A Decision Unit Inspired by Cognitive Sciences for Future Robotic Applications

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***Abstract*—The complexity of technical systems is constantly increasing. To manage the amount of data several strategies have been followed and a lot of achievements were made especially in artificial intelligence. But still the capabilities of human intelligence are unrivaled. The contribution of this article is an introduction to a decision unit based on psychoanalytical models and a description how the findings can be used in future robotic applications. The neuro-psychoanalytical theories used, cover a comprehensive model of human intelligence and presents structures for all aspects of human decision making. The psychoanalytic-inspired decision unit shows promising prospects that standard planning and control units lack in various respects. Amongst others, scenario and experience-based planning, drive-based intention models, and the 3-tier (neuro-symbolic, thing presentations, word presentations) data processing architecture, are very promising methods. In order to validate the model, a simulation environment was implemented holding various agents with the neuro-psychoanalytical decision unit. This first implementation shows the possibilities of the system and gives a great outlook for future investigations of the capabilities.**

I. Introduction

In today's households a high integration of automation and electronic's can be found. Especially robots are a growing application field of automation in our homes as well as in many other application areas. Most industrial robots are perfectly able to interact within the environment they were designed for. For industrial robots limited degrees of freedom an precise defined application fields avoid problems caused by unexpected situations. For the design of household-robots new challenges occur, since these robots are deployed in very different application areas. Almost every household looks different from another, widely differing objects can be found and unusual architectural buildings challenge the developers of household-robots. To allow robots to move independent through an environment safety considerations have to be made. Moving objects like people, children or animals have to be considered and included into safety thoughts. Beside other safety issues arise with dangerous obstacles like hot cookware or infants in the sphere of the robot.

In order to detect scenarios like the described, the project Smart Kitchen was initiated at the Vienna University of Technology's Institute of Computer Technology in the late nineties. Prof. Dr. Dietrich and his research team took biomimetics as archetype to create a cognitive system which is able to detect scenarios within a kitchen. Through sensor abstraction in different layers, a multi-modal representation of the perceived input can be used to detect complex scenes represented by a massive amount of sensory values. A detailed description of the model can be found in [1].

Based on the scientific work of the smart-kitchen project, the Artificial Recognition System (ARS) was started with the aim to model a decision unit completely inspired by biomimetics. Since no state of the art decision unit is capable to cope with scenarios like the above mentioned, the human psyche was taken as archetype to develop a decision unit completely based on psychoanalytic know-how. Through Sigmund Freud's metapsychology and especially the second topological model, the research team had a description of the human psyche that could be used to create a technical feasible, functional model of the human mind. Based on the three instances Id, Ego and Super-Ego, including the drive-theory and data-representation based on thing-presentations and word-presentations, a homogeneous model of the human mind that can be used as decision unit for many application fields in automation, has been developed. A detailed description of the the current development progress can be found in [2].

In contrast of former work from Sloman [3] and Brooks [4], the developed model completely is based on one psychoanalytic model to avoid interconnectivity and interoperability problems between different psychoanalytic beliefs. To model such a complex control system like the human mind, a top-down design approach was chosen which refines the abstraction level on every functional layer. The modeling process and the developed model is described in detail in Section II and Section III.

The research team does not aim to develop a complete robot but a decision unit that can be used to control an autonomous robot. Because no physical robot is available, a multi-agent simulation environment based on the MASON-Toolkit was developed to test the functional model of the human psyche. The simulation environment is explained in detail in Section IV.

II. Modelling the Human Psyche

When looking into research papers of the last 30 years, it is noticeable that research has shifted from artificial intelligence, that was dealing with mostly logical problems solved in a very strictly defined state space, towards analysis of problems situated in complex unrestricted environments. Decision making was and is still one of the main topics in Artificial Intelligence (AI), especially in agent-based modeling. In this article we present one possible approach to design such agents, the Believe-Desire-Intention (BDI) architecture and then show our approach, the differences and the integration of our introduced concept. The following paragraph will cover a brief discussion of the BDI structure followed by a brief introduction why neuro psychology is necessary and closed by a paragraph about our approach to this research field.

