Modeling opportunistic reasonings : the cognitive activity of traffic signal setting technicians

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The cognitive activity of traffic signal setting technicians

Programme 8

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MODELISATION DE RAISONNEMENTS OPPORTUNISTES:

L'activité des spécialistes de régulation des carrefours à feux

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Résumé.

Dans le cadre de recherches sur la modélisation de l'activité de résolution de problème de conception, une expérience a été réalisée sur l'activité des concepteurs de la régulation des carrefours à feux. Les buts étaient de vérifier l'hypothèse d'un raisonnement "opportuniste" chez ces concepteurs et de recueillir les informations nécessaires à une modélisation de ces raisonnements.
Huit experts ont été soumis individuellement à la résolution d'un problème relativement difficile. La technique de "l'information à la demande" de Rimoldi a été utilisée. Outre les protocoles verbaux enregistrés, les diverses traces de l'activité des sujets étaient recueillies (schémas; calcul...).
Ce matériel a été interprété en vue d'une formalisation au moyen d'un modèle de type "blackboard". La structure du "blackboard", les diverses représentations des "sources de connaissances" ainsi que le fonctionnement général sont esquissés en vue d'une future implémentation du modèle sur ordinateur.

Mots-clés: Résolution de problème, raisonnement opportuniste, conception de carrefours à feux, modèle "blackboard".

Abstract.

The activity of experts in traffic signal setting for junctions has been studied as a design activity. The aims were to test the hypothesis of an "opportunistic" reasoning and to gather the information necessary to model this kind of reasoning.
Eight experts had to solve, individually, one rather difficult problem. Rimoldi's "information on request" technique was applied. The verbal protocols were recorded and the traces of the activity (sketches, hand-made computation...) were gathered as well.
These data were analysed within the "blackboard" model framework .
The structure of the blackboard, different kinds of representation for the definitions of "knowledge sources", and the problem-solving mechanism have been outlined in the perspective of a future computer implementation of the model.

Key-words: Problem solving, opportunistic reasoning, traffic signal setting design, blackboard model.

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1. Introduction

Following the works of Newell and Simon (1972), psychology now studies problem solving in terms of problem space. According to Newell (1979), "a problem space consists of a set of symbolic structures (the *states* of space) and of a set of *operators* over the space. Each operator takes a state as input and produces a state as output [...]. Sequences of operators define *paths* that thread their way through sequences of states."

A problem in a problem space consists in a set of initial states, a set of goal states, and a set of path constraints. The problem is to find a path in space that starts from an initial state, reaches a goal state and respects the constraints. In this framework, the notion of optimal path is an important one (Nguyen-Xuan & al. 1984).

Besides the question of the subject's representation of the problem, i.e. the elaboration of a representation of its different elements (Richard, 1984), an important question concerns the processing strategies (cf. the survey of Caillot, 1984)

In the problem space framework, the path can be thought of as a sequence of problem solving steps; the elementary step is the application of an operator (which may be complex) on a state. The main question about the problem solving activity is then: which problem solving steps are in use, when and how? (Nii, 1986).

Two main strategies have been well specified, in particular because they clearly differentiate between experts and novices, in a given domain: novices use a backward strategy (using very general heuristics such as the means-end analysis) which consists in finding a path from the goal towards the initial data, while experts develop a forward strategy, findind a path from the data towards the goal (cf. particularly Sweller & al., 1983).

However, the results obtained in this perspective have only considered a specific class of problems: "well-structured" problems, for which (because they are well-structured) the states (notably the solution), the operators and the constraints can be well specified beforehand, in a restricted problem space. They often are games, experimental problems, or school exercises.

Now, as Simon (1973) rightly notices, problems set to man by the environment are in general "ill-structured". They become "well-structured" only when they have been formalized for the problem solvers, and this mainly by a selection among the huge set of knowledge units (available in memory or in the environment) that may be relevant, which characterize "ill-structured" problems.

So, for not (yet) formalized problems, the main effort bears on problem definition; solving in itself is only a secondary part of the activity.

