Perceptive Learning – A psychoanalytical learning Framework for Autonomous Agents

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Abstract— **Reacting to unpredictable situations is one of the main problems in technical automation. This article introduces two developed framework for decision units for embodied autonomous agents. The models are compared to an existing architecture, the BDI architecture. The basis of the described model is using psychoanalytical concepts. Drives, emotions and wishes are the basics that build a reaction due to an existing situation. A concept of strategy planning, using the Freudian wish has been described. Using a concept of thinking of the humans psyche that develops during childhood, the difference between thing presentations and word presentations is shown and based upon that, a possible learning strategy is elaborated.**

Keywords— **Autonomous Agents, Perceptive Awareness, Decision Unit, Ubiquitous Computing.**

I. Introduction

THE following work shall provide the reader with a framework for a decision unit of an embodied autonomous agent emphasizing the problem of perceptive learning. Using the research results of the last three years, this article shall also bring the developed models and theories to state of the art, showing what theories can be used within the new, pure Freudian-inspired decision unit and what theories are contradictory to a Freudian examination. To show a structured framework for a decision unit, the BDI-architecture (Believe-Desire and Intention) as described by Michael Georgeff in [1] is used as a reference model for comparisons.

II. Prerequisites and State of the Art

In 1998, a project called SmartKitchen was founded at the Vienna University of Technology's Institute of Computer Technology. The purpose was to gather data from different sensors and extract higher semantic meaning to deduce situation awareness. Since the word situation awareness has been used most frequently in the scientific world around robotics and automation, it has been emphasized to keep in touch with concrete examples within real world environment. Over the years, a scenario within the authors project SmartKitchen, which is the sensory equipped institutes kitchen, established, that seemed to be the best example for situation awareness and we are still using it very common to visualize the idea: The child-in-danger scenario. Whether it is the hot stove or the open fridge door that may probably harm the child, we focus exactly on such situations to support young, grown or elderly people in an every environment.

After simulations and tests, it has been shown, that an engine for recognizing predefined scenario recognition has narrow limits within a world full of demands of ubiquitous computing. What was missing, was the possibility for a system to act during or after an exception, that have not been foreseen and therefore not predefined. Suddenly changing environments within our everyday environment is very often unforeseeable but nevertheless we can cope with the situation. During research and our quest for intelligent behavior, we soon found, that artificial intelligence (AI) was also facing this problem and worked out two different types of solutions: Artificial neuronal nets or statistical methods. Both solutions are offering powerful methods that has been used within the institutes projects. Artificial neuronal networks and Hidden Markov Models are giving a great opportunity to build systems that can automatically learn patterns. Within the authors project field those patterns are situations within environments like a kitchen, business buildings or airports. After a learning phase, situations can be recognized on the fly, which for example results on demand in a computer-generated message:"Child 'Max' in kitchen No. 146 close to the hot stove. Danger!".

This scenario as well as unknown scenarios in such systems are usually resulting in an alert message which has to be redirected to a human operator. A resulted action was not taken by the system and the intelligent behavior was assured by human interaction. A procedure that takes at least time if not talking about money. The first developed systems were not able to carry out any action due to a lack of decisive behavior. With the vision, to bring an intelligent behavior into building automation, the authors compared different decision frameworks in the field of AI and found lots of useful and inspiring models, ideas and frameworks. Rodney Brooks subsumption architecture [2], which included parallel processing of different task levels that can produce actions and inhibit or amplify actions of other levels is one of the early architectures that are very fast to apply because of there simplicity of each single module. The sum of all modules itself are providing the system with a complex output behavior. Other decision units were using models of the human psychic apparatus as very soon S. Turkle depicts in [3] or most recently A. Buller [4], who introduces psychodynamics to the field of autonomous agents.

