PLANNING THE ACTIVITY OF ROBOT WITH ARTIFICIAL INTELLIGENCE

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Abstract

The paper deals with a number *of* problems involved In planning a robot's activity. A formalized statement of the planning problem Is proposed and the theoretical principles of design and requirements to structure of the problem environment models and planning algorithms are discussed. A problem environment model is conoelved as a set of interrelated data on the real world of a robot's functioning that are necessary and sufficient for the solution of all problems belonging to a certain class. Algorithm is understood as a generalised procedure defined on a problem environment model.

Let us consider the functioning of a certain class of artificial systems performing actions in a three-dimensional space. We shall introduce the notion of the working space of a system, conceiving it as the space which is physically accessible to the system for performing the actions it commits. Then by robots we shall understand a class of functionally similar automata having a memory and intended for executing directed changes of the properties of the components of environment or relations between these within their working spaoe by means of manipulations with tools and (or)objects. We presume the existence of potential feasibility of manipulating according to any spacial law.

The simplest robots are devices functioning on the basis of a rigid program. Programs are supplied to the robot to be subsequently implemented in the form of certain influences on the environment in a sequence which is in advance defined by man (in the general case by a metasystem, i.e. system having a higher level of control as compared with the robot). Moreover in some cases the choice of actions of the robot may be additionally controlled by changes of its physical state and resource capacity. The further sophistication of the robots accompanied by an increase of their autonomy necessitates incorporating in their control systems such mechanisms as affoxd during the choice of action automatically to take account of situations arising in the robot's working space (and in more developed systems also situations embracing the entire problem environment of the robot is a pre-trained system classifying situations arising in the environment and choosing the a priori stated action sequences that are adequate to these situations. However, in complex environments involving a great number of components which affect the robot's activity, an a priori classification of situations may prove practically impossible. In this case the robot must be able to form independently the sequenoe of actions that would be adequate to any situation arising in the problem environment, i.e. it must be able to solve the planning problem. The control system of the robot must in this case be potentially prepared for executing a great set of actions in perception control of movement of executive organs, decision making and dialogue with the metssystam.

In posing tasks for the robot and correcting its activity by way of dialogue the metasystem proceeds from perception on analysis of a far wider problem enTironment than is accessible for the robot. In this sense the more perfect robots should be endowed with the capacity of an interlocutor with the metasyetem or an active observer of some of the components of its problem situation so as to take part in the metaaystem's task setting process and sometimes automatically to perform such an adjustment of tasks set before the robot by the metasyetem as would be desirable for the latter in taking account of the metasystem's problem situation.

One can visualize a system having "maximum" potentiality in this sense as a certain idealized autonomous robot which, being capable of adaptation and learning, could be able in any situation independently to form models of the results expected of it by the metaaystem in keeping with its functional purpose and efficaciously to achieve these results.

Efficient solution of the planning problem is a key aspect in the activity of any autonomous robot having a sufficiently high level of development. A more detailed analysis of this problem is the subject of the following discuesion.

Planning is understood as the task for the robot automatically to form a sequence of actions (by means of which it can influence the environment) as well as such corresponding subgoals achieved by fulfillment of these actions as would lead to the required goal.

To provide for the planning process, it is necessary to enter into the robot, before it begins to function, a model of the problem environment (henceforward,PE model) and algorithm-like information (henceforward,planning algorithm) reflecting the logic and information processing rules specified in the form of the PE model. In the general case the P£ model or fragments thereof may be formed and entered either by human operator or automatically with the aid of learning mechanism during preliminary eimulation of the robot's possible activity.

The model of problem environment is a totality of interrelated data about the real world where the robot is functioning which are necessary and sufficient for solving a majority of problems of a certain class. (The problem class is determined by the designers according to the robot's purpose). Since the P£ model is developed for the solution of a certain class of problems, information it contains should be problem oriented in the framework of that class. However, in the general case it does not seem possible to take into account in a P£ model all data that are necessary and sufficient for solving all problems of a given class. Furthermore,since robot's activity takes place in a real environment, information reflected in the P£ model is of a limited accuracy. Therefore in real cases one should reckon with the fact that PE model is incomplete and inaccurate.

Information contained in the PE model includes both data of a general nature that are valid for the entire problem class as well as special information valid solely for a given particular problem of the class.

The information of the former kind includes:

- data on the regularities of the real environment, i.e. data on environment components, ties and relationships existing between these components;
- data on the possible influences upon the environment on the part of the robot (actions) and the changes these cause;
- data on the possible changes in the environment independent of the robot;
- data on the robot itself and on its potentialities.

