BLACKBOARD ARCHITECTURE FOR INTELLIGENT CONTROL

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Contents

Summary

The blackboard architecture is a flexible and powerful expert system framework. It represents a general approach to problem solving that is useful in many domains of applications especially in the area of intelligent control. The blackboard architecture can provide an environment for achieving intelligent control behaviors in many AI systems. In this paper, a description of the blackboard architecture and its development is presented. The potential and usefulness of this structured framework is examined. Discussion on several applications of the blackboard architecture is also given. The future trend and some perspectives are given.

1. Introduction

The definitions and structure of an intelligent control system is still an arguable subject. The subject arises because some researchers found that the control theory by itself is not adequate to deal with many control problems in existence. Many researchers are not satisfied because control theory can only tackle a narrow class of problems and there is little it can offer regarding problems like the control of mobile robots, autonomous vehicles, flexible manufacturing systems and network traffic.

These problems are generally very complex. The systems may consist of many different components interacting with each other, and the solutions of these problems require the integration of large amounts of diverse expertise and algorithms. Very often, the coupling of symbolic and numerical computations is needed. In additional to complexity, these problems are generally ill-structured. The goals are often poorly defined and decision path from an initial state to a goal may not follow any pattern.

Most of these problems are real-time control problems. The control actions of these systems need to be monitored continuously for achieving a goal. Explicit control decisions are very often required. The control of these systems requires the selection of the best and most appropriate action from among the next possible actions. The control is also faced with the problem of having incomplete information. There may be significant uncertainties in the system models or the operating conditions can change drastically. Alternatively, there may be conflicting and unreliable data or information from the input. Hence, intelligent decision-making is required to generate actions so that a certain performance level is maintained.

Many of the conventional techniques of artificial intelligence and expert systems cannot offer a lot to the solutions of these problems. They tend to deal with heuristic knowledge of a single problem domain. Also, most of them work in a consultation mode and are not suitable for use in real-time control of intelligent systems. This paper describes a flexible and powerful expert system framework called blackboard architecture for tackling intelligent control problems.

2. Characteristics for Intelligent Control

At each point in a problem solving process, an intelligent system has to decide on the next action to perform. Each action can generate or modify the solution elements that would again require decision to steer or control the intelligent system towards its final goal. In order to make the best decision, the intelligent system has to decide either explicitly or implicitly, on what methods or strategies to apply. The system determines its own cognitive behavior when solving the problem.

The kind of behaviors that an intelligent system should exhibit are given below:

- Make Explicit Control Decision

The first behavioral goal of an intelligent control system is that it "knows" what actions to take and when to carry them out. There could be a number of possible next actions at each instance. Intelligent problem solving means deciding which actions to perform and when to perform them.

- Reconcile Between Desirable And Feasible Actions

The control heuristic of an intelligent system establishes the kinds of actions that it should perform. The system also identifies the feasible actions by checking its currently executable knowledge sources. The system decides what actions to perform by reconciling between the desirable and feasible actions.

- Vary The Details Of Control Heuristics

An intelligent system adopts control heuristics whose grain-size is appropriate for the problem-solving situation. In some situations, the control heuristic prescribes specific actions, while in others it prescribes classes of actions.

- Adopt The Most Suitable Control Heuristic

An intelligent system should adopt control heuristics that focus on whatever action attributes are useful in the current problem-solving situation. For example, if a mobile robot can perform tasks that vary widely in priority, it adopts a standard heuristic to execute actions whose knowledge sources have high priority values. However, if problem-solving time is critical, it adopts a heuristic favoring actions whose knowledge sources are efficient and reliable.

- Vary The Control Heuristic Dynamically

The environment can change rapidly during the problem-solving process. In different problem-solving situations, we may have to adopt different control heuristics. Ordinarily, an intelligent system adopts a heuristic that favors action triggered by high-priority tasks. However, if the environment surrounding a mobile robot gets more dangerous, it may adopt a heuristic favoring actions that would maximize the chance of the robot to return to the base safely.

- Integrate Multiple Control Heuristics

There may be several operative control heuristics on a particular problem-solving situation. The system integrates all operative heuristics in deciding what specific action to perform next. For example, different ratings can be put against different control heuristics and the action that has the highest weighted sum of ratings is chosen for execution.

- Plan Strategic Sequences Of Actions Dynamically

Sometimes, it is more important to prescribe a strategic sequence of actions rather than independent chosen actions. For example, a sequence of actions that generate abstract partial plans are prescribed which may be followed by more refined, detailed solutions consistent with the original plans.

- Reason Between Domain And Control Actions

An intelligent system performs domain actions to achieve the goal of a domain problem. It can also perform control decisions for the control problem. The system has to reason the relative priorities of domain and control actions and perform the action it considers most important.

