Multi-level architecture and human mental activity : connections and feedback during expert system building

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MULTI-LEVEL ARCHITECTURE AND HUMAN MENTAL ACTIVITY : CONNECTIONS AND FEEDBACK DURING EXPERT SYSTEM BUILDING*

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Abstract :

We want to point out in this paper how expert knowledge acquisition may induce the choice and the refinement of a software architecture for an expert system and how, in return, this architecture may provide a guide for knowledge acquisition.

This idea will be discussed along two axes, through the example of the *Rosy* multi-ES, designed in the domain of urban road management. First, we show that the first meetings between the expert and the knowledge engineers led us to choose a multi-expert, then a "multi-level multi-expert" architecture for the system, and that this choice improved the phase of knowledge acquisition. Secondly, we stress the close cooperation between knowledge acquisition and modeling, on one side, and the system structure organization, on the other side, until the final state of the system.

We have come to the design of a methodology including the concept of *constructors* for building expert systems and we think that this approach may be generalized to other systems concerned with a similar kind of expertise.

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N° de programme INRIA : 3 (Intelligence artificielle, sciences cognitives et interaction homme-machine)

ARCHITECTURE MULTI-NIVEAUX ET ACTIVITE MENTALE HUMAINE : RELATION ET CONTREREACTION DURANT LA PHASE DE CONSTRUCTION D'UN SYSTEME

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Résumé :

Le présent article montre comment la phase d'acquisition d'un savoir expert peut influencer le choix et l'affinement de l'architecture logicielle d'un système expert et comment, en retour, cette architecture peut servir de guide pour l'acquisition d'expertise.

Cette idée sera discutée selon deux axes, à travers l'exemple du système multi-agents *Rosy*, dans le domaine de la gestion de voirie urbaine. Nous montrons tout d'abord que les premières rencontres entre l'expert du domaine et nous-mêmes, les ingénieurs de la connaissance, nous ont conduits à choisir une architecture d'abord multi-agents, puis multi-agents multi-niveaux pour le système à réaliser, et que ce choix a facilité par la suite la phase d'acquisition d'expertise. Ensuite, nous mettons l'accent sur la coopération étroite entre l'acquisition et la modélisation des connaissances, d'une part, et l'organisation de la structure du système, d'autre part, jusqu'à l'état final du système.

Nous sommes arrivés ainsi à la mise au point d'une méthodologie de construction de systèmes multi-agents multi-niveaux incluant le concept de *constructeurs*, généralisable à des types de connaissances expertes de nature voisine de celles de notre étude.

Multi-Level Architecture and Human Mental Activity:
Connections and Feedback during Expert System Building

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This idea will be discussed along two axes, through the example of the *Rosy* multi-ES, designed in the domain of urban road management. At the beginning, we show that the first meetings between the expert and his domain and us, the knowledge engineers, led us to choose a multi-expert, then a "multi-level multi-expert" architecture for the system, and that this choice improved the phase of knowledge acquisition. Secondly, we stress the close cooperation between knowledge acquisition and modeling, on one side, and the system structure organization, on the other side, until the final state of the system.

We have come to the design of a methodology including the concept of *constructors* for building expert systems and we think that this approach may be generalized to other systems concerned with a similar kind of expertise.

Keywords: Multi-expert systems, multi-level architecture, expert knowledge transfer, cognitive levels, decision making for urban road maintenance.

1. INTRODUCTION

Eliciting knowledge is a difficult and decisive phase in building expert systems (ES). Actually, the performances of an ES and, thus, its intrinsic value depend on the amount and the quality of represented knowledge. We want to point out in this paper how expert knowledge acquisition may induce the choice and the refinement of a software architecture and how, in return, this architecture may provide a guide for knowledge acquisition. This idea will be developed along two axes, through the example of the *Rosy* multi-ES, designed in the domain of urban road management for assisting the specialist in planning the list of streets to be repaired. At first, we show that the first meetings between the expert and his domain and us, the knowledge engineers, led us to choose a multi-expert, then a "multi-level multi-expert" architecture for the system, and that this choice made more efficient the phase of knowledge acquisition. Secondly, we stress the close cooperation of knowledge acquisition and modeling with the system structure organization, until the latter is completed.

For that purpose, we first present the object of the study : the problem of urban road management, calling for planning, diagnosis and constrained decision making. We explain the first analysis of the specialist's work, the levels of abstraction in his reasoning process and the choice of the *Atome* shell, developed in our laboratory. Then, we describe the phase of knowledge acquisition and modeling in this context.

We have come to the design of a methodology including the concept of *constructors* for building expert systems and we think that this approach may be generalized to other systems concerned with a similar kind of expertise.

2. THE OBJECT OF THE STUDY

The urban technical services are in charge of the maintenance and the renovation of the road network, with due consideration for the interests of the city. This is a difficult task which appeals to much expert knowledge and much information, not always available. Moreover, there does not exist any specific techniques for urban road maintenance and the techniques used for interurban ways cannot be applied to town streets because of their characteristics: networks, pavements, gutters, ...

The specialists in urban road maintenance need to make their decisions more rational and particularly to make the best possible assessment of road condition to optimize money investment. Such an approach would lead to money savings up to 10 or 15% of the total budget. So, they wished to have a tool available for helping them in establishing the road maintenance planning. For that purpose, we are developing an expert system named *Rosy* (*Ro*ad *Sy*stem), in cooperation with the Municipality of Nancy and the CRIN/INRIA.