Information of the second kind which characterizes the conditions for the solution of a particular problem includes:

- data on the environment components which are concerned by the particular problem posed;
- data on the required solution result;
- data on restrictions imposed on the process of solution of the problem under consideration.

The major difficulties to be surmounted in solving the planning problem spring from the necessity of efficient representation of information about the real world in the framework of a certain formal system (in other worlds from the choice or development of a suitable language for the description of the problem environment) and also from the necessity of elaborating algorithms adequate to this representation and implemented in the same formal system. One such system is described below using the notions of set theory.

For description of the environment, abstract finite sets R, Π, B, S, are introduced which may be respectively interpreted as mapping, in the problem environment model, of the set of relations, characteristics, objects and situations existing in the real environment. For simplicity's sake, the terms situation, relatione, etc. will be henceforward referred directly to problem environment model without additional stipulation. Each feature $\Pi_i \in \Pi$ may assume a certain finite set of values $\{\pi_i^{j_i}\}$ which is either a subset of real numbers or an ordered set whose elements are qualitative descriptions. Among the elements of $\pi_i^{j_i}$ there can exist the element λ which designate the absence of a characteristic.

Within the framework of the formal system the concept of structure is introduced. The simplest structure is a triplet $x_i \tau_k x_j$ which may be interpreted as a proposition. The other types of structure can be represented as a set of triplets $\{x_i \tau_k x_j\}$

where x_i, x_j are the elements of the set of relations, characteristics, characteristic values, objects, situations and other categories introduced for representation of PE model

and τ_k are the elements of the set of relations.

Then the object $b_j \in B$ may be represented in two fashions:

$$b_j \longrightarrow \{b_j \tau_k x_i\} \qquad (1)$$

where $\tau_k \in R$, $x_i \in \{\pi_i^{j_i}\} \vee B$, b_j - the object being sought for. (In substantial terms this corresponds to representing the object through its relations with other objects or as the set of characteristic values)•

- or as a set of triplets of the type

$$b_j \longrightarrow \{x_j \tau_k x_i\} \qquad (2)$$

where $\tau_k \in R$, $x_j \in \{\pi_i^{j_i}\} \vee B$;

$x_i \in \{\pi_i^{j_i}\} \vee B$

(In substantial terms this corresponds to a certain structure to which the name of a given object b_j is ascribed).

Situation is understood as description of a certain situation in the environment taking shape under certain conditions. Presumably it is permitted to consider as the problem environment not only situations obtaining by fixing a certain time point but also situations due to fixation of other environment parameters. Examples of these are situation of hunger, thirst etc.

At the formal level, the situation $s_\alpha \subset S$ may be represented as the set of triplets

$$s_\alpha \longrightarrow \{x_i \tau_k x_j\} \qquad (3)$$

where $\tau_k \in R$, $x_i \in R \vee \{\pi_i^{j_i}\} \vee \Pi_i \vee B$;

$x_j \in R \vee \{\pi_i^{j_i}\} \vee \Pi_i \vee B$

The action $u_j \in U$ is introduced as the structure

$$u_j \longrightarrow \{x_i \tau_k x_j\} \qquad (4)$$

in which substructures are distinguished that characterise the conditions of applicability of the given action, the consequences of its application and the parameters liable to change. In the structure of the action the objects to which it may be applied are also specified.

Actions may be aimed at transformation of the environment or at its exploration (in particular, actions involved in perception of environment). In the latter case the result of application of the action will be a change not of a real environment but of the notion the robot has about it. The presence of the latter category of actions is justified by two reasons. First, for autonomous functioning of an integrated robot current Information about the environment must be obtained directly from the perceiving system. In a broader sense, robot's activity in exploring the environment regularities is due to the need of a periodic correction and updating of the PE model.

A rational organization of the planning process calls for a hierarchical organisation of actions: from simple (elementary) up to composite (generalized)actions of various levels.Simple actions in this case are conceived as those which within the framework of a given PE model are not representable (in contrast to composite actions) as sequences of more elementary ones.

The possible changes of environment independent of the robot may be incorporated by introducing input influences $g_i \in G$ defined by means of the mapping formula

$$g_i : S_{i_1} \longrightarrow S_{i_2} \qquad (5)$$

where $S_{i_1} \subseteq S$, $S_{i_2} \subset S$ g_i - is stochastic or deterministic function.

The description of various environment components and relations between them, description of robot's actions and influences independent of it as well as the description of the components of the environment in relations to which the particular task is posed constitute the initial model of the problem environment for a given task, which is henceforward denoted as Mo • It should be emphasized that all components of the PE model are closely interrelated and expressed (explained) in terms of one another.constituting jointly with the planning algorithm an integrated system of knowledge.

