Validation of Cognitive Architectures by Use Cases

Examplified with the Psychoanalytically-Inspired ARS Model Implementation

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***Abstract*—Evaluation and validation of software architectures in cognitive science often lack objective evaluation criteria and test mechanisms. Hence, in this article we present an in-house developed use case to evaluate the cognitive architecture ARS, together with its psychoanalytically-inspired functionalities. The use case was developed by a team of psychoanalysts and comprehends human's behavior patterns in a competitive situation. We describe the preconditions, the development, and the setting of the use case, followed by the results and screenshots to document the dataflow within the modules. Different outcomes of the use case depending on the variation of personality parameters of the ARS system play a pivotal role. Furthermore, we provide a general description of the ARS system, of the top-down development process, and of the psychoanalytic theory behind it. We give insight into functionalities of ARS like the decision making process and the association of objects. Finally, we evaluate these functionalities by implementing and simulating the developed use case.**

Keywords—cognitive science; cognitive automation; artificial general intelligence; software agents; evaluation criteria; use case; psychoanalysis; personality parameters

I. Introduction

Among the various architectures in cognitive science only few provide evaluation documentations and/or test scenarios to evaluate the functionalities and to verify the usability of the implemented cognitive system. Moreover, there are no standardized tools or standardized criteria to compare different cognitive architectures. Tournaments like [1] or [2] where artificial intelligent systems can compete with each other to succeed in a certain task or goal only cover a small range of cognitive abilities.

In the work at hand, we provide a use case scenario and different desired outcomes of the scenario to evaluate the psychoanalytically-inspired functionalities of the cognitive system ARS (Artificial Recognition System) [3]. In principle, with minor adaptions, the use case can be applied to any other artificial intelligent system that simulates human behavior in competitive social situations like, for example, the search for nutrition.

Performance measures concerning time constraints are not covered by the use case we provide. In general, time analysis is not subject of the present article. Time constraints are neglected in the described use case and in the resulting evaluation. Rather, the evaluation of proper functionality and fulfillment of the desired tasks in the simulation environment are subject of the introduced use case. In addition to past use cases [4], [5], and [6], the present use case evaluates certain psychoanalytically-inspired functionalities, provides insight into the inner dataflow of the system, and shows the state of emotions and drives over time.

In Section II we give an overview of evaluation and test scenarios in other cognitive science projects which have implemented social behavior or implemented psychoanalytic notions. In Section III we describe in short the principles of the ARS cognitive architecture and the basic functionalities of the ARS system. Section IV introduces the use case, while Section V describes some key functionalities required to run that use case. In Section VI we present results and charts of the simulated scenario. Finally, we give a short outlook on future developments in evaluation tools.

II. State of the Art

As of today, different projects exist where the behavior of software agents for specific tasks is evaluated with the help of a predefined scenario. Other articles compare different architectures of software agent systems by using focused comparison criteria for a small domain like the interaction of agents [7], knowledge processing [8], or fault handling [9].

As stated above, fault handling in multi-agent systems is the topic in Dellarocas' project dating back to the year 2000 [9]. In this project, Dellarocas and Klein evaluate the exception handling capabilities of self-developed services for the Contract Net[1] multi-agent coordination protocol.

A different perspective of a multi-agent scenario description is shown by [10]. There, Billard proposes Use Case Maps[2] to describe scenarios in multi-agent systems. Use Case Maps provide abstract descriptions of complex systems and can, therefore, be used to describe multi-agent systems. Use Case Maps are a good tool to describe multi-agent scenarios which can then be used to run system tests.

In [7] evaluation criteria for multi-agent systems concerning their interaction are described. The scenario is about agents that communicate while they search pieces of ore in a certain environment. In their article, Joumaa, Demateau,

[1] Contract Net is a protocol to coordinate tasks in a multi-agent system. It was developed by R. G. Smith in 1980.

[2] Use Case Maps are a graphical way to describe scenarios in complex systems by keeping a high level of abstraction.

and Vincent count the weighted messages sent between agents while collecting pieces of ore. As weight they define an importance of the message for the agent.

A comparison of multi-agent systems producing knowledge management under the aspect of the knowledge life cycle process is given in [8]. The knowledge life cycle process is generating, storing, transferring, and reusing knowledge. Miled et al. compare nine architectures by using different properties of multi-agent systems which are compared. The properties are, for example, the underlying model, the type of knowledge they store, and the means to store knowledge.