A. The BDI architecture

The fundamentals of the BDI architecture were defined by Bratman [5] and the first practical implementation was done by Georgeff [6]. In the BDI architecture decision making is done by defining what targets are to be accomplished and how they can be reached. Under the restriction of finite resources the BDI architecture is supposed to provide weighted alternative solutions. In the DBI architecture the agent's possible actions are determined by the knowledge of the current situation. This knowledge is gained by perceptions of the outer world. From the list of possible actions the desires that can be fulfilled are generated. These desires are the reasons to get active for the agent. The desires are the goals to achieve. This goals are predefined and activated by the external perceptions of the world. The intentions of an agent are structured into plans and when a current goal is selected one of these plans is adopted and becomes the current intention. According to the current goal sub goals are defined. They are created by using the knowledge of the agent and the history of similar superior goals already achieved. At the end of this process a single action is selected for execution.

This process defining intentions, desires and believes is widely used for autonomous agents. However, the three inputs of the architecture are predefined by a system designer, making the decisions of the agent strongly dependent of the designer itself. The concept of the desire (wish) used in the BDI architecture is not completely satisfying. To improve the concept a more detailed information of the wish is necessary. In the following sections a model is introduced inspired by concepts of psychoanalytical metapsychology as a model for generating an intrinsic motivation for agent's plans and actions and how it can be realized within a decision unit.

B. Interdisciplinary Approach

In research of AI and Robotics it is noticeable that findings of psychoanalysts or even neuro-psychoanalysts are hardly used. There are some suggestions how psychoanalyses and engineering can work together, for example in [7], but they are not commonly used. What is used are terms like 'emotion' or 'feeling' without the proper knowledge of the scientific field defining those terms (see eg. [8] or [9]). The terms are taken from theoretical work, often mixed together from different theories and used without proper check for interoperability. To overcome this problem the project ARS uses advisors specialized in those fields.

The basics of the current article are introduced by Deutsch [10] using a top-down design approach to model the human mind by using the psychoanalytical theory and transferring it into a technical model. The model was the reason for founding an international forum that is discussed and depicted in detail in [11].

C. Top-Down Design

Computer engineers are used to think in hierarchical layers or in distributed systems. Additionally, the general definition of a computer as data-transferring, -saving and -manipulation information-processing-entity is still valid. The internationally acknowledged neurologist Lurija organizes the human brain in three layers (with undefined amount of sub-layers) [12]. In the design process for the artificial mental apparatus the layers of the brain are compared to the layer structure used in computers which are familiar to computer engineers.

The brain is an information-manipulating system managing the human body. In the model of a computer, software is the information-manipulating instance for the computer's hardware. If we further accept that software is nothing else then another description of hardware, we see the similarity to the neural systems of the brain. Neural networks of the brain are nothing else then information processing entities and the mental functions are nothing else then another description of the underlying hardware. When the overall architecture of both systems are compared, the underlying models and especially the design process of the models gain similarity. The layered approach for designing computer systems can be used to design the model of the mental apparatus.

Former attempts to define and understand the principles of the human brain in AI used a bottom-up-approach. First the lower neurological layers were defined and then the behavior out of this base should emerge. But when designing a model for the human mind we have to use a top-down-approach and start by defining the behavior and higher functional blocks before we can start with simulation or emulation of the human mental apparatus as a whole.

Defining a System by using a hierarchical model is a technique widely used by computer- or communication-engineers. Abstract layer-models are defined where every layer shows a more detailed view of the previous one. When the first layer is defined the next layer is created using information about the functional demands of the upper layer. The approach to designing these layer follows the top-down approach.

Designing a computational model for the human brain means we can not start at the neurological layer. We need to start at the highest definition of the mental apparatus for the conscious procedures. Psychoanalysis defines all conscious and unconscious operations and thus gives us a good starting point to define the upper layers. For the lower layers we have to use models and findings of neurology like proposed in [1].