The goal set before the robot by certain metasystem (in a majority of cases, human operator) in the general case is to achieve a certain situation in the environment, which will be henceforward referred to as the goal situation. In non-trivial problem environments the goal situation $S_Z \in S$ is usually multicomponent and such that the determination of its various components is of an unequal importance. Accordingly, at the formal level the result is introduced as a set of weighted goal situations $S_Z \subset S$.

the weights may be determined with the aid of the goal function f :

$$f : S_Z \longrightarrow F \qquad (6)$$

where $S_Z \subset S$

However, in complex problem environments an exact analytical (or tabular) specification of the goal functions may prove to be difficult. In these cases the preference scale of individual subsets of the set of goal situations S_Z need not always specify clearcut boundaries of the variation of its values. That is,goal situations may be estimated using such vague notions as "desirable","necessary" etc.

Over and above goal situations, it is possible to define the set the unfavourable situations *SH* that the robot seeks to avoid, introducing to estimate them the functions h :

$$h : S_H \longrightarrow H \qquad (7)$$

where SH IS the set of unfavourable situations, $S_H \subset S$

In expressions **(6), (7):** F, H **-** are subsets of real numbers or ordered sets whose elements are qualitative descriptions. With respect to the function h the same stipulation is valid as concerns the goal function fi . On the basis of the PE model and the planning algorithm the planning system must draw up a plan for the accomplishment of a particular task, i.e. it must state such a sequence of actions and their correspondent current goal situations which would lead to the result required by the given task. Or, in more exact terms, specified for the robot's planning system are:

- initial environment model Ho;
- finite set of goal situations and unfavourable situations S_z, S_H;
- estimator functions f, h;
- algorithm-like information (planning algorithm).

The system is required to build a plan ℓ_i which would maximise the following functional:

$$\Phi(\ell_i) \longrightarrow \max_{\forall \ell_i \in L} \quad (8)$$

In the general case a plan is understood as an ordered set of duplets:

$$\ell_i = \langle (S_0, U_m^i), (S_m^i, U_{m-1}^i), \ldots, \hat{\ell}_j, \ldots (S_{m-k}^i, U_{m-k+1}^i), \ldots \hat{\ell}_k (S_1^i, U_0)(S_z\lambda) \rangle \quad (9)$$

where Mo is the initial environment model;

$S_m^i, \ldots S_{m-k}^i, \ldots S_1^i$ **- current goal situations,**

$U_m^i, U_{m-1}^i, U_{m-k+1}^i, U_0$ **- simple actions.**

$$\hat{\ell}_j = \langle (S_1^j, U_1^j), (S_2^j, U_2^j), \ldots, (S_n^j, U_n^j) \rangle \quad (10)$$

$$\hat{\ell}_k = \langle (S_1^k, U_1^k), (S_2^k, U_2^k), \ldots, (S_p^k, U_p^k) \rangle \quad (11)$$

- subplans corresponding to composite actions.

In relations (9), (10):

$U_1^j, \ldots U_n^j; S_1^j, \ldots S_n^j$ **- are simple actions and current goal situations corresponding to the subplan** $\hat{\ell}_j$ **;**

$U_1^k, \ldots U_p^k; S_1^k, \ldots S_p^k$ **- are simple actions and current goal situations corresponding to the subplan** $\hat{\ell}_k$ **.**

It is appropriate to note here that the planning process in a sufficiently complex problem environment may be practically (and all the more so, efficaciously) executed only provided it has a multilevel and hierarchical character. That is to say, at the generalized (composite) actions of the highest level should be found that would enable achievement of these subgoals. At the next level more detailed subgoals are specified etc. The planning process ends when the whole sequence of actions constituting the plan is composed of elementary actions alone. In relation (9) only two planning levels are represented for the sake or simplicity.

We shall now consider some principles of design and requirements to the structure of problem environment models and planning algorithms.

A prime requirement to FE model structure is that it should be build in keeping with the principle of generalization and aggregation (otherwise, given a high diversity of data, the model could become unmanageable). Generalization is in these cases understood ae building the generic relationships between concepts, and aggregation, as ascribing names to certain structures.

Aggregations and generalizations like the whole of PE model in the general case, may be formed either automatically by learning mechanisms or with participation of man on the basis of a priori analysis of the class of problems that the robot will have to solve. However, even in the latter case, over and above invormation introduced a priori, the PE model due to its incompleteness and inaccuracy must be updated and adjusted by information obtained both during the planning process and during the functioning of the robot in the real environment. This process, too, may be either automatic or performed by man interacting with the robot through a dialogue system.