We conclude this section with a positioning of the ARS architecture among other cognitive architectures. In general, cognitive architectures are divided into cognitivist, connectionist, and hybrid architectures [11], [12]. Concerning the ARS architecture, the top-down structure with complete symbolic data structures represents the cognitivist part of ARS. But on the other hand with the need of embodiment we classify ARS as a hybrid model. According to the criteria of [13] ARS is a ca. 80% cognitivist and 20% connectionist cognitive architecture.

Other architectures which can be compared to ARS are, for example, SOAR [14], BDI [15], and LIDA [16]. Compared to the related architectures, due to the focus on the theory of psychoanalysis, the focus of the ARS model so far is put on the motivational part of the model with its foundation in the embodiment of the agent. This part has its equivalences in the Desires of the BDI architecture [15] and in the drives in LIDA [16].

III. Artificial Recognition System

The original intention behind ARS was to develop an agent for building automation, which is able to perceive a huge number of sensor data, activate associated symbols in order to recognize a certain situation and to act on it according to known knowledge about the situation [17]. A bionic solution was searched for in order to provide human-like abilities for recognition.

The theoretical base of the ARS model and a possible solution of that problem were originally provided by the neurologist A. R. Lurija [18], who defined a three layered hierarchical model of the brain. The lowest layer, in ARS the *neural layer* contains the hardware of the system, the neurons. In the next layer, in ARS called the *neuro-symbolic layer*, the sensor data is translated into symbols and, vice-versa, action symbols are translated into neural signals. The symbolic data is then processed by the third layer in ARS, the *mental layer*. In Fig 1, those layers are shown from the left to the right. The most left block, the "sensors and neural nets, actuators" forms the *neural layer.* The *neuro-symbolic layer* is located in the middle in "neuro(de-)symbolization. Finally, all blocks to the right are in the *mental layer*.

The theory of the third layer is provided by the theory of psychoanalysis as defined by S. Freud in the early 20th century [19]. Psychoanalysis is one approach, which can explain several human behaviors and, as it is a top-down as well as a functional approach to the functionalities of the human psyche, is well suited for use in computer engineering. The top-down approach distinguishes it from many other psychological theories [17]. The ARS model based on psychoanalysis provides a model with defined modules and functions. Instead of describing complex competing behavior, this model describes the functions behind observable behaviors.

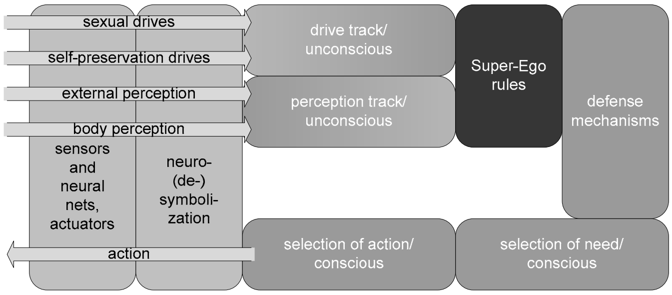

Figure 1 The ARS Model

Currently, the ARS model only applies on the *mental layer*. Following a top-down approach, first the interface of the mental layer is defined properly, then the other layers will be completely developed.

In the following, the mental layer of the ARS model will be briefly explained. The description of the mental layer can be split into levels. On the highest level, there is the complete mental apparatus. Its inputs are symbols of the current state of the homeostasis, which generates the *sexual drives* and the *self-preservation drives*, as shown in Fig. 1 on the far left side of the picture. A *drive* is the motivation of the agent to do something in the world, in order to fulfill its bodily needs. They originate in the unbalance of body states of the agent. An example is if the blood sugar is low, hunger is a need to be satisfied. The body internal sensors generate symbols and the external perception provides the agent with information about its environment. The output of the model are action commands.