It is possible to define the highest layer using psychoanalytical findings. Based on the functional requirements it is possible

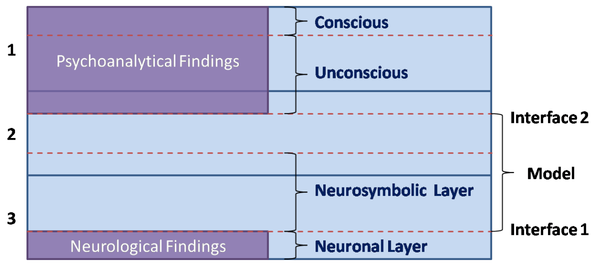

Fig. 1. Hierarchical Layer Definition

to define the interface for the lower layer. The same is true for the lowest layer using the bottom up approach. Based on the requirements for the middle layer, defined by the interfaces to the others, it is possible to define the functional model in between. Figure 1 shows the hierarchical layers and the model space between as described above. Using this approach three functional models can be defined. The topmost layer, the psychoanalytical model, will be described in more detail in Section III, as well as the subjacent layers.

III. Model

The lowest layers can be seen as a hierarchical system according to [1]. In contrast, the psychoanalytical model can only be developed as distributed system [13] [2], where different functions are fragmented in different brain regions attached to the hierarchical layer. The described model originated from detailed examination with our psychoanalytical supervisors based on the theory of psychoanalytical metapsychology – founded by S. Freud – and was designed in respect to a technical implementation.

A. Foundations of Metapsychology

Using the top down design process a first functional model was introduced in [11] and [14] and described in more detail in [2] using the second topographical model of S. Freud. The functional model describes in detail how the different input parameters of the system form the intention to do something (a wish). It shows how this wish originates and decisions are made. After that the path from action planning to fulfilling a action shows how the mental apparatus is able to maintain the satisfaction of its needs.

The mental apparatus mediates between three instances (the Id, Ego, and Super-Ego complex) and the requirements coming from them. The first instance, the Id, generates the drive demands triggered by bodily needs or an imbalance in the internal homeostasis. The second instance, the Ego is responsible for the reality demand combining knowledge about reality and the possibilities, constraints and subjective consequences of outer perceptions. The third instance builds the demands of the Super-Ego. Those demands are coming from social and cultural rules and believes. These three instances build the first and highest layer of abstraction of the model.

A more detailed view of the mental apparatus is shown in the next section.

B. Information Processing / The Functional Model

Based on this top-down designed model a functional model has been defined. Figure 2 shows a simplified view, a more detailed discussion of the model can be found in [2]. The mental apparatus is influenced by the drive tension of the internal and external world. The outer world is represented as perceptual sensor data (world sensation) and from sensor information from the body (body sensation). This raw data is neuro-symbolized and composes the external perception information. The inner homeostasis generated by physiological imbalance is also neuro-symbolized and triggers the generation of a drive tension. The drive is the first mental representation of a bodily need. In a next step life sustaining and aggressive drive tendencies are merged. The information is passed along in the form of thing presentations, a psychoanalytical data type used for unconscious information processing. The thing presentation is combined with an affect whereas the affect represents a quantification of the thing presentation. The still unconscious representation of the drive content is thus formed by affect and thing presentation.

The unconscious data in this part of the model is represented with the data type of a thing presentation. In this bodily information path it is the thing presentation of a drive. It contains information of its content. The origin of the bodily tension itself is not consciously accessible but during the deliberation process conclusions can be drawn where the tension is coming from [15]. The other part of the drive is the affect. The affect holds the information about the quantity of the thing presentation, the amplitude of the tension. The higher the tension of the bodily need, the greater the affect that represents the drive quantity. The thing presentation of a drive is connected to other components. There are other drive-contents connected which are defined by metapsychology. This drive-contents are represented again as thing presentations.