It is admissible that information represented in PE model may be at individual stages of system functioning redundant and moreover contradictory. The contradictory character reflects the insufficiency and inaccuracy of the knowledge about an object or phenomenon as possessed by the robot and it may work as stimulus for further exploration of the environment. By redundancy we mean the possibility for deriving one and the same information from various statements about a certain object or phenomenon that are comprised in the PE model. Redundancy ia typical of a great many problem environments that are to some extent untrivial, especially if models of these environments are formed automatically during robot's functioning in the real environment.

In contrast to PE model where information is predominantly assortive, knowledge in the planning algorithm is expressed only in the imperative. In other words, the planning algorithm is a generalized procedure or, more exactly, a set of procedures defined on the PE model. This procedure must be built as universal at least within the scope of a certain class of tasks to be decided by the robot and possibly within the scope of a family of classes. The latter means that the algorithm must produce a correct solution independent of the conditions of a particular task of a given class.

It is appropriate to note here that the division of information into knowledge containing the PE model and the knowledge expressed as algorithm is nominal and again to emphasize the integrated character of the entire system of knowledge possessed by the robot. Indeed one and the same information may be specified either in the form of prestated facts (and incorporated in the PE model) or obtained by way of a certain procedure (included in the algorithm). Besides, the procedures included in the planning algorithm may be described similarly to actions and included in the PE model. The point is to provide such relationship between facts and procedures as would enable the system efficiently to perform the planning function.

The planning procedure must provide for a purpose-oriented activity of the robot. Stimuli for such activity are a mismatch between the result required by a particular task and the initial environment model and detection of uncertainties during comparison of the goal situations with the initial environment model. Uncertainties are all those cases which necessitate additional exploration of the problem environment by the robot. The robot may accomplish this process by means of its own perceptor system, failing to do this, it must have the possibility of referring for explanation to the metasystem (human operator). In the latter case metasystem - robot interaction should be organized by means of a dialogue system.

A mismatch may be a difference in the values of characteristics, relations, etc. In the formal language adopted, the mismatches by characteristic values are determined by the conditions (12): if the propositions $x_i \tau_k x_j \in S_2$ and the propositions $x_m \tau_l x_n \in M_0$ then the mismatch is fixed, provided that

$$x_i \equiv x_m,\ x_j \supseteq x_n,\ r_k \equiv r_l \quad (12)$$

where $x_i \in B_k,\ x_m \in B_k,$
$x_j \in \{\Pi_i^{j'}\},\ x_n \in \{\Pi_i^{j'}\},$
$r_k \in R,\ r_l \in R$
B_k **- is a subset of the object set** B**, and** $\{\Pi_i^{j'}\}$ **- is the set of values of the characteristic** Π_i **.**

The mismatches of relations are determined by the conditions (13):

$$\cdot\ x_i \equiv x_m;\ \ x_j \equiv x_n$$
$$\cdot\ r_k \not\equiv r_l,\ \ r_k \in R_i,\ r_l \in R_i \quad (13)$$

where R_i **is a subset of the set** R **; and** x_i, x_m, x_j, x_n **- are elements of the set** B **.**

The solution of the planning problem can be presented as a sequence of cycles, in each of which the action (simple or composite) is sought that eliminates (or reduces) this or that mismatch or uncertainty but in the general case requires, as a condition for its application, a new situation, which, in turn, appears as the current goal at the next planning cycle. The efficacy of this process largely depends on the choice of the current mismatch (or uncertainty) and the its eliminating action; this choice may be conveniently based on checking upon the applicability conditions of each "candidate" action and assessing the consequences of its application. The ultimate plan should be chosen on the basis of a criterion connected with the main functional (see relations (8)). By way of such a criterion it is possible to use, for example, the requirements of minimum time and power spent on problem solution.

We should like to note on conclusion that the planning problem as stated above may occur in various subsystems of an integrated robot: the perceptor system, the effector system, and the central system. For instance, the planning in the perceptor system may be elaborating a sequence of operators affording, say,to identify some body or establish relations between certain objects existing in a given scene.

The planning in a manipulator control system or locomotion control system may involve elaborating a particular trajectory of the movement of the "hand" or the carriage. In relation to the planning performed in the central control system (CCS), the planning in other subsystems is of a local and subordinate character in the sense that the goals of each local planning are formed in the robot's CCS and transmitted to its subsystems. Consequently, similarly to the hierarchy of integrated robot's subsystem, one should speak also about the hierarchy of the planning problems arising in these subsystems.