The *Rosy* system is designed for modeling the road maintenance specialist's work. This expert has to plan the actions to be done every year upon the urban road network. He must choose both the streets to be dealt with and the repair mode for each of them, taking into account domain specific and external factors which constrain his reasoning process. For that purpose, he first analyzes the roadway surface, assesses the nature of the damages and then tries to account for them to draw hypotheses about the state of the foundations. Then, starting from these conclusions and from physical factors like the traffic or the suburban networks (water, gas, sewerage, ...), he decides which therapy is the best for the given street. Finally, he must consider the granted budget and some more subjective data such as strategic criteria (priority to main thoroughfares, urbanism features, ...) or some criteria in relation with the city policy (comfort or safety before all, but also aesthetics and durability).

This system is expected to operate right from the analysis of the roadway surface (the diagnosis phase) through to the completion of the list of the roads to be repaired.

3. FIRST ANALYSIS OF THE SPECIALIST'S WORK: TOWARD A BLACKBOARD ARCHITECTURE

3.1 Why an expert system?

In order to know how we were going to deal with the problem of urban road management, we observed the urban road manager at work.

We first got a familiar view of the domain (essentially the vocabulary) of expertise by studying specialized technical documents (especially handbooks coming from the national center for urban engineering). Then, we interviewed the experts and they introduced us to their way of working. As a first step, such interviews appeared to be an excellent way of learning about the domain and defining exactly the ES aims.

We thus noticed that the experts use a great amount of data, part of which being unavailable or uncertain and, overall, belonging to various categories. Actually, the specialist grounds his reasoning process on knowledge coming from both technical skills and a long practice. His approach of problem solving is non-deterministic and involves various kinds of knowledge (geological data, strategies in relation with the main objectives of the city, visual observations, ...), among which there is empirical know-how. Moreover, these data are continuously evolving, as attested by the various laboratories and companies concerned with the development of new methods or new products.

An ES has also the property of gathering the know-how of the specialists. Therefore, its interest is also to collect pieces of various knowledge that will become available for a larger public in charge of road maintenance, in order to help them to manage road networks.

That is why we first chose an ES approach.

3.2 Why a blackboard architecture?

We then kept acquiring the knowledge of our expert. The analysis of his way of reasoning made it clear that he has several tasks to carry out, as seen before in section 2, each of them appealing to a particular expertise. We identified activities of diagnosis, analysis, synthesis, planning and decision making distributed among the previous tasks. The specialist carries out one or another according to the current state of the problem. He always uses the same set of data which is shared by the different domains of competence coming into play during the reasoning process. There is therefore a close association between those domains to reach a same goal: building the list of the roads to be repaired.

We were facing a problem in which the multi-expertise feature turns up. In order to simulate the expert's way of reasoning, we obviously needed a multi-agent architecture, those agents having access to common data zones and communicating by acting on these zones. A blackboard architecture [Nii, 86a], [Nii, 86b] simply had to be chosen.

Moreover, the distribution of data into different levels in blackboards (BBs) allowed us to establish classes of objects which are the representation of all the concepts the specialist deals with in the actual world. According to some psychologists, this modularity presents the advantage of getting closer to the structure of human knowledge.

4. THE THREE LEVELS OF ABSTRACTION IN THE EXPERT REASONING PROCESS AND WHY WE CHOOSED "ATOME"

A human expert has characteristic features like the following ones:

- being the owner of an important amount of knowledge, he is essentially able to select, in a given situation, the relevant information,
- his knowledge presents such a degree of structurization that the access to useful elements is efficient,
- he relies upon reasoning strategies consisting of some short cuts,
- he weighs up individual items of knowledge after his experience.

As can be seen in these features, his knowledge is of various kinds: it ranges from knowledge about the domain strictly speaking to knowledge about its organization through knowledge (often implicit) about reasoning strategies. Researchers and designers stress the importance of knowledge elicitation, especially when expert knowledge is concerned [d'Agapeyeff, 88]; some of them propose specific cognitive methods for this task [Reitman and Rueter, 87]. So, as all human beings, the expert organizes his knowledge into different layers according to their levels of abstraction. This classification was revealed by some works in cognitive psychology which distinguish three complexity levels in the human mental activity. A distinction between several degrees of expertise was deduced from it: the knowledge, the know-how and what we call "the know how to do well". Let us first see the three levels in human mental activity:

- at the lowest level, mental activity consists in selecting and activating a scheme coming from a set of pre-instantiated schemes (it somewhat corresponds to a reflex activity directly responding to a given stimulus),

- at the intermediate level, the present facts induce the selection of one or several non-instantiated mental schemes, then their instantiation. This is the main level for an expert, which guarantees the greatest efficiency in decision or action making. He immediately "knows" how to react, thanks to his experience,

- the highest level corresponds to the real problem solving approach. The expert does not immediately "know" but succeeds in the end. Here, new facts activate the creation of new schemes relying upon theories or implicit models or meta-knowledge. In this case, the relevant facts are selected and these new schemes are instantiated.