On the next level, the mental apparatus can be divided into three instances: the *Id*, the *Ego* and the *Super-Ego*. The *Id* is representing unconscious bodily needs and desires, seen in the upper track in Fig. 1. The Super-Ego represents internalized bids and bans and depending on a situational trigger it is either punishing or rewarding the individual. The Super-Ego is located in the upper middle box in Fig. 1. The main task of the *Ego* is to negotiate between the other instances, in order to keep the individual capable of acting. The different functional units in the model are assigned to one of the three instances. Another aspect of the model is the concept of unconscious processing in the so-called *primary process* and preconscious/conscious processing in the *secondary process*. Processing in the *primary process* obeys the following rules: only two types of associations are allowed, associations between objects, which occur simultaneously and associations between similar objects. An object is either an entity like a food source or a situation. An important consequence of those rules is that no temporal or contextual structures (episodes, situational context) can be handled, only their fragments as independent units. Further, *primary process'* data structures are sensor-related symbolic data, different to the word-like data structures of the *secondary process*. In the *secondary process*, new data structures are added to the sensor-related data, which allows logical processing. Different to the *primary process*, the *secondary process* allows considering the reality, e. g. by considering the temporal order of situations or the effort of reaching a certain goal.

In the next level, the three instances of the psyche are divided into multiple modules, according to Fig. 1. The *drives* (sexual and self-preservation) are mainly separated from the perception (bodily and external). However, the *drives* may influence the perception, for instance, the current drive state influences, how entities are perceived. For instance, if the hunger drive is high, eatable entities are preferred in the perception. In the other way, perception does not have any influence on the *drives*. The inputs from the *drives* are processed by adding possible drive goals, i.e. entities, which are able to fulfill the drive. For instance, hunger, which is a bodily need, is satsified with a food resource. As the drive state is independent of the perception, the possible drive goals are chosen without considering any environmental or conceptual situations (unconscious processing by the *Id*).

In the perception part, all entities, which are perceived and matched with the internal representation of those entities within a small time frame form a *perceived image*. The *perceived image* is used to activate other *stored images*, memories, which are snapshots of already experienced situations. Attached to those activated situations are *emotions*, which are used to evaluate a certain situation. For instance, a negative *emotion* attached to a *stored image* could be used to avoid such situation. As the *stored image* was activated by perception, it may have a relevance to the current situation.

In the *defense mechanisms*, the drive state and the perception, including activated memories, are manipulated according to rules, which are defined in the *Super-Eo*. In general, the *defense mechanisms* have the function of a filter between the *primary* and the *secondary process*. In the next chapter, the functionality of the *defense mechanisms* is demonstrated.

After the *primary process* and manipulation by the *defense mechanisms*, the *drives* and *emotions* from the *stored images* are converted into *goals*. A *goal* is something that has a subjective meaning for the agent. It can be either pursued or avoided. After processing of the currently available *goals* regarding the relation to the reality (by the *Ego*), the decision is taken, which *goal* should be followed. This is a two-step process, where the first step is to decide about which *drive* shall be fulfilled or which *emotion* should be reacted at. In a second step in the planning (in the lower middle part of Fig. 1) all possible available *goals*, which could fulfill the *drive* or *emotion*, are associated with possible action plans of how to reach them. After evaluation, one of the goals with its associated action plan is selected and executed.

IV. USE CASE DESCRIPTION

With the expertise of psychoanalyst a use case is developed that considers basic human cognitive processes. The use case at hand describes a simplified agent-object interaction. It is used to evaluate basic cognitive processes in the ARS agent. The pre-conditions of the use case are described by the simulation's initial situation, which is given by a simulated world with Adam, the agent with the cognitive architecture, Bodo, a passive agent, and a food source (i.e. Wiener Schnitzel). In the initial situation Adam does not perceive any world objects and Adam's motivational state is dominated by aggressive drives.

The most important goals of the presented use case are:

- Usage of drives to motivate behavior
- Activation and association of memories
- Valuation of objects
- Dealing with inner-psychic conflicts between the agent's needs and Super-Ego rules (i.e. prohibitions)

For the evaluation of the use case we check if and how these goals are reached. Thereby we also check if psychoanalytic rules are considered in reaching the goals. Different scenarios show how Adam's behavior, and particularly its inner state, fulfills the use case's goals. Due to lack of space in this paper, we focus on one of these scenarios: Adam is motivated by its drives to search for food that would satisfy – according to its memory – its actual drives. After perceiving a Wiener Schnitzel Adam values the perceived object based on its memories as a proper object to satisfy its needs. While approaching the food source, Adam perceives Bodo and activates associated memories. Dependent on the memories that are associated with Bodo and the activated Super-Ego rules, different decisions and actions of Adam are considered. As mentioned above, in this paper we focus on a specific scenario. In this case Adam activates memories that are associated with its brother, who is associated with Bodo due to their similar appearance. This leads, together with Adam's actual domination of aggressive drives, to the generation of the emotions fear and anger. Because of the Super-Ego's prohibition of aggression and anger an inner-psychic conflict occurs, which is handled by a defense mechanism that mediates between the claims of the Id (i.e. satisfaction of bodily needs) and the Super-Ego's prohibitions.