Soon, two hypotheses were getting more and more urgent for our project. First, intelligent behavior needs embodiment as argued in [5] by R. Brooks and in [6] by R. Pfeifer. Embodiment can be realized using an agent. According to Franklin and Graesser an agent is a system that sense and

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interacts with the environment of which it is a part of and pursuits its own agenda [7]. The definition of intelligence is difficult to give, especially in the context of abstract concepts like agents. Nevertheless, Wooldridge and Jennings have defined reactivity, proactiveness, and social ability as capabilities which we might expect an intelligent agent to have [8], [9, p. 23]. Second, during discussions with cooperating neurologists and psychoanalysts the authors decided to use the human psyche as an inspiration to build a decision unit for autonomous agents. Additionally, sensor fusion techniques were applied to neurologically inspired concepts.

Therefore, about three years ago, we decided to go an all new way in AI, using the theories of psychoanalysis and its models to describe and create the basics for a decision unit of an autonomous agent within the project ARS (Artificial Recognition System) as described in the next chapter. At this step it was necessary for our research to leave the ground of building automation, as for example the project SmartKitchen, which made it very difficulty for us to define only the abstract concept of a kitchens body, that can be easily compared to the body a human has. We developed a first model for a decision unit of an autonomous agent.

After a redesigning phase, with the aim to build a new decision unit that shall be an improvement of the past research, one further hypotheses became essential. The area of psychoanalytical science provides a huge amount of different, partly contradictory models. In cooperation to our psychoanalytical advisors, the authors decided to make one step back and describe a decision unit for an autonomous agent which is only based on Sigmund Freud's second topical model — the model of ID, EGO and SUPER-EGO — in a functional top down way of description, instead of using different parts of theories from Freud, Klein, etc. The principles of this decision unit will be described in the following chapters.

III. The ARS Decision Unit

Figure 1 depicts the decision unit as developed by the project ARS. In this project, simulated but embodied autonomous agents have been developed to implement different types of decision units. Within a simulated environment, the agents can perceive their environment through sensors and act with the surrounding. The goal is, to survive as long as possible, by consuming different types of energy sources and interact with their team mates, that include the same type of decision unit. The perception receives sensor information from the world ("Environment") and from the body ("Internal State"). This differentiation is important for the embodiment of the decision unit. The information is symbolized to micro-symbols [10, p.31].

The unit *Pre-Decision* combines micro-symbols to snapshot-symbols and attaches an emotional evaluation to each newly generated symbol. This is done by using a set of predefined images from the image memory. The emotions, that can occur in this module are the four basic emotions as defined by [11]: Panic, Rage, Fear, and Seeking. Next to the emotional evaluation, drives representing the bodily needs are generated. If a very important image has been

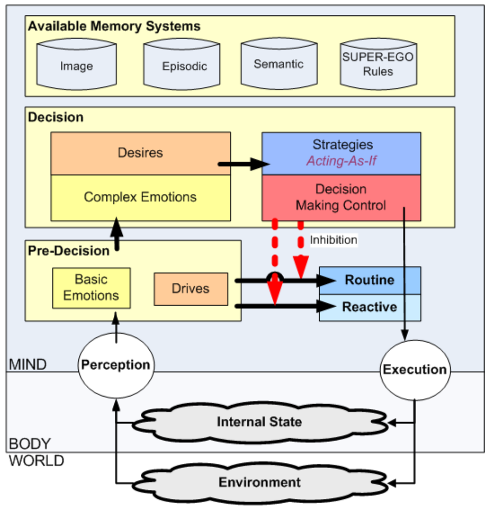

Fig. 1. Psychoanalytical inspired decision unit

matched—e.g. a room on fire—a reactive action is initialized and immediately executed by the execution module. Another possible direct action influence of the *Pre-Decision* is a routine action. Routines are longer sequences of small actions and are initialized by higher-level decision making modules. Once started they operate independently and automatically.