Some points should be noticed:

- the intermediate and highest levels correspond to conscious and unconscious processes requiring more or less thinking, which is not the case for the lowest one,

- a level of activity cannot activate a higher one. The opposite situation is possible,

- any expert reasoning process involves the three levels.

During the knowledge acquisition phase in the domain of urban road maintenance, those levels clearly appeared. Knowing if a diagnosis has to be made on a given road is not the same thing as knowing if a sewage network can be the cause of a damage on the roadway; it does not appeal to the same competence and require entirely different knowledge, even if the same concepts are used. The three levels correspond to different degrees of decision and abstraction, the higher being the more abstract:

- the first and lowest one is made up of various working groups, each of them dealing with concrete problems linked to a competence (diagnosis, analysis and so on) and having no role for control,

- the second one controls the management of each competence,

- the third and highest one consists in controlling the cooperation between the different competences identified, according to the objectives of the city and the expert practice.

The *Atome* shell, that was developed in our laboratory, perfectly suits our problem in so far as it provides those three levels, two of them being meta-knowledge levels dealing with control.

Such a distribution of knowledge into different levels of abstraction may be the backbone of knowledge acquisition. Furthermore, some psychologists stress how beneficial this distinction between levels may be from the start of the knowledge elicitation process. A multi-level organization of databases is a good means for taking the hierarchical links between concepts into account and for structuring large sets of production rules as welle as possible: that difficulty often occurs in the work of ES designers.

Atome provides such an organization in layers. The hierarchy it proposes and the partition into autonomous units of work can therefore be used as a framework for knowledge acquisition. That explains the interaction between the knowledge transfer phase and the choice of this architecture, which we have already mentioned and which we have outlined in figure 1.

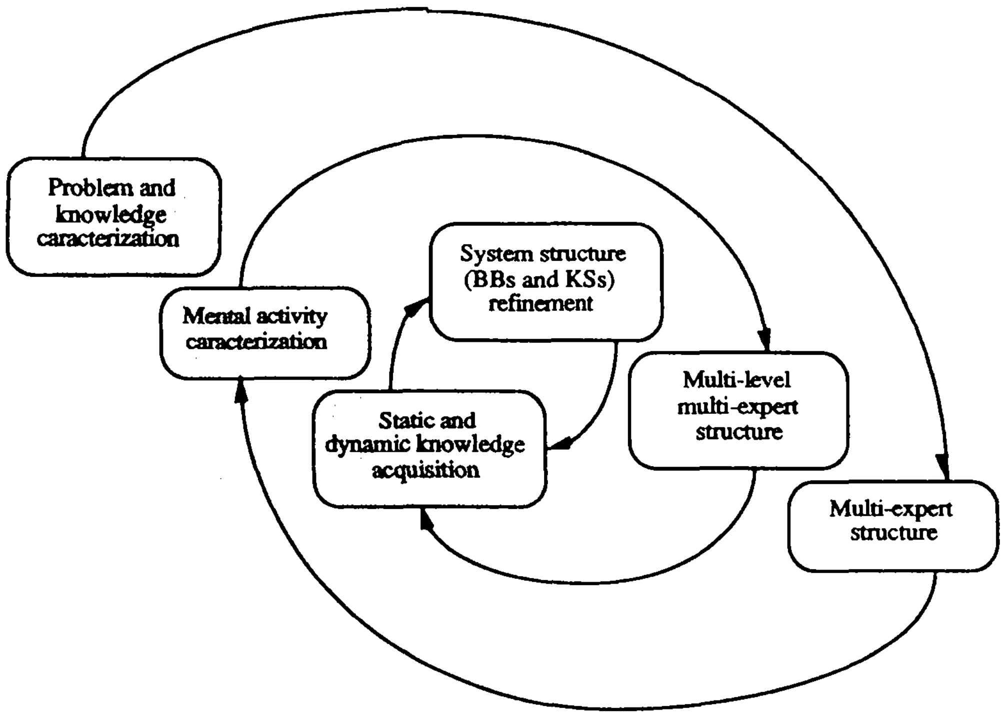


Figure 1. Toward the definition of the software architecture of the system

We can reduce the six items in this figure to two sets by merging those that refer to knowledge acquisition on one side, and to architecture on the other. A simplified version (cf. figure 2) is thus obtained.

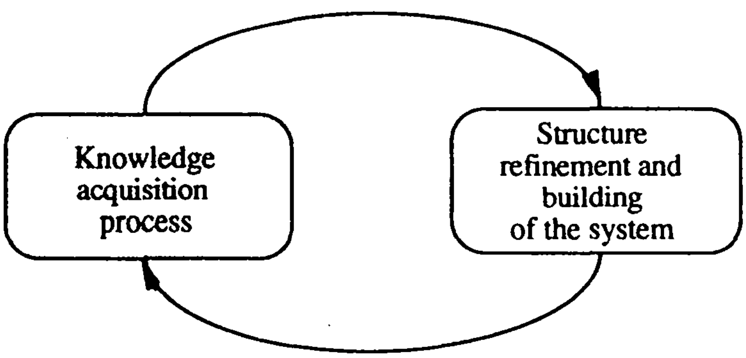


Figure 2. The basic loop of the process.

It does not correspond to the real process (see figure 1) but it is quite a good representation of our approach because it groups steps coming from the same generic idea. This scheme thus summarises what we want to highlight in this paper, i.e. interactions between knowledge acquisition process and system architecture, as we will see again in the next paragraph .