V. KEY FUNCTIONS

After presenting the use case, in this chapter some key functions that lead to the presented scenario are described. An analysis of the use case leads to the identification of requirements, which are satisfied by the conceptualization and implementation of various functions. The focus lies on the functions of the primary process. The most important functions for the achievement of the use case's goals are described next. In particular the use case requires functions that generate drives, activate memories, value perceived objects and provide defense mechanism. The need for these functions also emphasizes the significance of bodily needs and memories in a psychoanalytic inspired agent.

A. Drive generation

The generation of drives represents the central part of the agent's motivational system, which is used as a basis for the agent's decisions and actions. The concept of drives represents the influence of the body on the mental apparatus, i.e. the embodiment of the ARS agent. As already mentioned, a drive is the psychic representation of a bodily need. It comprises a drive source, a drive object and a drive aim. The drive source is the organ which signals the bodily need, e.g. the stomach. The drive is quantified according to the tension in the according organ, which leads to the drive's quota of affect. The drive aim represents the satisfaction of the drive by an act; the drive object is the object used in this act. The drive object and –aim are determined by the activation of appropriate experience. According to psychoanalysis this process is called hallucinatory wish fulfillment and comprises the search for possibilities to satisfy the drive, i.e. appropriate memorized drive objects and drive aims. Following the pleasure principle, the drive is then associated to the memorized drive object and -aim with the highest quota of affect, i.e. the drive object and –aim that would provide the highest pleasure for the agent. Nevertheless, all potential drive objects and –aims that would satisfy the drive are still associated to the drive for possible further exchange. In further processing the drive aim and -

object is used as a part of the agent's decision making and planning.

B. *Drive object categorization*

A key aspect of the described use case is the perception and valuation of world objects, particularly the perception of Bodo and the Wiener Schnitzel. Following a psychoanalytic approach, which induces a subjective approach to cognitive modeling, the primary goal of perception is the support of fulfilling the agent's needs, which are represented as drives. In this regard, in a first step, the agent categorizes all stimuli, i.e. perceived objects, regarding their suitability as drive objects. Such perceptual categorization comprises the determination of *graded category membership*. Due to the consideration of multiple drives, multiple category membership is considered. The result of such perceptual categorization is the valuation of perceived objects as potential drive objects. Thus it is called *drive object categorization* [20]. That is a goal-oriented and functional approach to perceptual categorization, with the result of determining the effects of perceived objects on the agent's needs and how the agent may interact with them to utilize these effects. To give an example: When the agent perceives a Wiener Schnitzel, it categorizes the object – according to its memory – as an drive object that satisfies the agent's hunger drives and oral sexual drive (see Figure 2).

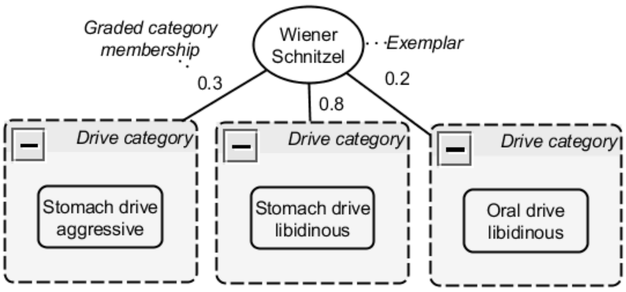

Figure 2 Valuation of a Wiener Schnitzel

Following psychoanalytic rules, an exemplar model [21] is the most appropriate categorization model in the ARS primary process and hence is used to implement perceptual categorization for the valuation of perceived objects. That is, the agent harnesses its concrete memories, i.e. exemplars, to use its experience for the valuation of objects. The usage of associative data structures in the ARS agent [22] enables the directed activation of memorized exemplars [20] (see Figure 3). This approach uses the activation sources as point of departure for directed memory retrieval and comprises the activation of those exemplars, whose drive categories are appropriate to use for the categorization of the stimulus. The appropriateness of activated exemplars is determined by using different categorization criteria, which are integrated into the exemplar model. The most significant criterion is the similarity of an exemplar to the stimulus.