The *Decision* unit connects the snapshot-symbols to longer lasting episodes which are compared to previously experienced episodes similarly to the comparison of the snapshot symbols to the images. Also a matching against pre-defined schematic episodes—the scenarios—is performed. Both comparisons can influence the complex—or social—emotions. Based upon the identified scenarios and the current basic and complex emotional state, desires may evoke. A desire is defined by an object of desire, a goal, and a plan to reach this goal. Within a simulation of autonomous agents such goals can be an energy source, consuming the energy, the shortest path to the energy source).

The action plans evoked by desires are matched against the rules stored in the *Super-Ego Rules*. The *Super-Ego* contains rules for social interaction like "you should help your teammate" or "you should obey the rules". If a desire is incompatible to one or more rules of the super-ego, further processing is needed. This conflict of interest is handled in the *Strategies* unit. The resulting action of routine is then passed to the execution. Action plans for desires and super-ego rules may inhibit the execution of a routine or reactive action. Thus, an undesired reaction to a perceived snapshot-symbol can be suppressed. Finally, the *Execution* unit performs the actions and alters the internal state or the environment.

IV. ARS vs. BDI architecture

In the following, the ARS decision unit shall be compared to an existing decision architecture to get a quick overview, what the model for the ARS decision unit is designed for. The BDI architecture, which has already been applied to real world applications [1]. It was developed for reasoning systems that can cope with the demands of continuously changing environments. It was first applied to e.g. handling malfunctions on the space shuttle or controlling autonomous agents and robots. One basic idea is the classification into three main blocks: Believe, Desire, and Intention.

Believe — In the BDI architecture, this layer contains the world representation. Within the ARS architecture, the (internal and external) world of the agent is perceived via sensors through the perception module. Predefined templates are compared to the actual situation and scenarios are recognized. Globally valid rules are stored in the semantic memory, past experienced situations and actions are stored in the episodic memory, following the concept of E. Tulving in [12].

Desire — It is the BDI's layer, that defines the behavior of the decision unit and its purpose. In ARS architecture, drives and desires vastly influence the behavior of the system and its purpose: Staying within the optimum levels of the internal states. But also long term goals have been considered partly within the desire module and partly in the SUPER-EGO structure, which holds social rules and goals.

Intention — In BDI, different processing paths can cause different actions at the same time that have to be prioritized. In the ARS architecture, the action unit is supplied with actions from three different paths. Reactive action, which is comparable to human reflex actions. The routine unit processes periodical action sequences that do not need extra processing. The reflective unit provides action based on reflected strategies, plans and 'acting as if'-simulations.

The ARS decision unit has been implemented to a simulated autonomous agent where internal values, like drives, emotions and desires and the behavior of an and between agents are evaluated. Based on this research a new model has been developed, that shall be described in the next chapter.

V. Freudian Theory

Since 2003, when the project ARS started, the project team has worked on a technical model of the human mental apparatus. With the help of scientific advisors who work in the area of neurology, psychology, and psychoanalysis, the decision was made to use neuropsychoanalytical theories as a basis for the system modeling. [13]

While the first ARS model, described above, mainly based on different neuropsychoanalytical theories, which were used in order to be able to develop a self-containing model, it became clear that because of the uprising complexity the subsequent model has to base on one single model. Because of its functional way of description, Sigmund Freud's second topographical model has been used as a basis for modeling the mental apparatus. When first mentioned in 1923 in [14], Freud divided the mental apparatus into three instances called ID, EGO, and SUPER-EGO, shown in figure 2. The ID represents the evolutionary basis of EGO and SUPER-EGO and contains the so-called *primary processes*, a very emotional flavored, fuzzy kind of information processing, mentioned in [15]. These processes are executed unorganized and independent from each other. The demands of the ID, basically concerning the satisfaction of needs, have to be fulfilled as fast as possible and within *primary processes* the restrictions of the