The first component is the source of the drive and represents the *origin of the drive*, the organ that generates the bodily tension. This information is not consciously accessible by the human psyche.

The second component is the *aim of the drive*. This component shows the intention of the drive, that is to reduce the bodily tension generated by the organ. But although the topmost target of this component is to remove or reduce the state of stimulation, there may be different paths leading to the same ultimate aim. That aim of the drive may have various nearer or intermediate aims, which are combined or interchanged with one another for full or partial satisfaction. This is possible because of the unconstrained data connections of the primary processes in this section of the human psyche.

The third component is the *object of the drive*. This object is the target to which or through which the thing presentation of the drive is able to achieve its aim. It is the drive object that reduces the tension of the organ. The object may not be originally connected to the drive but becomes assigned to it through learned satisfaction or is predefined through instinct. The object does not have to be something extraneous, it can be a target that is part of the body.

Depending on the internal states of the body or the external situation of the individual the object and the aim of the drive can change through decision making in the mental apparatus. In metapsychology the drives are classified by their drive contents which can be constructive and destructive [15]. Both types are tightly connected to each other and are always represented. The whole concept represents the overall data structure used to represent the unconscious drive content.

The drive content is transported to the defense mechanisms. Here, the moral rules and threats coming from the Super-Ego are weighted against the inner demands and it is decided if and in what form a drive content can be handled further or repressed. The repressed contents stay in the Id and wait to be associated with other content for another try against the defense mechanisms. Drive contents passing the defense mechanisms have the ability to become conscious and are therefore converted to the secondary process. This means that the thing presentations are connected with the according word presentations. Thus, presentations can be ordered logically (the task of the secondary process) and processed by further modules.

Hence, the drive demand generates a drive tension and if possible, this tension creates a conscious word presentation originating the wish for an action which is transferred to decision making. In order to connect the internal demands to the outside world, the information flow of the body sensation and the world sensation need to be connected in this unconscious part of the mental apparatus.

The outside world is represented as sensor stimuli of the outside world and as perception of the body itself. The raw data is transferred in neuro-symbolic information of the environment and the body. This perception information is absorbed unconsciously before it can be processed psycho-analytically. The symbolic information is available as thing presentations to the mental apparatus. These thing presentations come in contact with the repressed contents and activate memories. Similarly to drive contents the external perception generates affects thus making it possible for those thing presentations to be processed in the same way by the defense mechanisms like described above.

The perception informations accessible to the Id can now be transfered to secondary processing. At this stage the first impression of preconscious and conscious internal recognition of drive contents and perceptions is possible. Internal recognition means especially the preconscious or conscious perception of feelings connected to thing and word presentations.

The thing and word presentations are transferred to the preconscious Super-Ego and then to decision making and conscious external perception. This information is used to decide how and if the wish that is generated from the drive-content is processed and fulfilled. Action plans are generated by using this information and are processed by the decision making module. The different plans are evaluated and verified by the reality-check module. The decision and evaluation process is significally influenced by feelings. After evaluation and decision the resulting plan is executed by neuro-desymbolization of the information to physical motor control of the body.

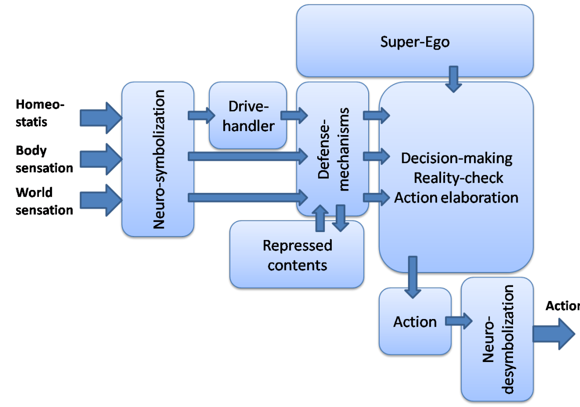

Fig. 2. Simplified Psychoanalytical Processing Sequence

IV. Embodiment and Simulation Environment

The aim of the project team is to design a decision unit not a complete robot including the described decision unit. To test the developed system a complex simulation environment has been created where embodied agents have to fulfill precise defined use cases. Every agent has the model of the psychoanalytic decision unit implemented and acts according to his needs and decisions while fulfilling different tasks of the use-case. The simulation environment is based on the multi-agent simulation toolkit MASON (Multi-Agent Simulator Of Neighborhoods). A detailed description of the simulation environment can be found in [16] and a detailed description of the toolkit MASON in [17] and [18].

