Cognitive and Emotional Human Models Within a Multi-agent Framework

Lucas Stephane

European Institute of Cognitive Sciences and Engineering (EURISCO International)
4 Avenue Edouard Belin 31400 Toulouse, France
lucas.stephane@eurisco.org

Abstract. In the industrial field, user behavior has been mainly addressed in terms of rational thinking. High-level cognitive processes investigated by Cognitive Engineering are described as logical or rational. We already proposed a cognitive multi-agent model that provides a framework for the peer user-artifact highlighting the roles, responsibilities and resources of each pertinent entity involved in the human-machine hybrid system. This cognitive model was employed for various experiments in the cockpit that assessed Workload and Situation Awareness [10]. Techniques such as Eye Tracking were also used. Definitely, the cognitive model helps to understand user behaviors. However, we noticed behavioral differences between users that are hardly explainable only by the cognitive model. So we started to investigate the non-cognitive aspects of the users that are their emotions. This paper presents the integration of cognitive and emotional models that comprise on one hand users' Situation Awareness and on the other hand users' Self Awareness.

Keywords: Cognitive modeling, Cognitive theories of emotion, Multi-Agent systems, Situation Awareness, Workload, Self Awareness.

1 Introduction

Human knowledge continues to expand day after day in both natural and technical domains. As this knowledge grows, reliable formalisms able to deal with complexity are needed. A good support has been provided by the information technologies. In this field, such formalisms evolved from function based to object based and finally to multi-agent systems. Roughly, the first formalisms rely on data input, data process and data output, like elementary functions in mathematics. The second formalism define entities as objects, each object having a set of methods that operate on its' attributes. The third type of formalism provides a societal or agency structure, using entities called agents. Agents are defined by their roles, responsibilities, resources and goals [4]. This last formalism is suitable for large and complex systems.

We employed a multi-agent formalism for our cognitive engineering purposes, i.e. we specified cognitive agents, and we identified their roles, responsibilities, resources and goals. We used this multi-agent approach as a generic container with the aim to integrate the cognitive theories and methods that we use in the design-evaluation cycle. These methods are the Cognitive Function Analysis *(CFA)* [2], Skills, Rules

D. Harris (Ed.): Engin. Psychol. and Cog. Ergonomics, HCII 2007, LNAI 4562, pp. 609–618, 2007.

Knowledge *(SRK)* [7], Cognitive Compatibility Situation Awareness Rating Technique *(CC-SART)* [11], Situation Awareness Global Assessment Technique *(SAGAT)* [3], NASA Total Load Index *(NASA TLX)* and Modified Cooper-Harper.

Working in the applied research field, our goal is to provide a framework for operational use. This framework may be considered as a modular set of tools that have to be used according to the industrial targets and goals. At the same time, this framework ensures completeness and traceability in space and time, aiming to integrate in the end results obtained possibly independently via each tool in the iterative design-evaluation loop.

The context of use has been studied mainly as external to the user (from physical comfort to Human Machine Interfaces), and Workload and Situation Awareness theories and methods used today have been set up related to this external environment. However, the user model should be investigated also in terms of introspection and internal states that define finally the users' ability to act, that we call here Self Awareness. Taking into account the need to consider emotional aspects of the user [9], we started to investigate theories of emotion that may be used in the industrial field and, as a continuum of an integrated approach, we tried to complete the user model using the same multi-agent formalism. The two emotion theories selected are the Schematic, Propositional, Analogical and Associative Representation Systems (*SPAARS*) [6] and the Self-Regulatory Executive Function (*SREF*) [12]. The first one addresses the relations between cognition and emotion, while the second one addresses the relations between attention and emotion.

We think both Situation Awareness and Self Awareness enable finally decision making and action.

2 Cognition Theories and Models

The rationale of using cognitive approaches in order to understand, design and assess Human Machine Interaction has been largely proved. However, even if these last times several sciences such as neurosciences, information technologies, psychology and philosophy are aggregated under the 'Cognitive' label, the main use of cognition in industry is based on rational thinking, logic, rules and procedures. In this paper, cognition will be used in these last terms. This section presents the set of cognitive theories that we currently use.

