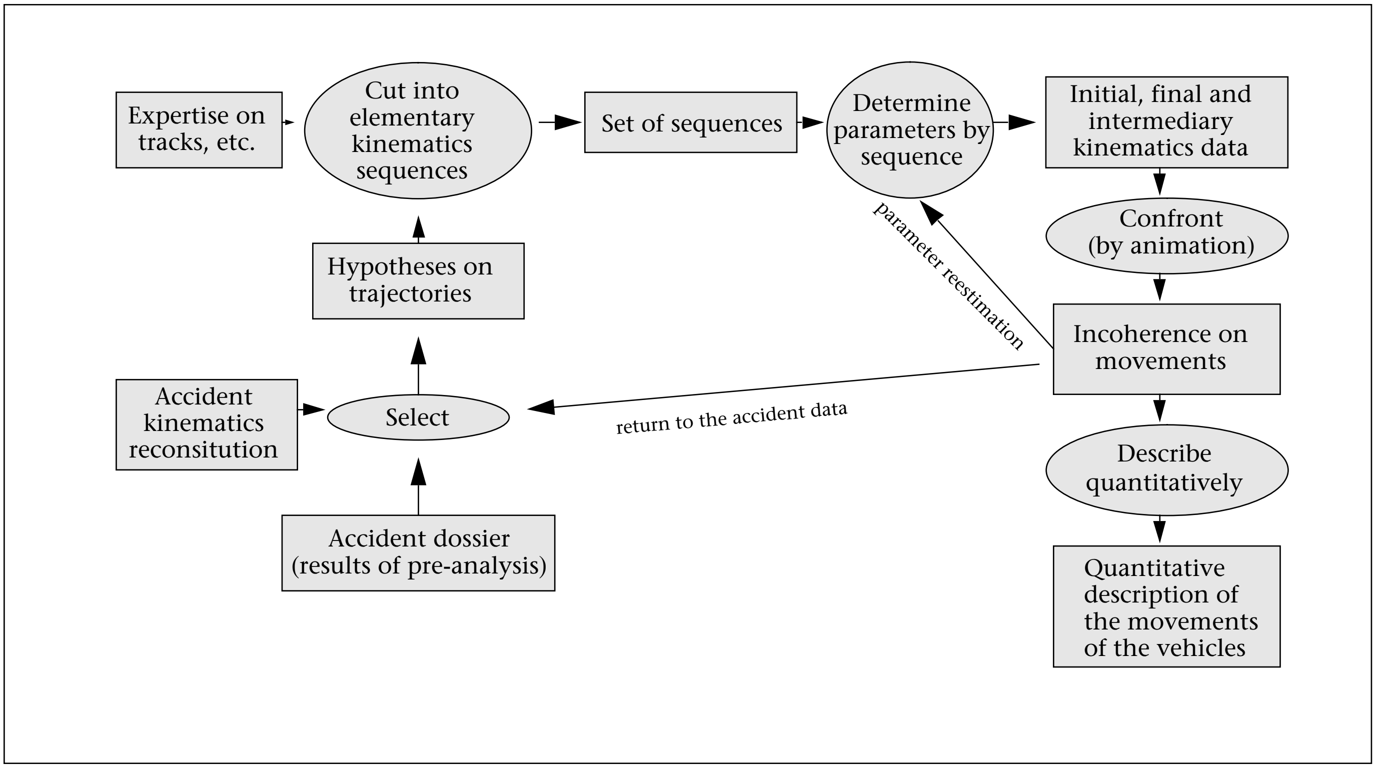

Figure 13. Model of Kinematics Reconstitution for a Vehicle Engineer (Inspired of COMMONKADS *Generic Model for Modeling).*

Summary

The common points revealed between the experts attest to the existence of a common expertise in accidentology and, based on the tasks of collection and accident analysis, the exploitation of the model of the DVI system and the decomposition of the accident into phases.

At the level of the expertise models, the specificities of the experts show the diversity and complementarity of their disciplines as well as the potential interest of a computational corporate memory that would include an interdisciplinary expertise, for example, the model of information processing by the driver and the cognitive model of the driver in some infrastructure types or on board some vehicle types (models exploited by the psychologists); the expertise on collection and analysis of tracks and the design of road infrastructures and pavements (expertise of the infrastructure engineers); and the expertise on the deep kinematics reconstitution (speciality of the vehicle engineers).

