Analyzing behavioral data for refining cognitive models of operator

Olivier Georgeon
Lescot, Inrets
Bron, http://www.inrets.fr
olivier.georgeon@inrets.fr

Alain Mille
Liris, Université Lyon1
Villeurbanne, http://liris.cnrs.fr
alain.mille@liris.cnrs.fr

Thierry Bellet
Lescot, Inrets
Bron, http://www.inrets.fr
thierry.bellet@inrets.fr

Abstract

We present a methodology and a tool for analyzing the activity of an operator interacting with a complex technical device. The goal is of refining cognitive models of the operator by relating them to patterns of behavior in real situations. The activity is observed to be modeled as a trace having a graph structure. The trace is transformed according to a "use model" in order to become meaningful in the context of modeling theories. Our "Trace Based System" thus gathers both a representation of the activity and of the analyst's expertise for facilitating the discovery of knowledge in the field of cognitive psychology. The approach is illustrated by its application for car driver cognitive modeling.

1. Main goals

The general objective is to better understand the behavior of the user of a complex technical artifact. By technical artifact, we mean a device designed to help a person carry out a given task. It is complex if it is not reducible into a small number of parameters and if it is engaged in a highly unpredictable situation. The user is then in a situation of "piloting" in the broad sense of the term: factory supervision, car driving, economic decision, plane flying... The growing complexity of these artifacts raises challenging issues concerning their usability. Meanwhile, they offer new possibilities of activity recording that may be useful for real time support or for subsequent improvement. These recordings include operator's actions, artifact performance and environment evolution.

This general objective constitutes the main research field of cognitive ergonomics and activity analysis which aims at explaining operators' behavior by their cognitive activity. In this framework, the behavior is classically associated with three levels of tasks, according to its time scale: the operational or motor level, lower than the second; the tactical level, about a few seconds; and the strategic level, beyond a few seconds. Our study focuses on the tactical level. At this level, modeling paradigms rest overall on the statement that operators do not act according to the objective state of the world, but according to a "mental model" of it. This mental model is regarded as being built in working memory, from knowledge in long-term memory and from elements perceived in the environment.

The modeling task then consists of describing this mental model as well as the mechanisms allowing its elaboration. This task is usually done by psychologists who refer to cognitive psychology concepts such as the concepts of "Frame" or "schema" [1], of "Script" or "Scenario" [2], of "Mental representation", of "Operative Image" or of "Situation Awareness" [3]. These concepts simultaneously cover the perception, the comprehension and the anticipation for describing how the elements of the situation are "mentally" taken into account by the subject, should it be consciously or not.

Psychologists use methods laying on the one hand, on techniques of subjective investigation consisting of questioning the operator while he is working or afterwards, and on the other hand on objective behavior analysis.

Our work seeks to facilitate the analysis of behavior from collected data, with an aim of inferring or validating assumptions about operator cognitive states and processes. It consists of providing psychologists with a means of consulting this data in such a manner that they can understand it in the context of their modeling theories. Then, the meaningful representation that is exhibited by the system can be confronted with a

subjective evaluation made by the operator, for confirmation or invalidation.

2. Knowledge discovery from sequential data

2.1. Issues

Methods and software systems fulfilling our objectives have to face most of the difficulties classically related to the field of knowledge discovery.

The data can be noisy or erroneous; which could make meaningless patterns emerge and generally makes data interpretation hazardous.

Patterns of data can only become knowledge if they can be interpreted in the context of previous knowledge.

The way the data is presented to users is of great importance. The knowledge does not come out as an output of the system but it is rather built by users with the interactive help of the system. Hence, the deployment of a modeling support system is an issue by itself.

The methodology and means for knowledge discovery must be based on a knowledge theory that allows the understanding of symbols handled and exhibited by the system.

2.2. Sequential data analysis

There are already a few software tools existing for analyzing data collected from human activity. Tools like Atlas.ti and Nud*ist allow qualitative data analysis but are rather directed towards analysis of textual or multimedia corpus. More specifically to Exploratory Sequential Dated Analysis (ESDA), we find Macschapa [4]. Contrary to these tools, we propose an approach that is resolutely placed in the field of knowledge systems by integrating functionalities based on knowledge description languages, ontology management and graph manipulation facilities.

Our approach is inspired from the theory of situated cognition [5], which for us, points out two main considerations: (a) the behavioral data must be "situated", because the behavior can only be understood by reference to the context in which it takes place. For this reason the data must include contextual information that is required for interpreting the behavior. (b) The data must be adapted to the analysts' knowledge, because it can only make sense to them in the context of their previous knowledge. The system must thus incorporate analysts' expertise for transforming the collected data into data that makes sense to them.