In many domains, this problem structuration effort leads to the elaboration of problem solving strategies, algorithms, solving plans, adapted to classes of problems, that may be used by experts beforehand, and that allow them to go straight to the resolution activity itself.

But, in other domains, even for the expert, the problem definition process remains the core of the activity without producing in the long run a resolution strategy (apart from a very general one) a priori usable (Carroll & Rosson, 1985). Situations of this type concern design activities (not mentioning creation activities).

A formalization in terms of problem space no longer seems suited. The problem space (if we stick to this terminology for a while) is very wide, often multiple, and the sets of states, operators and constraints are nearly impossible to define precisely. In fact, the problem for the subjects lies in choosing constraints under which they manage to elaborate a detailed description of a possible solution state.
An important characteristic of problems of these domains is that there is no single exact solution. Several evaluation criteria of solutions exist, often contradictory. The prototype example often given for these activities is architectural design.

Therefore, the hypothesis is that, in these activities, resolution steps do not appear according to a stable, pre-planned strategy, but rather dynamically, according to an "opportunistic" strategy (Hayes Roth & al., 1979; Nii, 1986).

The "blackboard" model, stemming from works in Artificial Intelligence, seems promising for the psychological modeling of these activities, and perhaps even for the modeling of problem solving in general: in this model, elementary, logically independent, reasoning units (knowledge units, action rules, local calculus, ...) intervene, but with no pre-determined order: partial and temporary solutions are elaborated, and their characteristics trigger the "opportune" intervention of such or such elementary unit of reasoning.

The research presented below is a contribution towards the evaluation of the psychological relevance of this type of model. The topic is still under investigation; in particular, the computer implementation is not yet running. The experiment we will describe is a step towards this implementation.

This experiment concerns problems of traffic signal setting. We will first show how we have attempted to test the hypothesis that this problem belonged to the "ill-structured" problems category and that its processing gave rise to an "opportunistic" strategy.
We will then show how the subjects' representations and processings have been formalized in order to sketch the model in preparation. For this purpose, a general description of the main aspects of the blackboard model will be provided.

2. The domain: traffic signal setting

Among other design tasks we study, this one has been chosen because, although not straightforward, it did not seem to give rise to a too wide problem space. Furthermore, the resolution activity is mostly done in the office, on paper, and in delays of about one hour: all this facilitates observation and experimentation.

This task is fulfilled by traffic technicians; it consists in choosing, organizing and setting the signalling (and flow channelling) devices to be implemented on a junction in order to optimize safety and free flow of the traffic of vehicles and of pedestrians.

A first analysis (Figeac-Letang, 1986) showed (classical) differences between prescribed methods and effective methods. Concerning the latter, differences appeared also between the technicians, concerning the types of solutions, the constraints taken into account, the criteria of solution evaluation, ... The problem was then to choose an appropriate model to guide the research: we have assumed that experts used an opportunistic strategy, characteristic of design tasks.

3. The experiment

3.1 Goals

An experiment has been conducted in order first to test this assumption, second to gather information allowing at least to sketch a model: the goal is thus to have the technicians verbalize their reasoning units and the strategies of activation of these units.

3.2 The experimental technique

A simulation of the solving of a junction problem has been proposed to the subjects (subjects were tested individually). The realism of such a situation is not a problem: technicians solve usually most of the problems in a paper-and-pencil situation.
The verbalization of the selected pieces of information being of great importance, the "information on request" technique (Rimoldi, 1963) was used: a blank map of the junction was presented, together with a request of intervention, the subject having to request to the experimenter the complementary information he judged necessary, when he needed it.

In addition, the technique of simultaneous verbalization of the reasoning was applied: the subject was requested to "think aloud" all along his activity of resolution.

3.3 The problem

The problem chosen is of a type frequently met in reality: an intervention on a junction already equipped with traffic lights, the functioning of which is no longer suited to the evolution of the traffic. Subjects were not allowed to modify the geometry of the junction or the traffic flows. However, the organization of lanes, the installation of islands or pedestrian facilities were allowed.