Conclusions

We proposed a general method for knowledge acquisition from multiple experts based on several elements. First is a protocol for elicitation of several experts with individual or collective case studies and various combinations of experts according to their speciality. This protocol, rather time consuming both for the experts involved in elicitation and validation and the knowledge engineers involved in modeling, cannot be applied to any enterprise. However, it allows a fine analysis of the differences between the experts according to the discipline and of their evolution as a result of cooperation with the other experts. Second is a model of the cognitive agent dedicated to such acquisition. It helped us to identify the individual and social characteristics of the experts or groups of experts and gave elements for an informal comparison at the knowledge level between such characteristics. Third are the techniques of comparison between conceptual graphs representing the knowledge of the experts. The representation through conceptual graphs enabled us to partially apply our techniques for formal comparison at the symbol level between the conceptual graphs representing the expertise models of the agents associated with the experts (Dieng 1997). It also enabled us to use the CGKAT tool for editing and visualizing such conceptual graphs.

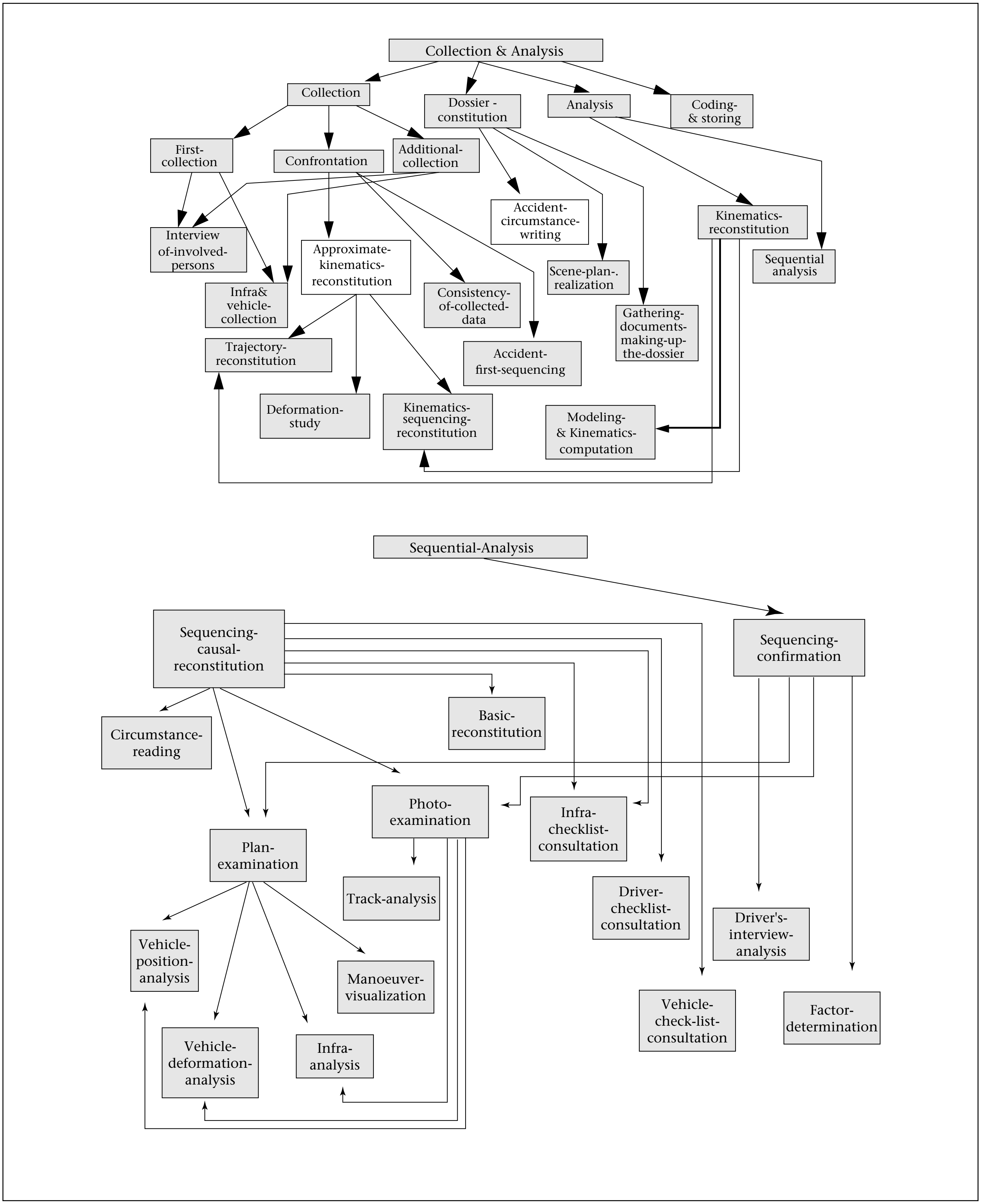

Figure 14. Task Hierarchy of an Infrastructure Engineer.

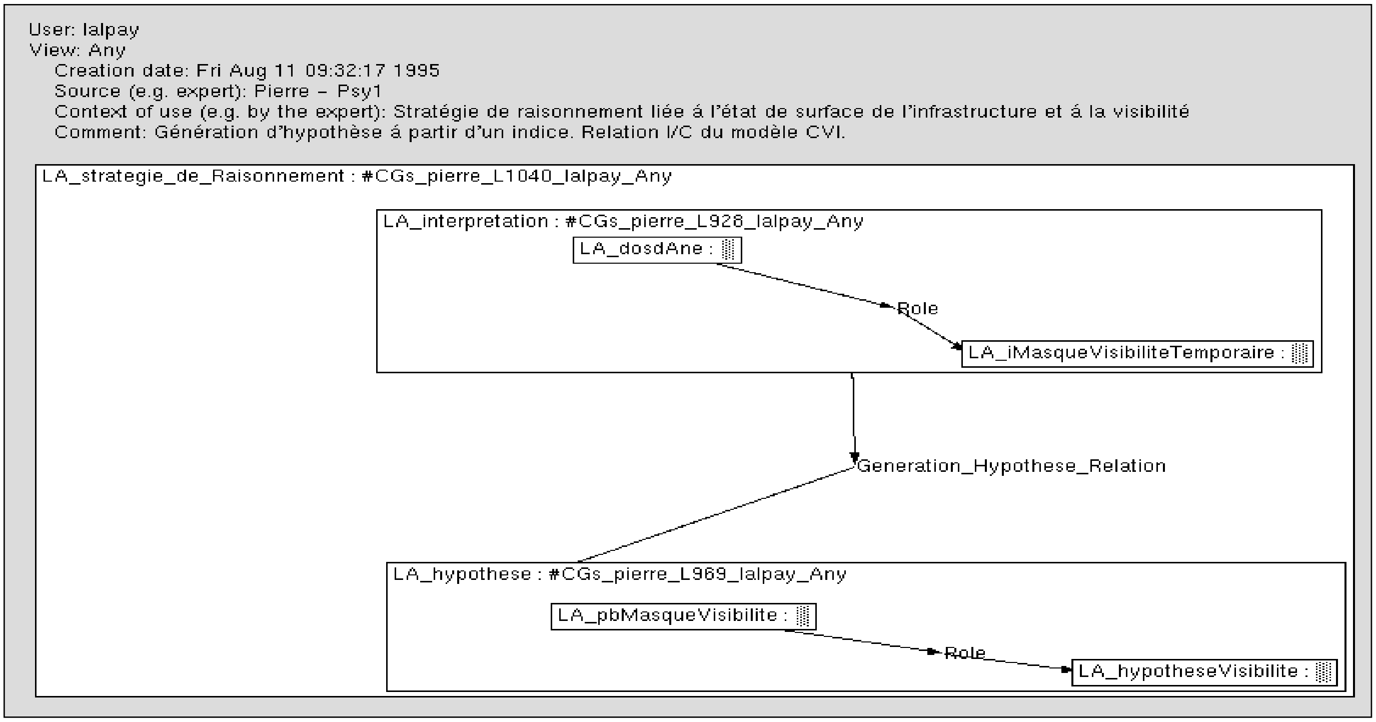

Figure 15. Example of a Graph in the Base of Reasoning Strategies of a Psychologist.

