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Action Planning for Autonomous Agents Based on Neuropsychoanalytical Concepts

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***Abstract* – Action planning methods for autonomous agents are necessary to successfully perform tasks and purposely achieve goals within the agent's environment. Based on already existing knowledge about the environment, action sequences are built. Development of actions is important for autonomous systems because the possibility of action generation determines the degree of freedom to act within an environment. This article introduces an action planning system for autonomous agents based on neuropsychoanalytical concepts of the human psyche. Based on a technically implementable model of the human mind, an action planning system is modeled and implemented to create a planning system for technical applications. The result is a flexible system that is able to create action sequences purposely achieving goals within the agent's environment. The system can be compared to the human planning process and is the first homogenous work in the field of Artificial Intelligence completely based on consistent and unambiguous concepts about the human mind. To test the developed model, a simulation environment is used where agents controlled by an implementation of the model have to fulfill use cases.**

***Keywords* – action planning, reasoning unit, artificial intelligence, biomimetics, neuropsychoanalysis**

I. INTRODUCTION

Planning is essential in every-day life situations involving decision making. Autonomous agents in logistics, distributed task allocation, traffic control but especially in the domain of service robots are challenging test beds for developing computational models. Agents should plan finding the most favorable course of action to solve complex jobs in constantly changing environments [1]. There are two general classifications: reactive agents which decide only on basis of sensory input and planning agents which take into account anticipated future developments. The benefit of reactive agents is their quick situation-specific decision making. However, as planning agents use a much wider scope recognizing global consequences of decisions, it is expected that unlike reactive behavior they are less prone to be trapped in local and temporal optimization, which prove to be suboptimal in global context. Nonetheless, while autonomous agents execute their plans their beliefs about the world might change and require constant deciding whether to keep executing their plans or generating and executing new plans. As long as planning methods are fast enough, this appears to be a favorable for real world tasks.

In retrospect, the last years of International Planning Competitions (IPC) showed tremendous progress in this area at the first view. However, as in [2] we argue that most competition winning planners possess only very restricted forms of temporal planning as the competition domains are temporally simple and inherently sequential. This does not match real-world domains which provide problems and task allocation that require concurrency which is supposed to be solved harder. It seems that all faster classical planners are based solely on sequential domains [2]. As the scope of Artificial Intelligence should be the development of problem solving systems for real world environments – inspired by human intelligence – we postulate a entirely different approach in this domain.

Based on a realizable model which implements principles of the human mind, developed at the Vienna University of Technology's Institute of Computer Technology, in project Artificial Recognition System (ARS), an action planning system is modeled and implemented, to create a planning system for technical applications. This highly concurrent system using competing drives and wishes allows plan generation in complex domains. The fulfillment of different drive schemes and hierarchies lead to detailed planning which has to be adapted based on continually changing environment and changing system state. Using the human mind as an archetype this model is based entirely on concepts of psychoanalysis and neuropsychoanalysis to achieve humanlike action planning which is - to our understanding - an essential concept meeting the demands of task allocation and action planning in real world environments.

II. STATE OF THE ART

In the area of autonomous action planning constant progress can be recognized like the advancement of results achieved by competitions like AIPS [3] or DARPA [4] demonstrate. Also scientific approaches to investigate the human psyche achieved tremendous results [5], [6]. Nonetheless, no approach exist which combines both disciplines for the creation of a homogenous model of the human action planning process for autonomous agents.

A. Artificial Intelligence Action Planning Concepts

In general, planning covers two major areas of Artificial Intelligence, search and logic, in order to advance decision making and problem solving. Unlike reactive solutions, planning uses problem-solving algorithms with related presentations of system states and actions. The state-space can be used in both directions and may inherit sub-goal independent assumptions. The planning graph itself can be designed solely incremental or it may contain mutual exclusive relations (concurrency). This research field generally uses the Planning Domain Definition Language (PDDL), that describes initial and goal states, based on literals and actions which are described with their preconditions and effects. The IPC is one of the well-known public test fields where different approaches can compete and benchmark. Many powerful planners, Graphplan, SATPlan, FF and STRIPS, had a high impact on this research area, raising performance in planning by explaining representational and combinational issues. Today's planners show tremendous progress during recent years of competition. Still the question arises, how these techniques scale and whether the assumed progress in performance shown may be illusionary as the benchmark domains of the competitions might be fairly sequential, temporally simple and may include potential error-models in describing temporal domains [7]. PDDL is dominant, but seems to be insufficient in modeling domains which require concurrency [7].

