ARTICLE IN PRESS

Biologically Inspired Cognitive Architectures xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Biologically Inspired Cognitive Architectures

journal homepage: www.elsevier.com/locate/bica

Behavior planning of intelligent agent with sign world model

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ARTICLE INFO

Article history:
Received 25 October 2016
Revised 21 December 2016
Accepted 23 December 2016
Available online xxxx

Keywords:
Behavior planning
Sign world model
Sign image
Sign significance
Sign personal meaning
Causal matrix
Semiotic network
MAP algorithm
Case-based planning

ABSTRACT

Behavior planning is an important function of any complex technical facility intelligent control system. Presently, a symbol paradigm of artificial intelligence offers a variety of planning algorithms, including those that use precedent information, i.e. algorithms based on acquired knowledge. A symbol grounding problem within the exiting approaches of knowledge representation does not allow effective use the developed algorithms together with learning mechanisms for the purpose of solving a wide variety of applied problems by actual intelligent agents (robotics systems). This article presents the original planning algorithm (MAP Planner), which uses a sign world model as the basis for acquisition and maintenance of knowledge for future use in behavior planning. the sign problem approach describes planning as a cognitive function actualized by the world model of a subject of activity. Apart from solving symbol grounding problems and ensuring psychological and biological plausibility, a sign planning process model allows interaction of an intelligent agent with other participants in solving a cooperative task. The article presents the description of the knowledge representation method used, a MAP planning algorithm, and a model experiment in a "block world".

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Introduction

The issue of behavior planning of a complex technical or virtual subject has a long history and is mainly associated with the successes in specific area of the Artificial Intelligence discipline — automatic planning. In this sphere, considerable success has been achieved and a number of sign-based planning methods were proposed — both for classical problem definition, where actions are deterministic (these are such planning algorithms as FF Hoffmann & Nebel (2001), FD Helmert (2006), LAMA Richter & Westphal (2010)), and in non-deterministic definition, which takes into consideration the nonzero probabilities of non-appliance of actions and probabilistic environment reaction (algorithms based on Markov processes and dynamic programming Barto, Bradtke, & Singh (1995) and Bonet & Geffner (2009)). However, the development of effective and fast planning algorithms is based on the preset heuristic graph search principles and on the assumption that a set of actions is known in advance, which makes a planning systems automatic adaptation to new problems with a new list of actions impossible. This implies that classical approaches do not offer a carry-over of planning experience or abstract actions, which may have varying realizations in different situations. Substantial challenges arise when the existing algorithms are adapted for multi-agent applications, which suggests that agents possess both different action sets and different knowledge of the environment Brafman (2015). In case of cooperative interaction, it is also necessary to ensure non-discretionary incorporation of learning elements to augment the database of an agent with information supplied by other participants of the group.

In more recent times, researchers in the fields of control and planning theory have focused on psychologically and biologically inspired models and architectures of agent control Kelley (2006) and Sun and Hélie (2012). The use of different types of memory (episodic, procedural, etc.) in cognitive architectures is aimed exactly at solving the task of reproducing biological and psychological methods of information interchange and organization to solve such problems as behavior control and planning. This is primarily driven by the fact that the increasing complexity of tasks performed by robotics systems (agents) requires their higher self-sufficiency, versatility, and flexibility, which the existing methods and algorithms are unable to provide. Researchers in the field of Artificial Intelligence once again turn to the natural examples of such problem solving — to the research of human and animal behavior Redko and Burtsev (2016) and Panov and Yakovlev (2016b). Psychologically inspired models of cognitive functions (including planning) are focused both on reproducing human behavior in complex, specifically cooperative conditions, and at complying, as fully as possible, with the existing psychological

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http://dx.doi.org/10.1016/j.bica.2016.12.001
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Please cite this article in press as: Panov, A. I. Behavior planning of intelligent agent with sign world model. *Biologically Inspired Cognitive Architectures* (2017), http://dx.doi.org/10.1016/j.bica.2016.12.001

concepts of human mind functioning. On the one hand, this may result in an increased resource intensity of the proposed algorithms, but, on the other hand, it will allow a realization of new possibilities, which previously had been left out of the scope of problems tackled by planning specialists, such as goal-setting or role designation capacity. In the past, cognitive psychology concepts have been also used in classical planning; however, mainly in behavioristic agendas. For instance, the concept of dividing the entire multiplicity of actions into automatic, fast actions, specific, voluntary actions and generalized actions predicted by psychological theory Kahneman (2011) was implemented by hierarchical planning and the concept of planning experience maintenance — in precedent planning Hammond (1990), De La Rosa, Garcia-Olaya, and Borrajo (2013) and Borrajo, Roubíčková, and Serina (2015).

