Control of vehicles and robots: creation of planning systems in the state space (MIPRA)

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Abstract. To control machines and robots, in addition to the well-known reflex level control systems, it is proposed to use logical level decision-making systems that are created on the basis of mivar expert systems. It is shown that the use of mivar expert systems makes it possible to solve problems of automatic planning of actions of robots in the state space. These tasks relate to STRIPS planning. The results of the study of the Mivar-based Intelligent Planner of Robot Actions (MIPRA) project have dramatically reduced the computing infrastructure requirements from servers to conventional computers and the time it takes to plan tasks for robot activities from weeks to seconds. Similar results after creating special knowledge bases can be obtained for groups of robots, multi-level heterogeneous robotic systems and cyber-physical systems of various bases and purposes, which is an important section in the control of machines and robots. Solving automatic planning tasks makes it possible to quickly develop driver assistance systems and move on to creating a fully autonomous smart car.

1. Introduction

The creation of intelligent robotic systems (RS) and robotic systems is currently an actual area of scientific work. Recently, a new term has appeared: cyber-physical systems (CPS), which combines robotics, and the Internet of things, and other scientific fields in which physical systems are studied with the ability to control their subsystems and / or elements. Of particular interest are complex CPS operating in dynamic and complex external conditions. By analogy with the Internet, which connects different networks, modern CPS can also consist of different cyber-physical systems and subsystems, united for some time to perform a specific task into some “CPS complexes” or metasystems from various CPS. This raises an important task, how to manage such metasystems and complexes. Note that the Mivar-based Intelligent Planner of Robot Actions in various state spaces (MIPRA) developed as a part of research at a logical level in the field of Artificial Intelligence (AI) can be used both for individual robots and for all kinds of their associations, up to metasystems and complexes.

Back in the 60s, at the initiative of the Artificial Intelligence Center of Stanford Research Institute, the Shakey project [1] was launched, which influenced the formation of a systemic idea of machine learning, methods, computer vision and understanding of natural speech. One of the important tasks of this project was the study of reasoning systems aimed at planning the actions of robotic devices. The solution to this problem was presented by scientists in the form of STRIPS (STanford Research Institute Problem Solver) [1]. The ideas embedded in the STRIPS algorithms are borrowed from the theory of
the General Problem Solver (GPS) [2]. The universal solver was based on the method of analysis of ultimate goals (Means-ends analysis, MEA) [3]. This approach implies that the solution to the problem can be described by finding a sequence of actions that lead to the desired goal. The STRIPS challenge has given rise to numerous researches in state-space planning. The importance of real-time solving of intellectual planning problems is only growing, thanks to the discovery of new methods and tools for training convolutional [4] and recurrent neural networks [5], the use of signed world models [6] as the basis for acquiring and maintaining knowledge for future use in behavior planning [7].

A new approach is proposed which involves the use of Mivar expert systems [8] with linear computational complexity of logical inference [9] for solving the STRIPS planning problem [1] in the modified classic Blocks World domain [10]. Earlier, the Mivar approach and the "Razumator" software product, on which the WiMi CESMI is based, was successfully applied in automated control systems [11], in decision-making systems for smart unmanned vehicles [12, 13], in the design of a platform for intelligent analysis of road transport accidents [14] and in the medical decision support system [15].

In addition, in our work, we made architectural decisions of the Mivar control system for monitoring the enforcing traffic regulations (MCS TR) [16], which helped to quickly solve the problem of developing the MIPRA [17]. It should also be noted that the MIPRA intelligent planner can work within the framework of hybrid intelligent information systems [18, 19], which include software modules based on Metagraphs [20-22], cognitive computer graphics [23], neural network algorithms [24] and methods of intellectual analysis [25]. In general, all of the above scientific results will be used to create a strong hybrid artificial intelligence, which is also called "general" AI (AGI).

2. Description of the task of mivar planning of actions of the robotic complex

The MIPRA project was first presented in [17] and described the solution to the "permutation of cubes" problems. An example of such a task is presented in figure 1. On the table at the specified sites number 0, number 1 and number 2 are placed towers of cubes. The initial position of the cubes on the table (Initial State) describes the initial state of the domain of the task. It is required to draw up a robot action plan, during which the cubes will be placed in the specified (target) position (Target State). Cubes can be placed either on empty numbered areas, or on top of each other. A detailed description of the "picture of the world" or the "domain of the problem" in which MIPRA operates is given in [1, 9, 17].

![Figure 1. An example of the problem of "permutation of cubes"

It is well known that "permutation of cubes" is a specially invented model problem, even some game with fairly simple rules, but even such a problem could not be solved for a long time at an acceptable time. The main reason was that when planning actions from a certain set of rules and using "pre-mivar logic", the researchers came up against the problem of actually double exhaustive search when trying to compose an algorithm for robot actions to achieve the goal: from one state of the pyramids with cubes it was necessary to go to another state with the same cubes. We emphasize that it was considered a good result to solve, for example, the task of rearranging 10 cubes in 10 hours using powerful multiprocessor servers. We emphasize once again that this is actually a double search of all possible options. For
comparison, we present the results from [17], in which the tasks of rearranging 300 cubes are solved in less than 90 seconds on one ordinary serial processor, for example, a laptop. The cardinal acceleration and the transition "in practice" to polynomial complexity (quadratic dependence) are obtained.