Real world environments possessing concurrency require at least mixed methods. Especially in a continuously changing world, sequential planning hast to be questioned permanently performing adaptations in planning as specific preconditions change triggered by exogenous events and goal deadlines. This strategic adaption process, as introduced by [1] can use mixed models, where simple locally optimized decisions might be overruled by computational extensive planning providing guidelines during runtime.

B. Neurological and Psychoanalytical Concepts

According to Damasio [8] goal oriented actions are guided by *images* which allow the human mind to choose among patterns and optimize these actions. These *images* are individual, refer to the experience of an individual and can be used – automatically and deliberately – to review mentally different options of actions, different future scenarios and different results of actions. After evaluating these actions, the human psyche is able to pick and choose the most appropriate action and reject the inferior alternatives.

Furthermore, *images* allow an organism to invent new actions to be applied to novel situations and to construct plans to achieve goals [8]. If an organism is confronted with a novel situation, stored *images* are accessed to retrieve possible reactions. Following the research results from Damasio, the ability to transform and combine *images* to different actions is mandatory for the creation of new and goal deliberate actions.

It is the task of a self-aware organism to adopt its action-planning by *images* to purposefully interact with its environment. This means for an efficient human psyche it is necessary to focus on the processing of *images* which represent the objects and events which exist inside and outside the organism. The effect is a purposeful preview and optimal planning for ordinary and extraordinary situations which an organism can be confronted with [8], p.19].

Solms [5] describes the process of executing actions in a neuro-physiological way, as a permanent operation between the action execution system and the perceptual system of an organism. He describes a *feedback-loop* [5], p. 27] that guides an action via perception. This self-monitoring is used to control the effects of the executed actions by asking: "Has the situation changed now? Has what I wanted to achieve occurred yet?". This means action planning is always guided by controlling the environment and evaluating the environment towards the desired goal. This evaluation is used to control the execution of the current plan.

The planning system of the human psyche generates purposefully planed actions. For efficiency reasons it mentally evaluates actions without endangering the body by executing actions in the real world. This prevents the usage of actions without an estimation how this action will succeed in the agent's environment. Trial an error is possible on the level of imagination and by doing so goal-oriented actions can be selected. For this functionality, which Solms calls "*feedforward-function,"* stored images are essential [5], pp. 26].

The psychoanalytical concepts of *thing* and *word presentations* and primary and secondary process are used in the functional model of project ARS to build data-structures which work according on how information is computed in the human mind. In the so called *primary process*, merged sensor-data is the base for *thing presentations* which are connected by *associations* und computed according to the psychoanalytical description of the mental apparatus. In a second step merged *thing presentations* - which passed a so called *defense process* and which are often validated by a quota of affect - are connected with *word presentations* to a combined data-bundle. That means *thing presentations* are "named." A *word presentation* itself is a connection of all stored sensor-data of a word of the natural language [9], p. 607-608] like described by Freud. Now in a so called *secondary process* the *word presentation* is used for further computation, although beneath the *word presentation* the before mentioned thing presentation still exists. The *word presentations* in the *secondary process* can be used for deliberate, logical processes in comparison to *thing presentations* which cannot be used for logical processes.

The planning process can only use *word presentations* (and quota of *affect*) from the data-bundle to generate plans and use data deliberately. *Thing presentations* remain in the background. The composition of *word presentations* forms a coherent entity which describes a situation in a wider scope.