2.1 Skills, Rules and Knowledge and Cognitive Compatibility Situation Awareness Rating Technique

A very well known cognitive model is Rassmussen's Skills, Rules and Knowledge [7]. In this model, human behaviors and activities rely on three levels that go bottom-up from automatic behaviors to rule-based and finally to knowledge-based behaviors. The distribution of behaviors to these three levels may change in time, top-down, rules emerging from knowledge and automation emerging finally from rules.

The Cognitive-Compatibility Situation Awareness Rating Technique [11] adapts SRK model to explain and assess Situation Awareness. The three main dimensions of CC-SART are the Level of Processing, the Ease of Reasoning and the Activation of Knowledge. Their direct relation to SRK is illustrated in Table 1 below. These two theories are centered on the understanding of the situation.

Table 1. The three dimensions of CC-SART related to the SRK model

CC-SART	SRK
Level of Processing The degree to which the situation involves natural, automatic, intuitive and associated processing	**Skill-Based Behavior** Activities take place without conscious control as smooth, automated, and highly integrated patterns of behavior.
Ease of Reasoning The degree to which the situation is straightforward and understandable and not confusing and contradictory. It is based on the understanding of the rules or procedures provided to the user and on the degree of affordance inherent to the artifact and/or situation.	**Rule-Based Behavior** A familiar work situation is typically controlled by a stored rule or procedure that may have been derived empirically during previous occasions. The higher level rule-based co-ordination is generally based on explicit know-how, and the rules used can be reported by the person.
Activation of Knowledge The degree to which the situation is recognizable and familiar, or is strange and unusual. The activated knowledge may be related to the domain of use of the artifact, or may be cross-domain and associative, if the situation is new to the user.	**Knowledge-Based Behavior** During unfamiliar situations, faced with an environment for which no know-how or rules for control are available from previous encounters, the control of performance must move to a higher conceptual level, in which performance is goal-controlled and knowledge-based.

2.2 Situation Awareness Global Assessment Technique

In order to behave appropriately, the user has not only to perceive information that enable to understand the current situation, but also to anticipate the evolution of the situation related to his own actions on the artifact, as well as to the context influence or impact on the artifact (i.e. wind impact on the plane trajectory). Thus, in SAGAT [3], Situation Awareness is declined on three levels – perception, understanding and projection – that are linked to the active goal and dynamically regulated by the Mental Models of the user.

Mental Models [2], [3], [6], are defined as representations of past experiences used in a predictive way. A Mental Model is generic. A Mental Model is the representation of the artifact features and contextual events and states that enable the user to mentally try out actions before executing them. The operative structure of the artifact is built as an operative mental mode or image [2].

A schema is an instance of a Mental Model for a specific system and situation. Schema [3], [6] are packets of knowledge, tuned by experience.

2.3 Cognitive Function Analysis

Cognitive Function Analysis [2] is an integrated task analysis method that tightly ties the user, the task, the artifact and the organizational environment. The role of a cognitive function or of a set of cognitive functions is to transform a prescribed task into effective activity. A Cognitive Function has a role, a context and a set of resources. Thus, Cognitive Functions have a teleological definition, i.e. the function of the eye is to see, rather than a mathematical definition. As such, Cognitive Functions are considered as agents. CFA provides powerful methods to describe and assess the context and the situation – context patterns and situation patterns; perceived versus desired situation –, the differences between novices and experts – the Situation Recognition and Analytical Reasoning model (*SRAR*) model –, as well as the Human Machine Interaction. For this purpose, Interaction Blocks are defined by triggering preconditions, action, context pattern, abnormal conditions and goal. CFA focus the automation issues, and provides solutions for the transfer and balancing of Cognitive Functions between the user and the system. Concerning the organizational environment, CFA proposes the Active Design Documents (*ADD*) that insure traceability through the various iterations of the Human Centered Design process. Active Design Documents are chunks of technical documentation defined by interaction descriptors, interface objects and contextual links. Each ADD contains four sections that are the Design Rationale, the Task, the Artifact (or prototype) and the Evaluation.