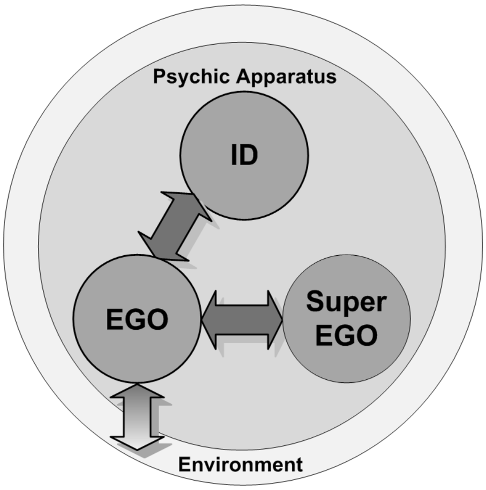

Fig. 2. Second topographical model in top down design.

environment ar not considered. Therefore, the ID may be in conflict with the SUPER-EGO which manages existing rules manifested in commandments and bans. The EGO serves as mediator between the ID's requirements and the SUPER-EGO's rules. In addition, the EGO represents the interface between the psychic apparatus and the environment. The so-called *secondary processes* form the basis for the IDs tasks. They are organized and lead to structured thinking by involving the reality. As postulated in the theory of psychoanalysis, the psyche allows conflicts between different decision instances. Freud's model has been analyzed by its functions to apply the common Top-Down Design. As a first step the brain has been functional divided into the following functional blocks: sensor interface, actuator interface and the psychic apparatus. While the psychic apparatus arise out of the *second topographical model* the sensor interface organizes the incoming information and the actuator interface represents the connection to the physical body. Ongoing work focuses on the functional description of the modules EGO, ID, and SUPER-EGO within the psychic apparatus. The next chapter uses the specified top-down design of the second topographical model and shows, how a desire described previously in the ARS decision unit can be implemented within this new model. Desires shall be called wishes in the following chapters, according to the Freudian notation.

VI. A Psychoanalytical Concept

Two concepts of neuropsychoanalytical research seemed to be well fitting to the theories of e.g. R. Brooks in [2] as mentioned in chapter II or M. Toda in [16], who defined an autonomous agent called the *fungus eater* for his research. First, it is essential for an autonomous agent to be aware of the values within its own body — the *inner world* — in contrast to the *outer world* that is the environment the agent is located in. Secondly, it is the values of the inner world, that forces the agent to adapt its environment to its own demands. These values are at humans the status of all bodily needs, the so-called homeostasis of e.g blood pressure, heartbeat frequency, breathing, adrenalin-, and sugar-level. Within an autonomous agent, values can be the energy level, CPU-load, internal network traffic, free memory, and many more values, depending on the environment and tasks the agent is designed for.

The agent's perception is the sum of internal sensor values as well as external sensor values. To recognize sets of sensory data, which are accumulating situations of single moments or scenarios that are sequences of situations in time, a concept of scenario recognition has been introduced in [17]. Predefined templates are compared to the current data stream of perception and result in a list of more or less recognized situations or scenarios. These templates imply internal and external sensor values and constitute a first step towards symbolic data representation as described in more detail by G. Zucker in [10].