A relatively complex situation was chosen (a cross plus a fifth branch), in order to avoid the use of a pre-defined solution.

3.4 Subjects

Eight technicians, working in different regions of France, have participated in the experiment. All are experienced technicians.

The sessions of two subjects have been used to refine the experimental procedure and apparatus. The six other protocols have been interpreted and provide the results presented below.

3.5 Data gathering

Three types of data were obtained:

- the verbalizations were tape-recorded, then transcribed;
- the written (or drawn) productions of the subjects were collected;
- the experimenter took notes concerning some behaviors of the subjects, in particular the use of documents at some points.

4. Results

We will first present the principal characteristics of the subjects' reasonings that tend to give credit to the hypothesis of an "opportunistic" strategy. We will then sketch the main elements of the blackboard model before (and for) describing the first results within the model framework.

4.1 General characteristics of the observed reasonings

The main observations are:

- the six subjects produce six different solutions;

- the subjects do not announce an a priori resolution plan. The ways in which resolutions proceed, as observed a posteriori, differ largely, from both standpoints of their plans and of the nature of the successive steps. A common plan can only be found at a very high level of generality: for all subjects, the following iterative sequence appears:

  1 - analysis and categorization of the junction
  2 - phase distribution hypothesis[1]
  3 - evaluation of this phase distribution
  4 - if satisfying then stop;
  else go back to 2.

But, as shown by the comparison of the reasonings[2], as soon as a less abstract level is considered (not mentioning a more detailed level), the resolution steps widely differ.

In particular, the following characteristics of the reasonings differ:

- the pieces of information taken into account in order to analyze and categorize the junction: out of the 29 categories of information that have been requested, only 5 have been requested by the 6 subjects;

- the number of iterations, in other words, the number of different hypotheses considered;

- the nature of the elements of solution that have been considered;

- the evaluation mode of the hypotheses;

- lastly, goals often change and previous decisions are often modified.

These phenomena, measured on *experienced* technicians, tend to give credit to the hypothesis set in the introduction on the basis of the observations of the first study: they are characteristic of an opportunistic mode of reasoning.

4.2 A model of the activity

Verbal protocols have thus been analyzed according to a blackboard model. This description allows a synthesis of the observations without yet constituting the

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[1] A phase is the time interval during which some specified movements of traffic are allowed (green lights). The phase distribution is a sequence of phases; it constitutes then an organization in time and space of the movements of the vehicles and of the pedestrians.

[2] The description of the reasonings of two subjects and tables indicating the distribution (across subjects) of the characteristics of the reasonings can be found in Figeac-Letang & al. (1987).

specifications of an implementable simulation of the activity: it is an intermediary stage towards the definition of such specifications, on which we presently work.

Before giving the results of this analysis, the architecture of such a model will be described.

4.2.1 General information on the blackboard model

The model includes three modules:

- the blackboard;
- a base of units of reasonings called "Knowledge Sources" (KSs);
- a control module (cf. fig. 1).

The blackboard

It indicates, at any time, the state of the solution of the problem. It is thus composed of the objects which are elements of solution; in particular:

- input data (the terms of the problem) which constitute the initial blackboard;
- partial solutions;
- possible alternative solutions;
- final solutions.

These elements are often organized in one or several hierarchical structures, but this is not compulsory; it depends in fact on the domain.