In course of the development of the action planning system, the combination of word presentations is called *image* which can be used for the generation of action plans.

III. Neuropsychoanalytical Action Planning System

Following the principle of *images* outlined above, a system can be designed that uses a snapshot of a situation to describe the initial situation of the environment before an action was executed and another snapshot, to outline the outcome after an action was executed. Like described, in the human deliberation process snapshots are also used to store information about an action for example how the action succeeded in various scenarios or to describe the side-effects the action has on the agent's environment. Following these concepts, snapshots of situations – in a neuropsychoanalytical way – can be used as basis for the construction of an action planning system inspired by the human psyche.

For the development of a homogenous model of the human deliberation process, data types have to be adapted to avoid a mismatch of various domains. Known data types from programming languages can be used for specific implementation purposes, but for the modeling process of the planning system, psychoanalytical and neuropsychoanalytical concepts are used. This ensures the creation of a consistent model and avoids the creation of a patchwork of different and contradicting disciplines. When following psychoanalytical concepts of Freud [9], p.607-608], the basic data types of the human psychic apparatus are grouped in thing presentations, word presentations, affects and associations.

As described in [10], thing presentations and word presentations consist of an identifier and a value. For example, a word presentation or a thing presentation can be *shape:round* if this thing/word presentation is part of a round object. Like outlined in the section before, thing presentations and word presentations are distinguished in the way data is processed. Thing presentations represent unordered, raw sensor data whereas word presentations contain logically and temporally ordered data. Only word presentations - since they contain ordered data - can be used for goal oriented mental processes like planning or deliberately decision making. Following these concepts, for the development of the planning system, word presentations are the data types which have to be used.

Nonetheless, within project ARS a complete model of the human deliberation process is developed - including thing presentations and their conversion to word presentations - in this article, only word presentations are considered.

The third data type which can be identified, namely the affect, is used to evaluate information. By combining affects with word presentations, individual experiences can be stored to objective and impersonal data. By doing so, actions can be evaluated in respect of how they influenced the agent's situation in the past or which effect the interaction with an object had.

Based on word presentations, snapshots of situations are defined as images in project ARS. Like described in [11], an image outlines information about a situation in a certain time-slot. Dynamic content is not included in this abstraction level. To create images out of word presentations, word presentations are related to each other by associations. This set of information, namely an image, represents a situation sufficiently to describe the initial situation of the environment before an action was executed and the effect of the action on the environment after the action was executed.

In Fig. 1 an example image is shown. In the situation the agent recognizes a table with a cake on it. The objects cake and table are connected by the association *on*. The third object in the vision area of the agent is a chair which is not connected by an association to the other objects. If the agent's desired goal is to eat the cake on the table, the planning system starts by searching for an action which meets the precondition image of the current perceived situation. All actions which have a precondition image that fits the current situation can be used as initial action.

An example precondition image of an action which can be applied in the situation outlined by Fig. 1, is illustrated in Fig. 2. Because the distance and the direction to the table match, the image matches with the situation. In the matching technique, no elimination attributes are added. This means, all properties of the precondition image have to be present in the situation perceived by the agent's sensors.