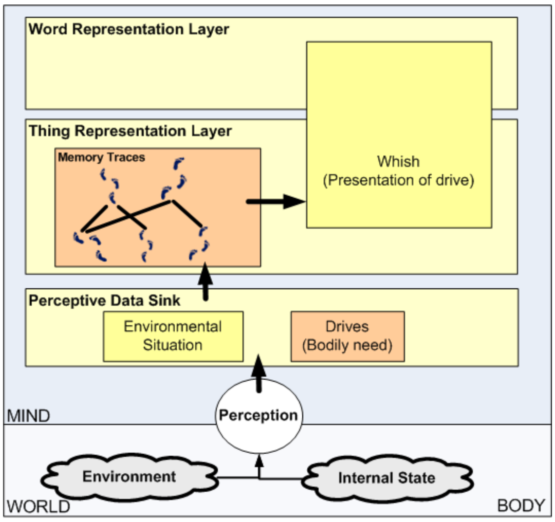

Fig. 3. Freudian inspired wish generation engine

These recognized perceptive templates that are produced by the perception module as depict in figure 3 are manifested in memory traces, that can technically seen as instances of objects within a collection that is holding these memory traces. Within this memory trace collection, traces of different levels of semantical meaning are stored. During development, cross connections between different traces are built. A concept of learning shall be introduced in the next chapter. Memory traces are occupied by a level of relevance, so that more often perceived situations are getting more relevant to the system than others that are rarely or not perceived. In the following, an occupied memory trace will be called *highlighted*. Since not only data from the environment but also from the agent's body can be perceived, bodily needs — in psychoanalysis labelled as drives — also have a corresponding entry within the collection of memory traces. If a bodily need is not sufficiently covered, the corresponding memory trace for this lack is occupied by an increasing level of relevance. When this level passes a specific threshold, a wish is evoked, which is the human psyche's representative of that drive. There are also higher level wishes, that are satisfying without satisfying a specific bodily need, but bring also pleasurable situations to the agent. Those cognitive higher wishes are including long term planning and shall not be described in this article.

During a wish, not only the corresponding memory trace to the bodily need is *highlighted* by increasing its level of relevance. Additionally, other memory traces corresponding with the satisfaction of this need are *highlighted*. If the satisfying object of a humans wish caused by hunger were in a specific situation a cake, also the memory trace of a cake would be *highlighted*. If the satisfying object of a robots wish caused by the lack of energy were a battery, the corresponding memory trace for a really perceived battery would be *highlighted*. The value of relevance, however, does not have the same quantity at real perception than it has caused by wishful thinking. When perceiving the satisfying object in the real world, the corresponding memory trace is *highlighted* in a higher level than it is highlighted as a result of a bodily need, a drive, and a resulting wish. To distinguish between this difference within the implementation of this model, the values have to be marked with a property, indicating the origin of the increasing value. A more detailed concept of how the memory traces are created, combined, and connected to each other during a learning process will be described in the next chapter. In the human psyche, according to S. Freud in [18], memory traces of possible satisfying objects are highlighted with lower intensity than by a real perceived object itself to avoid confusion. For humans where this part of differentiation does not work, this psychic disease is called hallucination, a perception in absence of perceptual input, produced by an unconscious or conscious wish.

A technical implementation of evoking wishes within the decision unit of an autonomous agent is described [19]. The wish can be seen as a collection of data that holds all relevant information for the satisfaction of the involved bodily needs, the drives. According to the Freudian Theory, wishes that are evoked by a bodily need are existing unconsciously. They are also represent as a memory trace, which is nothing else than the basic to the Freudian thing presentation, which is described by J. Laplanche in [15]. To reach an, at least preconscious level of a wish where the individual is able to rationally think about the way how the wish and therefore the need can be satisfied, a word presentation is necessary. Since a conscious word presentation of the wish exists, one of the most important parts of a wish can be built: A plan how to reach the satisfaction of the underlying drive. The word presentation as a linguistic form of presentation is the basic ingredient for planning and the so called 'acting as if', one of the core ego-functions of the human psyche, as described in psychoanalysis e.g. by P. Schuster in [20]. It would be a first step towards self reflection of an autonomous agent within a Freudian inspired decision unit.

In respect to the described theory, a somehow linguistic unit within a computers decision unit is essential for planning. More or less, the ability to speak, the language itself and the communication between individuals played a significant role during the development of humankind. To think and to plan on such a high abstracted and semantic level apparently offers advantages in creating planning strategies. AI has been working on several, of course machine-like and machine-understandable linguistics for ages, as described by G. Görz in [21]. Although, these linguistics are widely on a very low semantical level and do not meet the demands of the theory of symbol grounding, it is a first step for higher cognitive learning and is essential for future decision units.