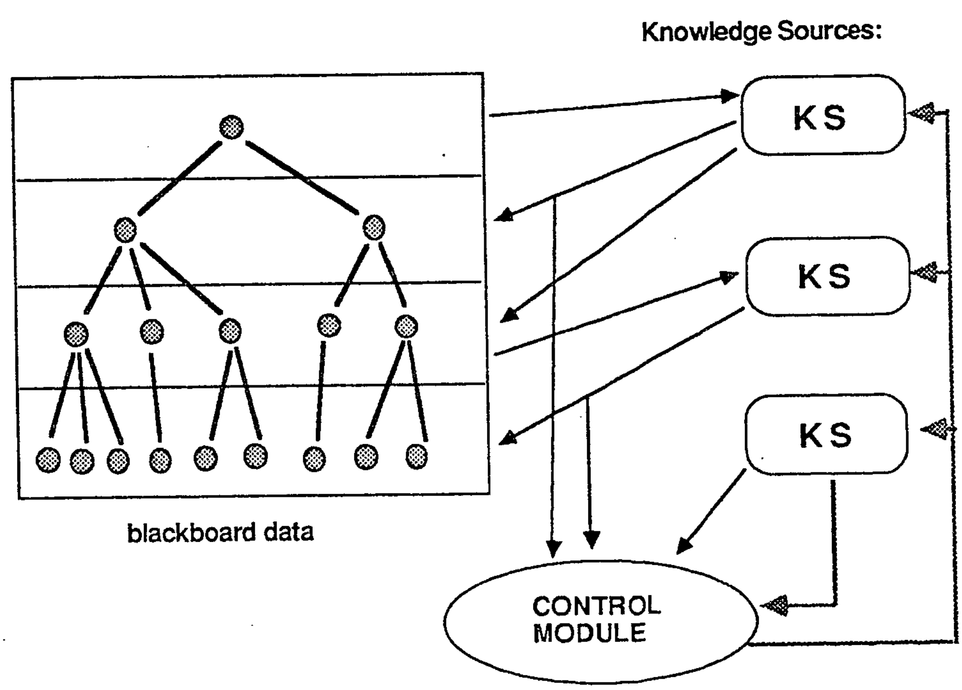

Figure 1: General structure of a blackboard system (from Nii, 1986)

The knowledge sources base

The knowledge useful for problem processing is divided into separate and independant elements. The goal of each of these "Knowledge Sources" is to produce information useful for the resolution.
Each source has access to the information appearing on the blackboard, may process it according to its specialized know-how[1], and may modify the blackboard consequently, i.e. transfer on it the result of its activity.

A source is structured in two elements: "activation preconditions" and a "body" which is the reasoning unit properly speaking, specific to this KS.
Each KS "knows" when it can contribute to the solution: its preconditions indicate the state of the blackboard which must exist in order to activate the body.

Sources may be represented with various formalisms: procedures, sets of rules, logical assertions, ...; some sources may function forward, other sources may function backward.

Thus, such a model allows to represent a resolution process which is not regulated by an a priori control structure; this is the case in "opportunistic" reasoning, in which the resolution steps are determined dynamically according to the present state of the solution. In other words, in theory, a KS does what it can do as soon as its preconditions are satisfied on the blackboard.

The control module

However, this assumes the possibility of "parallelism" of the solution steps, which constitute too strong an hypothesis for man. On another hand, we need to be able to give an account of other parts of the activity which are guided by pre-defined strategies, meta-rules, etc., and even in some cases by a complete plan, known a priori.

A control module is then present in the model. It allows to represent the activity which regulates the choice and order of intervention of the KSs. The control is said to determine the "focus of attention": it selects one among the possible resolution steps at a given instant, i.e. a KS and one of the objects of the blackboard on which it will act.

Control using a plan totally defined beforehand (hierarchical planning; algorithm, ...) may then be represented, but only constitutes a particular case of the model.

So the iterative sequence of resolution steps is:

1 - A KS makes one or several modifications on one or several objects of the blackoard; these modifications are taken into account by the control module.
2 - Each KS indicates its possible contribution starting from the new solution state.
3 - Considering information 1 and 2 and criteria of opportunity, the control module selects the focus of attention.
4 - Go to 1.

Criteria must exist to decide to stop the process[2].

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[1] Knowledge sources are sometimes named "specialists" (cf. Hayes Roth et al. 1979).

[2] For more details, cf. Hayes-Roth & al. (1979); Hayes-Roth (1983); Hayes-Roth (1985); Nii (1986).