Comparison with Related Work

This method, with a collective elicitation protocol, an agent model, and comparison of expertise models, seems rather original in comparison to previous knowledge-acquisition methods for multiple experts presented in Jagannathan and Elmaghraby (1985), McGraw and Seale (1988), and Mittal and Fenves (1984). By focusing on multiexpertise, our method also differs from the REX method (Malvache and Prieur 1993) that is dedicated to knowledge capitalization and based on modeling of elements of experience.

Our agent model can be compared to agent models recently proposed in the field of knowledge acquisition. For example, COMMONKADS (Waern and Gala 1993, p. 5) offers an agent model that "serves as a link between the task model, the communication model and the expertise model, by modeling the capabilities and constraints that the experts have, which are involved in solving a task." Our agent model has the same purpose, but in addition, it is aimed at knowledge acquisition from multiple experts and the modeling of cooperative problem solving by several agents. In the same way, Glaser, Haton, and Haton (1995) and Glaser (1997) propose extensions of the COMMONKADS method and, in particular, an agent model aimed at modeling multiagent systems. This agent model, more complex than ours, allows us to describe different types of agent (reactive, cognitive, cooperative, and social) needed in multiagent systems.

Few knowledge-acquisition methods take into account expertise conflict management and comparison of expertise models. Terminology conflicts because of disagreement between the experts on some concepts or the vocabulary were studied in Shaw and Gaines (1989) and Gaines and Shaw (1989): The authors offer a method for comparing the different conceptual systems of the experts. They define the notions of consensus, conflict, correspondence, and contrast and propose a method for detecting these different aspects. For our detection of terminology conflicts, we took inspiration from a part of this work. In Easterbrook (1989), a multiagent architecture is used to allow the coexistence of multiple perspectives-viewpoints in the framework of distributed knowledge acquisition. Techniques for comparing several viewpoints and solving conflicts among them are described in Easterbrook (1991). The techniques used for integrating new knowledge into an existing knowledge base (Eggen, Lundteigen, and Mehuset 1990; Murray and Porter 1990) can be relevant for integrating knowledge from multiple experts. A method for building a common ontology from multiple ontologies on the same domain is described in Kayaalp and

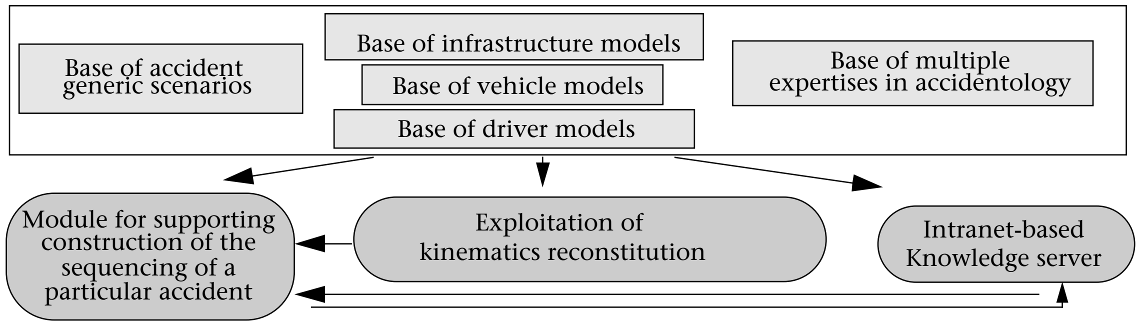

Figure 16. Architecture of the System for Support to Road Accident Analysis.

Sullins (1994). In Wiederhold (1994), the author presents an algebra over ontologies, with a set of operations for matching and integrating ontologies.

Our techniques of comparison between several conceptual graphs representing the viewpoints of several experts seem to offer a rather different approach from such previous research on terminology conflicts, integration of several knowledge sources, and conflict management. They also differ from the techniques and tools for cooperative design, described in Klein and Lu (1989) and Klein (1992), and allow the techniques and tools of Klein to detect and solve conflicts among design agents (that might be human agents or machine-based agents). As they exploit conceptual graph formalism, they can be compared to research on graph isomorphism and algorithms for matching conceptual graphs (Guinaldo 1996; Poole and Campbell 1995; Willems 1995). Our research is also linked to work on the building of shared or common ontologies (Garcia 1996; Mineau and Allouche 1995; Skuce 1995; Gruber 1993).