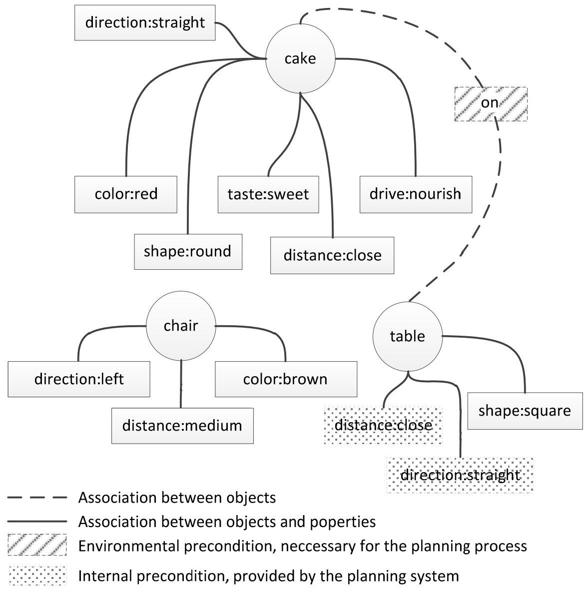

Fig. 1. Image – snapshot of a situation

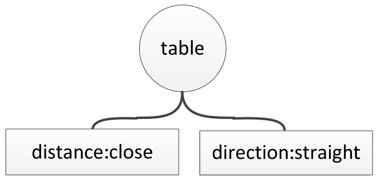

Fig. 2. Precondition Image

Following the concepts about images and the human action planning process, the transition from one image to another image can be described as an *action*. A diagram can be found in Fig 3. The image which describes the initial situation before the action was executed is called *precondition image* and the image which describes the actions effect on the environment is called *effect image*. The change, respectively the change recognized and deliberately intended by the agent, is called *action*.

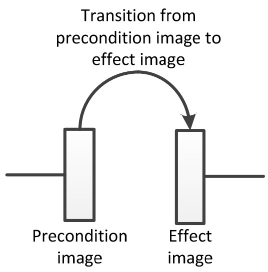

Fig. 3. Action

Based on these concepts, an action consists of three basic information parts, namely the precondition image, the effect image and the information, what kind of activity has to be executed to alter the environment from the current situation (which meets the precondition image) towards the effect image.

By the use of images to describe the environmental situation at a given point in time, actions are combined to action sequences. The last effect image of an action sequence describes the result of the action sequence. To achieve a certain goal, the planning system searches for a set of actions and combines them in order that the effect image of the last action has the desired effect on the agent's environment. A combination of actions to an action sequence is shown in Fig. 4.

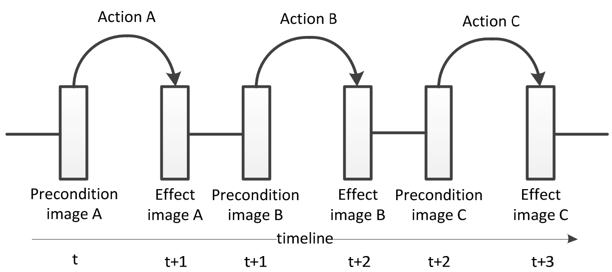

Fig. 4. Action Sequence

The planning process starts at time point *t*. This is the current situation the agent perceives by its sensors. The precondition image of *Action A* matches with the current situation. The desired goal the agent wants to achieve is described by the effect image of *Action C*. To alter the agent's environment towards the goal described by the effect image of *Action C*, the agent has to execute the action sequence from *Action A* to *Action C*.

To produce an action sequence like described above, actions have to be combined. The combination of actions is based on the *effect image* and the *precondition image* of two actions. According to the example above, *effect image* of action A and *precondition image* of action B match and therefore the actions can be combined. Respectively action B can be executed after action A was executed. The effect of the first action will provide the necessary changes to the environment, to ensure that the following action can be applied.

Like shown in Fig. 4, an action sequence consists of a set of actions which describe the changes of the environment during action execution. This process can be seen as inversion of scenario recognition concepts like described in [12]. In scenario recognition an action is analyzed, based on the changes an action causes in the environment. By doing so, a dataset gathered by sensors on a certain frame rate is analyzed. This data can be seen as a time-ordered set of images. In case of action planning, the process is reversed. A set of actions is executed in the environment with the aim to change the environment. While executing an action plan, the agent produces a set of images which represent the agent's action sequence respectively the agent's plan.

During the planning process, the system has to distinguish between environmental preconditions and internal preconditions. This distinction can be seen in Fig. 1. Objects marked shaded, like in the shown example the relation between the cake and the table, are necessary for the last action and will not be established during the execution of the previous actions. The relation between cake and table is necessary for the execution of the last action. The last action can be executed, since this precondition is already present in the current situation.