4.2.2 Elaboration of a model of the activity of junction regulation

The verbal protocols have been analyzed using the following process:

- *Segmentation of the protocol into reasoning units*: propositions or sets of propositions that may be considered as distinct steps in the resolution are isolated. This remains at the moment a very empirical task. It is done in interaction with the hypotheses of representation (see below) which help a lot in determining the reasoning steps.

- *Representation of these units*(or sets of units): a single form of representation is not assumed. Attempts to remain close to the subjects' verbalizations lead to suppose, according to the units, various representations: the "production rule" form is adopted when possible, but others too: "knowledge frame", "procedures", "plan of action", "categorization net " ...

- *Grouping of these units* into larger units which prefigure KSs: the criterion is the existence of a defined set of input data (preconditions) and of a defined transformation (produced by the unit) of a defined solution state.

- *Distribution of these KSs in two large categories*: on one hand those that directly contribute to the elaboration of elements of solution, on the other hand those that pertain to control, i.e. that contribute to the decisions concerning the triggering of the KSs of the first category: which KS should be triggered and when? KSs of the first category are domain-dependant, KSs of the second category are in part domain-dependant, in part domain-free. Illustrations of this interpretation process can be found in table 1.

- *Design of the blackboard structure*: this design is made in interaction with the two preceding steps.

So the main results are:

- a knowledge base made of the gathering of the knowledge structures (rules, schemas, etc.) of all subjects. It is being improved at the moment, in particular by a systematic organization in units such as KSs.

- a description of the subjects' reasonings in terms of a sequence of solution states (the content of the blackboard) and of solving steps.

Detailed results can be found in Figeac-Letang & al. (1987).

- a blackboard structure still being worked on. Figure 2 provides a simplified representation of the present state of our ideas on the blackboard structure and an example of reasoning episode of one subject.

Table 1: Examples of representations inferred from verbal protocols

Example of an inferred solving rule

S - Then I suppose there are 12 meters everywhere, yeah that's it... uh! there is a little bit more; well...
E - and why did you tell me "I suppose there are 12 meters"?
S - because it corresponds to 4 lanes; in an urban environment we generally use 3-meter lanes.

Consequently, the following rule is inferred:

R59: If urban junction, then 3-meter lanes

and of course the formula:

branch width = Nb of lanes * lane width

Example of inferred rule of control

...
S - well I'll try another solution ..I have to look at it a bit more; from this point there are two possibilities you see... either we try to manage with late release systems; it depends in fact on the remaining possibilities ... it is necessary to compare the direct flows; for example in phase 1 we have 240 vehicles going straight from 1 to 3 and there are 305 going from 3 to 1; we have 345 left-turns from 1 to 2 and 253 left-turns from 3 to 4...
E - yes, so ?
S - So it seems we are stuck! Thus we have to manage with no-hooking movements.

From this, the following control rule is inferred, which allows the choice of an alternative piece of solution (no-hooking movements rather than late release):

R50: If late release solution rejected for one left-turn of a phase
and if there are two left-turns in this phase
then no-hooking movements special phase solution.

Example of an inferred knowledge frame (for solving activity)

...
S - first of all what I would like to get is the traffic... I mean the oriented flows and also indication about the amount of pedestrians on each pedestrian crossing
E - OK what do you mean by "oriented flows"?
S - well, from each approaches the distribution of movements either to the right or straight or to the left
E - OK, then for approach 1: straight 240 vehicles/ hours; 235 Right-Turns; 345 Left-Turns...etc
(the subject goes on asking for volumes of traffic)

From this it is inferred that the subject possesses a "knowledge frame" which we call the**TRAF frame** that he is instantiating partially here, by means of questions which allow him to fill in slots of this frame.