We propose to manage the analysts' knowledge under four forms: an ontology that formally specifies all the concepts used to describe the activity, visualization style sheets for formatting the visual display of traces, transformation rules that implement the analysts' expertise for making inferences from the data, and schema signatures that specify the connection between models and patterns in the data.

2.3. Trace based systems

In the field of knowledge systems, our specificity is that our data consists of *traces* which we define as a succession of temporally located "*observés*". We mean by *observé* any time-stamped piece of data, produced by the observation of an activity with the aim of describing it. A software system which is dedicated to traces constitutes what we call a "Trace Based System".

The Liris laboratory has already implemented such systems in the field of computer environments for human training or in multi-agent systems. These implementations are based on a formalism called Musette [6] according to which the trace is structured into a succession of states and transitions. Owing to this structuring, it becomes possible to isolate some episodes which consist of passing from one state to another through a succession of intermediate states and transitions. This cutting does not mean that the activity is modeled as a Petri net. The states just correspond to temporal intervals which the analyst chooses to regard as stable and describable on their own by a set of *observés* valid over their whole duration.

3. Methodology and implementation

3.1. Architecture

Figure 1 presents the architecture of our system named ABSTRACT (Analysis of Behavior and Situation for Representation Assessment and Cognitive acTivity modeling).

The *collect system* produces a sequence of *observés* coming from the various collect sources. It gathers automatic processing tools, assistance tools for manual

collect and a merging tool. It also includes a visualization tool which is used to validate the *collected trace*.

The *Trace Based System* level constitutes the modeling workshop itself. It enables the analyst to handle the traces in the form of RDF graphs (Resource Description Framework). It gathers the various functionalities of trace transformation: an ontology editor to specify the various traces models, a transformation editor to specify the various transformation rules applicable to the traces, a transformation engine to apply them, a display system to visualize the resulting traces as graphs and a query tool to search for occurrences of signatures in the traces.
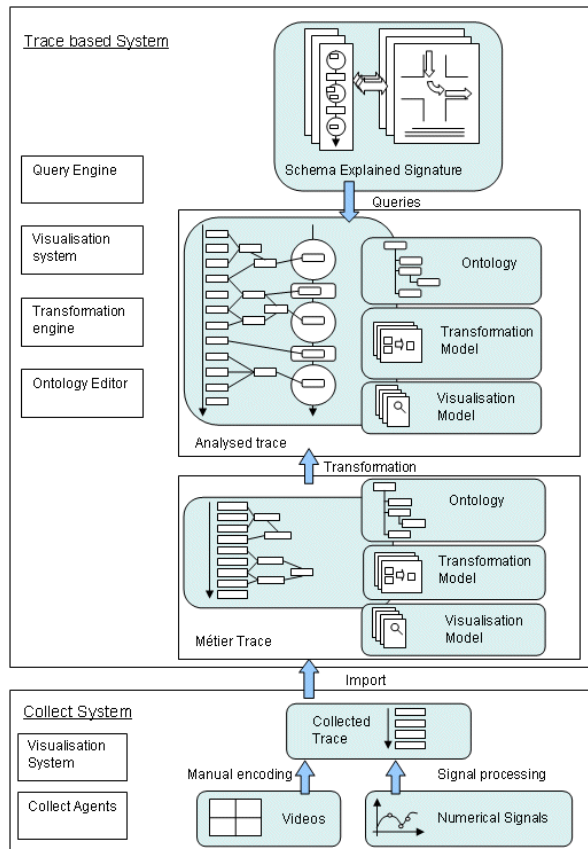

Figure 1 - Architecture

The mechanism of trace transformation consists of enriching them and filtering them. Enrichment consists of adding new nodes and arcs in the RDF graph, which are increasingly easier for the analyst to read. This addition is done by applying inference rules which add nodes to patterns found in the trace. These rules are specified by the analyst. Filtering consists of masking

low level *observés* which are not useful any more for the analyst.

We never remove *observés* from the trace; so that, the various transformed traces preserve their links to the collected trace. This allows the analyst to establish parallels between the various modeling approaches or various abstraction levels.

The system is designed to manage many transformed traces but we organize them into two principal levels: the *métier traces* which describe the activity in the operators' language, and the a*nalyzed traces* which describe the activity in the analysts' language. The *analyzed traces* are structured in a succession of states and transition according to the *Musette* model. This allows the analysts to find episodes corresponding to instantiations of tactical schemas.