The internal preconditions, marked dotted, are provided by the previously executed actions. At time point *t*, none of these properties exists, but after executing the set of actions, all requirements will be provided to match the requirements to execute the last action. Following the example, by executing the action sequence, the distance to the table will be reduced to provide the necessary precondition for the last action – which is to eat the cake. Nonetheless, the distinction is important, since this saves the system from the overhead of creating longer plans. For example, if the system would not check if the cake is on the table, probably an action plan for putting a cake on the table would be necessary.

A crucial part of the system is the matching technique between images. An image contains all available information about a situation. It is the task of the matching system, to decide whether the precondition image is different from the current situation or not. Based on the matching technique it is decided if an action can be executed or not. In the current implementation all data of the precondition image of the next action that will be executed are treated as necessary data. By doing so an action can only be applied when the sensors perceive a situation which contains all data of the action's precondition image.

Although the system uses an abstraction system[1] at this level of the deliberation process, the difference between objects is still relevant. Variations of the matching technique will be helpful to increase the flexibility of the system. By providing a softer matching filter, more actions can be combined which allows a greater variety of possible plans. Possible looser matching between images relies on the action

[1] Within project ARS the perception system maps sensor data to stored information. This stored information is further used and the raw sensor data is discarded.

execution system which has to apply an action to an environmental situation that does not perfectly suit the requirements. For example, the agent is facing a table diagonal in front of it while the action requires the agent to face the table straight, the action execution system has to handle the difference.

In order to generate a goal-oriented plan, the planning system starts by searching for an appropriate action which has a precondition image that fits the current situation. The search process is continued with the effect image of the first action in order to find a second action that can be combined by its precondition image to the first one. This process is continued until the desired goal situation can be reached by the generated plan.

Fig. 5 illustrates an example action in a higher detail level. Like outlined before, the action consists of a precondition image and an effect image. The action is evaluated by a dedicated drive and affect. These data types are used to store information about previous experiences the agent had, when executed this action. This enables the action planning system to generate an evaluation of actions based on previous gained feedback of the environment concerning the execution of this action. For example, if the agent got injured after it executed this action (for example touching a hot object), it will probably avoid this action in the future.

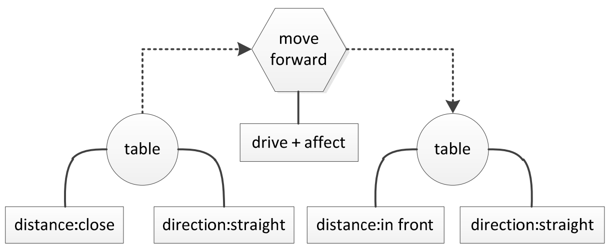

Fig. 5. Example action

During the execution of the plan, the success of each action is evaluated after the action was executed. This is done by comparing the information about the current situation of the agent's environment to the precondition image of the following action that was planned to be executed. If the precondition image of the following action matches with the data about the environment, the previous action was executed successfully. This evaluation process makes sure to keep track of changes in the environment concerning the current plan and enables to control if the previously generated plan still can be executed in the environment.

By this constant supervision process the response to side-effects can be kept short. For example, if for some reason the desired goal was reached earlier, the current plan can be shortened or stopped. This constant evaluation and re-planning of action plans is in line with the neuropsychoanalytical concepts about the human planning process investigated by Solms [5] and outlined in the section before.

IV. Implementation and Results

To test the developed planning system, a simulation environment based on the multi agent simulation toolkit MASON was developed [13]. Within the simulation environment embodied agents have to fulfill use-cases to evaluate the performance of the planning system. It is not the aim to simulate real world interaction by this simulation, more it depicts the problem solving capacity of the agent in various scenarios. The use-cases vary in their demands on the planning system, starting with simple tasks and extend to complicated, nested goals.

For the implementation of the search module of the planning system a bidirectional search was sufficient. To generate a goal-oriented plan, the system searches simultaneously from the initial situation and the goal situation until a connection for both states is found. This search proved to be faster than a single-direction search technique. Though the environment is kept intentionally simple, computational problems did not arise when using a bidirectional search. Although, with a growing knowledge base that has to be searched for relevant actions, performance issues will grow important in the future.