Example of an inferred classification net (for solving activity)

At the very beginning of his solving activity, the subject looks at the picture of the junction and declares:
S1 - that's a "cross" junction with a 5th approach; so firstly we must find the major axis...from the width of the axes I feel that we have 2 similar axes... secondary axes it seems; it looks like a boulevard... so a priori here it is an avenue, a street,therefore we can think that the major axis is this one...
or with another subject:
S2- that's a junction with 4 branches not really classic, because there is there a 5th branch there..uh apparently the more important branches are 1 2 3 4 because of their width and.. the 5th, well it seems less important; it's necessary now to look at the traffic flows...

The hypothesis is made that the subjects possess a **classification net for the objects "junction"**, probably built around **prototypes** which they use in order to immediately categorize the junction.
A complementary experiment has been carried out in order to describe more precisely this classification net and the features of the prototypes.

Example of an inferred (local) hierarchical plan (for the control activity)

S- Well uh, now there is a little calculation work to do to try to decide what is the optimal cycle; uh for the peak period of course,... timing of green ... before that we must make a fuzzy phase distribution, a draft of a phase distribution to see if we need 3 phases or 2 phases...

The inferred representation is in the form of the following hierarchical plan:

GOAL 1: timing of the greens
SUB-GOAL 1,1: make a phasing
SUB-GOAL 1,2: define the optimal cycle