3.2. Meta knowledge

We use the *Protégé* ontology editor from Stanford University for building the hierarchical definition of all the concepts with their properties. Various trace ontologies are actually managed by the system as different branches of a common ontology which is saved under RDFS format (Resource Description Framework Schema).

Visualization style sheets are defined under the GSS format (Graph Style Sheets) which is recognized by graphviz, the graph display utility that we are using.

Transformation rules are written under the form of Sparql queries. Sparql is a graph querying language that can insert new nodes and arcs connected to matching patterns in the graph. Queries are written in text files which are organized in corpus.

Explained signatures are also written in Sparql. They are said explained because they are associated with schema descriptions corresponding to modeling theories.

4. Application

4.1. Car driver tactical behavior

In the LESCOT, this modeling work concerns car drivers [7]. In this case, the artifact is the car and the task consists of going safely from one point to another. Real driving experiments are run with an instrumented

vehicle which collects information on driver's behavior, on vehicle status and on the road environment.

Among the various psychological concepts listed above, we focus more particularly on the concept of Situation Awareness. This concept is of particular interest for road safety as many bad tactical decisions leading to accidents can be explained within this framework. It also proposes interesting concepts for good design of adaptive assistance systems.

4.2. Métier Trace

Our *collected traces* come from five data sources: (1) video data coming from various cameras placed in the vehicle. (2) Sensor measurements in the vehicle: speed, steering wheel angle, pedal positions, gear position, indicator. (3) Information from the environment obtained through a laser telemeter and a laser scanner coupled with a stereovision camera system. (4) Navigation data from the GPS navigation system. (5) Events triggered by the experimenter according to the experimental protocol.

Observés are extracted from numerical data through signal processing algorithms. These algorithms collect specific points such as local extremums, inflection points and thresholds crossing. Each *observé* has specific properties such as derivate value of the variable or duration of the action.
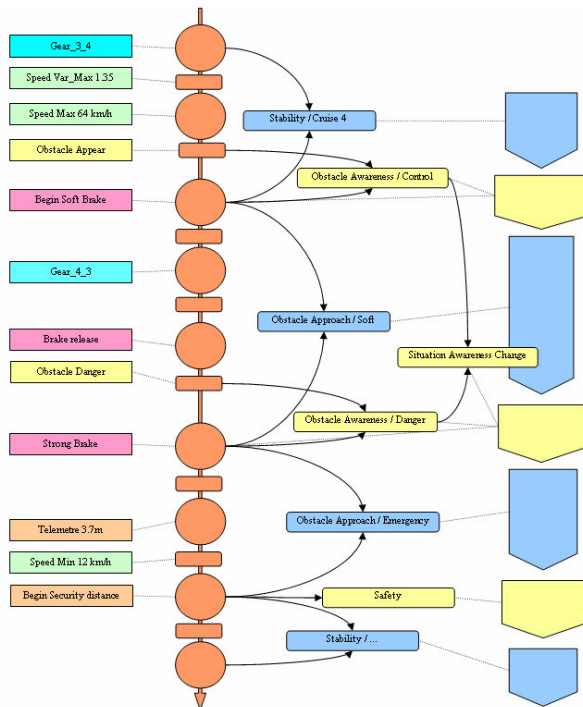

Figure 2 – Driving trace

Figure 2 presents the analysis of a driving sequence lasting about 20 seconds and covering 300 meters. *Observés* of the left-hand column are concepts from the field of driving practice. It is the *métier* level which is inferred from a corresponding *collected trace* of about 170 *observés*. It is seen that the driver shifted to the fourth gear at the sequence beginning ("Gear_3_4") to reach a cruising speed of 64 km/h ("Speed/Max") until an obstacle appeared ("Obstacle_Appear", inferred from the first obstacle detection over the last 5 seconds). She then moved into a gentle braking phase ("Begin_Soft_Brake", inferred from a threshold crossing of brake pedal position) and retrogressed into third gear (Gear_4_3), and then she started to release the brake ("Brake_Release"). But the time to collision fell dangerously ("Obstacle_Danger" inferred from time to collision falling under 2s), she then braked abruptly ("Strong_Brake"). Finally time to collision passed again to infinite and she gently accelerated again after a speed minimum of 12 km/h ("Speed/Min" and "Begin_Security_Distance").

4.3. Analyzed trace

To build the analyzed trace we attach *observés* of the *métier trace* to states and transitions and also to observé defined in the analysis ontology.