Interest for Corporate Memory Building

Concerning the questions related to the construction of corporate memory, we analyzed the INRETS Salon de Provence, its history and evolution, and the experience acquired from the Detailed Study of an Accident. We studied how the expertise models of several experts of different specialties could be integrated into a common expertise model that would be part of the INRETS corporate memory. We applied our solutions to the case of experts in accidentology: elicitation protocol applied with seven experts from INRETS, modeling of the knowledge of each expert (for example, terminology, expertise model, cognitive agents associated to this expert), representation of some expertise models through the formalism of conceptual graphs, implementation of conceptual graph bases in the CGKAT knowledge-acquisition tool (such bases, rather aimed at the knowledge engineers, will not constitute the actual computational corporate memory), and comparison of the knowledge models of the different experts. For accidentology, our research allowed us to build a significant base of expertise models of several experts in accidentology, stemming from different specialties (psychology, vehicle engineering, infrastructure engineering). Because of the capitalization of multiple expertises, the knowledge thus modeled constitutes a (partial) corporate memory of INRETS (Alpay et al 1996). It can be used as the basis for the construction of a system for support to road traffic-accident analysis, a system that would take advantage of the competencies of several specialists of various disciplines.

For evaluation of a knowledge capitalization operation, several viewpoints can be taken into account: economico-financial criteria (return on investment according to the company managers), socio-organizational (improvement of the users' individual and collective work), and technical (effective technical knowledge transfer in the company). Currently, quantitative measurements of these benefits are hard to estimate, but qualitative criteria are relevant in assessing the interest of our experiment.

One result of this experiment was the improvement of the practice of the experts: For example, after being implicitly influenced by an infrastructure engineer during the collective case studies, one psychologist started to more thoroughly use the photographs. He had realized that the information he previously extracted from the infrastructure or vehicle textual checklists was more accurate when visualized through photographs. Nonaka's theory (1991), as described in Morizet-Mahoudeaux (1994), considers that knowledge spreads through socialization, articulation, combination, and internalization. He distinguishes *tacit knowledge* (know-how that an expert gained from practice) and *explicit knowledge*. Because INRETS is a research center, some knowledge was explicit within paper-based documents such as articles and reports. Because the dossiers of the processed accidents were kept in archives and exploited by the current researchers for their thematic analysis, such dossiers can be seen as *cases* describing both problem data (that is, accident data) and a solution (that is, the accident synthesis, with the accident reconstitution and the accident factors determined). However, the reasoning leading to the synthesis was tacit, and our elicitation protocol (cf. the case studies) helped to make this knowledge explicit. We also made explicit the models used by the experts in their reasoning, in particular, models dependent on their discipline and models dependent on their previous experience, such as the thematic analyses they had carried out in the past. An explicit base of generic scenarios is a part of the corporate memory. If several accident dossiers characterized by a given parameter value (such as a driver type, for example, old drivers; an infrastructure type, for example, crossroads; or a vehicle type, for example, GTI) reveal similar types of accident factor, the expert performing this thematic analysis builds some generic scenarios of an accident based on such cases. The expert's reasoning seems close to a case-based reasoning: In front of a new accident, he retrieves similar previous cases or relies on a generic scenario he built based on previous thematic analyses. Thus, case-based reasoning can play an important role in building a corporate memory (Simon and Grandbastien 1995; Kitano et al. 1992).

During our experiment, the INRETS researchers wrote a book on their methodology of the Detailed Study of an Accident (Ferrandez et al 1995). This "guide of best practice," or "reference bible," will typically be useful for new investigators; thus, our experiment had an influence on (individual and collective) learning at INRETS. As cited in Morizet-Mahoudeaux (1994), making personal knowledge available to others is the central activity of the knowledge-creating company. We enabled a process of articulation (that is, making tacit knowledge explicit) and a process of internalization (that is, extending one's tacit knowledge by explicit one). Figure 16 shows the architecture of the future computational corporate memory that will be used by the investigators at INRETS.

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