After evaluating the perceived objects the agent is able to decide if the perceived objects are able to satisfy its drives and to which degree. Additionally Adam is able to prefer the object that would satisfy its actual drives best.

C. *Defense mechanisms*

Defense mechanisms are tools for the Ego to resolve conflicts between drive wishes of the Id and internalized rules of the Super-Ego (see also Section III). In the provided use case the defense mechanisms repression is validated as follows: In the use case, the agent Adam feels the drive-wish hunger and perceives a nutrition source. But at the same time Adam perceives the second agent Bodo. Adam has an internalized Super-Ego rule which says: "Avoid a fight with another agent!" The conflict in Adam is now: I am hungry, I see the nutrition source but if I grab the nutrition, a fight for the nutrition may be provoked. If the level of hunger is low, Adam's Ego solves the conflict by using the defense mechanism repression and Adam represses the hunger.

If the intensity of hunger increases over time a different outcome of the situation is triggered: Adam does no longer repress the drive-wish hunger and this time the Id wins and Adam grabs the nutrition.This way, different outcomes of the use case and various parts of the functionalities of the defense mechanisms can be tested.

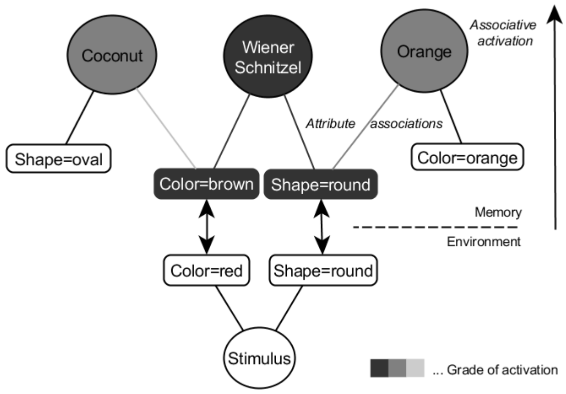

Figure 3 Activation of associative data structures

VI. IMPLEMENTATION

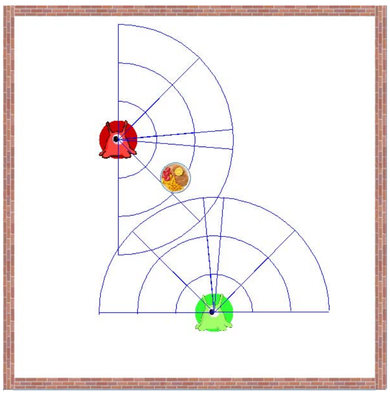

Figure 4 Starting situation of the use case

For the implementation of the ARS model, a multi agent simulation has been developed. Java has been selected as the programming language. The preferred development environment is Eclipse, however, alternatively NetBeans can be utilized. Version control is enforced by the use of Git (i.e. the eGit plugin for Eclipse). The whole system runs under Windows, Ubuntu Linux, and Mac OS. MASON and its simple 2D physics engine have been selected as the multi agent simulator. The code has been divided in packages for the simulated world, the agent's body, and the agent's mind, in order to allow different combinations of implementations as well as different applications in future. For instance, next to MASON, we implemented agents using the ARS mind into the Unreal Tournament 2004 engine, using Pogamut as Java interface. The agents and the world have been taken from the game, but control of the agent is taken over by the ARS model. Another application will be Aldebaran's Romeo, which has been purchased by our university. Romeo and its better known "smaller brother" NAO can be fully simulated in ROS, a great advantage on the path to a real application.

All ca. 40 modules of the ARS model have been implemented, resembling top-down level 1 of our model. Additionally, the other levels of the top-down design have been considered, such that each function from level 1 calls the respective functions in level 2, 3, etc. and sends its data. That way every level of the top-down design can be debugged independently. However, for this article level 1 is of primary interest, thus, only it will be considered in further descriptions.