Following the research work of Pfeifer and Bongard [19], embodiment is a precondition for intelligent behavior. The concept of a body that is controlled by a brain without interaction between body and brain has been proven wrong. As Pfeifer and Bongard describe, the body influences heavily the way decisions are made and plans are carried out. The concept that the body and the brain together form a decision unit has to be integrated in the design of control systems for autonomous agents. In our developed model embodiment is covered through the functional model. The internal state of the embodied agent is according to psychoanalytic and bionic fundamentals modeled and taken into account during the whole decision making process.

To provide the necessary data for the functional model the agents are equipped with internal and external sensors. For all sensor-types the human body was taken as archetype but with strong limitations. We do not aim to model the human body but the human mind. The current simulation environment covers basic internal sensors for example to perceive the digestion system, the temperature, the current energy level or the general health status. To recognize the agent's environment, external sensor like vision sensors, olfactory sensors or tactile sensors are available. To interact with its environment, the agent is equipped with grapper-arms, an eatable area and a motion system, that allows the agent to move within the simulation-environment.

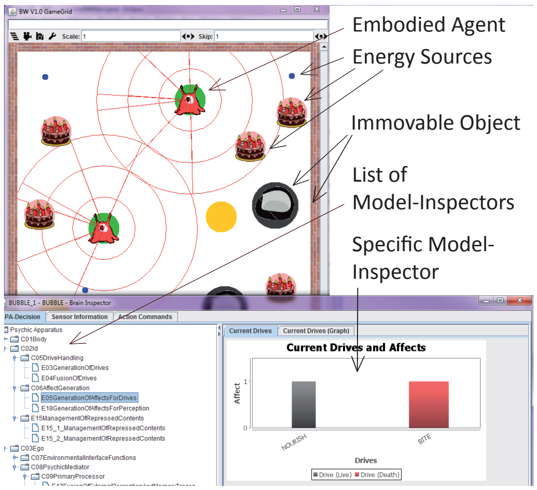

Fig. 3. Screenshot Simulation Environment

Figure 3 shows a basic simulation setup. Like outlined in the Figure, contains the simulation-environment consumable energy-sources like cakes and immovable objects like stones and walls. The environment is delimited by walls. To give the research team the possibility to concentrate on specific scenarios, the environment can be customized by configuration files.

To analyze and verify the information flow and functional activity within the model during runtime, several inspectors were implemented. Like explained in Section III, the model consists of numerous functional blocks which all cover different functionality and data-types. To precisely evaluate the functional blocks of the model, specific inspectors were implemented for each part of the model. A detailed description of the used inspectors can be found in [2].

V. Performance Measures and Results

The model described in Section III is the result of corporate interdisciplinary scientific work of researchers from the areas of psychoanalysis, neuro-psychoanalysis and engineering. Current publications of the model like [14] prove the validity and importance of the model for engineering purposes. The team is now focusing on evaluating the model concerning the psychoanalytic correctness and performance in comparison to state of the art decision units.

A. Performance Measures

An approach to measure performance of an autonomous agent is hard to define, since no general valid definition including different application areas exist [20, p. 35] . For industrial purposes it appears to be important to accomplish assembling tasks in a defined time-frame with low energy consumption. For autonomous agents like the embodied agents which were used in curse of the ARS-project, performance can be measured by the definition of use-cases. The success or the degree of fulfillment of a task, defines how good or bad the developed decision unit performs in different scenarios.