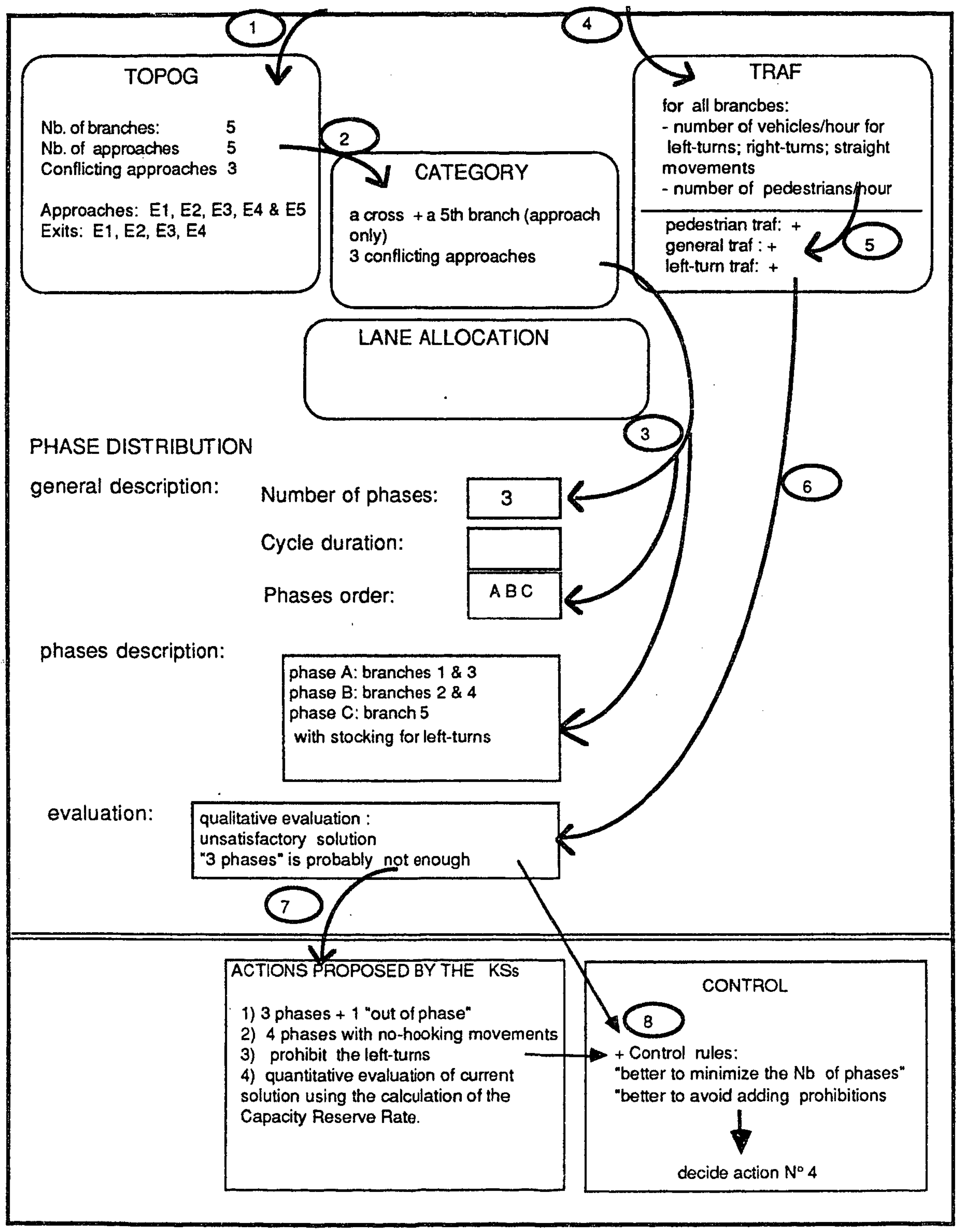

Figure 2 : Blackboard structure and example of reasoning

Figure 2, on the opposite page, is an attempt to represent, in a simple way, the blackboard e.g. the base where the solution of the problem is being built in an incremental and opportunistic manner.

The rubrics, in the upper part (above the double horizontal line), structure this solution. In the lower part have been represented the stack of the Knowledge Sources (KSs) which are activated (able to do something) at a certain time, and the area which represents the activity of the control module.

The model assumes that, following any change to the solution state, KSs indicate their possible contributions among which the control module trigger the most opportune one: this process is not systematically represented in the figure; it is however represented in 7 and 8 (see below).

An episode of reasoning has been represented by means of bold arrows which symbolize the actions of the KSs as they have been selected by the control module according to the numbers order.
Following are some explanations about these steps:
The experimenter has read the intruction to the subject who has just finished to examine the blank map of the junction (which has not been represented on the blackboard in order not to overload the figure).

in 1 - The arrow symbolizes the action of a KS which instantiates partly the "TOPOG"(raphy) frame, by means of inputs from external environment (questions to the experimenter): they are values for some slots of the frame.

in 2 - These values + the map compose the preconditions of a KS which then proposes to (and is triggered by the control in order to) categorize the junction: call for the "junctions classification net" and search of a prototype which could match the current junction.

in 3 - Considering the result of this categorization, another KS proposes a minimal phase distribution: e.g. a number of phases, in a certain order and a description of these phases: to this end this KS brings the following rules into play:

R3: If cross junction, with 2 two-way axes then each axis defines one phase.
R4: If cross junction and at least 2 conflicting approaches then 2 phases.
R5: If cross junction and at least 2 conflicting approaches and if one additional approach conflicting with the formers then 3 phases.

in 4 - The control module triggers the KS specialized in the instantiation of the "TRAF"(fic) frame (here questioning the experimenter).

in 5 - A KS gets activated and is triggered by the control to generate a qualitative classification of the collected figures (translating the figures into classes such as: low; medium; high)

in 6 - A KS generates a rough evaluation of the phase distribution currently considered on the blackboard (= here a negative evaluation). It uses the following rule:

R12: If n phases and Left-Turns=high and if Straight movements conflicting with these high Left-Turns then risk of having to increase the number of phases.

in 7 - This evaluation (+ other information already on the blackboard) triggers the activation of 4 KSs: they appear into the "proposed actions" stack.

in 8 - The control, provided with all this information and bringing into play some general solving rules, decides to go on with the current solution, hoping that a quantitative test (rather than the rough qualitative judgment just done) has some chance to be positive: so it triggers the calculation of the "Capacity Reserve Rate" on the data of the current solution.

5. Conclusion

This paper gives an account of a research dealing with the modelling of the activity of problem solving by opportunistic reasoning. At the moment, this first phase of elaboration of the model has studied experimentally a group of specialists of a target domain: traffic lights junction regulation.