3 Emotion Theories

Since a long time, several psychological theories dealt with human emotions [8]. Meanwhile, as long as they have not been validated with scientific arguments, they have not been considered in the engineering field. But since the mid 90s when the neurosciences brought serious evidence for emotional circuits [5], there is a renewal of interest in investigating emotions and the way they impact on human activity. For the consumer products for example, a new domain called Kansei Engineering (Kansei means ‘total emotion’ in Japanese [9]) provides systematic methods to design and assess the emotional impact of the product on users and on their decision to acquire or use the given product. However, in safety-critical domains, we need to investigate emotions deeper, and especially how emotion and cognition interrelate. In this section we define emotions, expose their rationale in the industrial field, and finally we propose two theories of emotion that might be used to complete the user model defined only in cognitive terms.

3.1 Emotion Definition

The word emotion comes from Latin *motere* that means movement. Thus emotion is immediately linked to action, and each basic or fundamental emotion has a vital role (function). There are different limited definitions of emotion, depending on the field of investigation [8]. Affective states are considered as the superset of emotions, feelings and humors. As a *state*, an emotion has a precise start, is linked to a specific object and has a given duration. The emotional *process* is the sequence of several emotional states. Emotions are characterized by physiologic activations, and the awareness of her (his) own physiologic changes becomes a cognitive stimulus for the subject. According to Ekman [8], a fundamental emotion has a universal and distinctive signal, is common to other primates than the humans, has a specific template of physiologic reactions, is associated to universal and specific triggering events, is fast detected, has a short life cycle, is appraised automatically and appears spontaneously. Panskepp [8] takes into account the neurophysiologic aspects of fundamental emotions. Thus, fundamental emotions rely on sensory-motor command circuits that are structured according to the circumstances and that are critical for the actions fundamental to survive. Located in the di-encephalic and in the limbic systems, these circuits coordinate behavioral reactions, autonomous and hormonal processes and subjective states or moods.

3.2 Rationale of Studying Emotions

Emotions may contribute to explain the differences between the prescribed task and the real activity. For the visual channel, emotion modeling could be directly linked to Situation Awareness. Emotion models contribute to better interpret physiological data such as heart rate that is currently an indicator of workload.

Together with a Swiss military pilot working at Eurisco, we identified several topics of the human factors domain where emotions might be taken into account:

- *Relationship User – System*: the emotional state of the subject depends on the degree of visibility and context understanding; emotions express also the degree of trust and security offered by the system, and are crucial in situations such as system failures and malfunctions
- *Graphical User Interface Design*: identification and implementation of invariable items, whatever the users' emotional state; assess user emotions when facing virtual versus real world scenes, i.e. simulators versus real situations; implement functions that appease the user
- *Training*: identification of emotions and comparison of experts and novices; investigate anxiety and risk correlated to expertise; implementation of risk management tools
- *Team collaboration*: identify the role of emotions in non-verbal communication, i.e. face expressions, gestures; analysis of co-worker expressed emotions as triggers for information gathering on the user interface; identification of non-verbal communication, i.e. gestures and facial expressions, intra-team patterns related to the context, i.e. extreme conditions versus normal conditions; comparison of information gathering on the co-worker(s) and on the system

The next step was to find theories of emotion that may be adapted to the industrial research, and furthermore integrated with the cognitive theories and methods already used. Two theories developed in the cognitive therapy field retained our interest. The first one focuses the relationships between cognition and emotion, and the second one focuses the relationships between attention and emotion.

3.3 Schematic, Propositional, Analogical and Associative Representation Systems *(SPAARS)*

SPAARS [6] uses four levels of representation. The first level is the analogical one that includes the sensory-specific systems: visual, auditory, tactile, proprioceptive and olfactory. The output of the analogical processing is sent to three semantic representation levels that work in parallel (Figure 1).