5. Knowledge acquisition and structurization in the framework of a multi-level architecture

In what follows, let us first say a few words about the *Atome* shell [Lâasri *et al.*, 88], designed for the development of multi-expert systems based on the blackboard model and providing a hierarchical control. Then, we will insist upon the phases of incremental knowledge transfer and division into various agents (i.e. Knowledge Sources), through the example of the ES Rosy already mentioned, showing :

- how knowledge acquisition led to a first identification of various skills involved in the system (first architecture of the system),
- how the focus of attention on each of these skills was transmitted to knowledge acquisition.

Those two steps are linked in a cyclic way. So we obtained a loop which is the basic component of the building process of the ES and which represents the way we built the current ES Rosy. We think that it could be a general way of modeling not only multi-agent and multi-level ES but also all kinds of ES.

5.1 The *Atome* shell

Atome manipulates blackboards and knowledge sources (KSs). Blackboards are structures which contain both the data of the problem P to be solved and hypotheses. They are divided into several levels, each of them corresponding to a class of objects defined by attributes and links between classes. Their basic elements are instances of those classes.

The KSs are working entities which intervene for solving one aspect of the overall problem P (i.e. a sub-problem of P). *Atome* takes three kinds of KSs into account, which are independent and organized in a hierarchical way, each level controlling the levels immediately below it.

At the highest level stands the "strategy", then the "tasks", followed, at the lowest level, by the "specialists". Note that the word "specialist" will refer further to the basic knowledge sources, and not to the expert persons. The specialists have no role of control; they are the only KSs that can act on the data of the blackboard, using heuristic and/or deterministic knowledge. Strategy and tasks are meta-KSs which attend to the coordination of the KSs they control. After having analyzed the quality of the current solution, they decide which KS to activate in order to contribute to solving the problem with the highest efficiency. This quality is evaluated by the tasks, according to the last "events" (changes) which occurred in the blackboards, and by the strategy, according to the presence of relevant informations in blackboard "summaries".

5.2 Division into KSs and elaboration of the blackboards: The current system

The *Atome* shell had to be adapted to the problem of road maintenance in order to model the knowledge we acquired. This was carried out in two main steps, both using two basic constructors. Let us first present these constructors before describing how they were concatenated in the main steps in order to give ourselves a methodology of development .

5.2.1 The two basic constructors

We have defined two basic constructors : the *descending* and the *ascending* ones.

Applying the *descending constructor* consists in considering a KS in charge of a whole problem and to divide it into sub-KSs. A "working group" is thus created, in which the main KS has a leading role (it controls the sub-KSs), as can be seen in figure 3.

It is just an identification of the several competences that are merged into the main KS. The knowledge used by the different agents is identified but not yet specified in detail. This is indicated, in the figure 3, by using empty circles to represent the KSs.