We begin now a second phase in which the first results will be implemented in a program: we do not believe to reach immediately our final goal, a program that simulates the processing activity of the traffic technicians. Much information is still missing about this activity. Nevertheless, it is clear that, when a certain state of elaboration has been reached, a first implementation attempt using the model chosen will help in defining what is lacking, and thus in orienting and facilitating data gathering.

Right now, and to give a provisional conclusion, we would like to insist on one of the major interests of the blackboard architecture for the research about the modelling of cognitive activity. This type of model has a great flexibility. It allows to represent the intervention, for a single subject solving a given problem, of a large variety of strategies, used locally during resolution.

In particular, the fact that control activity is explicitly represented and differentiated from actions of resolution properly speaking seems very heuristic for psychological research. A very important advantage is that, notwithstanding its opportunistic control basis, the model does not preclude an a priori defined control, but includes it as a special case.

This ability could very well prove to be interesting for modelling learning phenomena. One can assume that, in some learning situations, the crucial evolution consists in switching from opportunistic planning to a pre-defined method of resolution discovered by the subject, that can be activated a priori. It could be worthwhile to attempt to represent this switch within the blackboard model framework.

The major drawback of the model is to cost much in terms of memory and processing load for the host computer (Hayes Roth, 1985). This is an handicap only for application systems and not for research, particularly psychological research. We hope colleagues in psychological research can find interest in this model, certainly more complex, but also more fruitful for psychology that simple production systems.

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6. REFERENCES

CAILLOT, M. - La résolution de problèmes de physique: représentations et stratégies. *Psychologie Française*, 1984. *29*. 257-262.

CARROLL, J. M. & ROSSON, M. B. - Usability specifications as a tool in iterative development. In H. R. HARTSON (Ed.): *Advances in Human-Computer Interaction, Vol. 1.* Ablex Publishing Corporation, 1985.

HAYES-ROTH B. - *The Blackboard Architecture: a General Framework for Problem Solving?* Report HPP-83-30. Standford University, Computer Science Department, May 1983.

HAYES-ROTH B. - A Blackboard Architecture for Control. *Artificial Intelligence*. 1985. *26*. 251-321.

HAYES-ROTH B. & HAYES-ROTH F. - A cognitive model of planning. *Cognitive Science*. 1979. *3*. 275-27O.

FIGEAC-LETANG C. - *Analyse de la tâche d'aménagement des carrefours à feux*. INRIA Report, Ergonomic Psychology Project. 1986.

FIGEAC-LETANG C., FALZON P. & BISSERET A. - *Analyse de l'activité de conception du système de feux d'un carrefour*. INRIA Report, Ergonomic Psychology Project. February 1987.

NEWELL A. - *Reasoning, Problem Solving and Decision Processes: the Problem Space as a Fundamental Category*. Research Report. Carnegie-Mellon University. June 1979.

NEWELL A. & SIMON H. A. - *Human Problem Solving*. Prentice-Hall. 1972.

NGUYEN-XUAN A. & GRUMBACH A. - Apprendre en résolvant des problèmes: le système humain et les systèmes artificiels. *Psychologie Française*. 1984. *29*. 235-242.

NII H. P. - Blackboard systems: Part one: The blackboard model of problem solving and the evolution of blackboard architectures. *The AI Magazine*. 1986. *7*. 38-53.

NII H. P. - Blackboard systems: Part two: Blackboard application systems, blackboard systems from a knowledge engineering perspective. *The AI Magazine*. 1986. *7*. 82-106.

RICHARD J. F. - La construction de la représentation du problème. *Psychologie Française*. 1984. *29*. 226-230.

RIMOLDI H. J. A. - Processus de décision et fonctions mentales complexes. *Revue de Psychologie Appliquée*. 1963. 65-81.

SIMON H. A. - The Structure of Ill Structured Problems. *Artificial Intelligence*. 1973. *4*. 181-201.

SWELLER J., MAWER R. F. & WARD M. R. - Development of Expertise in Mathematical Problem Solving. *Journal of Experimental Psychology: General*. 1983. *112*. 639-661.

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