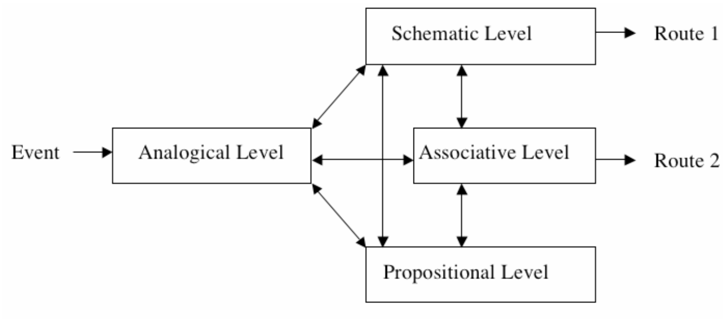

Fig. 1. The four representation levels of SPAARS

The lower one, fully automated, is associative (Route 2). Automatization of emotions within SPAARS occurs during cycles of appraisal at the highest level (hereafter) with the repetition of event-emotion combinations. Once automated, emotions are difficult to modify and happen invariantly in the presence of the triggering event. The intermediate level is propositional. This propositional language-like representation does not propose a direct route from proposition to emotion, but is linked either through appraisals to the highest schematic level (hereafter), either directly through the associative route, i.e. particular words directly linked to emotion such as swear words. The highest level is schematic and corresponds to the Mental Model representation. In relation to emotion, this level is very important because at this level occurs the generation of emotion through the process of interpretation and appraisal of any relevant input, of external or internal origin (Route 1).

SPAARS emphasize the roles, goals and plans of individuals related to the cycles of appraisal. The extent to which an individual experiences emotions depends considerably on the degree of appropriation of roles, on the degree of feasibility of plans and on the conditions of goal achievement. Basic emotions are considered as modules and they can be coupled together. Complex emotions as well as emotional 'disorders' are derived from the same basic emotion set. In SPAARS, the individual is not only aware of his own emotional state, but also aware of his own action potential (Figure 2).

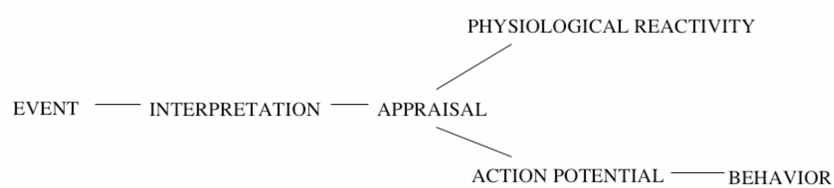

Fig. 2. Appraisal Cycle in SPAARS

3.4 Self-Regulatory Executive Function (*SREF*)

SREF [12] is an integrative model of cognitive-attentional processing which predisposes to emotional distress. The model proposes three levels. In the automated lower level, the elementary processing units are activation-driven, and the resources are domain specific. Processing is unconscious.

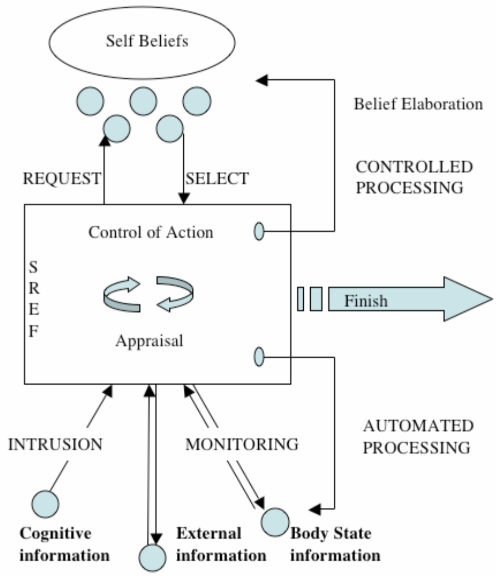

Fig. 3. SREF model

Three types of information can be represented at this level: (1) external stimulus information; (2) cognitive state information; (3) body state information. The second level corresponds to conscious appraisal and regulation of action. The third level consists of acquired knowledge about the self and strategies for self-regulation stored in the long-term memory. SREF performs the appraisal of lower-level information and regulates the action in order to reduce self-discrepancies and perceived threats to the self. The processing is influenced by self-beliefs that impact on both appraisals and strategies.