To evaluate the planning system an environment was designed that consists of various static objects including energy sources and immoveable objects. The energy sources could be eaten directly from the agent without any further processing like cooking or peeling. The task of the agent is to find and consume energy sources when it runs out of energy. Though the agent's vision system is limited to a certain distance, the agent has to search for the objects if it cannot see them directly.

Based on a sufficiently large set of available actions, the planning system is able to create plans toward the desired goal, situated in the above outlined scenario. The agent is able to create action plans to satisfy its demands in the simulation environment. Since learning is not included in the system at the current developmental stage, the agent cannot include changes within its environment into its world-model. For example, if the agent consumed a rotten energy source and becomes sick in cause of that, it does not store this kind of information in its knowledge base. Although, if the agent has this information previously in its memory when the planning system is creating an action-plan for this scenario, it is able to avoid negative effects and include this kind of information in its action plan.

This situation has to be distinguished from disappearing objects. For example, if an energy source disappears because it was eaten from another agent, the current plan is adapted to the changed environmental situation. The planning system uses sensory information to decide if plans have to be changed.

With the introduced implementation and simulation the general feasibility of the neurologically and psychoanalytically inspired planning system was demonstrated. Nonetheless, the planning system and especially the search technique have to be refined, but the feasibility for minimized simulated environments is demonstrated by the model, its implementation and the simulation including the use-cases to evaluate the problem solving capacity.

V. Conclusion and Future Work

This paper presents a new approach to action planning for autonomous systems which in contrast to existing action planning systems is based on homogenous, consistent neuropsychoanalytical concepts of the human deliberation process. This helps to bring the flexible, adaptive behavior of the human mind under uncertain environments with constantly changing situations requiring continuously decision making and action planning, to automation applications. The described action planning system is based on a homogenous model of the human mind including psychoanalytical data types, self-awareness and decision making involving primary and secondary process. By using this functional model and the underlying data types, the action planning system is able to produce situation specific action plans in order to reach certain goals.

Although the feasibility of an action planning system based on concepts about the human mind is shown by the introduced system, it is a first step to enrich artificial systems with the powerful problem-solving capacity of the human psyche to endow interaction with real world environments.

In the next step the architecture needs to be enhanced with a hierarchical structure representing concurrent planning strategies on different abstraction levels. A plan on the highest abstraction level gives the predominant intention in the biggest possible planning scope. This can be broken down into more detailed plan fragments which on the lowest level are explicit commands and actions based on given rules, as described in the previous sections. The hierarchical structure is a crucial part of the system since a layered model has to be designed to describe the refinement from a master plan to smaller, concrete sub goals. This will endow the system to handle different sub goals independent and optimize the planning strategy.

Though the current implementation is executed in a simulated environment, the execution system is relatively simple. When the system is brought to real world domains, new challenges will arise.

The evaluation of the system can be derived based on the existing common (human) knowledge, split down in every-day-life-scenarios that are the target domain of these systems. This shall help to prioritize and label actions and their potential outcome (results).

In order to extend the knowledge of the agent, learning will be an important issue soon. Since now, all information is pre-saved in the agent's memory. In future applications the action planning system will be adapted to store information about success or failure of an action or an action plan. This helps to interact efficiently with the environment and adapt to changes in the agents world.

With a growing knowledge base the search space for the action planning process will grow as well. This aspect will have heavy impact on the performance demands of the search algorithm. In future work the search for possible action plans has to be adapted and optimized to this growing demand or alternative planning methods have to be developed. Other problems known from logical planning systems, like the frame problem or the ramification problem have to be handled in future work.

The system aims to optimize planning with concurrency and evaluation that may come close to human behavior in order to work and cooperate with human operators in a for the user comprehensible way. This is the first step to design systems that are like autonomous cooperating colleagues for humans rather than mere tools.

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