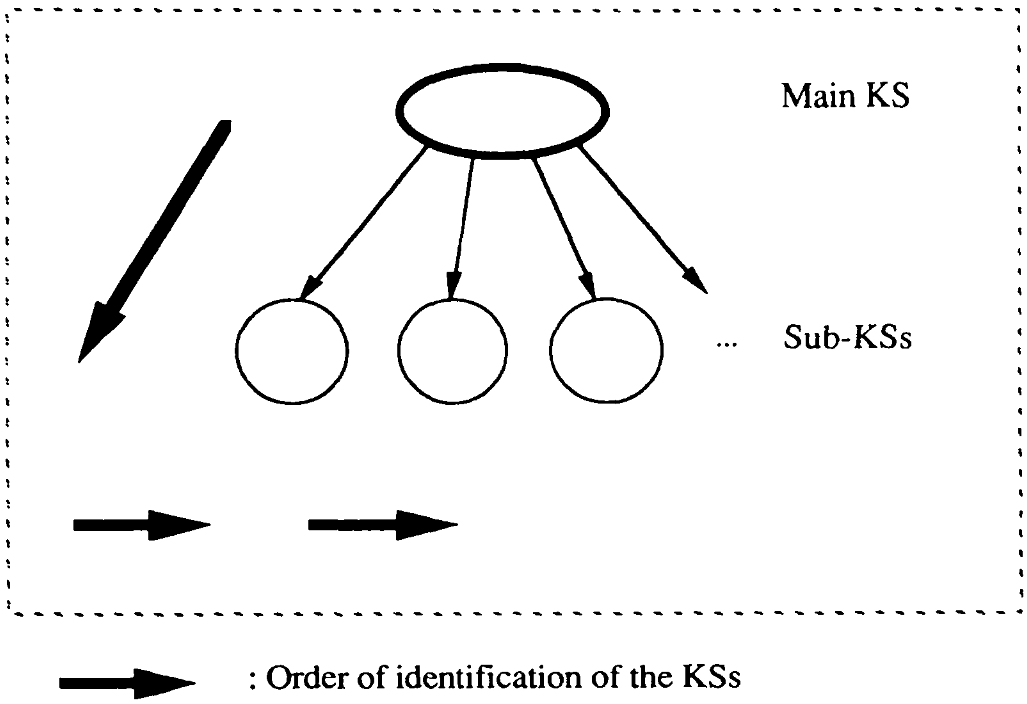
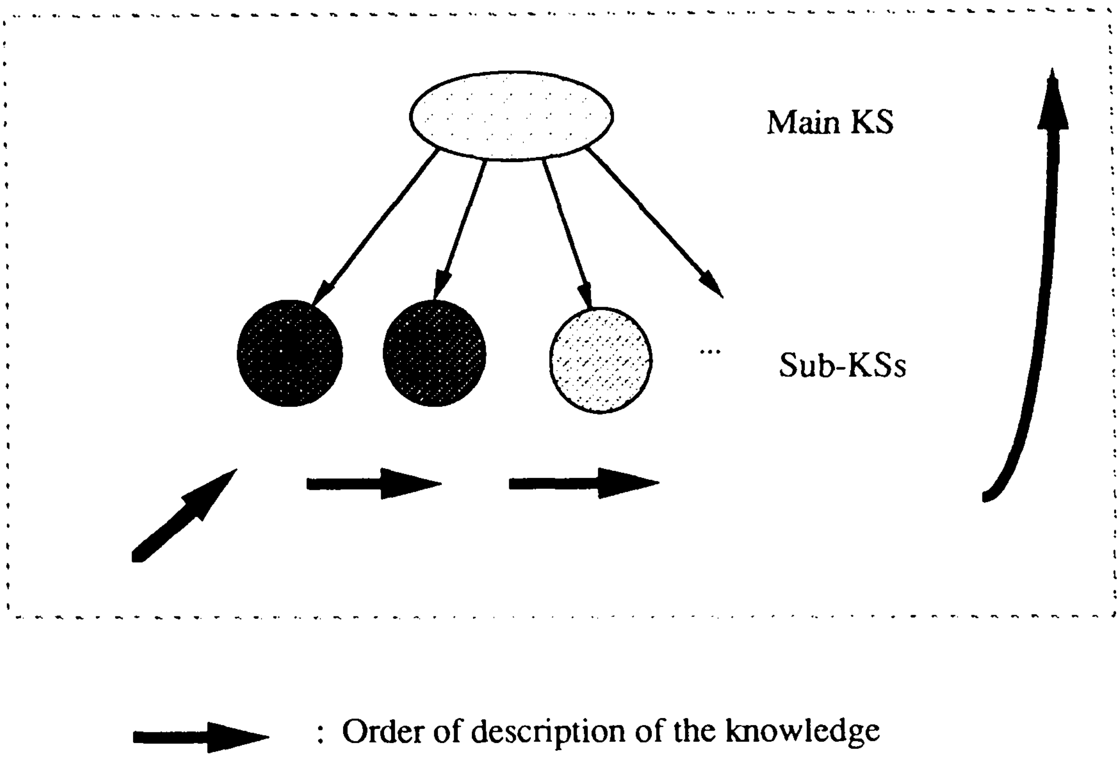


Figure 3. The descending constructor

The descending constructor focuses on the main KS in order to split it into sub-KSs. So, the main KS is called the *focus* of the constructor.

Applying the *ascending constructor* consists in considering a working group previously built by the descending constructor and perfecting each sub-KS before stating precisely how the main KS will control them. So, knowledge is the major concept: actually, attention is focused, for every component of the working group, on the set of knowledge to be manipulated. Then, the updating of these sets of knowledge (i.e. the corresponding KSs) makes it possible to study their chaining, and, thus, the updating of the main KS. This is represented, in figure 4, by dark-colored circles, as if the empty circles of figure 3 had been filled up with knowledge (the background gray level of the circles corresponds to the quantity of knowledge of the KS. The darker the background is, the larger the quantity of knowledge is).



: Order of description of the knowledge

Figure 4. The ascending constructor

Note that the knowledge of the main KS can be partially identified at any moment in the process (as mentioned in figure 4 by the rising arrow) but is complete only after all the sub-KSs have ben analyzed.

5.2.2 The two steps of the building process

Building the ES Rosy requires two phases, a first one that we call "descending phase" (by analogy to a top-down run in the hierarchy of *Atome*) and a second one that we call "globally ascending phase" (following an overall ascending line, from the bottom to the top of the hierarchy).

The *descending phase* (illustrated on figure 5) first consists in considering the whole problem of urban road maintenance and to split it into main tasks. For that purpose, the descending constructor was applied once, with the *strategy* as a focus (cf. figure 5.a). We thus designed the different tasks to be involved in the problem solving process :

. the *Init* and *Road-state* tasks share the initialization of the problem (creation of the blackboard static data, input of the list of damages which appear on the road),

. the *Diagnosis* task makes the diagnosis of the roadways preselected by the expert (evaluation of their "state of health"),

. the *Theoretical-Therapy* task has to select a suitable kind of therapy for a given roadway. It is a temporary choice which only takes into account the assessment of the road surface damages and some physical data in relation with the roadway. This task also draws up a list of sections to be repaired, these sections being sorted according to their deterioration degree (the more damaged is a section, the greater the priority),

. the *Last-Choice* task has to backtrack to the decision taken by the previous task and to eventually modify it by including the road management policy guidelines,

. the *Budget* task chooses the materials to be employed. It then provides the final renovation and maintenance planning, after matching cost with budget.