Top-down, SREF is triggered by conscious strategies and bottom-up by the intrusion of thoughts, sensations and external information into consciousness. Following the intrusion, the significance is appraised and plans of self-regulation are used. Expectancies concerning the ability to succeed depend on situation appraisal and on self-beliefs, and determine the selection of action. Monitoring is centered on self-relevant low-level information.

SREF has been used to explain the impact of negative emotions, i.e. anxiety, on the selective attention according to a plan or strategy to achieve a specific goal. If the goal is not achieved successfully, then in some cases negative beliefs may intrude either at the automated level of processing, either at the controlled level. There is an impact of negative beliefs if SREF is activated with time-sharing between the plans to achieve the goal and the self-regulative plans. Furthermore, strategies of hypervigilance for threat that increase monitoring or active search for threat may be adopted. Self beliefs have also been mentioned as important in the operational field [1].

4 Integration

The effort of integration is motivated by the structural similarity of the theories presented above. All of them propose several levels, with the distinction between automated processing and controlled processing. All of them deal with goals, and the concepts of Mental Models or Schema are also present in most of them, either defined as such, either defined as cognitive processes. It is interesting to notice that the theories of emotion emphasize clearly the final output as a concrete behavior or action, while the cognitive theories emphasize more on the description of cognitive processes.

Figure 4. illustrates an attempt to put together most of the theories presented above. The bottom-left part under the Self Awareness Situation Awareness dot-line shows the SAGAT model of Situation Awareness, while the top-right part above the Self Awareness Situation Awareness dot-line shows the SREF model of Self Awareness. Labels corresponding to the levels of SRK and SPAARS appear related to their equivalents proposed in the other models. Outputs of the SAGAT model have been connected to inputs of SREF, and the output action of SREF loops back to the SAGAT goal.

In order to keep a neutral unifier for all these theories, we propose as in previous studies multi-agent systems as a flexible and modular structure. Indeed, we find in the Belief, Desire and Intentions (*BDI*) [4] model most of the concepts used in the cognitive and emotion theories.

Beliefs contain the informational state and are only required to provide information on the likely state of the environment. Desires refer to the motivational state, and Intentions refer to the deliberative state.

There are two models in the external viewpoint of BDI: the Agent Model that defines and creates instances of agents and the Interaction Model that defines the interaction and communication between the agents.

There are three models in the internal viewpoint of BDI: the Belief Model that describes the information about the environment and internal state that an agent may hold, and the actions it may perform; the Goal Model that describes the goals that an agent may possibly adopt and the events to which it can respond; the Plan Model that describes the plans that an agent may possibly employ to achieve its goals.

A BDI agent can be completely specified by the events it can perceive, the actions it may perform, the beliefs it may hold, the goals it may adopt, the plans that give rise to its intentions.