To compare the ARS decision unit with other approaches, we designed the simulator with the idea in mind to embed different decision units. By that we can compare the ARS model to other models like an implementation of the BDI structure [6]. To interact manually with an agent controlled by the ARS-model, we integrated a remote-bot as well, which can be controlled by a human.

B. Internal Performance Measures

In order to measure the performance of an agent, measuring points have to be defined. If the agent's task is defined by a simple action like finding food, it is still not trivial to measure the degree of fulfillment of the task. For example, if different food sources are available, that have different impact on the agent's body, all possibilities have to be taken into account. Besides it has to be considered how the agent fulfills its task. Actions set by the agent have to be evaluated in a time-dependent context. Some actions might seem promising at the moment but have negative aspects in the future, either on the agent's environment or the agent itself.

Due to the high integration of the bodily state of the agent, a wide range of internal performance measures can be defined within the ARS-model. The measure points are taken into account during the whole decision making process which is one of the big advantages of the developed system. Every carried out action is evaluated and optimized according to internal demands and desired actions in the environment. The described measure points can be physical ones, like the health status or the energy-level or they can be mental ones (e.g. regarding the current plan or the degree of fulfillment of earlier plans). The measure points differ according to the application field of the agent. For example, if the decision unit is implemented into a cleaning robot, measure-points can be defined by the internal energy-level, tidiness of the current room, fill level of dirt-container, the (expected) constitution of the dirt in the current room and so forth.

C. Results and Current Implementation

The current implementation of the model, like also discussed in detail in [2], is capable of controlling agents within the in Section IV described simulation-environment. In a first simple test-scenario the agent has to navigate through the environment in order to find and consume energy sources. The action is triggered by an internal demand, like running out of energy or another imbalance in the bodily state. During the decision making process past situations and experiences are taken into account and are internally represented by the drive-model mentioned before. According to the psychoanalytical model it is decided if a drive will get satisfied or suppressed. If a drive is chosen for satisfaction an appropriate plan is generated. Plans are build up of smaller plan fragments, namely images. A detail discussion of images, scenarios and acts can be found in [21] and [22]. Currently the research-team is focused on evaluating and refining the implementation. Since a high amount of functional blocks exits, implementation is not seen as trivial part of the development process.

VI. Conclusion

This article gives an overview on a psychoanalytically-inspired decision unit for autonomous robots. The scientific foundations that motivate this approach is detailed and it is argued what are the basic requirements on the model development process. In Section III, the model itself is presented on a medium abstract level to give robotics engineers an impression on how the human decision making process can be modeled and used for robotic applications. The model bases on the in psychoanalysis widely accepted second topological model, which contains the three mental parts Id, Ego and Super-Ego. This structure was designed by evolution to handle conflicting interest of body and environment and gave our species great advantages in survival. In order to validate the model, a simulation environment based on MASON was implemented. Section IV introduces this environment while in Section V methods how to use the simulator for model validation are presented. Finally, a use case is mentioned that implements all of the functional units of the model and shows the applicability of the model. In future work the functional blocks will be implemented in more detail in order to allow for the agent the fulfilling of ever-more complex use cases. In the meantime it has to be investigated how to evaluate the fulfillment of use cases in a most automatic way. This is not a trivial task since the use case is not fulfilled with reaching the described goal, but with doing it the right way! For assessment of the motivational system it is e.g. of vital difference if an energy source was headed to by intention or if the agent was stumbling over it by chance. However, in deep analysis of the data structures even the intention for actions has to be questioned if it was intended by the application or only a side effect. From the results achieved up to now we can conclude that the model is able to control a software agent and this agent is able to survive in some simulation environment under given constraints. The model structure is intended to perform complex control tasks and gaining an understanding into the matter which has to be controlled that outperforms standard control systems based on purely mathematical considerations. Future experiments will proof this statement.

Acknowledgment

The authors would like to thank the Doctoral College on Computational Perception of the Vienna University of Technology for their funding and support.

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