The strategy determines which actions must be performed according to the contents of the "blackboard summary" (the blackboard summary is an abstract of the various blackboards which keeps in memory all the data considered as being necessary for the reasoning process). Hence, the tasks are not invoked in a sequential way. For instance, a task may provide a result in contradiction with results inferred before by another task. Backtracking will then be used.

Actually, the reasoning process will imperiously end by evoking the *Budget* task but it is impossible to know a priori if this task will not have been already fired. For example, some constraints depending on political choices can be inconsistent with a limited budget. The strategy will then decide to backtrack to the *Theoretical-Therapy* or the *Last-Choice* task in order to re-analyze the roads list.

We then focused on one particular task and identified the various kinds of expertise into which it can be divided, creating for each of them an *Atome* specialist. This was the result of another application of the descending constructor, focusing on the chosen task (cf. figure 5.b). At this moment, as we have just used descending constructors and not yet ascending ones, tasks and specialists of the focus task are only semantically specified : their roles and goals are globally known but the knowledge is not formally and precisely described.

That first decomposition of a task into specialists was used twice in order to build the current system, first with the *Init* and *Road-state* tasks, then with the *Diagnosis* one as focus task. The descending constructor will be used again with the other tasks as a focus, once the specialists of the *Diagnosis* one will be completely validated (validation is ongoing).

The descending phase can thus be considered as an iterative process made of several basic steps : the applications of the descending constructor focusing, by turns, on the control KSs (i.e. tasks and strategy). This is represented in figure 5. The basic steps are surrounded with dotted lines.

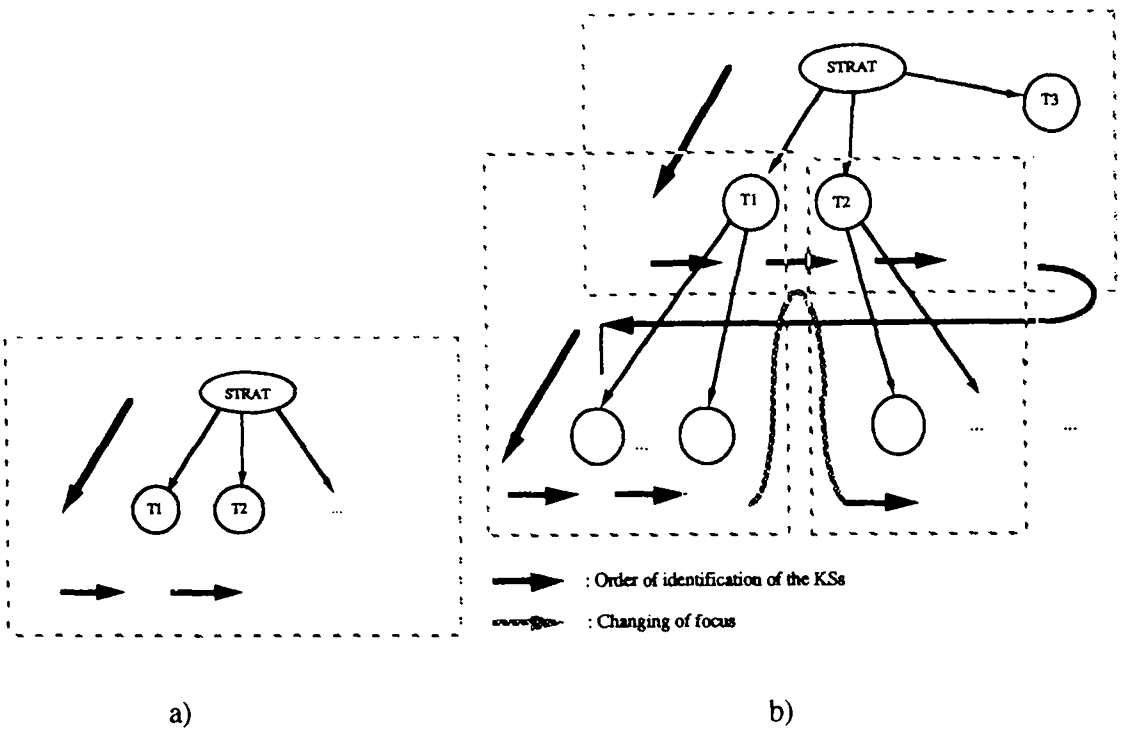


Figure 5: The descending phase in the system building process

- the *globally ascending phase* consists in applying ascending constructors, first to the different specialists of a task, then to the specialists of another, ..., and finally to the tasks themselves in order to work on the strategy.

One could imagine that this process always proceeds strictly from the bottom to the top of the hierarchy. In fact, there is constant backtracking between the study of one KS and its sub-KSs. Let us take the example of a task and its specialists. Taking the specialists into account permits, in a first step, to define the control mode. Then, refining the control leads to detect the badly distributed or not enough dissociated knowledge, and so, to update the specialists. Finally, these alterations react upon the task control. This general process is iterated until reaching a satisfactory balance between the task and the specialists it controls. The same process will be then performed between the global strategy and the tasks when the latter are all defined.

So, we can see that the globally ascending phase also sometimes appeals to the descending constructor when the division into KSs is invalidated. We are then facing loops between the use of the ascending constructor and the use of the descending one. These loops occur on each working group designed in the descending phase, i. e. by focusing on the various tasks and on the strategy. At the strategy level, another descending phase can be fired again if the division into tasks is not satisfactory, iterating once more the whole process with less data to examine.