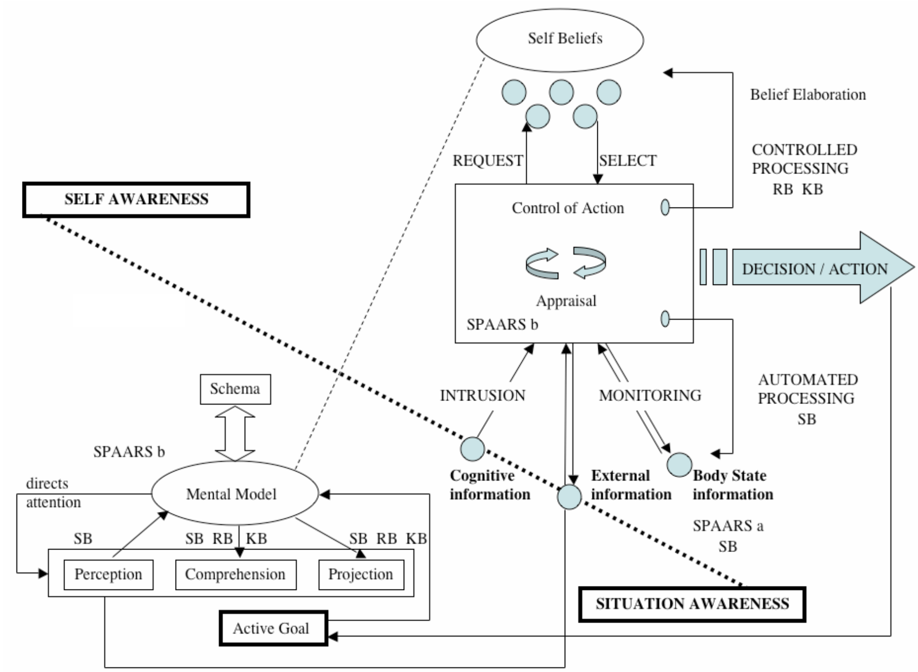

Fig. 4. Situation Awareness and Self Awareness based on SAGAT and SREF diagrams; the other theories are represented by labels: *SB*, *RB*, *KB* stand for Skill Based, Rule Based and Knowledge Based levels; *SPAARS a* stands for the associative level and *SPAARS b* for the Schema level

5 Discussion and Conclusions

The integration effort has to be continued in order to obtain a complete and coherent theory that can provide solutions to assess Workload, Situation Awareness and Self Awareness (emotions). In the end it would be easier to use one theory than a patchwork.

However, in the current state of practice there is still a need to use methods individually, and not necessarily to mix all of them, according to the actual certification documents used by industrials.

The integration is purposeful especially for the design phase as well as for the result analysis step in the evaluation phase, when data and results from different methods have to be correlated. Operational tools for emotion assessment in safety critical industry have to be built and tested.

Self Awareness may profitably contribute to better understand user behaviors, and to finally systematically address emotions in safety critical systems [1].

References

1. Beaty, D.: The naked Pilot. Airlife Publishing Ltd, England (1995)
2. Boy, G.A.: Cognitive Function Analysis. Ablex. Distributed. Greenwood Publishing, Westport (1998)
3. Endsley, M.R.: Designing for situation awareness; An approach to User-Centered Design. Taylor & Francis, London (2003)
4. Kinny, D.: Georgeff, M.: Modeling and Design of Multi-Agent Systems. Technical Note 59. Australian Artificial Intelligence Institute (1996)
5. Lane, R.D., Nadel, L. (eds.): Cognitive Neuroscience of Emotion. Oxford University Press, New York (2000)
6. Power, M., Dalgleish, T.: Cognition and Emotion. From order to disorder. Psychology Press. Taylor & Francis, Hove and New York (1997)
7. Rasmussen, J.: Skills, rules, knowledge: Signals, signs, and symbols and other distinctions in human performance models. IEEE Trans. Syst., Man, Cybern. SMC-13, 257–267 (1983)
8. Richelle, M., Requin, J., Robert, M. (eds.): Traité de Psychologie Expérimentale. vol. 2 (chapitre IV), Presses Universitaires de France, Paris, pp. 3–78 (1994)
9. Schütte, S., Eklund, J.: Product Design for Heart and Soul. An introduction to Kansei Engineering Methodology. Linköpings Universitet, Department for Human Systems Engineering, Uni Tryck Linköping, Sweden (2003)
10. Stephane, L., Boy, G.A.: A Cross-Fertilized Evaluation Method based on visual Patterns and Cognitive Functions. vol. 1 - Engineering Psychology, Health and Computer System Design. HCI International 2005, July 22-27, Las Vegas, NV USA. MIRA Digital Publishing (2005)
11. Taylor, R.M., Finnie, S.E., MacLeod, I.: Enhancing Situational Awareness Through System Cognitive Quality. Defence Research Agency, Farnborough, Hampshire (1996)
12. Wells, A., Matthews, G.: Attention and Emotion. A clinical perspective. Psychology Press. Taylor & Francis, Hove UK (1994)