3. Blackboard Architecture

The blackboard architecture is a powerful expert system architecture and model of cooperative, distributed problem solving. It can deal with large amounts of diverse, erroneous and incomplete knowledge to solve problems. The basic blackboard architecture consists of a shared data region call the blackboard, a set of independent knowledge sources, and a control unit, also called the scheduler. It provides a means of organizing the application of this knowledge and the cooperation needed between the sources of this knowledge.

The main advantages that a blackboard system can offer are its flexibility of control and its ability to integrate different kinds of knowledge representation and inferencing techniques. For example, a production rule system or a frame-based system can be part of a blackboard system.

A blackboard system consists of three components (Figure 1) :

- Blackboard (BB),
- Knowledge sources (KSs), and
- Control unit.

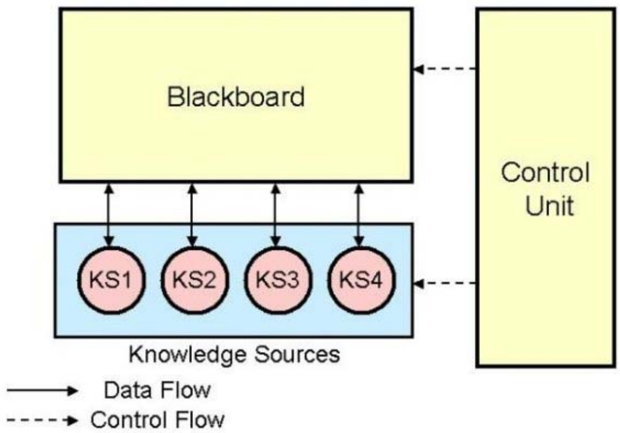

Figure 1: Components of a blackboard system

3.4. Blackboard

It is the part of the system that is used for storage of knowledge accessible to all the KSs. It is a global data structure used to organize the problem-solving data and to handle communications between the KSs. The objects that are placed on the BB could be input data, partial results, hypotheses, alternatives and the final solution. Interaction among the KSs is carried out via the BB. A blackboard may be partitioned into an unlimited number of sub-blackboards, also called planes or panels. That is, a BB can be divided into several BB levels corresponding to different aspects of the solution process. Hence, the objects can be organized hierarchically into different levels of analysis. However, this partition is not mandatory and is dependent upon the nature of the application. An object may be stored as a list of attribute values. An event that specify the occurrence of a certain situation is created or modified on the BB. It is used to determine which KSs can take part in the problem-solving process at any given moment. An event created on the BB may trigger a number of KSs.

Each entry to the BB can have an associated certainty factor. This is one way the system handles uncertainty in the knowledge. The mechanism of blackboard ensures that there is a uniform interface between each KS and the partial solutions found so far. Hence, KSs are fairly independent of each other.

3.5. Knowledge Sources

Knowledge sources are self-selecting modules of domain knowledge. Each knowledge source can be viewed as an independent program specialized in processing a certain type of information or knowledge of a narrower domain. Each knowledge source should have the ability to assess itself on whether it should contribute to the problem solving process at any instance. The knowledge sources in a blackboard system are separated and independent. Each has its own set of working procedures or rules and each has its own private data structure. It contains information necessary for a correct run of the knowledge source. The action part of a knowledge source performs the actual problem solving and produces changes to the BB. It can allow for different kinds of knowledge representation and different inference mechanisms. Hence, the action part of a KS can be a production rule system with forward/backward chaining or it can be a frame-based system with slot-filling procedures attached to some slots.

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Biographical Sketch

Dr. Grantham K.H. Pang obtained his Ph.D. degree from the University of Cambridge in 1986. He was with the Department of Electrical and Computer Engineering, University of Waterloo, Canada, from 1986 to 1996 and joined the Department of Electrical and Electronic Engineering at The University of Hong Kong in 1996. Since 1988, he published more than 130 technical papers and has authored or co-authored six books. He has also obtained two U.S. patents.

His research interests include machine vision for surface defect detection, optical communications, expert systems for control system design, intelligent control and intelligent transportation systems. He is in charge of the Industrial Automation Research Lab. (http://ial.eee.hku.hk). In 1989, he was awarded the ICI Prize for authorship of the best paper on the application of the theory of control published in the Transaction of Institute of Measurement and Control.

Dr. Pang was the Organizing Chair of the 1996 IEEE Symposium on Computer-Aided Control System Design. Dr. Pang is an Editor of the International Journal of Intelligent Control and Systems, Machine Intelligence and Robotic Control, and Control and Computers. Dr. Pang has acted as a consultant to many companies, including Mitsubishi Electric Corp. in Japan, Northern Telecom and Imperial Oil Ltd. in Canada, MTR Corp. and COTCO Int. Ltd. in Hong Kong. In 1994, he worked as a Senior Visiting Researcher at Hitachi Research Lab. in Japan. Dr. Pang is a Chartered Electrical Engineer, and a member of the IEE, HKIE as well as a Senior Member of IEEE.