In spite of all, the purpose of the globally ascending phase is to model the knowledge acquired from the bottom to the top of the KSs hierarchy. That is why we called it "*globally*" ascending phase.

The figure number 6 illustrates this second phase :

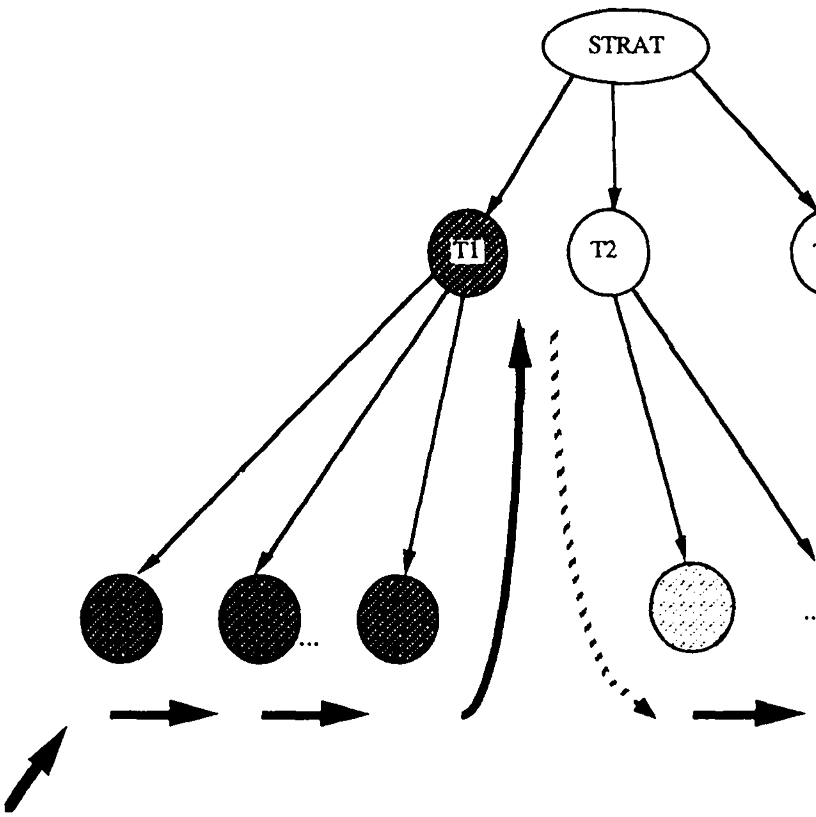


Figure 6. The ascending phase

After chaining these two phases, we obtain a real strategy for building "multi-level multi-expert systems".

The blackboards are built and enriched according to the same method, during these two phases. The study of the problem we deal with allowed the identification of the main concepts (roads, damages, materials, ...) and led us to divide the static knowledge into four blackboards. We enriched the first skeletons obtained previously by identifying several levels involved in each task on which we had focused during the descending phase. These blackboard levels correspond to objects manipulated by the expert. We then used techniques of development of relational databases in order to define these objects, their relevant attributes and the relationships between them. The following levels were found:

- the section i.e. the part of a street which runs from one crossroad to the next one and which can be divided in several roadways,

- the roadway i.e. the elementary entity on which the expert reasoning is based. A great amount of visual data is required to describe it: the appreciation of its longitudinal section and cross-section, its homogeneity, the details of all the surface damages and the excavations or the local repairs it encountered. Moreover, particular features are needed in order to assess the damages : data about the traffic, the suburban networks, the nature of the foundation, the history of the street (latest rehabilitation, traces of all roadworks, ...) and special fittings which might be inserted into the street (for example, the installation of a pipe-work for urban heating),

- the damages and their causes (those two levels are linked by the means of *Atome* "links"),
- the materials used to repair the roads and their physical properties,
- maintenance and renovation treatments.

So, we get quite stable a structure which will be definitively updated during the building of the specialists in the ascending phase. We may insist again upon comings and goings between two kinds of entities, here the specialists and the blackboards, similar to the ones seen before: the blackboards initiate the creation of heuristic knowledge inside the specialists; dealing with the specialists permits detection of some missing data in the blackboards; the updating of the blackboards leads to the updating of the specialists, and so on. Again, the process will run till a satisfactory balance is obtained (i.e. corresponding to the expert way of reasoning).

It should be noticed that the method used to make the partition into KSs includes a lot of such comings and goings and corresponds to how a neophyte approaches a new domain. He first has a look at the entire problem, before going through the details. It is quite natural a way of learning.

5.3 The multi-level blackboard architecture, a guideline for knowledge acquisition: the example of the diagnosis task

In a parallel direction, we did not use very sharp techniques of knowledge elicitation during the descending phase. The conversations with the experts were not strongly directed. They became more and more sophisticated in the second part of the descending phase (which consists in dividing a given task into specialists) and in the ascending phase as well because they had to be more and more adapted to the task or a given specialist. Actually, we focused on one task and then one specialist. Each specialist has a proper and well delimited domain of competence. Knowledge acquisition is facilitated by such a structurization:

- we are going to focus on the data linked to the competence of a specialist. These data are provided by identifying the input and output levels of the specialist in the blackboards. They are automatically delimited within the competence of this specialist,
- then, we try to explicit the heuristic knowledge associated with those data and, consequently, with this competence.