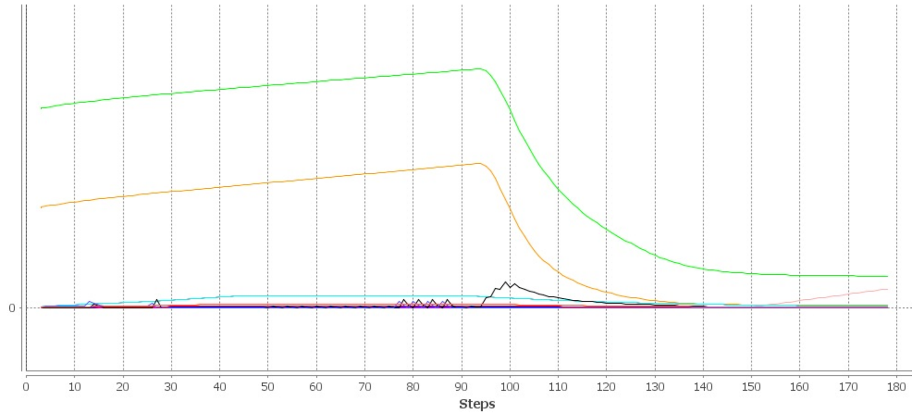

Figure 5 Adam's pleasure and unpleasure (partial drives) during Use Case 1. Initially, hunger dominates (aggressive component in green, libidinous in orange). From step 75 (Adam localized the Schnitzel) on, pleasure is sometimes added in the form of anticipation (black). From around step 95 Adam is eating the Schnitzel, whereby simultaneously great pleasure emerges and both parts of hunger are reduced. After some time the food is digested and the drive for excretion emerges (aggressive in pink, libidinous in brown, from step 160). The trinagles in violet show the drive exhaustion that rises during walking. The other colors are used for the partial sexual drives, which are however assumed to be low.

Fig 4 shows the starting conditions of the aforementioned use case in our simulator. It shows two agents, Adam in green, and Bodo in red, a food source between them (Wiener Schnitzel), and walls surrounding the scene. The blue circular segments next to the agents indicate the resolution of their field of sight in terms of distance and angle. For instance, Bodo sees the Schnitzel half right in middle distance. As agents move closer to objects, the objects get into the small area "in front" of the agents, where they can better focus on the object.

For comprehending the course of the use case, a number of tools had to be developed, our so-called inspectors. Each function within the ARS model was equipped with one inspector. An inspector is able to show inputs and outputs as well as inner states. The presentation comes in different forms, either text or graphical: line, bar, or net diagrams or trees. For the use case two inspectors are needed to show the results of the use case, the one showing drives and the one showing emotions.

The inspector showing partial drives is depicted in Fig. 5. It shows all 16 partial drives (which are implemented at the moment) as well as pleasure (that arises when drive tension can be released). The partial drives are divided in four self-preservation and four sexual drives, each of which consists of a libidinous and an aggressive component. The partial sexual drives are named after the psychosexual development phases: oral, anal, phallic and genital. The sum of all partial sexual drive (tensions) is the libido. The four bodily needs that trigger self-preservation drives are ingestion, excretion, stamina, and physical integrity. The respective drives (i.e. unwanted states) are hunger, rectal drive (fecal stasis), exhaustion, and injury.

In the following, the simplest alternative of the use case is presented. Here, Adam does not associate negative emotions with Bodo (in contrast to the description above). This means that hunger is the dominant perception for Adam, leading to no inner conflict when he eats the Schnitzel right in front of Bodo. Additionally, since there is no inner conflict, no defense mechanism is triggered. Altogether, we defined eight alternative courses for the use case dependent on the personality parameters of Adam at the moment. However, for reasons of space only the simplest is presented.