VII. Perceptive Learning

Taking a closer look to *psychoanalytical developmental psychology*, some of the theories of J. Piaget are describing the pre-symbolic cognitive way of thinking of infants right after birth and until the age of the completed second year. As described by M. Dornes in [22], Piaget divides the period of those first two years into six sections. During the first phase that lasts the first month after birth, the infant uses only pure reactive actions as a result of perceived objects. In the last phase, between the eighteenth and twenty-fourth month, recognized objects are getting permanent and also permanently stored and completely independent from resulting actions.

This only becomes possible because of the ability of symbolic thinking the child is learning during those first two years. Within this period, a first set of thing presentations — which is a very huge set — is built until the ability to use word presentations establishes. During these two years thing presentations, which are nothing else but the memory traces discussed earlier, are built and new thing presentations are learned. According to Piaget's model, the concept of assimilation and accommodation is used for the learning process. As an example, the mothers breast is a presentation that is assimilated to the infant's behavior of sucking in order to get food. During development, the infant accidentally gets its thumb in its mouth and tries to apply the same behavior pattern of sucking to it. The thumb is assimilated to be the same object as the mothers breast. Due to unsuccessful ingestion, the presentation of the mothers breast has to be accommodated and is getting a new thing presentations 'thumb', which has generally comparable properties except the fact that it is not nourishing. This behavior pattern is the basis of mental development.

As outlined by A. Luria in [23], higher cortical layers can only evolve if lower levels have already developed. In [13], M. Solms pointed out that certain patterns in the brain have to be predefined by genes to allow the development of higher cortical levels. R. Velik uses these neuroscientific and neuropsychologic research findings in [24] to develop a model for humanlike perception based on modular hierarchical neurosymbolic information processing, which supports learning from examples. In the model, so-called neuro-symbols serve as basic information processing units. Neuro-symbols stand for perceptual images like edges, certain sounds, objects, a person, a face, or a voice. By using such neuro-symbols, advantages of neural and symbolic information processing — two disparate approaches to explain information processing in the human brain — can be combined. These basic processing elements are interconnected and structured in hierarchical layers. A certain number of lower-level neuro-symbols is always combined to a higher-level neuro-symbol. At the lowest level, neurosymbols emerge from data coming from sensory receptors. In the lowest hierarchical levels, correlations between sensor data and neuro-symbols have to predefined. In higher levels, correspondences between neuro-symbols are learned from examples in a supervised learning process.

VIII. Conclusion and Outlook

Developing models of decision units for autonomous agents was the main topic that was outlined in this article. Out of the demands of modern building automation, the project ARS - Artificial Recognition System, has been introduced, searching for new concepts to handle unpredictable, in building automation often safety- or security-critical situations. Dropping the ballast of the demands for building automation, two concepts for the decision unit for an autonomous agent has been introduced. Both are inspired from and strongly referencing to theories of psychoanalysis. Whereas the ARS decision unit took different models within the psychoanalyses as a basis, the Freudian inspired decision unit uses only the second topographical model as bases. This model has been described in a technical top-down-design approach, so that it can be used for further implementation. A concept of strategy planning, using the Freudian wish has been described. Using the concept of development from a thing presentationed way of thinking to a word presentationed way of thinking, a possible learning strategy has been elaborated. In contrast to the ARS decision model, that has already been implemented and tested in simulated autonomous agents and implemented in solutions for modern building automation (e.g. the concept for scenario recognition), the new described concept has to be implemented in future time. Using the same test platform, the simulated autonomous agent with the same sensors, placed into the same environment, the two reasoning units will be directly comparable. In future, a way should be found, to extend the concept of a decision unit of an *embodied* autonomous agent to the origin area: building automation.

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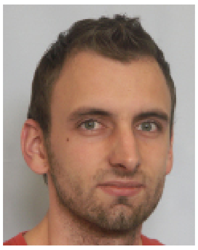

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