It is clear that the task of planning the actions of the RS and various systems and complexes of the RS, as well as cyber-physical systems, is in general more complicated than a simple permutation of the cubes. But this difficulty consists only in the need to compile a new mivar database and rules for the used RS, CPS and their complexes. Currently, such knowledge bases in the mivar network formalism are created by human cognitive scientists based on the study of various instructs for RS and descriptions of the subject areas of application of RS. It is as an analogue for real RS that we will consider the task of rearranging "cubes" [17]. To solve this problem, Blocks World [10] identified the main possible objects and rules, on the basis of which the required Mivar network was then automatically generated to solve the problem with a specific set of cubes and pyramids, as well as one robot manipulator.

We emphasize that the task of planning actions for rearranging cubes for a robot is a modification of the classic Blocks World domain [10]. In this domain there is only: cubes, a table and a robot. From cubes create towers of various heights, including a height of one cube. In total, according to the conditions of the problem, a maximum of $M$ towers can be arranged on the table. Then the task of planning the CPS is as follows: you need to build a robot action plan for rebuilding from the initial state of the towers from cubes in space to the desired state of the towers. An important limitation: the robot is equipped with only one arm-manipulator for moving cubes and technical vision tools that allow you to recognize the position of the cubes in space.

If in the task the number of pyramids or manipulators of the robot is changed, it will be necessary to create a new Mivar network for describing the task. These studies will be continued, and now, by analogy with the Shakey project [1], it was decided to fix the number of pyramids, which is equal to 3, and limit itself to 1 robot manipulator. But depending on the number of cubes, specific mivar networks were generated automatically. For example, to rearrange 300 cubes, a mivar network consisting of 3311 objects and 1200 rules was automatically generated [17].

To create planning systems in the state space, depending on the conditions of the task description, it is necessary to compose or develop the required new mivar networks that describe the specifics of a particular task. As an example, we will show the transition from architectural solutions to the MCS TR [16] to the creation of the logical intelligent scheduler MIPRA [17]. At the entrance to the system, data is received from the technical vision systems, car sensors and the navigator, then the information is processed to fit the parameters of the mivar models. These models are created in advance by experts in cooperation with cognitive scientists – knowledge engineers. We emphasize that Mivar models correspond to sections of the traffic rules. Further, the obtained parameters are stored in the working memory – the memory area in which many facts are accumulated that describe the current state of the subject area, which is a description of the traffic situation. To solve the problem of making recommendations on driving a vehicle (or monitoring compliance with the rules), I will transfer to the system a description of the current traffic situation, and "Razumator" performs the automatic design (construction) of the maneuver algorithm. Then each step is placed on the action stack and the resulting set is sent to the driver information system, thereby completing the processing of the task.

To solve the problem of traffic control, when the system is required to evaluate the actions of the driver, information about the perfect maneuver is supplied to the system input along with the characteristics of the traffic situation. In CESMI WiMi "Razumator", an algorithm is constructed from the set of actions required from the driver and the resulting set of actions (algorithm) is compared by the actions performed by the driver, and the result is issued to the driver information system. It is clear that the result of the assessment of the driver’s actions can be transferred to the owner of the car, insurance company, dispatcher in the case of work on the transport of goods or people, or immediately to the traffic police to take measures to punish violators.

The traffic rules described by Moscow traffic laws were published at the beginning of 2018 [16], and at the beginning of the work on planning the actions of machines and robots it was revealed that these architectural solutions can be successfully applied in the development of MIPRA [17]. Let us consider
the architecture of MIPRA. In the architectures MIPRA and MCS TR there are differences that are determined by information flows. The MIPRA system receives a planning task and it generates (in some cases, automatically) a Mivar network describing the subject area of the task. The model generation algorithm is designed to decompose the planning task into subgoals. The consistent achievement of subgoals leads to the solution of the problem. A plan of a step is a set of actions, by performing which one can gradually approach the achievement of an intermediate goal. After completing the step, MIPRA analyzes the information about the current state and builds a new action plan for the step, which is issued for execution to the robot. Further, in the decreasing cycle "loading the current situation → generation of the step execution plan" all intermediate goals are achieved and, therefore, the solution to the problem of rearranging the cubes in the towers is found.

The theoretical basis, test bench and practical results obtained in the development of MIPRA were applied in the further implementation of the Moscow traffic laws. Our theoretical results will allow us to put into practice a project that is conventionally called: "smart cars on smart roads and in a smart city" [13].

3. Conclusions
The Mivar approach and architectural solutions used in the development of the mivar control system for monitoring the enforcing traffic regulations allowed us to move on to the development of a new class of systems – logically reasoning intelligent planners.

Practical experiments have shown that instead of many hours and powerful multiprocessor servers, the Mivar scheduler on a regular computer solves the task of rearranging even 300 cubes in less than 90 seconds. At the same time, MIPRA automatically creates a mivar model with 3311 parameters and 1200 rules, which with other approaches requires double exhaustive search and the computational complexity will be more than 1200! (factorial) and will require billions of years to solve.

The created MIPRA software product, based on the Mivar "Razumator", qualitatively reduces computational complexity and many times (by orders of magnitude) speeds up the algorithm construction time for solving robot action planning tasks (STRIPS) for moving cubes in the Blocks World domain.

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