For the use case we assume that libido is low compared to the self-preservation drives and thus plays no role in the further descriptions. The agent is initialized with mediocre hunger, of which the aggressive part (green in Fig 5) is, based on the agent's personality, stronger than the libidinous part (orange). Adam needs the first steps of the simulation for orienting himself, since there are no landmarks in sight. After he doesn't find some, even after turning around he starts walking ahead (after step 75; can be seen in the figure based on the rising of exhaustion, printed in violet). After short time he perceives the Schnitzel, which triggers anticipation, a form of pleasure (printed in black). Adam needs 15 steps to get himself close enough to the Schnitzel to be able to bite off it. After starting to do so, his hunger drops and simultaneously he feels great pleasure, much more than compared to mere anticipation. After some time of digestion, the rectal drives increase. The implications for Adam's emotions are depicted in Fig. 6. Not only is the constellation of drives determining the emotions, but also perception. All perceived objects are associated with memories, whereby they are associated twofold, the object alone in terms of drive satisfaction, and several objects in combination, representing a situational context. Objects are rated regarding their ability to satisfy the various partial drives (in so-called quota of affects per partial drive), which represents a potential for pleasure gain. For instance the Schnitzel is able to satisfy three partial drives, viz. the libidinous and aggressive parts of hunger and the oral sexual drive. Situations are rated more abstract in terms of emotions. During the association with memories a spreading activation approach is utilized that associates additional memories along weighted connections, until a threshold is reached. Both, objects' quota of affects and situations' memorized emotions are used to compute the overall emotional state of the agent together with the drives' quota of affects. Not all possible emotions are present at every time, but dominant emotions are derived and then computed. In the case of the presented use case, anger is dominant for the beginning, induced by the high aggressive drive parts, as well as anxiety of Bodo (and the associated brother). Additionally, mourning plays a role. After the meal there is a phase of saturation and elation, whereby elation is felt more intense.

The functions of the secondary process that select the dominant need and construct action plans for its satisfaction work rather straight forward as one would imply in this use case, thus are not further detailed here.

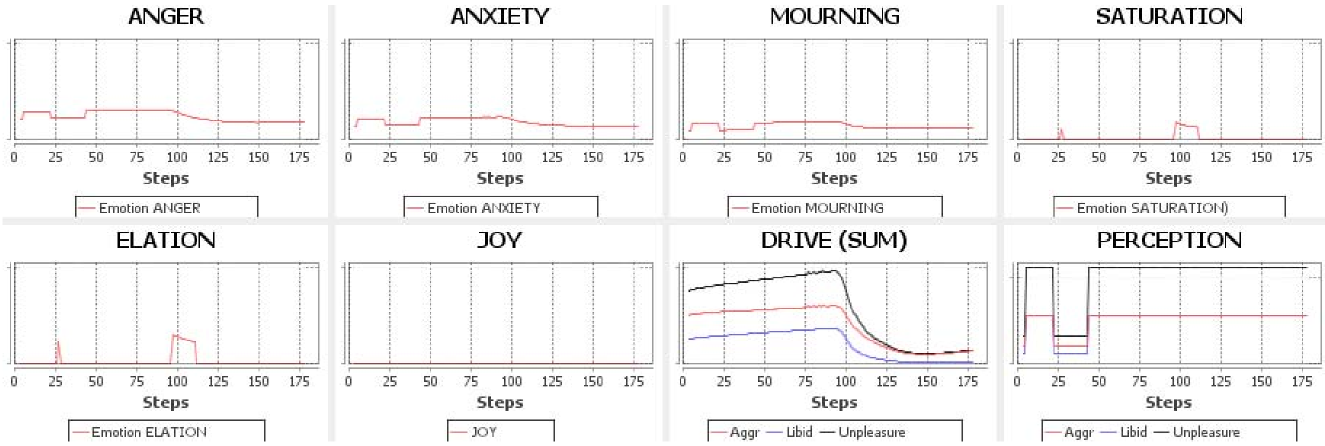

Figure 6 Adam's emotions during Use Case 1. The emotions are composed of his drive status and perception. Based on the aggressive aspects in both parts for long periods, the emotion anger prevales. As soon as Bodo comes in sight, anxiety and mourning add. Joy plays no role during this use case. After eating short periods of saturation and elation ensue until the drive for excretion becomes dominant.

VII. SUMMARY AND DISCUSSION

This article presents the implementation of a use case for a cognitive architecture. It does not make sense to use standard engineering applications as bringer of requirements, but use daily human situations as such for the use in human-inspired cognitive models, since they implement human's cognition, not engineering products. The presented use case 1 represents a basic situation with two actors. However, it still poses requirements for the whole chain of functions within a cognitive architecture. On the other hand it lays the base for many potential extensions of the situation. At the moment, as long as the basic functionality is implemented, only basic use cases are executed. Further developments will be in the area of decision making and planning, where drives and emotions will contribute to evaluate multiple action alternatives, like backup actions in the case of erroneous behavior or evaluating the potential pleasure gain of executing stored experiences in the form of sequences.

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