So, there is real structurization and real scheduling of the knowledge acquisition, through the two development phases described before. In fact, it is the multi-level and multi-expert structure of the *Atome* shell itself that truly reacts upon the knowledge elicitation process, by providing a kind of framework into which it will settle.

Then, the working sessions with the experts are getting more formal: every session focuses on a special theme which corresponds to a particular kind of knowledge to be acquired. The sets of knowledge manipulated are of various kinds. This diversity has already been mentioned in litterature : it has been emphasized that knowledge representation modes must be as various as knowledge is [Kayser, 85] [Haton, 89]. It is the same thing for knowledge acquisition. Because several kinds of knowledge exist, knowledge acquisition methods themselves have to be varied and adapted to the kind of knowledge to acquire. The splitting into several specialists takes such a variety into account and that is why it is so interesting for knowledge acquisition. So, because each working session with the experts focuses on the knowledge of a specialist, it appeals to particular knowledge acquisition techniques, chosen according to the kind of knowledge to be acquired. To every identified specialist will be associated an appropriate knowledge acquisition technique.

To illustrate this fact, let us consider the *diagnosis* task and the special techniques of knowledge transfer we used.

After having designed the *initialization* task, we focused on the *diagnosis* one. This task deals with a given roadway and is split into five specialists which were detailed during the ascending phase in close cooperation with the expert. Each specialist contributes to the global incremental solving of the diagnosis problem: one of them evaluates the state of the foundations of the road, another one the state of the suburban networks; a third one has to search for the most likely cause(s) of a given deterioration, if needed; a fourth one deals with the roads where special fittings are programmed, while a last one makes the synthesis of all the deduced information in order to evaluate the health of the road and its quality with respect to comfort, savety, duration and aesthetics.

A specialist is not aware of the existence of the other KSs. When it is fired, it is satisfied with doing only what it is supposed to do. The whole solving process (planning of the works, cooperation, conflict resolution) is carried out by the *diagnosis* task. This one is concerned with a given street. It tests at first if some fittings are to be done in the street. In such a case, a complete diagnosis is useless and the *Special-Fittings* specialist takes over the street. Otherwise, a full study is performed. The *Foundation-State*, *Cause-Search* and *Network-State* specialists take turns to explain the state of the roadway. The last two are fired only if *Foundation-State* has been unable to draw a conclusion alone or if special degradations have been detected on the street (unknown origin or very severe ones).

When the task estimates that enough data have been analyzed to settle the "check-up" of the street, it gives way to the *Synthesis* specialist in charge of giving the final conclusions for the diagnosis. It then appreciates these conclusions and, if it not satisfied, it decides which specialist is able to yield the most relevant information and to allow the reasoning process to start again.

So, we used different methods to acquire the knowledge of the diagnosis part. For instance, protocol analysis was first used to obtain a global view of the overall problem. Actually, diagnosis making is based on visual observations of the roadway and we are fortunately in a domain where it is easy to watch at the expert working on a real problem. For the *Cause-Search* specialist, we rather used bibliographical readings and observations on the spot. In order to validate the concepts we had mentioned in this document, we used the following method : we first designed a questionnaire gathering the data necessary (at least, they seemed to be so) to describe a road with a view to making a diagnosis. Then, we exchanged questionnaires: an expert had to fill one out; another one was asked to make the diagnosis in a blind-eyed way (i.e. without knowing anything about the road, without having seen it and by using only the data provided by the first expert), as the ES will have to do.

Knowledge acquisition is thus both conditionned by the "multi-level multi-expert" architecture of the system : first, by the focus on a competence provided, secondly, by the kind of focused knowledge which will judiciously and efficiently direct the choice of an adequate knowledge acquisition method.

5.4 The loop "knowledge acquisition - refinement of the multi-level multi-expert system structure"

We have just seen in the two previous paragraphs that the division into KSs of different levels is of great help for the choice of a specific knowledge acquisition technique. We now want to lay the stress on the cyclic nature of the phenomena. Actually, the new knowledge acquired within the framework of protocol analysis, interviews, questionnaires, ..., may lead to redefine the current splitting in order to make it more relevant. This retroaction, which is the aim of our paper, is illustrated in figure 2 that we have already presented before.

Note that the "multi-level multi-expert" architecture reacts not only on the knowledge acquisition process but also on the way of building the ES by providing both of them with a guideline. That is why we think it may be possible to generalize the approach presented in this paper to other ESs, even if no shell based on the model of the blackboard is used to develop them. The decomposition into competences by the means of the descending and ascending phases remains valid and will guide the knowledge acquisition process.

6. CONCLUSION

We have presented in this paper the main ideas that underlie the modeling of knowledge in multi-expert and multi-level systems, taking as an example the multi ES *Rosy*. We explained how the analysis of the expert knowledge led us to a hierarchical blackboard architecture and how this particular architecture allowed to efficiently plan the knowledge acquisition process. The acquired knowledge induces the system architecture refinement, which, in its turn, reacts upon the knowledge transfer. So, we have insisted on the mutual interactions between knowledge transfer and global system building, thanks to the specificity of the multi-agent blackboard architecture, especially its multi-level structurization that may be related to the structurization of human knowledge.

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