Cognitive psychology has a number of branches that study the phenomenon of planning, within which three main areas should be mentioned: planning as part of a cognitive scheme Neisser (1976), planning as a meta-process Flavell (1979) and Sternberg et al. (2000) and planning as part of an activity Leontyev (2009). The first branch uses cognitive schemes to describe behavior of humans. For example, a perceptive scheme is a program of gathering information about objects and events, as well as acquisition of new information to provide its consistent interpretation. The scheme simultaneously incorporates a plan and its implementation; it is both an actionable structure and a structure of actions. The second approach provides for the existence of metacognitive processes allowing a person to control his/her cognitive processes and knowledge. From Sternberg's point of view, one may talk about global (strategic) and local (tactical) planning. Global planning requires more time, but this is compensated by the reduction of time dedicated to local, tactical planning. Finally, the third approach, which is one of the most general concepts, considers hierarchical activity theory. This theory is used in this article and is described in the following section.

It is also worth mentioning that psychologically and biologically inspired control and planning models provide a new perspective to the symbol grounding problem Harnad (1990), Barsalou (1999), Chella, Frixione, and Gaglio (2003) and Besold and Kuhnberger (2015). Neurophysiological models of brain cortex sensor region functioning together with psychological categorization and perception theory form the basis for the development of new consistent models of association of symbols and sensor data. Success in this field has made it possible to implement certain models in robotic systems Heintz, Kvarnstrom, and Doherty (2010).

This article will present a new psychologically and biologically inspired method of behavior planning based on sign theory of activity and structural models of cortical-thalamic regions of brain. Apart from its value in terms of modeling of human cognitive functions, sign approach may be used to solve a number of cooperative robotics problems (e.g., for intelligent movement problems Panov & Yakovlev (2016b, 2016a)), which cannot be solved by classical or other psychology-oriented methods (such as BDI Sardina, Silva, & Padgham (2006)).

The main purpose of the article is to demonstrate the sign approach for modeling of such an important cognitive process as a behavior planning. The proposed planning method (MAP-algorithm) does not build more efficient plans than other existing planners and is faced with the same problems (such as a Sussman anomaly). Also considered is that MAP-algorithm does not use all components of a sign leading to a simplified model similar to a frame approach and rule systems. However, inclusion of the learning process and another components of the sign enables us to describe the goal setting process and models of coalition formation Skrynnik, Petrov, and Panov (2016) and Osipov, Panov, and Chudova (2014).

This article is further organized as follows: Section 'Sign world model' introduces the main concepts used in the article: a world model, as well as a sign and its components are defined and substantiated from psychological and biological standpoint. Section 'Sign elements' introduces the concept of a causal matrix as a mathematical structure for the description of sign components and considers its main characteristics. Section 'Causal network' discusses the networks, which are formed on the basis of sets of causal matrices and which represent relations of sign components. Section 'Semiotic network' introduces the concept of semiotic network as a model of world model and discusses the main types of processes of activity propagation within a semiotic network. Section 'Planning in sign world model' presents the description of a MAP algorithm of behavior planning in a sign world model (in a semiotic network). Section 'A model experiment: cube world' concludes with a model example of operation of the presented MAP Planner.

Sign world model

In this article, the method of knowledge representation is based on a sign world model Osipov et al. (2014), Osipov, Panov, and Chudova (2015) and Osipov (2015), which both stores knowledge about objects, processes and relations of external environment and represents the internal parameters of the intelligent agent that determine its motivational constituent and activity experience. The world model also includes the procedures of operation with knowledge, its acquisition and its use in various processes, such as perception, reasoning, goal-setting and behavior planning Osipov et al. (2015). The representation of the world model is based on psychological concepts of human brain functioning, in particular on the concepts of cultural and historical approach Vygotsky (1986), activity theory Leontyev (2009), Verenikina and Gould (1998) and Igira and Gregory (2009) and dual systems Evans and Stanovich (2013) and Stanovich (2009). According to psychological views, a world model component is a four-element structure: a sign, which represents all entities of external environment and inner space for the subject (in our case, an intelligent agent); objects and their properties; processes; and relations between objects and processes. It should be noted that a sign is a product of interaction between several subjects of activity forming a certain group (a cultural environment), thus, the concept of a sign inherently assumes that an individual's world model interacts with the world models of other individuals.

Below we will give informal definitions and examples of a sign and each its components and then introduce a formal structure (causal matrix) (see Section 'Sign elements') to define all of them more precisely.

An image element of a sign holds specific attributes of the represented entity and, at the same time, is a function of representation of the entity on the basis of the stream of data drawn from both external and internal sensors, in which key attributes are distinguished. An image element is individual for each bearer of a world model and is formed as the result of observation and generalization Osipov et al. (2015) and Skrynnik et al. (2016).

An element of significance for a sign represents the generalized conceptual knowledge of a subject about the entities of the external environment, as well as about the internal space, both its own and that of other participants of the group. This knowledge is coherent, that is, similar for all representatives of the group. Communication processes occurring in a group of subjects (intelligent agents) are based on the messages built with signs having common significance, which in such way determine the syntax of the communication protocol.

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