This trace gives a description of the activity in terms of driver's subjective interpretation. These assumptions are the kind of work that psychologist are used to doing in the Lescot, with our tool they have the opportunity to formalize it. The result makes a comparison with other available means possible, such as interviews with the driver.

The subject cruises in fourth gear ("Stability/Cruise 4"), and then she becomes aware of the presence of a slow vehicle in front of her ("Obstacle Awareness/control", inferred from the fact that she engaged a deceleration action after the obstacle appears). She begins a phase of gentle deceleration ("Obstacle Approach/Soft") based on the fact that she anticipates an acceleration of the slow vehicle. The configuration of the situation let her infer this anticipation, and let the analyst infer it as well. But her assumption proves to be false. Time to collision ends up becoming dangerous, which she perceives ("Obstacle Awareness/ Danger", inferred from her strong brake reaction) and she begins a phase of emergency deceleration ("Obstacle Approach/ Emergency"). This phase finishes when the two

vehicles are synchronized and when the time to collision increases again to infinite ("Safety" then "Stability"). An indicator of "Situation Awareness change" was possible to infer in that trace.

This analysis highlights a typical schema of situation awareness change, in a situation involving an obstruction. The subject engages an operational schema of emergency braking, and becomes aware (perhaps afterwards) of her evaluation error. The right hand column represents the basic steps of this schema, it is the explanation made by the analyst. *Schema explained signatures* are the association of this level of description with the query allowing the analyst to find their occurrences in the trace.

5. Discussion

Our approach proposes a knowledge based system dedicated to the management of sequential data. It is potentially usable for the analysis of any "piloting" activity of technical artifact. The data is structured into graphs which has the advantage of preserving a link between a low level description and various more abstract higher level descriptions. In this way, abstract concepts remain defined in a formal way by their referents. Moreover, this makes it possible to put in parallel various angles of analysis, for example an approach which focuses on the mental representations of operators with an approach which focuses on their emotional states. Limits of this approach come from the learning effort required to get used to the system. So far, it is used in collaboration between a computer scientist and a psychologist.

The separation in various levels of abstraction does not mean that the low levels do not evolve. They can be stabilized only insofar as the collect tools do not change. Variations of styles between operators may also imply adaptation of inference rules. For these reasons, all the processing levels, from bottom to top, are part of the knowledge discovery process. Our goal is not to mask the low level from the analysts; but rather to facilitate its evolution, by providing functionalities for capitalizing their expertise.

This approach can lead to new paradigms of psychological investigation by supporting interviews of operators including confrontation to a description of what they did and of how it can be interpreted. We should also point out, more philosophically, that it relates to the question of how human beings may develop themselves their own abstract knowledge by reflexively observing the course of their living experience.

6. Conclusion

This work is the result of a close cooperation between a computer science laboratory and a cognitive sciences laboratory for transport. It made it possible to build a tool and to define a methodology for activity analysis which is based on a Trace Based System.

Practically, we are now using this method to continue our work of car driver modeling, and we are still improving the usability of the tool. On the theoretical level, this works connects two different approaches of cognition: a "represetationalist" approach coming from cognitive psychology, with a more "situated" linked to phenomenology. We keep on exploring the issues of this confrontation that we believe to be fruitful.

7. References

[1] M. Minsky, "A Framework for Representing Knowledge", *The Psychology of Computer Vision*, P.H. Winstons,Mc Graw-Hill, New York, 1975, pp. 211-277.

[2] R.C. Schank and R.P. Abelson. *Scripts, plans, goals and understanding*, L. Erlbaum, Hillsdale, N.J., 1977.

[3] M.R. Endsley, "Toward a theory of situation awareness in dynamic systems", *Human Factors*, vol 37 (1), 1995, pp. 32-64.

[4] P.M. Sanderson and C.A. Fisher, "Exploratory sequential data analysis: Foundations", *Human -Computer Interaction*, vol 9, 1994, pp. 251-317.

[5] W. Clancey, "Situated action: A neuropsychological interpretation response to Vera and Simon", *Cognitive Science*, vol 17, 1993, pp. 87-116.

[6] P.-A. Champin, Y. Prié, and A. Mille, "Musette: a framework for Knowledge Capture from Experience". *EGC04*. Clermont-Ferrand, 2004.

[7] T. Bellet and H. Tattegrain-Veste, "A framework for representing driving knowledge", *International journal of cognitive ergonomics*, vol 3 (1), 1999, pp. 37-49.